Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 58 (1989)

Artikel: Knowledge-based system for automatic design of glued laminated structures

Autor: Žagar, Zvonimir

DOI: https://doi.org/10.5169/seals-44911

Knowledge-Based System for Automatic Design of Glued Laminated Structures

Système expert pour le calcul automatique des structures en bois lamellé-collé

Wissensbasiertes System für den automatisierten Entwurf von Glulamstrukturen

Zvonimir ŽAGAR
Prof. Dr.
Zagreb University
Zagreb, Yugoslavia

Z. Žagar, born 1931 received his Civ. Eng. degree at the Faculty of Architecture, Civ. Eng. and Surveying of the Zagreb University in 1957. He worked from 1965 to 71 as senior lect. at the BT, Faculty of Arch., UST Kumasi, Ghana. He holds the Chair for timber structural design at FCI Zagreb.

SUMMARY
We have developed a knowledge system for cost optimisation design of two and three hinged glued laminated framed 3D structures. The system incorporates all the necessary standards and codes of practice. On the basis of input building's clear-area-height dimensions, the geographical location and current prices of material used and the past «learned» experience, it designs the optimally priced 3D structure with all the details included.

RESUME
Nous avons développé un système pour l'optimisation des coûts des structures en bois lamellé collé du type ferme à deux ou trois articulations avec la possibilité de minimisation du côut global du bâtiment. A partir des données de base, représentées par la portée, la longueur du bâtiment, la position géographique ainsi que le prix du bois et de l'acier, les résultats fournissent le coût optimal du système à trois dimensions. Les résultats sont conservés dans la base de données pour une utilisation ultérieure.

ZUSAMMENFASSUNG
Ein Expertensystem zur Kostenoptimierung von 2- und 3-gelenkigen räumlichen Brettschichttragwerken ist entwickelt worden. Die entsprechenden Normen und Vorschriften sind dabei berücksichtigt. Aufgrund der Innenmasse der Gebäude, der geographischen Lage, der aktuellen Baupreise sowie der früheren «Erfahrungen», entwirft das System eine wirtschaftliche Tragstruktur in allen Details.

1. Introduction

We gradually embarked upon the development of the knowledge system (KS), until involvment at the present stage. First, some team members (under late Prof. Dr. Sablic) had developed programs for automatic glulam beam table generation for the timber industry in Yugoslavia. Fig. 1. [23] [12]. In the meantime the SZS (the Standard Scecification Office) updated the JUS (Yugoslav standards for wood structures: JUS UC 9.200, and JUS UC 9. 300) valid from 1985.[15]. Also we were involved in writing those standards, we recognise the shortcommings of these standards: they have the "old form" and the oddly arbitrary naming of the variables, and some in accordance with internationally accepted standards. Some of us had the idea about writing the standards in modular form suitable for direct computational use: in FORTRAN, PASCAL, BASIC etc. This could be then distributed with the usual standard written form to various legal users [33], [34], [35]. But this idea, based on work of prof. Fenves and others [9], [10], [11], [13]. was rejected at that time.
I made an attemt to write some parts of the standards in modular forms suitable for direct computer use. But this was not done systematically. The idea of optimization was actually old and dated to the times when we did some considerably complex optimization of very large and complex structural use in the realm of architecural planning, based on generalised linear model for optimization of planning based on the works of Aguilar, deNeufville & Stafford and Stark & Nichols [2], [6], [25], [30]. We did it on the then Interdisc. Interfaculty Traffic and Transportation Study of the Zagreb University where I lectured on structural design (1971-1980). In those works we just assumed that the reif. concrete structure was already rationaly designed, and the model developed took into account multiused facilities and considered realistic design constrains such as zooning and parking regulations and requirements, space use, rentals of floor areas (depending on the use and architecural quality and marked preferences), construction costs, budget and the maximisation of profits [2]. There was a considerable disapointment, because nobody from the authorities responsible for planning and investments was interested in the use of the model. This was done in 1975 and well described [30] in 1977. The computers were rare and the knowledge to use it mostly limited just inside universities. Later at the Faculty of Civil Engineering (FCE) I made (with the help of some students) some optimization programs for planar wooden structure design based on the JUS standards. We developed some simple programs for ratioinal design of two and three hinged glulam arches, glulam (variously shaped) beams, some steel structural parts, foundations etc., some written in FORTRAN and some in BASIC [17], [31], [37], [38], [39].

2. The first steps

The appempt to write an ES or KS as a rather elementary or primitive version was a tempting foundation base for more elaborate systems. The idea to start to write an rudimentary ES (KBS) was born at the time of the Zagreb Universiade games (in 1987.), when we got the contract to design three (over 30 m spaned) glulam roofs over sports halls. So I made a program for spatial optimization of planar glulam roof structures and then started to

develope it into a rudimentary KBS [39]. This immediately highlights the fundamental problems of ES: that they are usually quite knowledgeable about a limited (in that case a very narrow) domain, but have no knowledge of wider world. It should be noted that we always checked the obtained results with parallel computations on the mainframe computer using FEM and the ICES STRUDL 2 system [15]. We latter even checked some assumptions and theories of glulam beam behaviour (Mohler, Heimeshoff), and the theory of spring back effects-initial stresses due to manufacturing processes of streight and curved glulam members and the "size effect", etc.
In that then written system the various embodied theories, the standards and the codes of practice could be reveiled by the use of various HELP routines in graphical or printed/written forms on the CRT devise. The system for the design of spatially braced glulam planar structures could do the optimization quite independently form the structural engineer, the "man in the link" was accepted to give some explanations, details of codes and the theories used, just to give him the feeling of a master over the program [5], [7], [32], [39].
We have recognised the shortcommings of separate unlinked (or linked) optimisation programs as well as the 2D towards the 3D comprehensive approach in design, and the role of the partialisation of different architectural forms in the design of timber structures.
A small program which was able to find the 2D optimal solution among several predeterminated 2D forms had shown that an optimization should include comparission of architectural forms and as well as materials on the price basis. This program was able to compare the structures shown in fig. 2. [7], [37].The efforts of research work and some of the student diploma works were cricial for the development of such system.
It was enlightening to run this program for different spans, building heights, bearing capacities of soil and different prices of materials involved. In running it I learned much of the design decision making and was able toobserve the generation of the thumb-rules. To my suprise the, with the program gained solutions, were the same as the stated in books and known as "thumb rules", gained in practice by healty workmanship and past economical gains.

3. Development

We were seeking to develope a model for writing a real KBS which could be gradually expanded to more complex one. In the case of timber design we were aquanted with the Basic wood design for minicomputers [18]. We developed on the past experience a KBS for wood design on the 3D (spatial) design basis which we are trying to enlarge to other structural forms. One part of the system is operational and this is represented here .

4. The KBS for design of framed glulam structures

Such systems embody the accumulated technical and technologycal knowledge, the contemporary state of standards and codes of practice, the past "thumb-rule" experience, and the new knowledge obtained by the use of the system. In this way the knowledge is gradually increased, but because of the limited scope of the narrow active area (the one bay space system) there is a limit

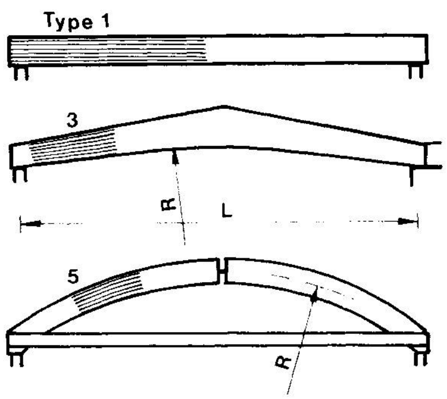

Fig. 1. The early approach to optimization of glulam beams.

for the growth of the knowledge base. This limit is obtained quickly. The acumulated knowledge saved in the data bank could be applied by practical design of glulam timber structures.
The well known ICES STRUDL system is very close to this definition but the searching of the DD2 data base file (where the past experience could be saved) is unpractical without an intelligent interface for revival of the, only to that specific problem related, data.
There have been some sporadic attempts to solve some optimisation problems in design (for example to solve the question of optimal design of simple structures: glulam two hinge arches, optimization of purlines, design of simple glulam beams, reinforced concrete one bay frames) [12], [17], [29], [31], [36], [37], [38], [39]. The described automated program for 3D optimization of one bay glulam framed building could learn and the learned experience knowledge is saved in a data base which could be expanded by interpolation or /and by further learning in future runs.
We have in this program established the "man in the link" to:
(i) help in re-education of users (students, str. engineers),
(ii) to force "experts" to critically review their knowledge and thought processes, which than could lead to new ideas for more effective solutions to problems,
(iii) to put a point to the role of contemporary structural engineers.
It was a policy from the beginning that the role of the program users was a supperficial role only, but this shouldn t be apparent to the user. This is far from deskilling the role of structural designer but we are on the way to do just this.
It could sound unbelievable that the first steps were done on a SVI 328 and then tranfered to and developed on IBM XT/AT PC, where the KBS is now operational. Now it is transfered to CONVEX.
The steps described, are the total minimum cost optimisation of an architecturaly prediscribed one bay conventional glulam timber 3D workshop buildings based on two- or three- hinged glulam frame stuctures. To be able to start with this we have to rewrite in digital forms the relevant Design specifications, specification for loads and code of practice. Therefore we have proposed the writing of the "new generation" of design codes and specifications in a way of verified subroutines expressed in different languages: Pascal, Fortran, Forth and why not McBasic [8], [9], [10], [11], [11], [13], [33], [34], [35]. These subroutines should be the integral part of the new code representation of the

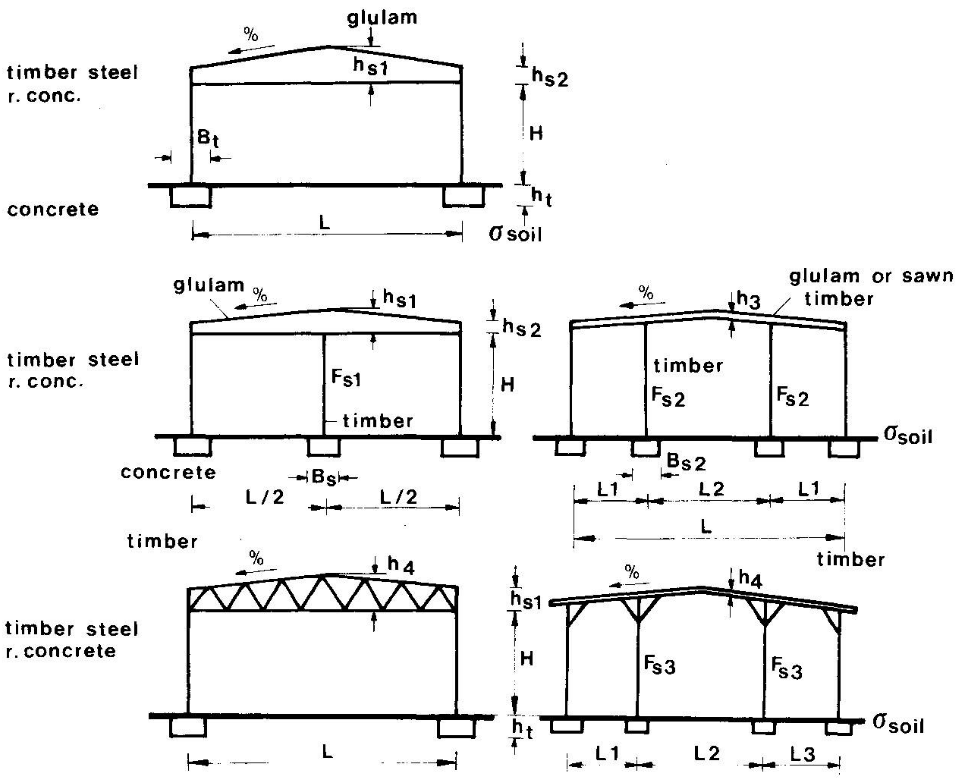

Fig.2. An early 2D optimization approach to different structural systems.

JUS codes and standards [15], closely related to ISO standards. We have imagined the whole building standards codes as a system of drawers in a cupboard. The old outdated rules scould be taken out and the new rules pushed in without affecting the whole. These standards should be distributed to the prospective legal users on floppies and suplemented by textual parts. They could be used in various programs as modules. The standards should be constantly upgraded and distributed to legal users. An institution should be in charge for testing, distributing and upgrading the rules.This work is closely related to the selection of variable's names, the choice of letters (notation) used etc., which could be obtained only by mutual agreement at the level of the Yu Standard specification Office. On this level there has not been much interest, nor financial support. So we were forced to do the task to write some of the parts of such a system in hope that somewhere in the future the SZS (Bureau for National Standards) will accept the whole idea. After that we have started to write the main managing routines for structural calculations, code managing, stability checking, price optimisation, and optimisation of mutually interlaced building parts etc.

On the basis of the architectural choice of the main outside dimensions of the building, the geografical position inside Yugoslavia (governing the snow and wind loads), the choise of exposion to wind loads (closed, open, partialy closed building etc.),

the type of roofing (and the roof's slope), the choice of timber (glulam, sawn timber), the class (1st or 2nd) and species of timber (soft or hard), the environmental exposure (pH level), the choice of supervisions (and the level of meintenance), the proposed duration of the structure, the current prices of materials and some other choices, the optimisation process starts and after a while the optimal solution will be obtained (fig. 3). The described data colection (input) is done in a converstion mode and there is no chance left to omit any question. There are several choises to input the data for wood classes and species: this could be done by the user or could be left to be decided by program according to price levels of materials used.
Starting from the purline distance the spacing among the frames, the optimisation of the steel bracing system and its form, the choice of the glulam framed system (the two- or three- hinged glulam frames), the system longs for the minimum priced feasible 3D building. When the global economy is obtained the details (the circular dowell connection between post and beam etc.) are optimised (fig. 3.), and searched for the most economical solution. Up to the last bolt, dowell and nail.
The optimal solution is saved in the data bank. This data bank is searched first, when a new run is started.
In this way the data base is growing and accumulating knowledge about such systems. After some number of runs, there is only a sporadic need for new runs of the whole system. It is clear that the various dimensions are dependent of the geometry, the geografical position of the building and other parameters, but mostly from the current prices of the material used. The to day obtained economical solution, if for some time not realised, might not be economically erected by another future price relation. This is by the way the current position with us. At present, the system is "learning".
There are some shortcommings which we are trying to correct now. One is the intelligent search routine and the range of economical decisionmaking in a stabilised and an inflatory environment. But the heuristic search should include such realities. At present we are trying to develop the heuriustic search and logical save routines and to embody in the program the typical truss structures supported on "I" steel [20], and/ or reif. concrete columns or surrounding walls (with or without openings). This is being done as a PHd and a MSc thesis and should be finished in a year or two.
For the intelligent heuristic search routine, we did among us some brainstormings to discover how an experienced structural engineer should use the past experience.
There are some problems in the (by us) hectically inflating economy: the prices are rising, but the relations of prices of different materials are changing too and are not constant. The second schortcomming is threefold: - the interface language communication, - the JUS standard embodied, and - the various variable's names (reflecting our language). For the language (for interfacing the program with the outside world) I feel that it should be written in english as a standard language. But there exists among us a strong feeling to use native croatian language. The variables should reflect the ISO (by my opinion outdated) recommandation and this could be changed easily. The JUS standards are outside the program (as a module) and could be changed and updated to level needed.
Parallel to this work we are developing an epoxi-glued with four HTB perpendiculary prestressed corner joint for framed structures instead of the expensive and time consuming circular bolted

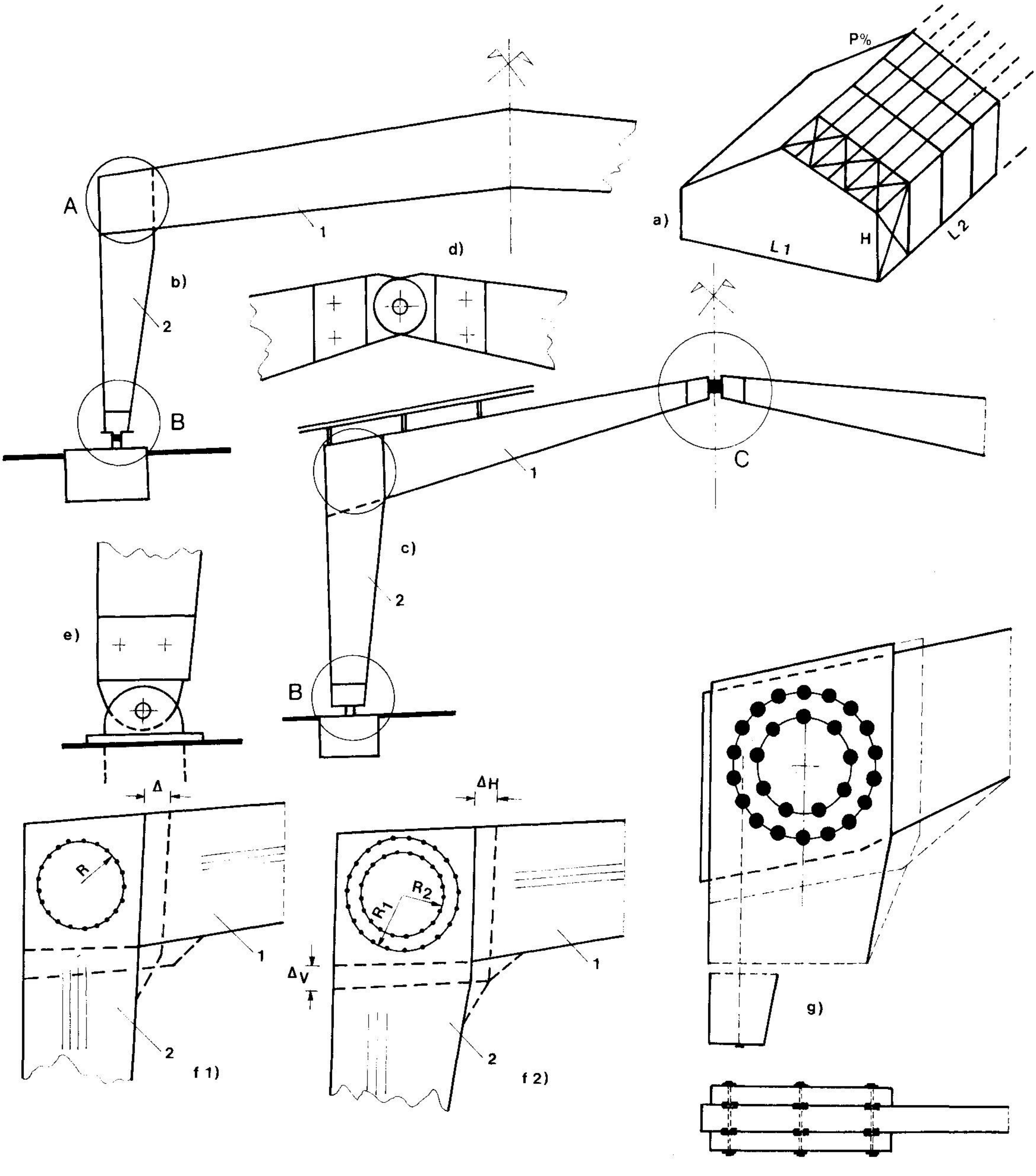

Fig.3. a) The outlines of the building, b), c) the two and three hinged glulam frame, d) the top joint of the three hinged frame, e) detail of the support hinge, f), g) details of the generated circular bolted corner joint (one or two rings).

connection already included in the KBS. This corner joint is being tested in lab and the results compared withe a large 3D FEM simulation including the anisotrophy of the wood and the epoxi glue layers, done with the IBM version of ICES STRUDL 2 system. This recent development (which could be economically feasible) should be then included as one of the possible solution of the corner joints.
As shown by this development, a number of experts with some degrees of understanding and expertise in this technique have been increased significantly.
We do hope that the glulam timber industry will be interested in further development and in the use of the developed system.
At the present time they are not very interested in joining such project and this is quite strange knowing the present economical situation at home.
In the described KBS the structural calculations are done inside the program in a close form solution modul. For the intended inclusion of truss structures we are using a outside routine using some common programs. Only the preliminary dimensions for the structural calculations are as "thum rules" embodied in the system.

5. Discussion

There is one question sticking out in the discussion: the obvious deskilling of the structural engineers and the changed role of a new bred structural engineer's generation, also the scope of their education. What of the future? The new generation of computers will manage knowledge and therefore be capable of making decisions on the ground of quantity, and maybe quality too. Such systems should give expert assistance rather than replace completly the human thougth and decission processes.
As the first runs of our system started (with all of the subroutines debuged), we have discovered a system bug so that the system was giving us plausible but strange solutions. We discovered the bug in the system on the sole basis of the only past design and manufacturers experiences,the past experience and engineering logic, at the end the diploma candidate told me "the Germans have been right".
This poses a question of how to debug ES or KBS in the future when experience will be based on the past experiences gained by ES alone and not by experienced professional structural engineers.
How far then can we trust the system (with uncovered bugs in the system), and whose is the responsibility? How much trust we should have in future expert systems? Should we be cautious in the use of expert system, or try to verify them when still there is time left and experts around? As knowledge erodes the effort should be made to obtain good experienced structural engineers, capture their knowledge and educate makers of such systems as to avoid undiscovered bugs in systems on the sole basis of their past experience, until it is not too late [21].
It seems that the quality assurace of the ES should be administred by appropriate professional and learned societies or by institutions which can be entrusted with the task: exchange, validification and updating of data banks, programs etc. This is necessary but it seems to us that it will not be done until an outcry demands it. We reported the problem through various papers and also notified the SZS authorities to take charge of it on a higher (even international) level.
As for the development of the described system (which is operable

on PC) I am not very optimistic. The progress is by us slow and mostly not financed or is financed symbollicaly.
Confronted with economic crisis lack of hardware, (CAD systems, CAD stations and lack of plotters), an inadequate and virtually nonexistant information network, the lack of research funds, the diminishing standard, that I clearly believe we do not have much chance to go further from this described first step - the very beginning.

References:

1. Arnold A., Artificial Intelligence, Prentice Hall, 1986.
2. Aguilar R. J., System Analysis and Design, Prentice-Hall, 1973.
3. Bundy A., Catalogue of Artificial Intelligence Tools, Springer-Verlag, 1986.
4. T. Bernold, Expert System and Knowledge Engineering, North-Holland, 1985.
5. Baljkas B., Numerical modelling of timber structures (Numericko modeliranje drvenih konstrukcija), Simp. Contemporary structures: Timber structures of today, Brijuni, 265-294, (1987).
6. DeNeufville R., J.H. Stafford, System Analysis for Engineers and Managers, McGraw-Hill, 1971.
7. Diploma works, S. Ferebuš, N. Petrinić, M. Miljak, Z. Glavinić, FGZ Zagreb (1985-1988).
8. Forsyth, Expert systems, principles, Chapman Hall, 1984.
9. Fenves, Rankin, Tejuja, The Structure of Building Specifications, Build. Science Series 90, NBS, Washington D.C., 1976.
10. Fenves, Recent Development in Methodology for the formulation and Organisatio of Design Specifications, Eng. Str., Vol. 1., 1979.
11. Garret Jr., A Generic Standard Processor for Use in Computer-Aided Structural Design, Ph. D. Thesis, Carnegie Mellon Univ., 1985.
12. Haiman M., Types of glulam systems (Tipski drveni lamelirani lijepljeni nosači), Simp. Suvremene gradjevinske konstrukcije: drvene konstrukcije danas, DGKH, Brioni, 141-174, (1987).
13. Howard, Fenves, Representation and Comparison of Design Specifications, Dept. of Civ. Eng., R-83-141, Carnegie Mellon Univ., 1983.
14. xxxx, ICES STRUDL manuals.
15. JUS Standards, SZS, Beograd, 1985.
16. P. Jorrand, V. Sigurev, Artificial Intelligence I, II, North-Holland, 1986.
17. Magerle M., Žagar Z., M. Haiman, B. Baljkas, Optimization of two-hinged wooden glulam arches using FDM (Optimizacija dvozglobnih lukova od lameliranog drveta metodom konačnih diferencija), The 2nd Simp. Suvremene drvene konstrukcije, ZTI, Ljubljana, 145-156, (1986).
18. Morton, Newman P.E., The Structural Engineering Design Programs, Volume 1 - Wood Design, The McGraw Hill Professional software Series, McGraw-Hill Books Co., N.Y., 1985.
19. McNitt L. L., Basic Computer Simulation, TAB Book Inc., Blue Ridge Summit, 1983.
20. MacGinley & T.C. Ang, Structural Steelwork, Butterworths, 1987.

21. Oakley B. W., Expert systems: artificial intelligence research comes of age, Sci. publ. Affairs 3 37-51 (1988).
22. **Roth, Waterman, Lenst**, Building Expert System, Addison Wesley, 1983.
23. **Sablić S.**, Types of current industrial glulam structures (Tipizacija kurentnih industrijski proizvodjenih nosivih elemenata od ljepijenog lameliranog drva), Simp. Wooden structures, GI/FGZ/ISZ, Cavtat, B4-6-1 - B4-8-9, (1977).
24. **Sparks L. E.**, Investment Analysis with your Microcomputer, TAB Book Inc., 1983.
25. **Stark R. M., R.L. Nicholls**, Mathematical Foundation for Design: Civil Engineering System, McGraw-Hill Book Co., 1972.
26. **C. Weisbin**, Artificial Intelligence Applications, IEE CS Press/North-Holland, 1985.
27. **Wright,R.**, Virtual Reality, The Sciences, 11-12,1987., 8-10.
28. **Žagar, Z.**, O osnovama ekspertnih sustava u graditeljstvu (About expert systems in structural and civil engineering), VIII Kongres SDGKJ, Cavtat, 1987, T-91., 247-251.
29. **Žagar, Z.**, Expertni sustavi, Simposium Suvremene gradjevinske konstrukcije (Contemporary wooden structures),Bled,1987.
30. **Žagar Z.**, Nosive konstrukcije (Structures), 1, 2, 3, Liber, Zagreb, 1979.
31. **Žagar Z.**, A program for design of two-hinged glulam arches (Program za proracunavanje dvozgl. lukova iz lameliranog drveta), Simpozij '85, SDGKJ, Dubrovnik, Book R, 216-228. (1985).
32. **Žagar Z., B. Baljkas, M. Magerle, M. Haiman**, FEM modelling of glulam beams (Modeliranje drvenih lameliranih nosača MKE), Simpozij '85, SDGKJ, Dubrovnik, Book R, 435-442 (1985).
33. **Žagar Z.**, A new generation of standards for wooden structures (Nova generacija standarda za drvene konstrukcije), Simpozium on contemporary wooden structures, ZTI, Bled, 1-10 (1986).
34. **Žagar Z.**, The role of standards in the development of CAS and ES (Uloga standarda u razvoju CAD-a i ES), 9th Internat. Simp. CAD/CAM, Zagreb, 125-130, (1987).
35. **Žagar Z.**, Expert systems (Ekspertni sustavi), Simp.: Contemporary structures: Timber structures of todays, DGKH, Brioni, 411-482, (1987).
36. **Žagar Z.**, Experten systeme, Simulation & Prognosen (on 5 1/4" diskete), SVI BASIC Lib. #19, SVI/MSX-Club Deutschland, 1988.
37. **Žagar Z.**, The optimal solutions (Optimalna rješenja), The 2nd Simp. Suvremene drvene konstrukcije ZTI Ljubljana 301-312, (1986).
38. **Žagar Z.**, Automated design of lamella roof structures (Automatski dizajn mrežastih svodova), The 2nd Simp. Suvremene drvene konstrukcije, ZTI, Ljubljana, 329-349, (1986).
39. **Žagar Z.**, A system of programes for design of glulam beams (Sustav programa za dimenzioniranje drvenih lameliranih grednih nosača), Gradjevinar 37 (1985) 12, 499-507.