Computer aided design and manufacturing

STEP lecture D11
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Objectives

To provide information about the state of today's CAD/CAM technology, i.e. computer-aided design and manufacturing systems, in the field of timber construction.

Summary

The lecture covers the specific requirements for CAD systems used in timber construction and on the direct control of wood working machines. CAD systems are no longer used as pure drawing devices, but are capable of simulating complete building designs and thus producing consistent building models and planning data. An example taken from the timber frame construction industry is used to illustrate the level of development.

Introduction

In aircraft, automobile and machine construction the use of CAD/CAM systems is already a part of everyday work to simulate a product and its construction on a computer. The aim is to ensure that the geometry, properties and behaviour when simulated deviate only marginally from the real product.

Currently the microprocessors of workstations are so powerful that almost any degree of similarity can be achieved. The similarity is only limited by the amount of work necessary for the data input, which is of course subject to cost-effectiveness and directly dependent on the number of pieces and/or components that are to be manufactured. This number is much higher in the series production of the manufacturing industries mentioned above than in timber construction, in which usually only unique products (Figure 1) are manufactured.

However, there are also good reasons for timber engineers to portray and simulate the planned building in a full three-dimensional form on a computer:

- By means of a complete 3D-simulation of all main components a consistent model of the building is produced. The consistency, for example of fitting-accuracy, and assembly can be controlled visually on the screen in the planning phase.
- The complete 3D-simulation automatically generates complete parts and production lists.
- By means of the complete 3D-simulation all the geometric and working data of each component can be obtained and the trimming installation or the wood working centre can be numerically controlled.
- The complete 3D-simulation enables the generation of photo realistic representations by means of shading and rendering. Downstream image processing programs may be used to project buildings into existing surroundings. Use of these techniques can offer decisive advantages in acquisition and sale.

For the simulation of timber constructions powerful 3D-CAD-systems are already available (Kessel, Gnutzmann, 1992). Due to the three-dimensional complexity of the timber constructions they have become more and more popular in practice. In the field of computer-aided manufacturing (CAM) ever more powerful computerised numerical control (CNC) woodworking machines (e.g. trimming machines) are being developed. They allow for flexible, rational and very high quality manufacturing.

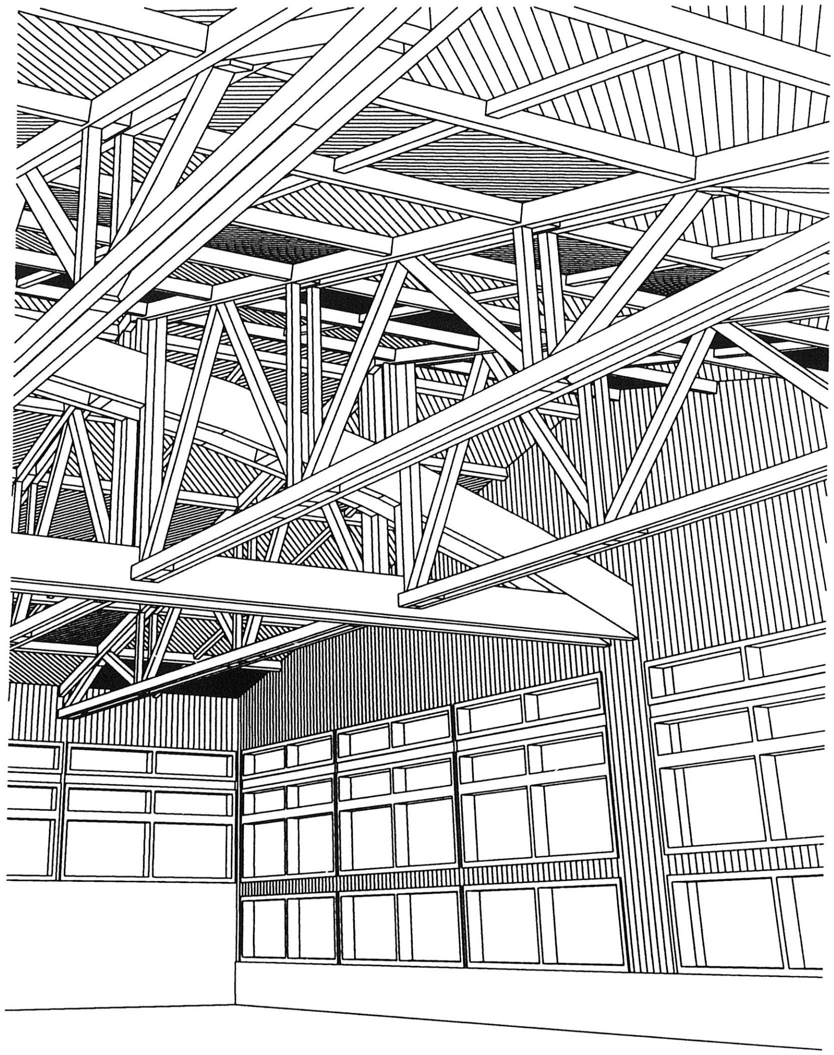

Figure 1 Simulation of a gymnasium.

When combining CAD and CAM, geometric and material information about each component is transferred in the form of parameters from the CAD simulation to the woodworking machine. Each working process on a component consists of several working steps of the CNC machine. The number of steps depends on the complexity of the working process.

Timber and CAD

By the use of CAD it is possible to design a consistent building model with any desired dimensional accuracy of its components. This accuracy is only limited by the accuracy of the numeric representation in the computer. The dimensions of the building model are usually transferred to the manufacturing system by means of shop drawings or records that are used for tracing dimensions of individual components or for direct machine control. When the components manufactured in this way are installed on the project site the building geometry planned should be precisely realised because of the consistency of the CAD model. But the accuracy realised depends on the accuracy of the production and the dimensional accuracy of the construction material used. The latter is especially important in timber construction.

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The target sizes needed for the calculation of the effective cross-section and the geometric properties of the supporting structure and thus the basis for the CAD building model refers to timber with a moisture content of 20%, corresponding to service class 2.

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Therefore the dimensions for structural timber of softwood also refer to a moisture content of 20%. Thus it can be assumed that when used in service class 1 with an equilibrium moisture content of 12% the cross-section will be reduced by several millimetres due to shrinkage. Usually this is taken into account by referring all dimensions in the shop drawing to the upper edge of the component.

In order to meet today's quality demands in building construction only structural timber should be used, the moisture content of which should be equal to the equilibrium moisture content of the corresponding service class. Only when the quality of planning, production and building material is consistent can the building geometry be satisfactorily realised.

3D-CAD-Simulation

CAD may no longer be understood as a tool for electronic drawing alone. The data generated by CAD contain much more information than a conventionally produced drawing and, above all, are much more reliable. This is illustrated in the roof construction in Figure 2.

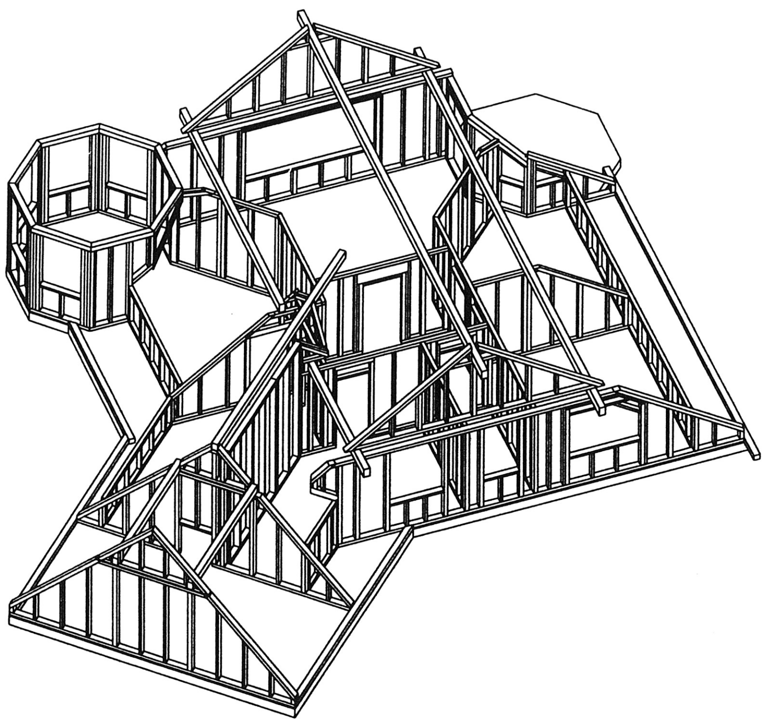

Figure 2 First floor walls and purlins of a house in wood frame construction.

The useful and defect-free development of the detail solution shown in Figure 3 requires an experienced carpenter with a very good three-dimensional imagination for both conventional and 2D working procedures. Even when the carpenter meets these demands the final verification regarding defects in the design can only be carried out in the building process itself. This is the essential difference to the 3D-CAD-simulation of a construction where, by means of immediate visual control, defects can be detected very early in the design process.

Due to 3D-visualisation and extensive edit-functions there is a lot of room for new developments and unconventional solutions. New solutions can be found on the screen and their practicality can be verified at very low cost.

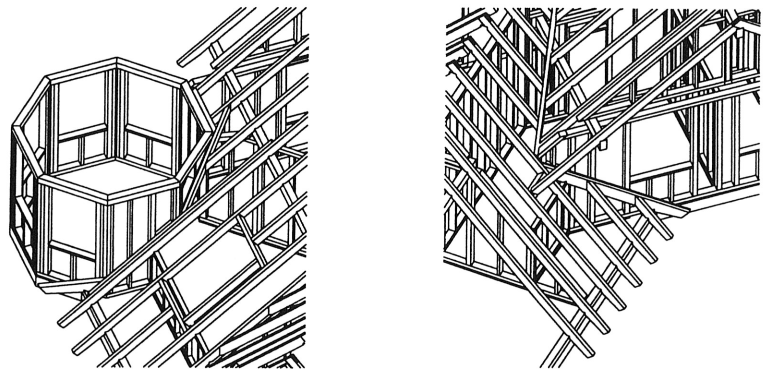

Figure 3 Intersection of the main roof with tower (left) and side roof (right).

The three-dimensional building model is the basis for all subsequent working steps in the design and manufacturing processes. Lay-out plans (Figure 4), projections, sectional views and shop drawings (Figure 5) are automatically generated from the 3D-model. Dimensioning shop drawings is also done automatically for standard components. Therefore the amount of work necessary for postprocessing is usually very small. However, the main point is that because of the consistency of the building model the design is very reliable since, for example, transcription errors are avoided.

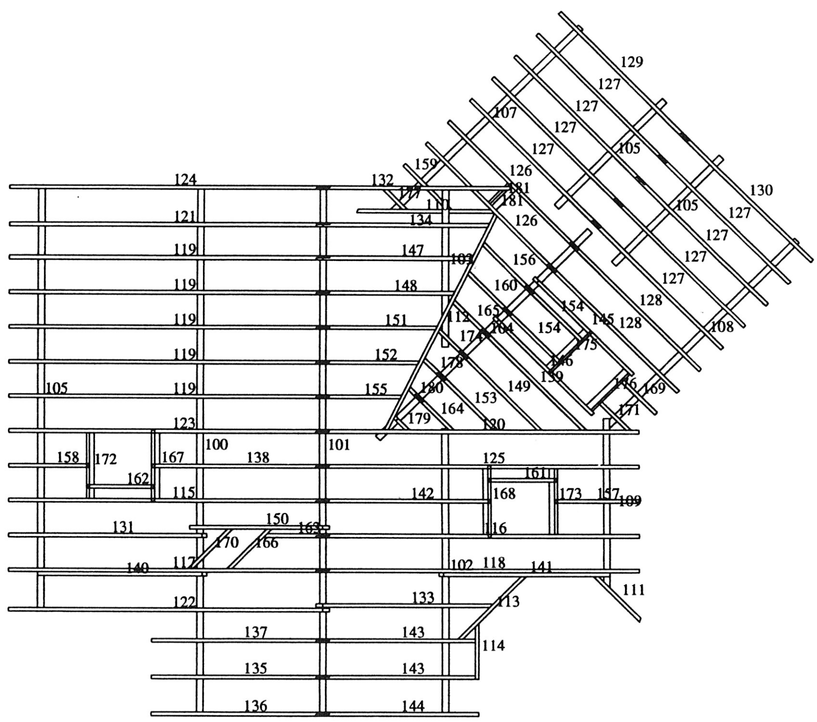

Figure 4 Rafter and purlin layout.

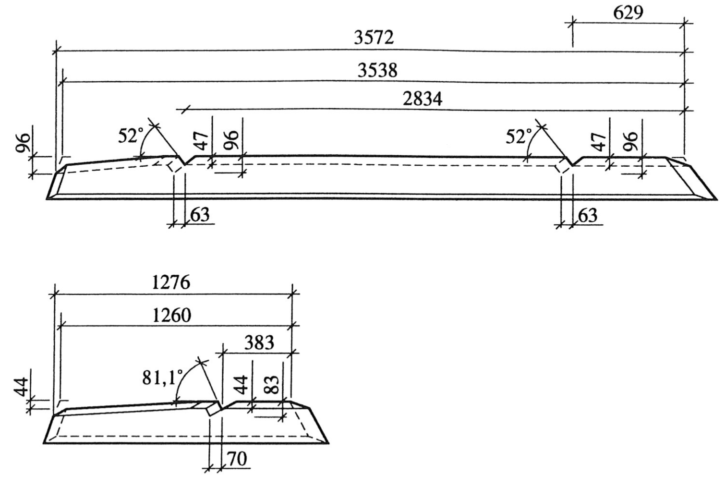

Figure 5 *Shop drawings. Top: rafter position 110, bottom: rafter position 111.*

Some time ago CAD was only used as a tool for processing graphic data. Nowadays a complete 3D-CAD-system is able to archive and process non-graphic data. Furthermore, the existing geometric data can be combined with subject-specific data and processed in various ways. An example of this is the fully automatic generation of parts and production lists (Figure 6). These lists are generated by the system without any additional data input on the basis of the current machining state of the components. Subsequently they can be used as an important tool for inventory control, manufacturing, building and calculation.

ARCHITECT	:	....	PROJECT NAME	:	SCHMIDT
CUSTOMER	:	SCHMIDT	PROJECT NUMBER	:	....
COMMENT	:	rafters + purlins	DATE	:	18-MAY-94

No.	No.TL	Constr. group	Constr. element	Pcs.	Mat.	b.	h,d	l	l (tot)m	V(m^3)
100	0	PURLINS	CENTRE PURLIN	1	C24	140	240	11713	11,71	,394
101	0	PURLINS	RIDGE PURLIN	1	C24	140	240	11713	11,71	,394
102	0	PURLINS	CENTRE PURLIN	1	C24	140	240	6360	6,36	,214
103	0	PURLINS	CENTRE PURLIN	1	C24	140	240	3547	3,55	,119
104	0	PURLINS	RIDGE PURLIN	1	C24	140	200	6500	6,50	,182
105	0	PURLINS	CENTRE PURLIN	2	C24	140	200	3295	6,59	,185
106	0	PURLINS	EAVES PURLIN	1	C24	140	140	9415	9,42	,185
107	0	PURLINS	EAVES PURLIN	1	C24	140	140	5891	5,89	,115
108	0	PURLINS	EAVES PURLIN	1	C24	140	140	5818	5,82	,114
109	0	PURLINS	EAVES PURLIN	1	C24	140	140	3868	3,87	,076
110	0	RAFTERS	JACK RAFTER	1	C24	80	240	3810	3,81	,073
111	0	RAFTERS	JACK RAFTER	1	C24	80	239	1622	1,62	,031
112	0	RAFTERS	COLLAR BEAM	1	C24	80	220	5747	5,75	,101
113	0	RAFTERS	BAR	1	C24	80	200	2420	2,42	,039
114	0	RAFTERS	BAR	1	C24	80	200	1230	1,23	,020
115	0	RAFTERS	RAFTER-ZA-3	1	C24	80	180	8797	8,80	,127
116	0	RAFTERS	RAFTER-ZA-1	1	C24	80	180	8797	8,80	,127
117	0	RAFTERS	RAFTER-3	1	C24	80	180	8797	8,80	,127
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166	0	RAFTERS	JACK RAFTER	1	C24	80	180	1594	1,59	,023
167	0	RAFTERS	TRIMMER-2	1	C24	80	180	1582	1,58	,023
172	0	RAFTERS	TRIMMER-3	1	C24	80	180	1582	1,58	,023
168	0	RAFTERS	TRIMMER-1	1	C24	80	180	1577	1,58	,023
173	0	RAFTERS	TRIMMER-2	1	C24	80	180	1577	1,58	,023
170	0	RAFTERS	JACK RAFTER-1	1	C24	80	180	1525	1,52	,022
----	-----									
180	0	RAFTERS	RAFTER	1	C24	80	180	665	0,67	,010
181	0	RAFTERS	TRIMMER	2	C24	80	180	600	1,20	,017
TOTAL				82					452,57	7,515

Figure 6 *Production list.*

Computer-aided manufacturing

The use of CNC-woodworking machines (e.g. trimming machines) has substantially increased over the last years. In Figure 7 a NC-record for a trimming machine is shown. Up to now these data are often generated directly on the machine by taking the data from a shop drawing and then transcribing them into a NC-program. On the one hand transcription errors can occur in this process and on the other hand the component geometry is generated twice; once in the CAD system and again on the machine.

012	ba-10-1								
115	RAFTER-ZA-3								
115	1	800	1800	0	0	0			
115	9	0	0	0	200	0	0	0	0
115	1	0	0	0	1040	0	0	0	0
115	3	0	1855	0	1040	0	400	0	0
115	2	0	2431	400	520	0	0	0	0
115	2	0	36446	400	520	0	0	0	0
115	2	0	66002	400	520	0	0	0	0
115	2	0	80951	400	520	0	0	0	0
115	1	1	87967	400	1762	0	0	0	0
115	1	1	87967	0	900	0	0	0	0
180	RAFTER								
180	1	800	1800	0	0	0			
180	9	0	0	0	200	0	0	0	0
180	1	0	0	0	843	0	400	0	0
180	3	0	1809	0	843	0	0	0	0
180	2	0	2410	400	421	0	0	0	0
180	1	1	6075	0	421	184	0	0	0

Figure 7 Machine control (2 NC-records).

Company philosophy and interfaces

Using computers in planning, design and manufacturing offers a large number of advantages. However, benefit can only be derived from them if primarily isolated components such as CAD-simulation were to be integrated into company internal or inter-company philosophies. Then data for machine control could be generated in the CAD-system resulting in substantial time-saving and minimised error rate. The main problems with computer-aided concepts as a whole are the necessary interfaces. In the following the present state and possible developments of the three main interfaces are discussed below:

Man-computer interface

Data input is still very time-consuming since only primitive devices such as keyboard, mouse or tray are available for the interface between man and computer. The improvement of communication between man and computer, i.e. the acceleration of the data transfer, becomes more and more important for further CAD/CAM developments since the computer internal data transfer has been accelerated in such a way that earlier processing bottlenecks, such as the time necessary for producing pictures and calculating the suppression of covered lines, have been eliminated.

Important developments concerning this interface are not expected in the near future. By means of an even more user friendly design of the user surface of CAD-systems only minor improvements can be achieved. A substantial improvement could be achieved if expert knowledge were to be stored in the operating surface. This would have to include the restriction that this knowledge could only be applied on special geometries and designs. An important acceleration can be expected through developments in sensor technology. In this field it might be possible some day to transfer human knowledge into the computer by means of sensors without using manual input devices.

Interface to external programmes

In order to achieve a higher degree of efficiency and reliability it is necessary that generated data can be further processed without having to repeat the corresponding data input. This requires the ability to exchange data between CAD-systems, calculation programmes and CNC-machines. The currently existing interfaces are only individual solutions for communication between specific programmes. Except for a few exceptions (e.g. STEP-2D and DXF) there are no interfaces that have become European standard and that meet all the demands of timber construction. Therefore, a general interface for timber construction is needed (see Deutsche Gesellschaft für Holzforschung 1994).

Interface CAD-machine

CNC-woodworking machines still possess machine specific interfaces which enable the machine to memorise processing records (Figure 7). These highly differing records often describe the geometry of a component incompletely, because only data which can be processed by the machine can be memorised. Therefore a general, machine-independent interface is being developed which contains the complete geometric and specific description of the component.

Due to the often very high complexity of timber components it is not expected to achieve a complete automation of the data generation for woodworking machines in the near future. The automation will at first be restricted to standard components. Therefore a CAD-system should allow the possibility of identifying components or complete construction forms by hand. This can be realised by the identification modules shown in Figure 8.

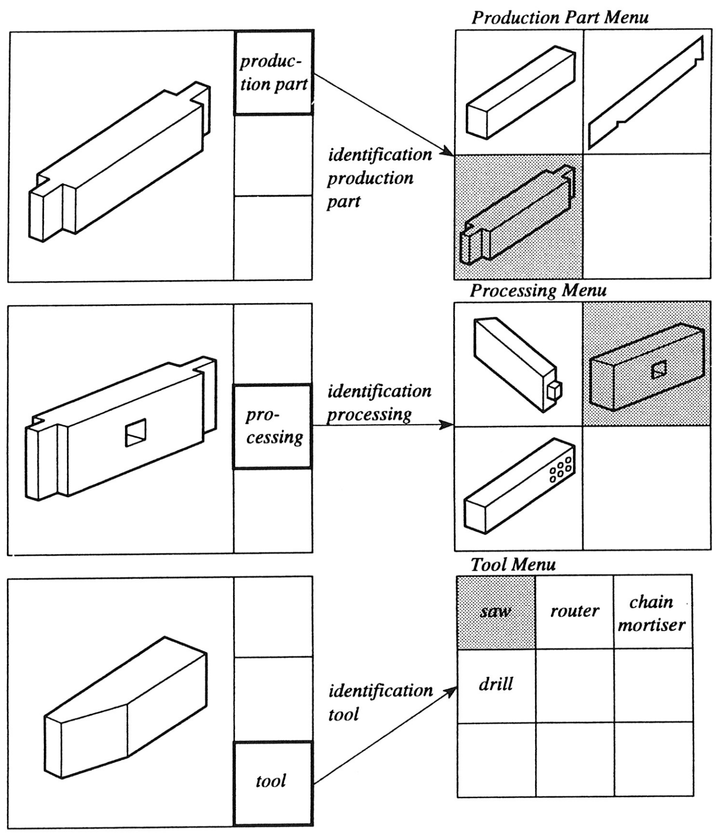

Figure 8 Identification modules.

By means of these modules it is possible graphically to choose the type of process to be used for a component, designed and simulated by a CAD system, from a menu. The choice can be made on three different levels. The menu contains components for which all analysis algorithms are stored parametrically. On the upper level the complete working process can be chosen for a complete component if its form is similar to the form of a component in the menu. At the middle level the process for realising individual details can be chosen in the same way. At the lowest level the machine unit which should work on the component can be selected together with the particular operation that is required. However, the lowest level should only be available directly on the machine since the user must possess machine-specific know-how and furthermore, no machine-specific data should be transferred via the interface CAD-machine.

Staff

The use of computer-aided design and manufacturing systems requires staff that is motivated, trained in computer technology and possesses a good three-dimensional imagination. CAD/CAM does not lower the demands on the qualification of the staff but raises it. Since usually only young employees possess the qualifications required, they should be given the chance to gradually become familiar with the complex CAD/CAM system of the company until they finally master it. However, it must be taken into account that it is not enough to be able to master the technology alone, but also its influences on the design (fitting details) and manufacturing and building processes. So far only a little experience has been gained in this field.

CAD/CAM is not a tool that can be used efficiently if the staff are trained only once on how to handle the system. These systems are still being further developed and in relatively short periods better and extended versions and possibilities will be available. Therefore continuous training courses should be attended and the staff must be motivated, able to detect new possibilities themselves and to use them in the company-specific conditions.

Concluding remarks

- The complete 3D-simulation of a timber construction on a computer provides a consistent model which allows for the visual control of consistency and assembly of all main components already in the planning phase.

- In order to meet today's quality demands in building construction only structural timber should be used, the moisture content of which should be equal to the equilibrium moisture content of the corresponding service class.

- Investments in CAD/CAM-technology are only useful, if the technology will be applied by well trained, motivated and creative staff.

- Only when the quality of planning, manufacturing, building material and staff is harmonised i.e. consistent, can the building construction be satisfactorily realised.

- After 10 years of experience in CAD/CAM-technology in timber construction it can be assumed that future developments will continue to be as fast as in the past, particularly in the fields of CAM, the connection of CAD and CAM and knowledge-based systems.

References

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Deutsche Gesellschaft für Holzforschung DGfH (1994). Projektschnittstelle Holzbau Version 1.04. München.