STRUCTURAL STEELWORK PLANNING AND DESIGN EVALUATION - A KNOWLEDGE-BASED APPROACH

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ABSTRACT: This paper discusses the application of design-for-manufacture and design-for-construction methodologies to the building industry through the use of electronic prototypes developed by using knowledge based engineering (KBE). A working group representing British Steel divisions and consulting engineers agreed key processes and rules affecting initial structural steelwork solutions. The pilot scheme now in progress will allow the structural designer to use concurrent engineering techniques to work with other members of the design team, to investigate the functionality of the design, agree design parameters across design disciplines and freeze the design at an earlier stage than was previously possible. The result should produce design solutions which are both functionally and financially viable.

KEYWORDS: Project process, steelwork, costing, concurrent engineering, KBE .

1. INTRODUCTION

Buildings are becoming technically more complex. At the same time, the building industry is facing ever-increasing client-lead pressure for a reduction in the total project time and cost, and improved quality. These circumstances have fuelled the investigation of innovative approaches and techniques in design and construction within the industry, aimed at improving the quality and cost of building project. Over the last decades many research projects aimed at improving the performance of the industry were dedicated to improving performance on site, both in terms of management and construction techniques. For example, the procurement and fabrication phases of structural steel frame has been halved over recent years and this has been achieved by a better organised and automated fabrication. Despite the effort, construction productivity has not however improved to the same extent (Atkin et al. 1994; Constructional Steelworks, 1987).

Studies conducted in the manufacturing industry, of which construction is increasingly considered to be a part, reveal that 80% of the costs are committed during the first 20% of the project live cycle and up until now the technology is been primarily aim at saving time and cost out of another 80% of the project but this can be expected to yield saving base on the minor part of the total cost base (Boothroyd 1994). In the light of intense market pressure, manufacturing organisations have become increasingly aware of the importance of product design evolving from a valid basis right from the very beginning of a project. Consequently in order to gain the greatest competitiveness, manufacturing organisations, particularly the car and aircraft industries, have been targeting conceptual design leading to the establishment of streamlined processes which give improved quality, lower cost and faster time to market. The industry has been using been 3D prototypes as an integral part of the problem-solving process which can test the feasibility of legislation and manufacturing issues in real time so that high quality products can be generated at the end of the process.

The latest evolutionary development in manufacturing industry is the application of knowledge based engineering (KBE) systems technology. Advanced manufacturing industry has been able to create generic electronic prototypes of products at an early stage in the design process by using KBE. This has allowed refinement of the product by incorporating automatic testing of all relevant rules and ensured that considerations of standardisation of components, manufacturability, assembly and other process requirements are built into the model. The technology has provided manufacturing organisations with the means to develop effective prototypes that yield advantages in product development time, improved quality of problem solving, increased productivity of engineers, better use of capital resources, and a smoother process by which products move into commercial production (Martin 1994).

The potential benefit of the KBE systems technology to the construction industry has been demonstrated by the recent research work by BAA Plc., the University of Reading and others on the application of KBE electronic prototype technology to the design of airport terminals (Barlow et al 1995). The ability of the system to develop generic non project-specific models of airport terminal elements using BAA's harnessed knowledge of planning, designing, building and operating airport allows them to generate a number of alternative design solutions for evaluation. The key strength of the system is the ability of its software to rapidly generate new designs and the 3D modelling capability that allows visualisation of designs, how they will function and how they will be maintained from an early stage of the design process. Some construction industry experts believe that KBE is the technology that could have a massive effect by presenting real choices for clients, and promoting better construction performance (Latham 1994).

This paper is extending the novel KBE technology to the detailed design of building by developing structural design systems to augment the structural designer's creativity and expertise in designing steel buildings at the early stage of the design. The greater proportion of prefabricated components used in steel frames can strongly benefit from the system where they must be customised or reconfigured to meet the different requirements of a variety of different spatial plans for buildings. Structural engineers can generate more alternative structural configurations that could provide the intended structural function and in conjunction with the design team could evaluate them more thoroughly. This will produce unique, high quality buildings from project-independent standard products, and through the careful design of structural connections, fabrication and erection. The costs for structural steel frames will be predicted early in a project with greater certainty, and it is believed that the degree of confidence generated will contribute to the goal of an overall reduction in project cost.

2. METHODOLOGY

2.1 Industry Working Group

The project is based on work sponsored by the UK Department of Trade & Industry and by British Steel, as part of the Steelwork 2000 initiative. A working group was set up comprising representatives of different interest groups, including consulting engineers and divisions responsible for hot-rolled sections, tubular and cold-formed steel sections. Through a series of meetings and interviews the key processes and rules affecting initial structural steelwork solutions were identified. The proposed KBE design system is based on techniques identified from aerospace and automotive industries that is specifically configured to capture engineering process description (Fisher 1993). It will allow an engineer to create design solutions which can replicate the complexities of engineering design. KBE models are descriptions of a design process written in design language that supports both geometric and non-geometric attributes.

2.2 Published sources

The initial phase of the development of the application was to define as closely as possible the requirements of the design solution to be written in the KBE system. The principal concern was to generate feasible solutions from very basic data; the work by CIMsteel (1995) which culminated in the Design for Manufacture Guidelines gives an acceptable starting point for incorporating rules to generate economic solutions which are not based solely on minimum weight.

Formal presentation of the model is to follow the principles of CIMsteel Integration Standards/STEP. This will allow engineering data to be transferred to downstream processes, and the use of an advanced database-driven CAD system is the preferred method for visualising the generated model.

3. THE CONCEPTUAL DESIGN PROCESS

Given the spatial extent of the potential building, the engineer first task is to generate basic configuration of structural steel frame systems that may provide the structural function for the building layout. This configuration should include the system definition and the location of the structural members. There is an enormous number of alternatives for the basic configuration. For each configuration the sizes of the typical members, connection design considerations and costings need to be determined. Even at this stage there are many alternatives that satisfy the imposed design requirements. Theoretically every conceptual decision should be taken after a thorough evaluation of alternatives. In practice, however only a single or a few alternative configurations can be considered for a given building due to the time required to determine the structural feasibility and efficiency of each alternative, and limited time available for preparing the preliminary of the project. This may result in a possibly advantageous solution falling out of consideration. Artificial intelligence (AI) based approaches for the support of generating and evaluating all plausible solutions of a given design problem should prove to be useful in practice.

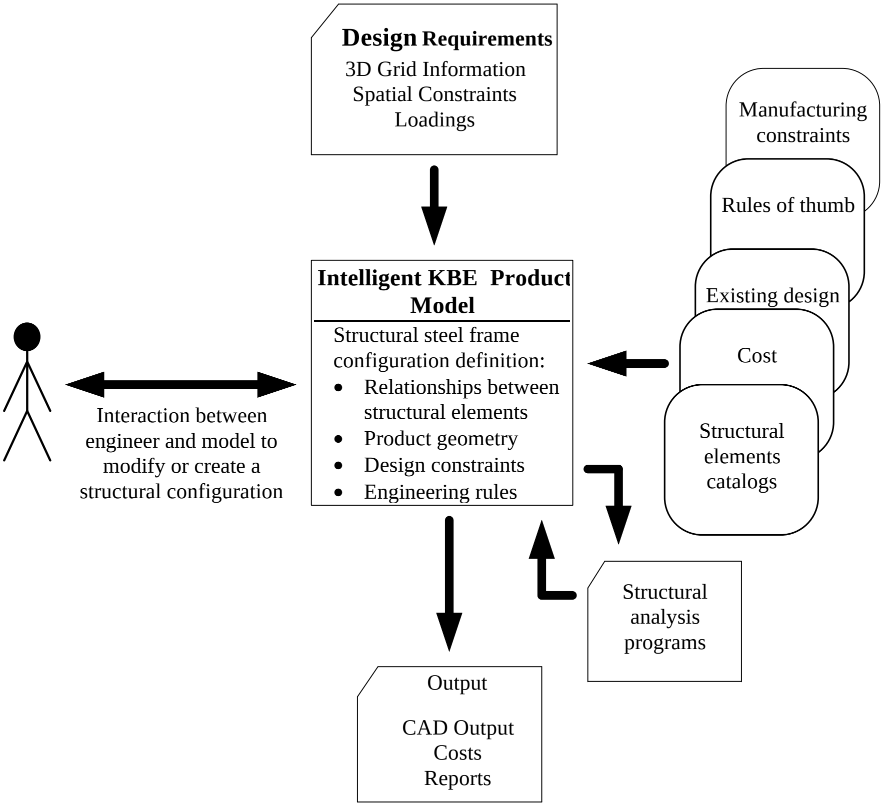
3.1 Expert Systems

The whole process of conceptual design may be viewed as a searching process in a hierarchical tree composed of nodes representing stages in the design process. The design process moves from top to bottom and at each node, structural designer employs intuition experience and some design rules of thumb dictated by engineering practice to select the most suitable solution from several alternatives. These circumstances have stimulate the efforts to apply AI expert system techniques for creating computer tools that would support the conceptual design process. Thus many prototype expert systems that have been developed for conceptual designs are reported in the literature (Adeli 1988; Harty et al 1994).

Expert systems can offer advantages in design automation, however they tend to produce solutions one would classify as routine design. The design solutions were obtained through selection of the best structural configuration alternatives from *a priori* known hierarchies of available structural systems. Structural design on the other hand is characterised by a large and often unbounded number of design possibilities. Except for the simplest of design problems, design that is based purely on selection is unlikely to be entirely satisfactory. A process of synthesis, analysis and evaluation has to be performed at all levels of design in order to achieve a design solution. Structural design problems pose challenging difficulties to existing expert system technology.

Positive creative responses must be achieved for all aspects of every new design problem. AI-based design approaches for the support of structural design must be sufficiently expandable and modifiable so as to reflect changes in practice (Fenves, 1995).

Figure 3.1 ***Use of Intelligent Model***



3.2 Knowledge-based engineering design techniques

A fruitful approach that would provide significant support at the preliminary design stage is the adaptation of KBE systems that have been evolved from the roots of AI, driven by the distinct need to solve engineering problems that were impractical to tackle using traditional computing technology. The concept of design process using a KBE system is illustrated in Figure 3.1.

The requirements of a new design task, e.g., geometric grid information, number of stories, design load etc., are represented as inputs to the intelligent KBE product model. The model contains information on how the inputs affect the structural configuration, components and geometry to create the structural configuration variants. It also retrieves information such as sizes of structural elements and their connections from design databases, and structural analysis result files to construct the structural configuration. The automation of design together with integration of data/information sources into the model allows the designer to rapidly evaluate many structural configuration possibilities and make informed decisions that help to optimise the design of the steel building.

The structural design process of building is not performed in a vacuum. The structural designer has to interact with and co-ordinate his work with a host of professionals engaged in parallel design activities: architect, building services engineers and quantity surveyor. The role of the structural engineer is to provide feedback on the structural implications of spatial layout decisions and to influence spatial layout from the standpoint of structural considerations. The available structural alternatives ought to be optimised to the same objective function in order to serve as a basis for making choices on factors such as costs, aesthetics, architectural function, and so on. The 3D CAD output of the model allows the design team to investigate all aspects of functionality of the design, agree design parameters across all design disciplines and freeze the design at an earlier stage than was previously possible. This eliminates the risk of destructive changes to structural arrangement or form during the fabrication stage and therefore the full benefits of prefabricated steel frame can be exploited.

The goal of the KBE application is to augment the structural designer's creativity and expertise in designing steel frame by automating tedious, time-consuming and repetitive task, and capturing heuristics for the preliminary design within a knowledge-based engineering environment. Structural engineers can generate more alternatives and evaluate them more thoroughly and quickly. As true concurrent engineering becomes a real possibility with the growth of the Internet, World Wide Web as well as private networks, knowledge based engineering techniques will become essential if structural engineers are to keep pace with the demands of the design team. An integrated data model requires tools to modify the structural steel components in response to requests from other professionals in order for them to function efficiently. The ability to present concurrent cost information should assist the decision making process. This will inevitably speed up the design, manufacturing and construction processes, making the specification process more efficient, and improving the quality and costs of the end product.

4. SCOPE OF PILOT SYSTEM

It was agreed that a pilot system should be produced, as a "proof of concept" to demonstrate the possibilities of the concepts described above. The ICAD system, in its presently available implementation on UNIX platforms, was chosen for stability and availability; a decision on the eventual choice of platform for implementation will be made at a later stage, when the PC version has been evaluated.

The principal objective is to show the level of information which can be generated using initial data which is acceptable to a range of interest groups in the structural steelwork industry. The intention is to validate models thus generated in conjunction with architects and other involved design professionals.

Early results indicate that the work will be well received, particularly by structural engineers who will have a tool for rapid generation of viable alternative schemes at the critical early stages of a project. They will be able to justify, for example, the selection of heavier sections to simplify connections; it is believed that the greater degree of certainty this demonstrates will allow the industry to move towards the 30% savings targeted in the Latham report (1994).

The deliverable of the project will be published guidelines and a system which will allow those initial assumptions to be tested with real project data.

5. INTEGRATION

This research is concerned only with the earliest part of the complete design process for steel structures. To maximise its benefit, the prototype KBE design system developed in this project needs to be integrated into a larger engineering design activity. The design system is treated as a part of the evolutionary process which end up with the production of the design documentation or even supporting the fabrication of different building elements. It contains rules that generate data for the structural design and analysis packages and send the data electronically to the packages for evaluation. This ability would greatly enhance the efficiency by reducing the effort necessary for multiple input of identical data in different programs and it also would minimise the probability of errors typical with multiple data input. At present, the possible benefits of technical software for structural design and analysis are inhibited by lack of an efficient data transfer between different software packages. Users and related organisations demand strongly, that the data created within one program may be automatically exchanged with any other program, which requires some or all of the same data. Thus, the exploration of data modelling technique facilitating the sharing and management of engineering information is a very active area of research in universities, related construction industry organisations and software development firms. Much of the good work in developing practical product data exchange standards relating to structural steelwork frames has been done under the Eureka CIMsteel project which is aligned with STEP, and this project will draw on that work. The decision to adopt data exchange protocols (DEP) developed under the emerging CIMsteel Integration Standard (CIS) will enable the prototype KBE design system to communicate with different design applications to form the complete steel building (CIMsteel 1995). Figure 5.1 shows how the prototype KBE design systems may be integrated in the overall design activities using CIMsteel DEP.

6. CONCLUSIONS

This research has focused on the stage of the project process where changes can have maximum impact on real designs. It has worked on the assumption that appropriate tool-kits will be available in the industry for integration into larger product models; interim solutions, based on writing transfer files into existing CAD systems are seen as a solution to allow delivery of a working system, and are not necessarily seen as the most desirable method for the future. One of the significant lessons learned has been the value of a cross industry steering group to focus the researchers on producing useable results.

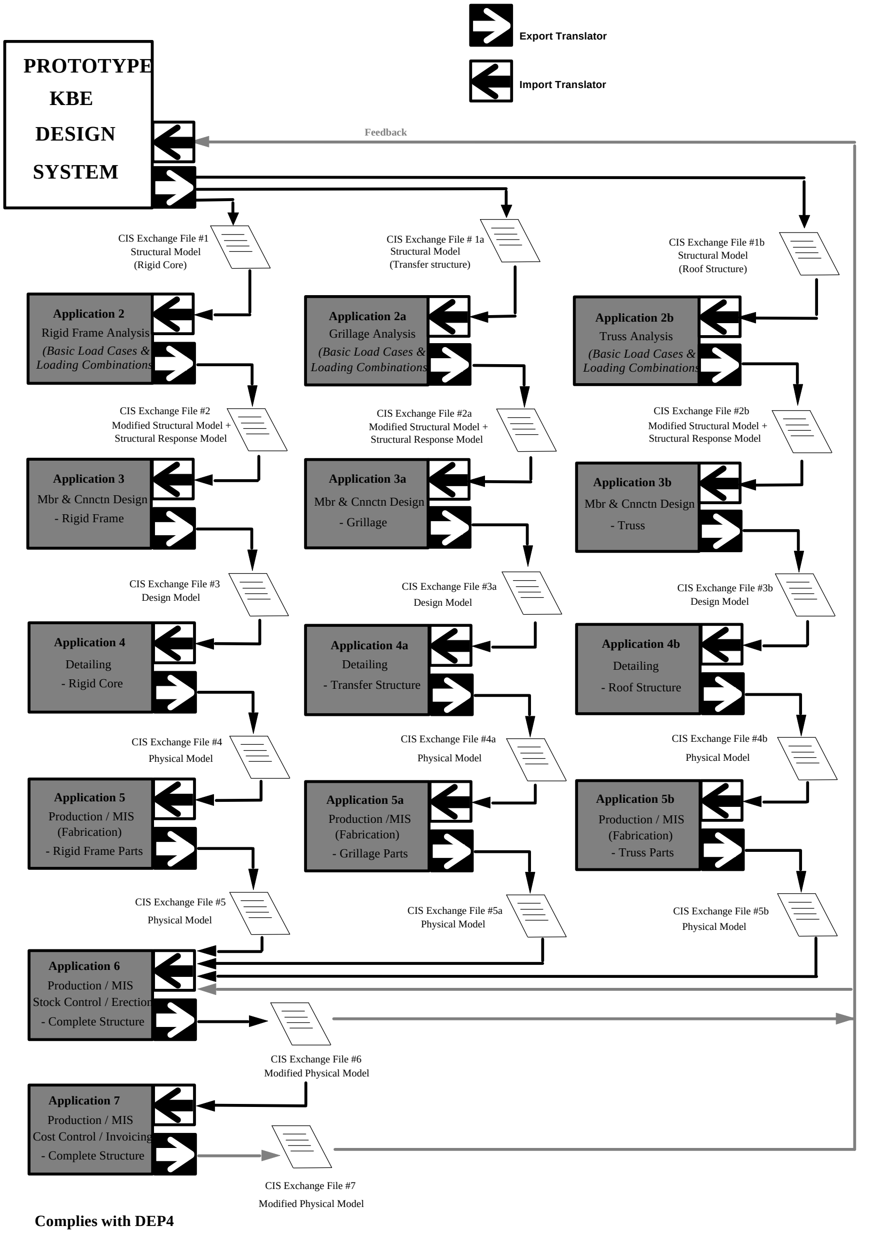


Figure.5.1 Integration of Prototype KBE Design System With Downstream Design Activities Using CIMsteel Data Exchange Protocol (CIMsteel 1995)

7. REFERENCES

Adeli H. (ed.), 1988. Expert Systems in Construction and Structural Engineering, Chapman and Hall, New York.

Atkin B. And Pothecary E., 1994. Building Futures. The University of Reading, UK.

Barlow R P G, Fisher G N, Papantonopoulos S N, 1995. The Application of a Knowledge-Based Engineering System to the Planning of Airport Facilities, Institution of Electrical Engineers, Digest No: 1995/129, pp. 1/1-4.

Boothroyd G., 1994. Product Design for Manufacture and Assembly. Computer-Aided Design, Vol. 26, No. 7, pp. 505-520.

CIMsteel, 1995. Design for Manufacture Guidelines, The Steel Construction Institute, England, Pub. No. 150, ISBN 1 85942 022 2.

Constructional Steelworks, 1987. Challenging Tradition - Innovative Techniques For Steel Construction. Report by Robotics and Prefabrication Sub-Committee, Constructional Steelworks.

Fenves S.J., 1995. Successes and Further Challenges in Computer-Aided Structural Engineering. Pahl and Werner (eds.), Computing in Civil and Building Engineering, Balkema, pp. 13-20

Fisher N., 1993. Construction as a manufacturing process? An Inaugural Lecture, Department of Construction Management & Engineering, University of Reading.

Garnett N, Barlow R, Papantonopoulos S, Fisher N, 1995. The application of knowledge based electronic prototyping to a project process at concept phase, Modeling of Buildings through their Life-Cycle - CIBW78-95 Proceedings Publication 180, Stanford, pp. 415-426.

Harty N. and Danaher M., 1994. A Knowledge-Based Approaches To Preliminary Design Of Buildings. Proceeding Institution of Civil Engineers Structural and Buildings. Vol. 104, pp. 135-144

Latham M., 1994. Constructing The Team - Final Report Of The Government/Industry Review Of Procurement And Contractual Arrangements In The UK Construction Industry. HMSO.

Maher M.L., Fenves S.J. and Garrett J.H., 1988. Expert Systems For Structural Design. Adeil H. (ed.), Expert Systems in Construction and Structural Engineering, Chapman and Hall, New York, pp. 85-121.

Martin N., 1994. Knowledge-Based Engineering. Automotive Industries, July 1994, pp. 50-51.

Papantonopoulos S N, Barlow R P G, Fisher G N, 1994a. The application of an intelligent knowledge based engineering system to the optimisation of design, cost and quality of finished products in construction, IN: Fourth International Conference on: Factory 2000 - Advanced Factory Automation, Institution of Electrical Engineers Conference Publication No. 398, York, pp. 369-376.

Papantonopoulos, Sotirios N; Barlow, Richard P G; Fisher, G Norman, 1994b. Concurrent Knowledge Based Engineering: Strategic Issues in Product Modelling for the Construction Industry, IN: ECPPM '94 - Product and Process Modelling in the Building Industry, Dresden, pp. 91-94.

Pine II, B J., 1993. Mass Customization: The New Frontier in Business Competition, Harvard Business School Press.

Winograd T., and Flores F., 1986. Understanding Computers and Cognition. Addison-Wesley, Reading, Massachusetts.