New tools and methods in furniture design

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Abstract

The ”Material and Design Studio” at Chalmers University of Technology was established with the aim of developing an approach allowing experts in material science, structural mechanics, aesthetics and manufacturing to combine their efforts, with use of IT support, in the designing of new furniture. The long-range goal of this endeavor is to increase the competitiveness of the Swedish furniture industry in various ways: by improving the effectiveness of the designing process, optimizing the use of materials, determining the effects of new combinations of materials, reducing customer complaints and responding more quickly to the needs of the market. The work carried out is being followed with interest by a number of furniture manufacturers, as well as by the Swedish Product Testing and Research Institute and the Swedish Association of Furniture Manufacturers.

In one project, supported by Vinnova (a project entitled ”Innovative Use of IT in an Occupational Setting with the Aim of Creating a Good Working Environment”), several case studies have been conducted. These aim at developing different forms of integrated, IT-supported methods for furniture design and to investigate how a working place where such methods are employed can best be conceived and organized.

The present report is concerned primarily with describing an integrated furniture design procedure of this type and discussing continuing efforts being made to develop and implement new tools and methods for use in furniture design. The report consists of four parts. The first takes up the background of the work. The second part describes an integrated design project that was carried out. The third part presents an example of how the IT support tools that have been created were used to solve concrete problems in two separate furniture companies. In the fourth and final part, the overall results of the projects thus far and the need for future work and research in this area are discussed.

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Background

Swedish design generally, and Swedish furniture in particular, are renowned for their high quality. The lightweight and functional character of Swedish furniture has attracted considerable attention internationally. Nevertheless, the import of furniture into Sweden is increasing more rapidly than the country's export of it. Clearly, the Swedish furniture industry is in need of developing working forms and tools enabling new, attractive and long-lasting furniture to be designed in a maximally effective way in terms both of time and of the utilization of materials.

In a recent report, "Large Scale and Small Business – a Study on Strategic Groups within the Swedish Furniture Industry" (Vinnova Report, VR 2001:41), the following was stated:
"…the Swedish furniture industry is a complex industry with substantial differences between strategic groups, implying that critical issues and need for support varies significantly between different groups of producers. Generally speaking the results show large scale segments to be more profitable and to have a higher growth potential then the small business oriented to strategic groups". Further on it was stated of producers oriented to furniture design that they *"…seem to have a hard time achieving good profitability, in spite of all the attention their products receive."*

The continued success of large-furniture producers such as the IKEA-cluster, and smaller producers as well, is critical for maintaining the positive image of Swedish design. Producers who are dependent upon furniture design operate within an exclusive market segment and need to be able to adapt quickly to changing trends as well as to maintain a high level of quality of their products. The problems of profitability that many smaller producers experience could be due in part to the fact that the series they produce are relatively small, leaving little room for innovative designs that could improve profitability. Using new IT-tools to predict how innovative designs will behave could prove useful as a means of reducing the otherwise extremely high risks involved. For large-scale producers too the use of collaborative methods of design could prove fruitful as a means of maintaining quality control at a time when outsourcing is becoming increasingly common.

Designers nowadays can create 3-dimensional geometric models of furniture with the help of CAD (Computer Aided Design). This allows sketches of furniture to be assessed in different respects at an early stage and the design and details to be readily revised. In the airplane, automobile, machine and building industries, sketching in connection with design often leads to a variety of potential designs that are analyzed in terms of such aspects as deformation behavior and strength, usually by means of computer programs based on FEM (Finite Element Method). The results of such analyses can be visualized in terms of virtual two- and three-dimensional models. In the furniture industry, however, designing aids of this sort are used to only a limited extent. FEM analyses, in order to be really relevant there, need to make use of three-dimensional models allowing the structural mechanical characteristics of furniture joints to be studied and, in the case of wooden furniture, permitting the characteristics of the wood in different directions within it to be examined. A particular difficulty with wooden furniture is that of modelling glued joints. Few of the FEM codes that are commercially available can do this satisfactorally.

Although so-called CAE (Computer Aided Engineering) systems in which geometric modelling, construction and manufacturing functions are integrated have been developed, the designing of furniture traditionally takes the use of established models as a starting point when attempting to create new designs. Despite the dimensions chosen for the furniture thus conceived taking account of the loads to be expected, its strength cannot be tested before a full-scale prototype of it has been built. Prior to that, the deformation characteristics of the furniture and its ability to withstand unexpected loads cannot be investigated. With the methods presently employed, furniture of innovative types cannot be produced for sale to customers without comprehensive testing of prototypes being performed.

The combining of IT tools for geometric modelling with the use of FEM analysis and visualization would enable new furniture designing methods to be developed that would also facilitate collaboration with experts in the engineering sciences and in esthetics in the designing of furniture. This would allow work concerning matters of form, structure, strength and choice of materials to be intregrated into a single process.

The project ”Double the strength and half the weight!”, the results of which were reported in part at the Stockholm Furniture Fair in January of 2001, raised two important questions: How should the interface linking three-dimensional models with the physical behavior involved best be designed so as to be accessible to experts of various types? How can knowledge of advanced IT support for integrated furniture design best be implemented for furniture designers and furniture manufacturers, particularly in view of the fact that the IT tools and FEM analyses needed are presently so expensive and advanced that few furniture manufacturers (perhaps no more than the 2-3 largest ones) possess the specialized competence that would be required. The work reported here can be seen as being in part a continuation of that project.

Projects in parallel

The report deals with one of several projects currently in progress at the Material and Design Studio at Chalmers, all of them concerned with IT support for furniture designing in an industrial context. Various of the further projects are taken up in detail in a series of separate reports.

Olle Anderson's [1] report *Nya designmetoder för möbelbranschen, Redesign av Karmstol KS 263* ("New methods of design in the furniture industry. Redesigning the armchair KS 263") is a commentative summary of the project "Double the strength and half the weight!". Dealing with the work of furniture designers within the project and their assessment of the project, it aims at making the results accessible both to furniture designers and to representatives of the furniture industry.

The report *Use of Static Eigenmodes in Mechanical Design* by Karl-Gunnar Olsson and Carl Thelin [2] concerns a new approach to describing the inherent sensitivity of an object such as a piece of furniture towards loads of varying size and type. An example is presented of the three-dimensional deformation behavior of a piece of furniture and of the strain energy required to create deformation. The major problem considered is that of unexpected and unknown loadings of the object that can occur. The form and material properties of the object and their effect on the object's stiffness and strength can then be studied with the use of different animated deformation modes and the load states corresponding to them.

The report *Provning av trämöbelförband* ("Testing joints in wooden furniture") by Bertil Enquist, Hans Petersson och Karl-Gunnar Olsson [3] concerns a series of tests of joints in wooden furniture carried out within the "Double the strength and half the weight!" project. Joints are often the most complex parts of a piece of furniture and are often too the parts that largely determine the furniture's strength and stiffness. Particular limitations of computer simulations are that it can be difficult to assign initial values to stiffness of joints and to compute the strength of complex joints. More than 30 chair joints were constructed and their stiffness, strength and resistance to cracking were investigated. The results obtained should be highly useful in providing a basis for developing a more systematic approach to testing of both the material and the joints used in furniture.

The report *Applied visualisation of structural behaviour in furniture design* by Pierre Olsson och Karl-Gunnar Olsson [4] deals with a computer interface that can serve as a sheet or sketching pad on which designing can take place. Examples are presented showing how this interface, with its symbols and diagrams, can provide a common language for uniting the designing efforts of persons of varying knowledge and background, contributing to the creative process involved.

Collaborators

The knowledge and experience of the Material and Design Studio staff, of designers and of furniture industry representatives were utilized in the efforts reported here to develop new tools and new methods for supporting furniture design. The results obtained were achieved through the collaboration of all those involved.

The section of the report that follows deals with how two members of the Studio's staff – Per Eriksson, an architect who is also an expert on rapid prototyping (i.e. with CAD, virtual prototypes, 3D scanning och plotting) and Pierre Olsson, a civil engineer who is an expert on applications and programming involving CAE and FEM – produced a set of two closely integrated computer programs aimed at facilitating collaboration between persons belonging to two different occupational groups concerned with the designing of furniture.

The insight this provided was the basis then for two case studies. The Swedish furniture manufacturer Svensson & Linnér took part in both studies, the English furniture company HJ Berry participating in the second study, represented by its production manager Mark Barell and its designer Colin Watson. It was the latter who developed the chair that was studied here. The furniture company representatives concerned with production contributed with their special knowledge, providing both a useful orientation to what was realistically possible in this area and insight into new production methods. The designer from the latter company also contributed with his knowledge of design and his views regarding furniture generally.

Karl-Gunnar Olsson, Senior Lecturer in Structural Design, whose specialty is Structural Mechanics, participated in all the meetings and working sessions connected with the case studies dealt with here. Three of the four case studies have been reported to the reference group for the furniture projects conducted within the Material and Design Studio. That group, in turn, has presented various of its ideas concerning coming and future needs for research and implementation in this area.

Collaborative Designing – two initial case studies

The two initial case studies to be described, of exploratory character, concern the attempt to further collaboration between designers and structural engineers in the designing of furniture and investigate how this can function in the best possible way. Per Eriksson and Pierre Olsson were both involved in these studies, conducted at the Material and Design Studio. Traditionally, designers and structural engineers, when confronted with a complex design task, tend to differ in the methods and tools they employ. Engineers attempt to divide a problem into parts and to make predictions for each, analyzing the different parts separately, considering them as a system consisting of a set of well-defined parts. This is often done by use of CAE-software. The designer, in contrast, attempts to grasp the problem in its entirety, viewing matters of structure, function and form as pertaining to the entire system. This difference in perspective has led to much confusion in discussions between members of the two professions. An innovative use of CAE software for facilitating communication enables one to handle both perspectives at the same time. Simulations of an object's overall behavior when deformed or strained as well as in terms of stress can be performed virtually in real time, providing a useful basis for creative dialogue concerning which alternative or alternatives can be best. The case studies carried out aimed at investigating how this could best be done in a practical situation.

The collaborative design process described in the first part of the report deals with a method and a tool for taking advantage of the know-how important for ensuring good quality and adequate control of the product. In the two cases to be described, a designer and an engineer worked together. Their primary aim was to develop a designing approach they felt would be useful, rather than to achieve a perfect design as such. In a later part of the report, possibilities for using the methods and the tool developed in efforts to perfect an existing design are explored. Again, a designer and an engineer worked together. In the two case studies there, the designer made use of a 3D-software package based on NURBS, as well as of a 3D-scanner and a 3D-printer, together with pens, paper and materials used to build a simple prototype in full scale. The engineer used conventional CAE software based on FEM. In order to be able to perform computations and simulations relating to various conceptions developed at the Studio, it was necessary to use the computer programs in ways not planned by those who developed the programs in their original form.

In the presentation of the first two case studies, the approach taken is as follows: The distinction is made between successive stages in the working out of the design, these being referred to in both case studies as designs 0, 1 and 2, presented in that order. In connection with the second stage (design 1), the distinction is also made between three alternative versions that were considered (1:1, 1:2 and 1:3). In connection with each stage, three separate matters are taken up in the order given: the design itself at the stage in question and how it was produced (under the heading of e.g ”Design 2”), simulation of the design (under the heading of e.g. ”Simulation of design 2”) and a summary of what was said or could be observed by the participants in their discussion with each other (under the heading of e.g. ”Results of the dialogue concerning design 2”). Considerable visual material is provided to clarify the characteristics of the various stages and versions of the designs.

First initial case – collaborative design at an early sketching stage

Using collaborative design at an early sketching stage involves shifting between working with a design presented in a 3D-model and making simulations of deformation modes and states of stress. In efforts to close the gap between the know-how of the engineer and of the industrial designer, a continuous process of dialogue was pursued as modelling and simulation were being carried out.

Design Conception

In the one design conception that was explored, a sheet of material to be used in the chair in question was to be formed in such a way that the seat would be comfortable and could readily be stacked. Since use of upholstery would reduce the stacking efficiency, the aim was to achieve comfort by use of an ergonomic shape and flexibile material.

Figure 1 An initial design conception of a chair made of a sheet of material bent in a way intended for sitting comfort.

On the basis of the overall design and a study of the dimensions that could be appropriate, a simple 3D model was first made in the computer. Since a cheap and fast way of determining whether the chair design was comfortable would be to make a frigolite prototype model of it, this was constructed using a computer-controlled (CAM) grinder. MDF-boards shaped in an NC milling machine were used as guides when the frigolite was hollowed out. The backrest was first made thicker than necessary and was then reduced in thickness step-by-step with the aim of achieving the proper degree of flexibility. When persons sat in the chair to try it out, it was found to be too low, which would not have been as easy to detect if one had simply had a computer model available. Computer models cannot fully replace prototypes, but they can be very useful as a complement to them. A 3D (CAD) model of the styrefoam chair was first made by the designer, after which a simulation of its characteristics was performed by the CAE-program.

Figure 2 A Styrofoam prototype used to test whether the chair in question is comfortable enough.

Design 0

Figure 3 Design 0, with the bent section at the back earlier replaced by two legs to improve the chair's stability.

Simulation of design 0

Any object can be deformed in an indefinite number of ways in accordance with the forces applied and the boundary conditions. Eigenmode analysis ranks different deformation patterns of an object in terms of the strain energy (eigenvalue) needed to achieve the pattern in question. The deformation patterns themselves (eigenmodes) are ranked from that requiring the least strain energy to that requiring the most. The eigenmode requiring the least strain, which is called the first eigenmode, represents the way in which the object can be most easily deformed. This method, which analyses an object's "mechanical nature", provides a good starting point for close collaboration between designers and structural engineers. In the present case study, use was made of a static version of eigenmode analysis (Olsson and Thelin, 2002, see above) based not on the material of which the object is made but on the object's shape.

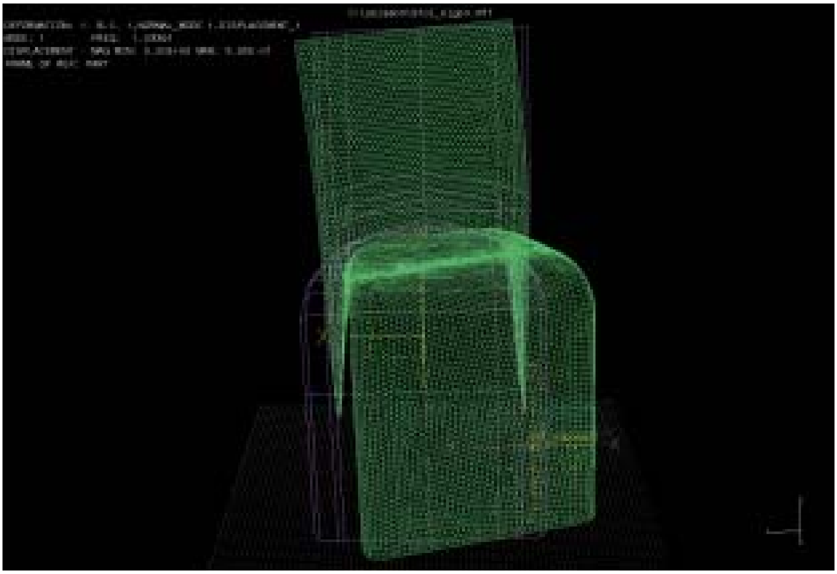


Figure 4 The first eigenmode of design 0.

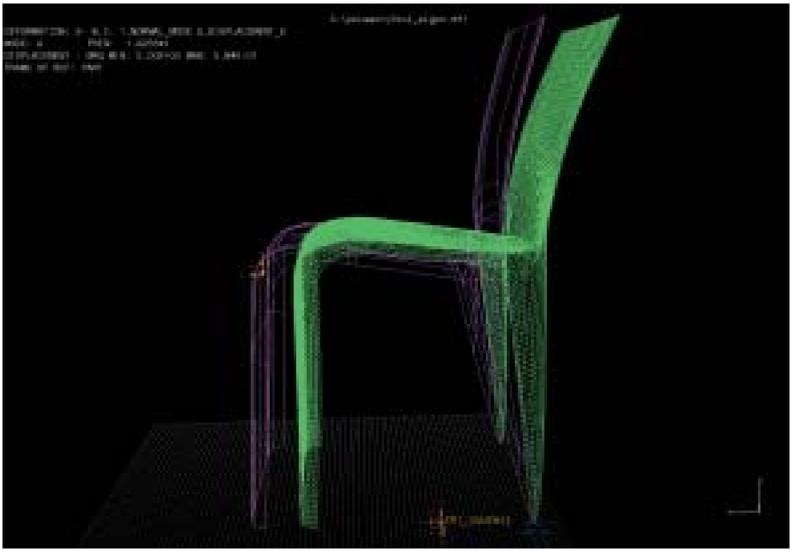


Figure 5 The second eigenmode of design 0.

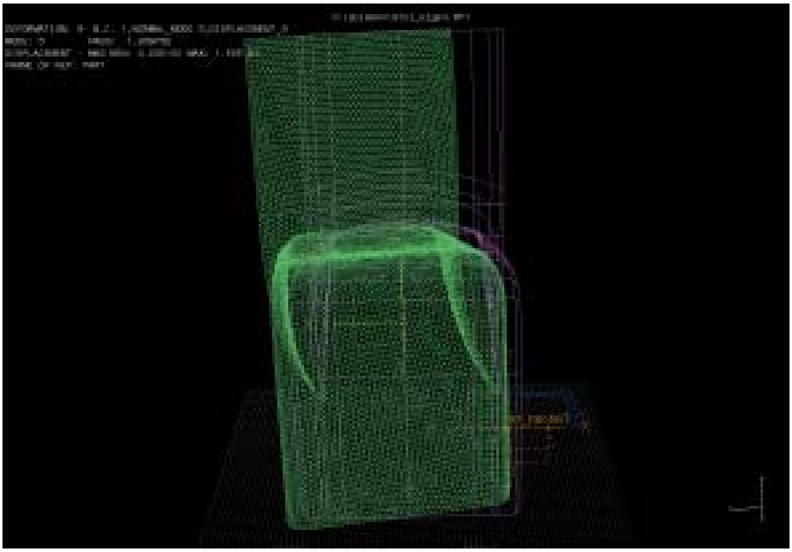


Figure 6 The third eigenmode of design 0.

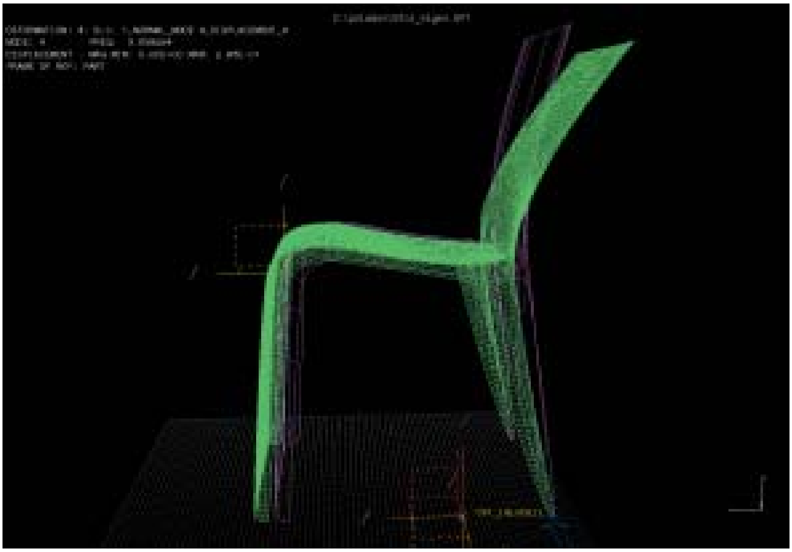


Figure 7 The fourth eigenmode of design 0.

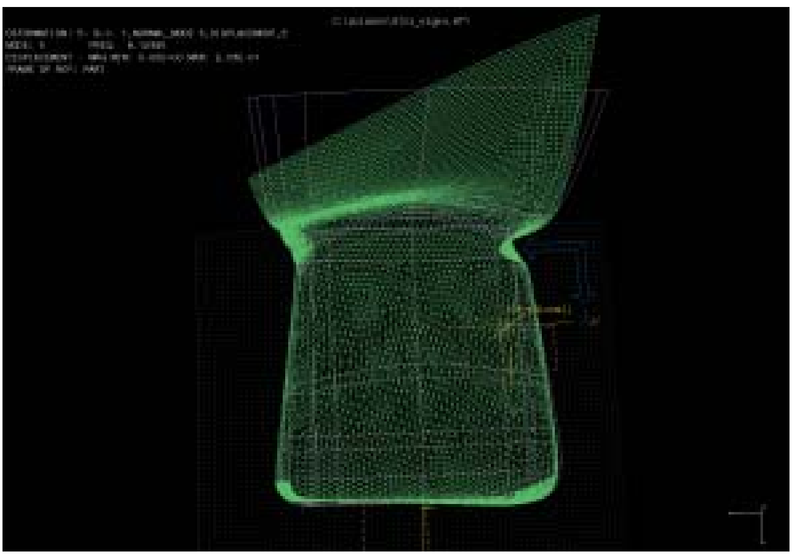


Figure 8 The fifth eigenmode of design 0.

In order to determine how local changes in shape affect the global behavior of an object, the first five eigenmodes from different designs were compared.

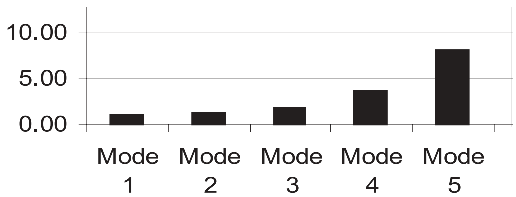


Figure 9 Eigenvalues, design 0.

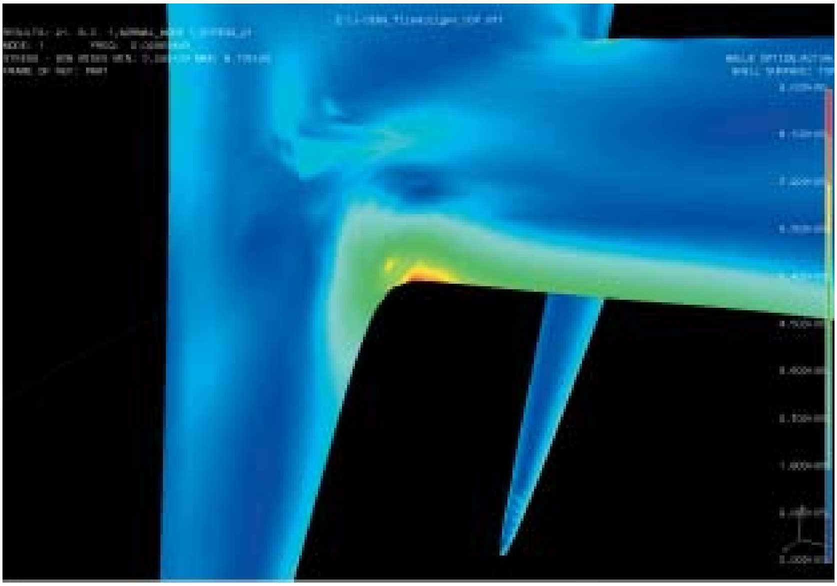


Figure 10 The von Mises stresses associated with the first eigenmode. Detail: the joint between the seat, a rear leg and the backrest.

To investigate how strained the material was, von Mises stresses were shown for the first eigenmode of each design. Stresses were mapped on the surface of the object using a color scale that allowed the stress concentrations that could prove troublesome to be easily identified.

Results of the dialogue concerning design 0

Only the fourth mode possesses the deformation pattern desired. For the first three modes, the shape of the chair had to be changed in order to increase the strain energy required. The von Mises analysis resulting from the eigenmode analysis show internal stress patterns that appear alarming in the area where the rear legs, the seat and the backrest join. One way of solving the internal stress problem would be to add more material to this area. Although this manner of interpreting the results is commonly used in optimizing a structure, it is not the only way of reducing the stress concentrations involved. The stresses in a problematical area can also be reduced by changing the shape of other parts of the structure.

The designer tried here to shape the geometry of the chair so that the seat would be steady and the back flexible. The analysis showed the chair to display some of the behavior desired, although the steadiness of the seat still needed to be improved. The backrest did not move as an element of steady shape and the designer was worried that it might not provide sufficient support. Three different ways of reducing the undesired movements where discussed:

- moving the rear legs farther back,
- making the vault between the seat and the backrest deeper,
- changing the profile of the rear legs and the backrest.

Designs 1:1, 1:2 and 1:3

Figure 11 Design 1:1, in which the rear legs are placed further back in an attempt to reduce the stress concentrations and undesired deformations.

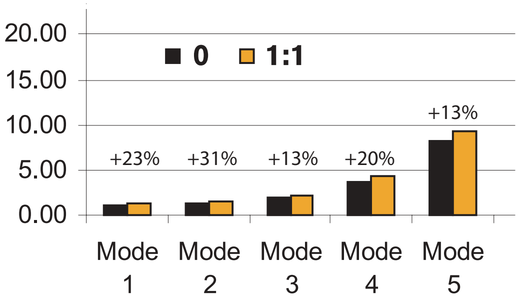
Figure 12 Design 1:2, with a deeper vault between the seat and the backrest with the aim of improving the stability of the chair without adding to its weight.

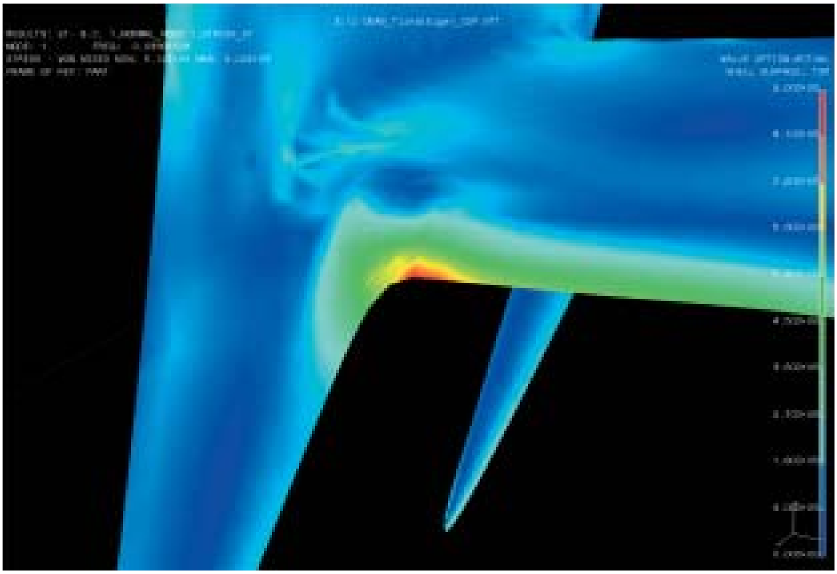
Figure 13 Design 1:3, with a change in the profile of the leg and backrest, seen as another way of improving the chair's stability.

Different versions of the chair were printed out on a 1:10 scale by use of a 3D plotter. No final decision regarding which was best was made then. A model of each of these three alternatives was then produced by use of 3D modeling software. The major concern at this point was not to explore the visual effects of the differences between the different versions but to see in what ways and to what extent changes in shape could improve the behavior of the chair. For this reason, the designer changed only one parameter at the time, although in a practical case it could be preferable to solve all problems at once insofar as possible. The following was found (see simulations below):

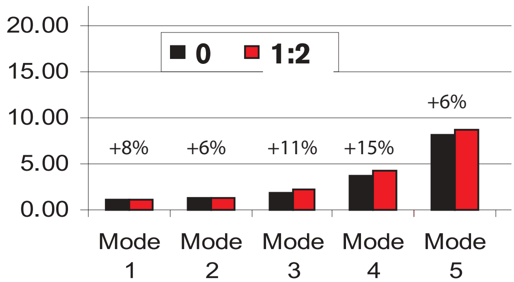
- placing the rear legs further back could be an improvement,
- making the vault between the backrest and the seat deeper might help,
- bending the back of the chair and the rear legs might improve the movement pattern.

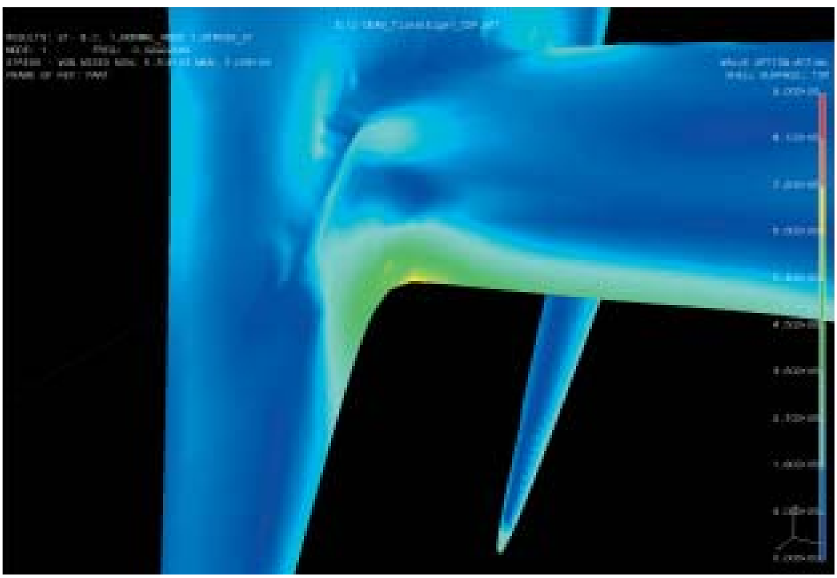
Simulation of design 1:1



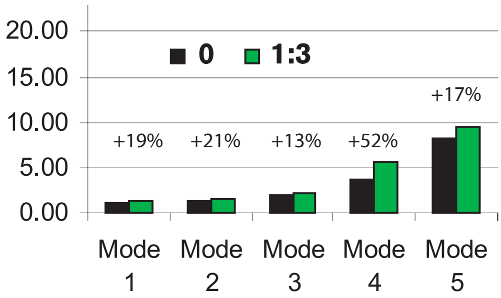


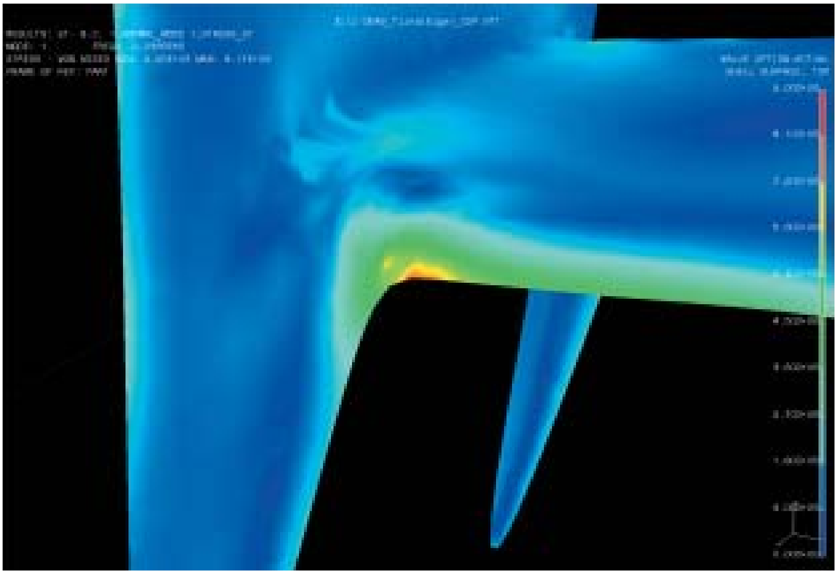
Simulation of design 1:2





Simulation of design 1:3





Results of the dialogue concerning design 1

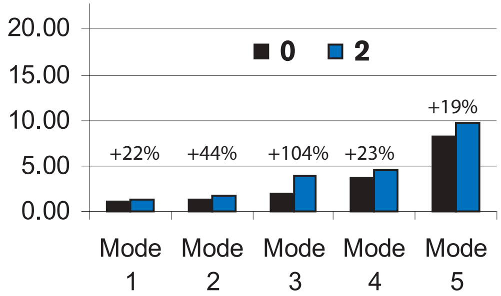
Each of the three alternatives was found to improve the stiffness of the chair, i.e. the amount of strain energy present being greater. On the basis of improvements of this type, design 1:1 was found to be best, followed by 1:3 and then 1:2. On the basis of these results, a new design was proposed in which the ideas contained in design 1:1 predominated and some of the ideas contained in designs 1:3 and 1:2 were also incorporated. Such design decisions also have to include consideration of material optimization and shaping.The von Mises plots indicated the second design idea to be the most advantageous for reducing the high stress values for the first eigen-mode in the connection between the backrest, the seat and the rear legs. Although the second design idea did not reduce the eigenvalues as much as the other design alternatives did, the von Mises plot showed it to have a positive affect of a different type. It was felt that this should likewise be considered in creating a new design.

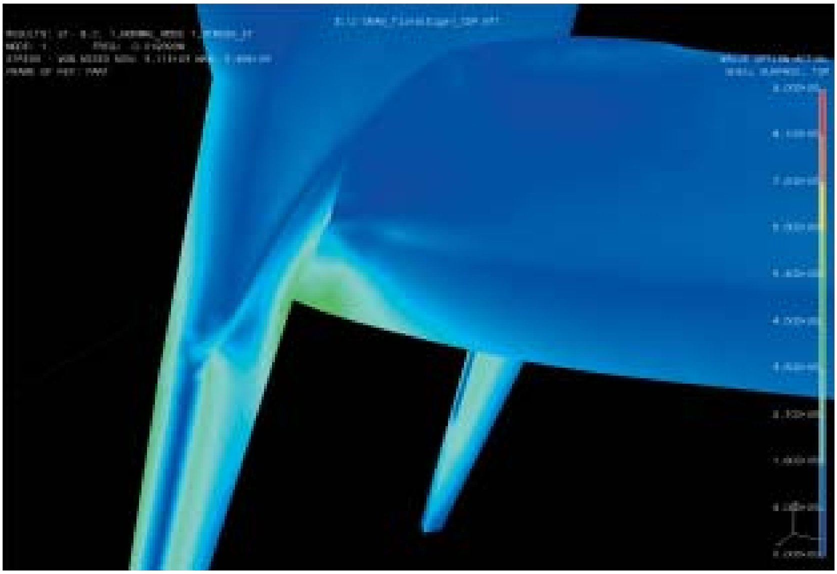
Design 2

The overall shape of this design was a result of what the designer who participated had learned from the earlier dialogue. This design has quite a different appearance. Here, the designer used sharp, well-defined angles instead of smooth curved surfaces, wanting to see how this would affect the chair from an aesthetic point of view. He also wanted to see how it would affect the chair in constructive terms. Although the shape was quite different here, the chair still had the properties the designer had sought in the original chair.

Figure 14 Design 2. Note that although the shape and detailing are quite different here, the chair still possesses the inner properties the designer was aiming at in the original chair.

Simulation of design 2





Results of the dialogue concerning design 2

In terms of the eigenvalues in the simulation, this new design was found to be stiffer, as was intended. This is especially true for eigenmode 3, for which more than twice as much strain energy can be present before it becomes problematical. Here the large local stress values appear to be a greater problem than the stress concentrations, which are smoothed out over a somewhat larger area. The von Mises plot of this design shows greater stress concentrations than in the case of the earlier design, although the local values are not as large. Since both the eigenvalues and the von Mises plot showed better results, this design appeared to be an improvement compared with the earlier one.

Relevant information made available to the designer at this early stage of sketching was adjudged to provide, at least for some designers, an inspiring input that could be translated into form. The process of doing so was viewed as being by no means mechanical or linear. It was pointed out that, as with any design project, the improvement achieved sometimes represents a leap forward, sometimes a step backwards, and sometimes seems to reduce to simply contributing to an understanding of the problem.

Second initial case – collaborative design in product development

Q-chair: Design 0

This chair, referred to as a Q-chair, consisted of a plywood-shell on a steel-frame. It had a formal look. Its flexible backrest and the quilted surface made it surprisingly comfortable.

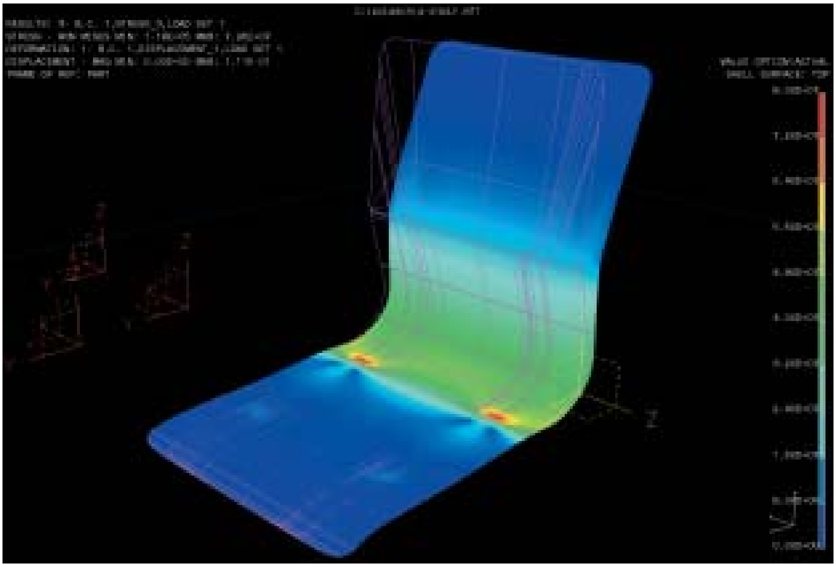
The measures for the chair were obtained using a 3D scanner.

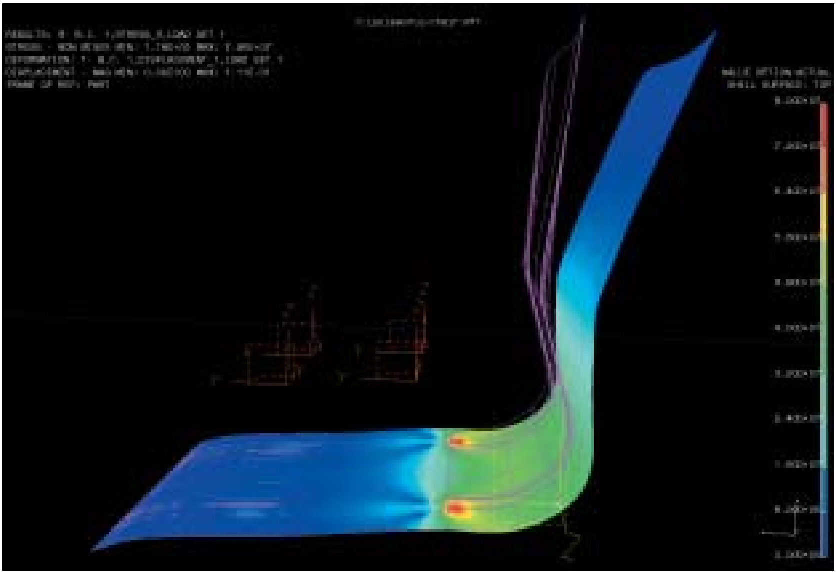
Figure 15 The Q-chair, design 0.

Simulation of design 0

The seat is locked at the four points where the steel frame is fitted to the shell. A load of 560 N is applied to the backrest, see the sketch. The quilting of the 12 mm plywood shell appears to reduce its strength somewhat. In the simulations, it was calculated to have an active thickness in constructive terms of 8 mm.

Figure 16 For the Q-chair, a rough estimation of the deformation behaviour.





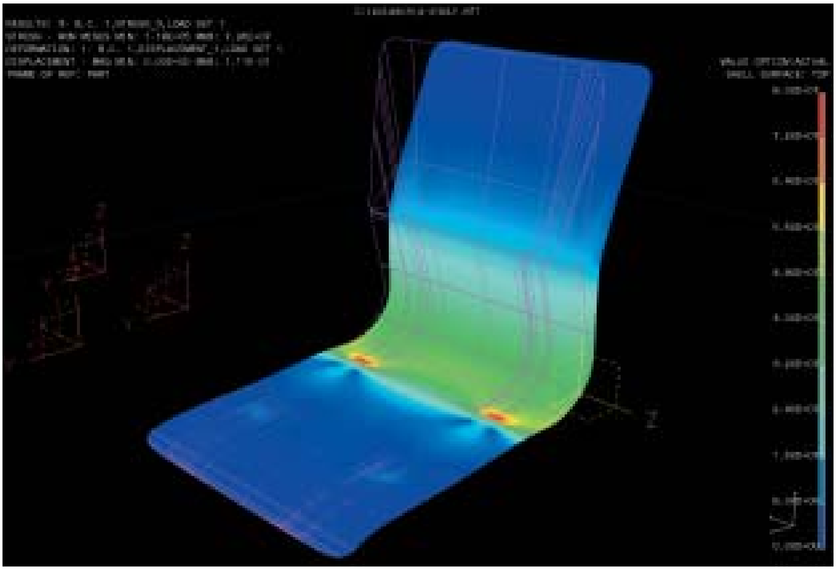
Results of the dialogue concerning design 0

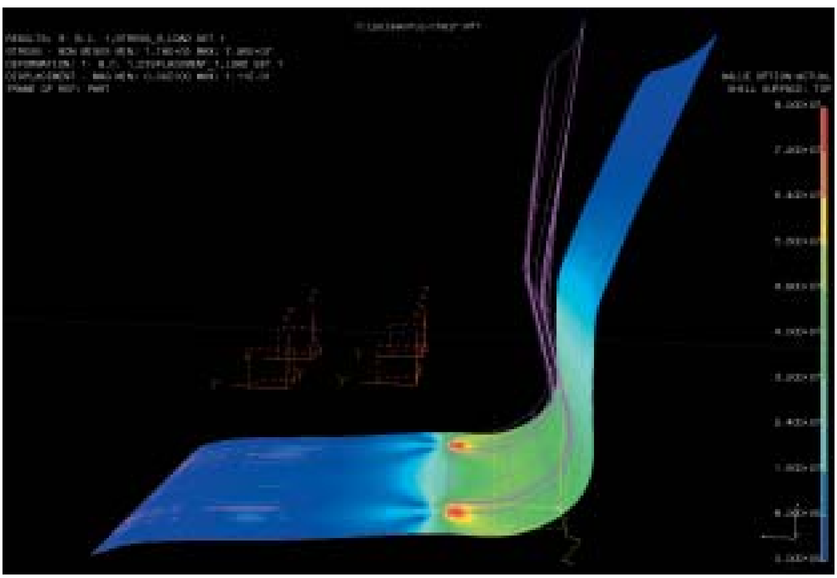
The question in the case of this chair was whether it would be possible to reduce the costs of producing it and at the same time maintain the flexibility of the backrest and the steadiness of the seat. One idea for making the chair cheaper to produce was to reduce the amount of material it contained. Efforts to achieve this began with a reduction in the amount of material in the plywood shell. It was decided that the top deformation value for the backrest could be used as a critical reference value that should not be exceeded after alterations had been made. Pressing the backrest backward in a manner somewhat similar to that of a person being seated in the chair provided a rough estimate of this deformation. It resulted in a critical deformation value of approximately 50 mm. Since the simulation showed there to be a top deformation of 47 mm, it was concluded that this involved a force of approximately 560N on the backrest. The same force was used in the other simulations so as to enable a valid comparison of the critical values to be made. Different approaches to reducing the number of plys used in the shell were tried out. In the simulations of the results this was done by changing the thickness of either the entire shell or parts of it.

Design 1

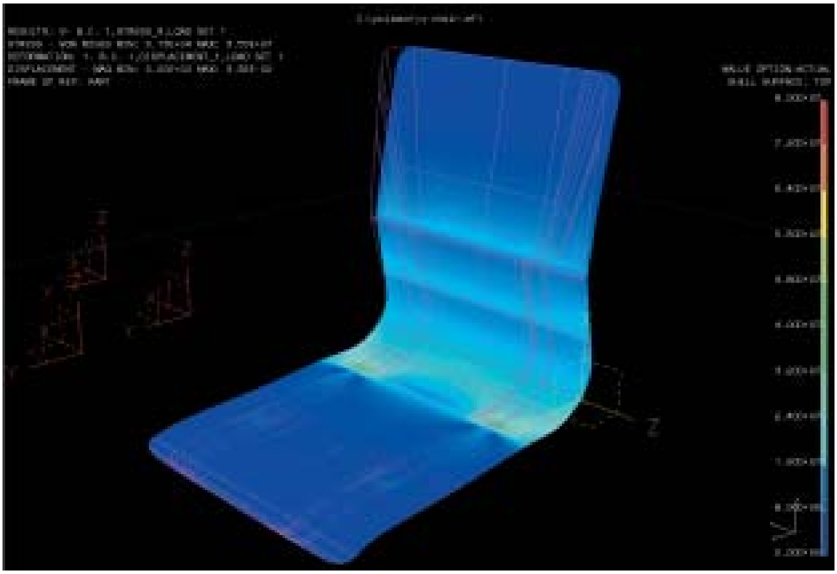
DESIGN 1:1 Reducing the thickness of the plywood shell to 6 mm.
DESIGN 1:2 The shell was divided up into five different parts. At the top and at the front it was made 6 mm thick, where it was bent the thickness being increased to 10 mm, the parts in between being made 8 mm thick.
DESIGN 1:3 The thickness was reduced here to 6 mm at the edges and 8 mm for the rest of the shell.

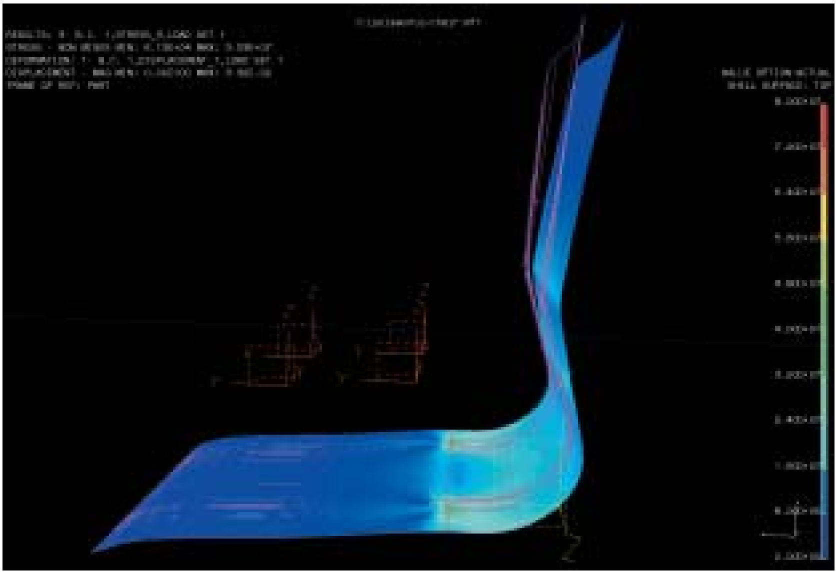
Simulation of design 1:1



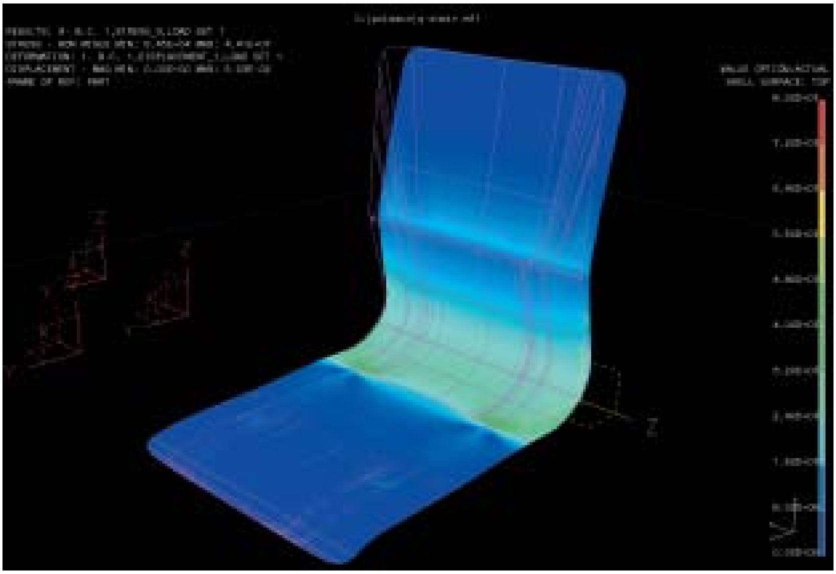


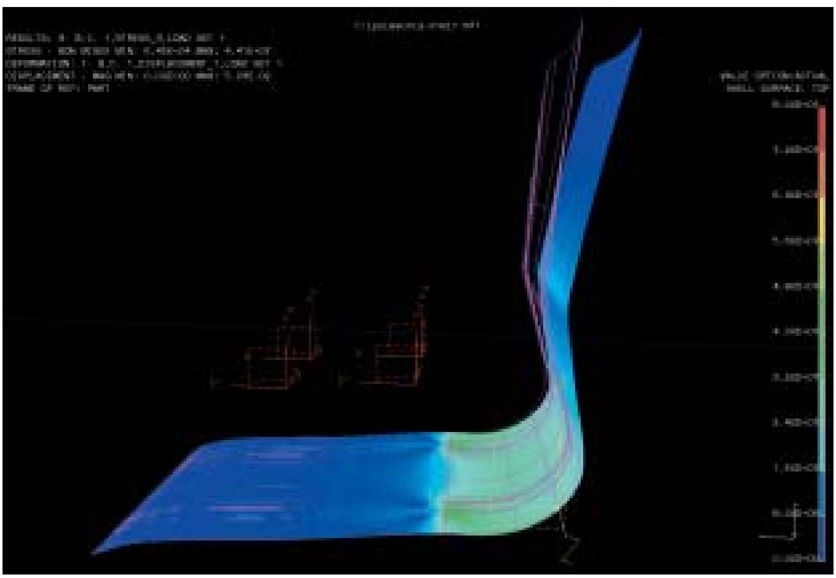
Simulation of design 1:2





Simulation of design 1:3





Results of the dialogue concerning model 1

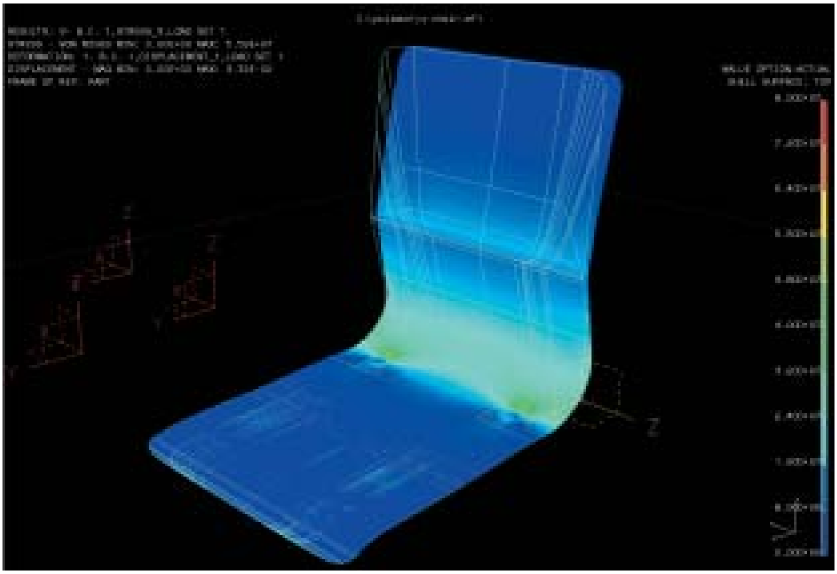
In the simulation 1:1 the critical deformation value was more than doubled as compared with the original chair. The stresses around the fittings were seen as alarming. More subtle changes in form were regarded as necessary in order for such a model to be successful.

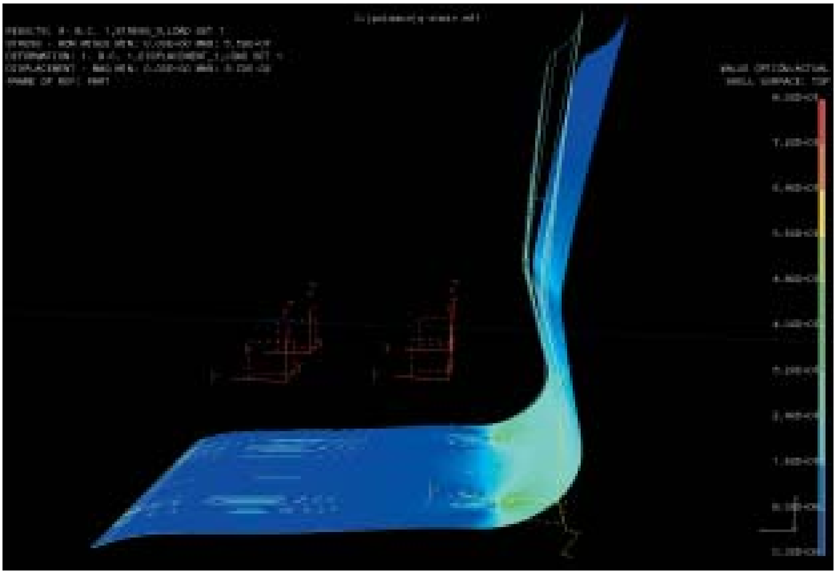
In the second simulation the thickness in the bent part was increased as compared with the original chair. This resulted in the chair becoming too stiff and in very little material being saved. In Simulation 1:3 the deformation was very close to the critical value. Another way of controlling the deformation so as to fine-tune the last small difference in deformation behavior was tried out. The simulations showed that the deformation of the backrest originated from two joints in the plywood shell, one behind the rear fittings and one in the bend between the seat and the backrest. It was concluded that if the fittings were moved further backward, this might possibly improve the critical value. Since Design 1:3 came closest to the critical value employed originally, it was used as the basis for the new designs.

Design 2

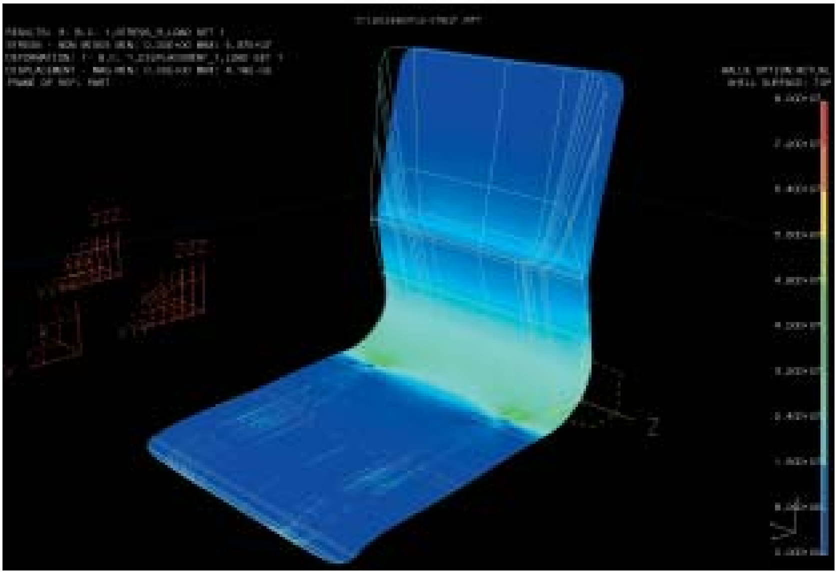
DESIGN 2:1 The fittings were moved back 50 mm.
DESIGN 2:2 The fittings were moved back 30 mm.
DESIGN 2:3 The fittings were moved back 10 mm.

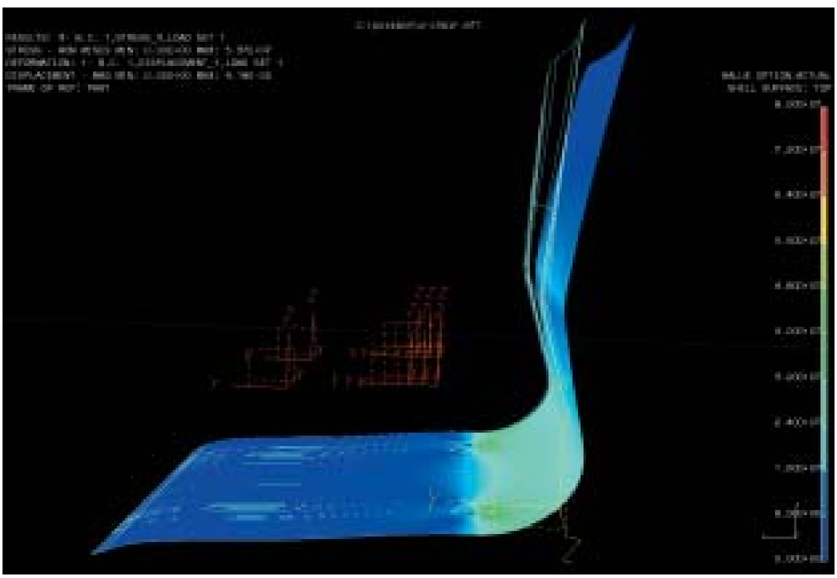
Simulation 2:1



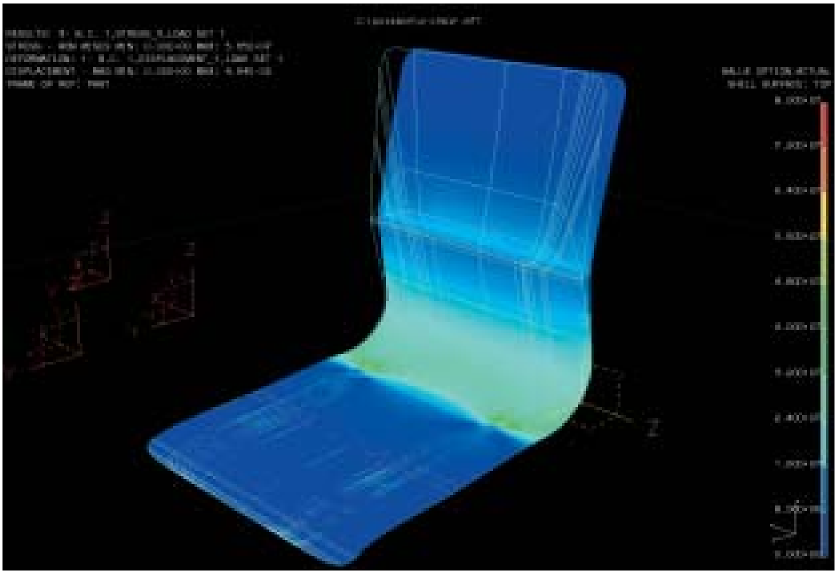


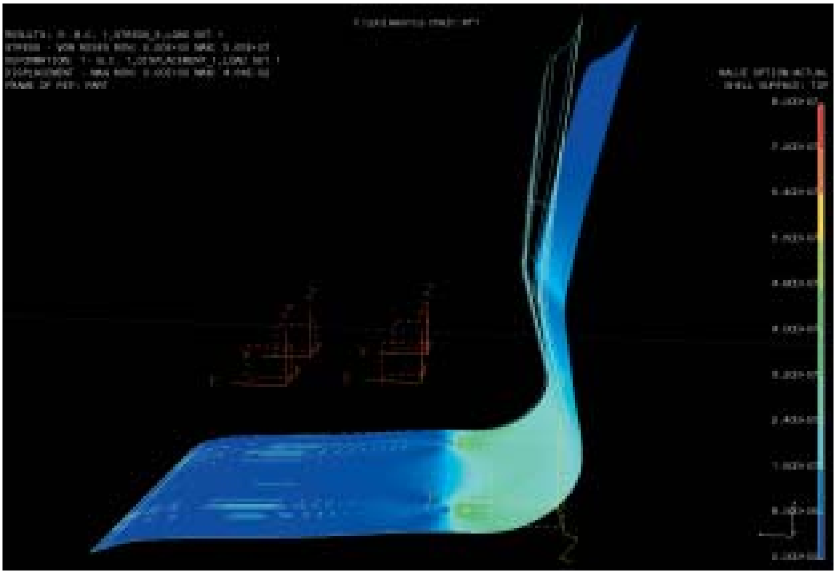
Simulation 2:2





Simulation 2:3





Results of the dialogue concerning design 2

Moving the fittings back 10 mm resulted in almost the same deformation as in the original chair. Here it was possible to save some material without changing the properties of the design aimed at. More importantly, the impact of different modifications could be predicted without a new prototype having to be built.

Conclusions

In early phases of the designing process, the use of eigenmodes gives the designer indications of the overall effect of a particular shape, a particular material and a particular set of boundaries. Analyzing the internal forces and identifying areas of high stress provides information useful for early decisions to be made. Information made available at this early stage of sketching regarding structural matters could be an inspiration to the designer, who could transformed it into concrete ideas regarding shape.

When a physical object such as a prototype is available or enhancement of a product is desired, CAE-tools provide the possibility of trying out a number of different solutions to how a particular detail can be improved. The physical object can provide points of reference in relation to which calculations regarding the overall behavior can be calibrated. The use of CAE tools can increase the amount information to be gleaned from an expensive prototype and can in the long run reduce the number of prototypes needed. When working with objects for which little material data is available, prototypes are indeed particularly useful.

The two case studies just considered emphasize the need for adequate dialogue taking place between the different professions involved. Calculations alone are of little or no use unless they are correctly interpreted. It is important that the designer have a proper understanding of the engineer's use of simulations and calculations so that

3D models that are produced in CAD can be used directly in the CAE program without needing to be modified. One difficulty encountered was that of finding a common approach to geometrical modelling that would work well in both CAD and CAE.

Although the two chairs just considered are in the area of furniture design, the results regarding collaboration in the designing process are of generic value in many areas of design. Two aspects of the designing of chairs, however, that make it of particular interest are that it represents a complex yet limited designing task and that, since CAE-tools are scarcely used today in the designing of furniture, potential for developments within this field are very great indeed.

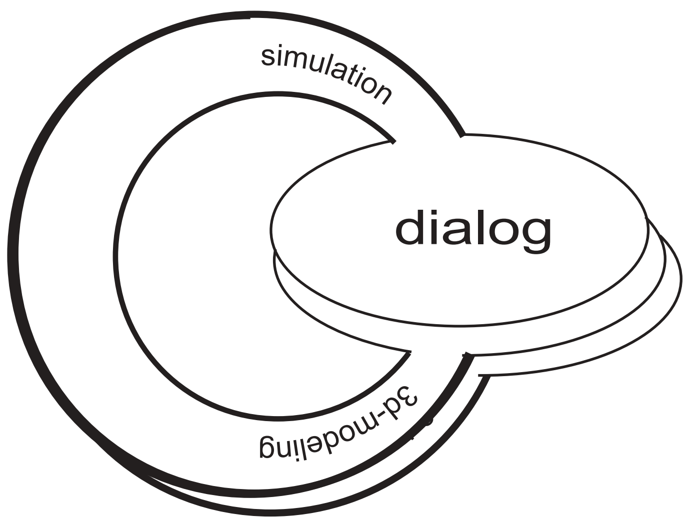


Figure 17 Diagram of the collaborate designing process.

Collaborative Designing – two case studies involving furniture companies

The previous section took up the initial efforts made at the Material and Design Studio of Chalmers Institute of Technology to develop and assess a method for collaboration between experts of differing types in the designing of furniture. The present section considers efforts made to try out this method and the associated IT tool in a practical context in two case studies involving furniture companies.

The first case concerns the use of computations and of visualization of the product so as to provide as adequate an understanding as possible of the behavior of a laminated wooden chair, specifically of the factors dictating what thickness and bending radius of the seat are best, the aim being to facilitate the production of as thin a seat as possible with a more sharply bent contour than the original seat had, though still of sufficient strength.

The second case, similar to the first, concerns the question of how the form adjudged as best for a chair can be affected by knowledge of the paths of forces within the chair and the internal mechanisms responsible for the chair's behavior.

First case – involving the furniture manufacturer Svensson & Linnér AB

Svensson & Linnér AB is a contract manufacturer of furniture and of both laminated and solid wooden products of various types. During 2002 it manufactured a form-pressed laminated seat for a chair to be used in public places. An alarming degree of delamination of the seats at a location where there was a sharp bend between the seat itself and the back of the chair had been observed in several of the chairs during normal use.

The ”Material and Design Studio” considered a problem of this sort to be an appropriate one for trying out its approach on. Particular questions considered were the following: What global and what local factors are limiting ones for the thickness of the seat and the bending

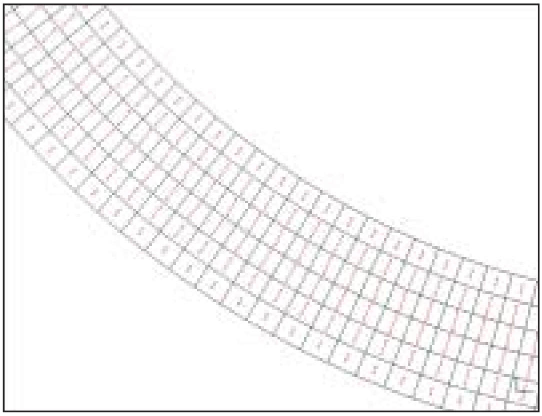


Figure 18 Delamination strains in a chair seat

radius it has? Can an understanding of the seat's behavior contribute to the developing of ideas regarding global or local aspects of the seat's construction which would make the seat stronger? How can the seat be made thinner and be given a stronger angle of bending while still possessing adequate strength?

The seat was modelled and calculations regarding it were by use of FEM. Parallel to this, analytical expressions for the factors that affected the delamination process were derived. The computations showed there to be a strong concentration of delamination strains in the cross-section of the seat at locations where the strongly bent sections began, Figure XX. These strains, perpendicular to the sitting surface, although lesser in magnitude than the forces parallel to the sitting surface, can result in delamination. The FEM calculations and the analytical expressions will be taken up in a later report, Delaminering i sittskal av frompressad kryssfanér ("Delamination of a form-pressed laminated chair seat"), by Pierre Olsson [5].

The computations were made on a chair seat that varied from 6 to 12 mm in thickness, Figure XXX. In investigating the effect of differing radii and thicknesses of the laminate, the load was kept constant. The computations indicate to what extent the strain increases when the bending radius or the thickness decrease.

In its dealings with Svensson & Linnér AB, the Material and Design Studio served as a consultant group. Visualizing the results of the computations made them easy to communicate. Svensson & Linnér AB lacked both the equipment and the know-how that the Studio could make available to them, but at the same time it felt a need in the future to be able to possess or have access to resources of this type. The knowledge the company gained opened the way for for the company's developing its production methods in such a way as to be able to produce very thin chair seats and/or ones of small bending radius that are of high quality. This provides the possibility of their saving on material in new designs they develop.

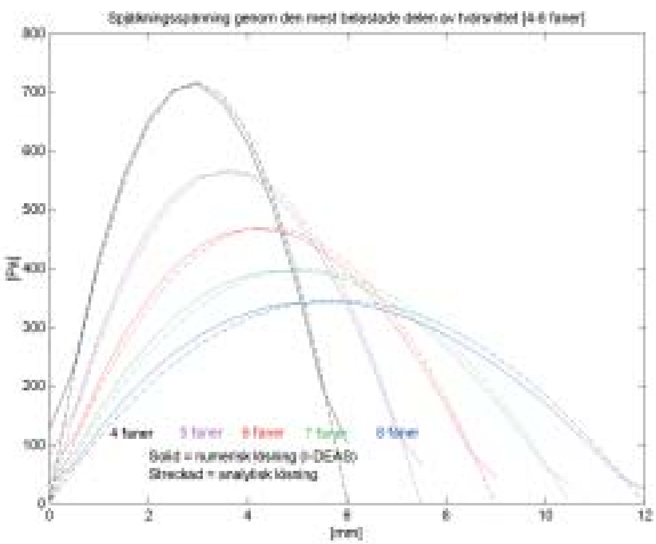


Figure 19 Delamination strains in laminates consisting of differing numbers of lamina.

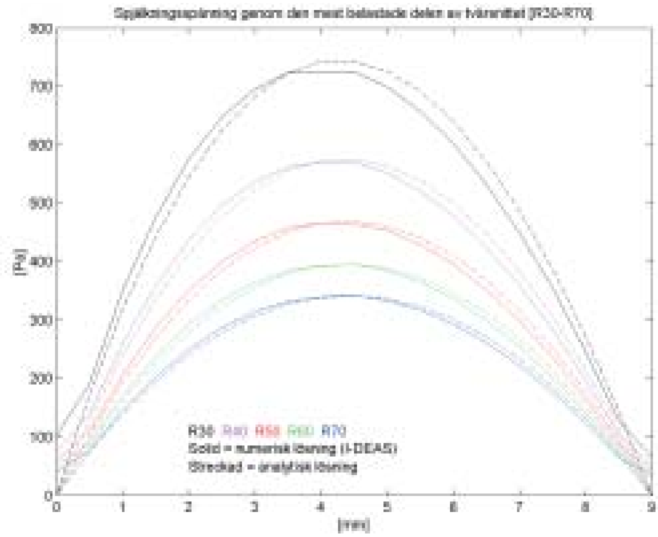


Figure 20 Delamination strains in chair seats with differing radii of bending between the seat and the back of the chair.

Second case – involving the furniture manufacturer HJ Berry

The Material and Design Studio gained contact with the British furniture manufacturer H.J. Berry by way of the Swedish Furniture Component Group, which is engaged in selling Swedish furniture production capacity and know-how to the European market. The British company was concerned about problems connected with the durability and the unneccesary appearing weight of some of its furniture. Its designer sent a 3D CAD model of one of its chairs to the Studio. This model could not be utilized directly since its structure was incompatible with the information use of the FEM program's computational model required. After a number telephone conversations and thoroughgoing changes that were made in the program's geometric data files, it became possible to implement a geometric model that could be used for the FEM analysis. At a workshop held at Chalmers, the chair was analyzed and its weaknesses, together with changes that could be made, were analyzed. Members of the Chalmers Studio along with representatives of the Swedish Furniture Component Group, of Svensson & Linnér AB and of H.J. Berry took part in the workshop. Use was made there of CAE tools for testing various ideas. Methods of making the chair more durable by making it more flexible in certain parts were tried out, an aproach which, though far from self-obvious, was accepted as a promising one after discussions that were surprisingly short. After having understood the principle involved, the designer suggested that cavities be hollowed out or built in to make the seat both lighter and stronger.

The meeting of experts within the areas of design, production and material strength developed to one involving respectful give-and-take in which all the parties participating sought constructive solutions to the problems at hand. The process of collaborative design stretched the borders separating the differing approaches represented through all the actors involved being present and being able to contribute with the knowledge they had.

All those concerned were interested in continuing work with the chair. Although certain problems of financing connected with the fact that furniture companies often have very thin margins of profit are yet to be solved, efforts to solve these problems are underway.

Special aids to communication

A process of collaborative designing places special demands on broadband and on the facilities available for the display of information. A considerable of communication took place in connection with the various cases described by way of Internet. Computer programs of high quality yet low in price for facilitating constructive Internet dialogue are available. The engineer can carry out a simulation by use of a CAE program and let it be displayed both on his/her own screen and that of the designer. The designer, in turn, can point at different spots and locations in his/her CAD model, which can likewise be displayed on the screen of both, to clarify matters that are discussed. If desired, one can also direct a web camera at a sketching block to enable additional information to be transmitted. If several persons are present in a room, models can be projected onto a screen to make them large enough to be readily studied by all. A limitation in this procedure is that it does not allow each of those present to manipulate the model directly. Alongside the computer tools described, traditional sketching materials such as paper and pencil can also be used. Models based on sketches made in this way can also be employed. Scale models created by rapid prototyping can be useful in this connection, paricularly when several persons work in a group.

Results, conclusions and future activities

In this final section of the report, conclusions that can be drawn concerning work with the collaborative designing process on the basis of the four case studies presented, together with questions of of the target groups to aim at and matters of procedure are discussed.

Better knowledge improves competitiveness

Ascribing to use of the collaborative designing process described can have many positive effects. One is that it can help to bridge the gap between the designer and the engineer. InAnother is that it can serve to bridge an additional gap, that between theoretical and practical, production-oriented knowledge in this field. It permits the knowledge and experience of members of the various groups and individuals concerned with the design process to be better utilized, and the time required to progress from the stage of ideas and plans to that of the finished prototype to be shortened. These effects provide a company a better opportunity to develop new designs and new and more effective production methods, making the use of materials more effective and improving quality control, increasing the company's competitiveness on the market.

In adopting an integrated design process, a furniture manufacturer increases its knowledge of how furniture behaves when used and how its behavior in this respect can be changed and improved. The IT-based method described here allows the behavior of a piece of furniture to be predicted in a manner which is not at all possible in the testing of different prototypes by means of applying loads of varying size and type to them. Such knowledge enables the designer to collaborate with both engineers and those involved in production in testing new and innovative forms and the use of new materials without needing to construct and test long series of prototypes. By simulating the global behavior of a piece of furniture, one can gain insight into both its weaknesses and its unused potentials. Similarly, the amount of material employed can be reduced without the strength and durability of the furniture being reduced. The method used in the designing process here can also be used to specify the level of quality one aims at. Since the method can be carried out quickly and is inexpensive, more money can be invested in production itself and limited series of high quality can be more readily produced.

In the cases that were studied, the real-time simulation-based models presented by means of a computer interface facilitated discussions in which all those involved participated. Although the designer and the engineer had the knowledge and skills required for use of CAD and CAE, whereas the manufacturers did not have the same intrinsic possibilities to express themselves or communicate in terms of three-dimensional real-time simulations of the geometry of a chair, the latter had no difficulties in understanding and interpreting what these simulations showed. The functioning of the methods studied here depends not only on the language of diagrams that all the participants were able to understand, but also on the personal attitudes they showed. It appeared to clearly be the case that with an interest of each participant in the knowledge, experience and views of the other participants the collaboration that developed was both positive and fruitful.

Needs of further measures being taken

Only a very small number of case studies were carried out here and each of them required that the CAE tools available be adapted to the needs at hand. The software available today is also not able to provide direct answers to the questions dealt with in the integrated designing process. This means that for the moment particular expertise is needed in order for the computer programs available to be able to provide the computational results and the diagrams that are needed. For adequate computer programs to be developed, a greater number of case studies are needed, so that the requirements such programs should meet in order to be useful generally can be clarified. The collaboration between designers and engineers functions well if each has knowledge of the other's way of working and if modelling routines are employed that all those involved can readily understand.

Also, whereas the computations carried out in the case studies concerned isotropic materials, the furniture industry makes considerable direct use of wood, which is an anisotropic material. Thus, in order for such computation to be relevant generally, the software involved needs to be revised so as to more readily take account of the characteristics of glued joints in wood. In addition, computational models for dealing with glued surfaces need to be developed further.

Target groups

Although the case studies concern furniture design and furniture manufacture, the question of how training in these areas can be integrated into the training provided at universities is of perhaps primary concern here. In addition, since the approach described is general in its scope, it can be used in areas other than that of the design and production of furniture in which a product's weight strength and form are important aspects of design.

Gaining access to target groups

Since further case studies are necessary for the adequate development of the designing process described and the tools it utilizes, it is highly important to establish closer contacts with furniture designers and with the furniture industry. Knowledge of the integrated designing process developed within the Material and Design Studio is made available today primarily through the efforts of a reference group attached to the Material and Design Studio. Among those belonging to this reference group are representatives of the Swedish Furniture Acssociation (SMI) and of the Swedish Institute for Product Testing and Research (SP). At a recent furniture conference the report of this work was adjudged to be the most interesting one of the day.

A workplace for collaborative design

The question of how a workplace where furniture designing is carried on should best be formed and planned was posed before the work reported here commenced. Discussions with the Swedish Institute for Product Testing and Research have been underway for some time concerning possibilities of establishing a workshop or studio there in which the possibility exists both of constructing and testing furniture prototypes in the traditional way and of having access to expert support and IT tools for the assessment and virtual testing of various design ideas.

For many years, SMI and SP have collaborated in ensuring furniture quality by use of a norm termed Möbelfakta, testing furniture by use of a variety of different loads corresponding to both normal and extreme use of the furniture in real life so as to investigate the strength, stability and lifetime of different furniture prototypes. A very considerable amount of knowledge regarding furniture and how it behaves has been gathered in this way. This knowledge could be put to very fruitful use, above all for furniture designing by furniture manufacturing companies, if a combined furniture workshop and design studio were established. Since a certain intensity of use is important if competence in the computations and analyses involved in collaborative furniture design is to be maintained, it is best for as many parties as possible to be involved. The activities of such a combined workshop and design studio could be carried on collaboratively by the Association of Furniture Producers, by one or more universities and by those university departments in which the equipment and expertise that are needed are available.

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