An Approach to Support the Design Process Considering Technological Possibilities

– Referring to the Example of Furniture –

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Doctoral thesis

This is an academic thesis, which the approval of the Department of Art and Design, University of Duisburg-Essen, will be presented for public review in fulfilment of the requirements for a Doctorate of Philosophy in Design. This public presentation will be made at the University of Duisburg-Essen, Essen Library, Universitätsstraße12, 45117 Essen, Germany, on 20 July 2006.

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Essen, März 2006
Alaa El Anssary

Zusammenfassung

Diese Dissertation setzt sich mit den Chancen und Herausforderungen auseinander, die durch technische Möglichkeiten eröffnet werden, wobei neue Materialien und Produktionstechniken in besonderer Weise berücksichtigt werden. Das Hauptziel besteht darin, ein besseres Verständnis des Zusammenwirkens von Design und technischen Aspekten zu schaffen und Designer dahingehend zu unterstützen, bessere Fähigkeiten hinsichtlich der Umsetzung dieser Möglichkeiten in einer frühen Phase des Designprozesses zu erwerben. Die Untersuchung wurde im Bereich der Möbelentwicklung durchgeführt, welche neue Materialien und Produktionsmöglichkeiten als wesentliches Element während des gesamten Designprozesses versteht und Designlösungen entwickelt, die diese neuen Möglichkeiten Rechnung tragen.

Das Forschungsprojekt basiert auf der Annahme, dass aufgrund neuer Technologien heutzutage die Nutzung neuer Materialien mit verbesserten Eigenschaften und die Anwendung neuer Formungstechniken nahe liegt, wodurch die Bandbreite der möglichen Designlösungen ständig erweitert wird. Sie bieten ein enorm großes Potential an, Formkonzepte neu zu überdenken. Dies dazu führt, dass Produkte nicht allein den funktionellen Anforderungen genügen, sondern dass sie auch emotional und intellektuell ansprechend sind. Gleichzeitig können diese Möglichkeiten den Designern eine vielseitige Reihe von Entscheidungen eröffnen.

Die vorliegende Dissertation hat drei verschiedene Anliegen: Sie bezieht sich erstens auf ein neues Verständnis technischer Möglichkeiten bezüglich der verschiedenen Designaspekte, indem Designern ein besserer Zugang zu Informationen im Bereich der bereitstehenden Möglichkeiten in einer frühen Phase des Designprozesses eröffnet wird. Zweitens zielt sie darauf ab, die Sichtweise der Designer zu untersuchen, um deren Verständnis des

Designprozesses zu erweitern und ihre Designmethoden zu verändern, sodass neue Arten von Informationen über Technologien in die Gestaltung einfließen können. In diesem Zusammenhang ist es schließlich wichtig, die Art und Weise der Zusammenarbeit zwischen Designern und Ingenieuren in den Situationen, in denen neue Materialien oder Formungstechniken in den Designprozess eingeführt werden, zu untersuchen.

Zwei Arten von Forschungsmethoden wurden angewandt, um ein besseres Verständnis dieser vielseitigen Aufgaben zu erlangen: Einerseits wurden theoretische Forschungsansätze genutzt, um die durch jene Technologien eröffneten Möglichkeiten darzustellen. Diese verdeutlichen die enorme Bandbreite von Chancen im Zusammenhang verschiedener Designaspekte im Möbelbereich. Andererseits wurden empirische Forschungsmethoden angewandt, um "externes" Wissen über Designprozesse zu sammeln, das den Designmöglichkeiten zugute kommen kann. Bei der Durchführung der empirischen Studien wurden drei verschiedene Befragungsmethoden: Erhebungen mittels Fragebögen, *in-depth interviews* und *action research*. Die Ergebnisse der Untersuchung zeigten beispielsweise, dass es trotz der Existenz verschiedener Informationsquellen zu Technologien nur wenige gibt, die jene Technologien für Designer als interessant und nützlich erscheinen lassen. Die Ergebnisse verwiesen ebenso darauf, dass Designer nicht nur unterstützende Methoden benötigen, um diesen Technologien mehr Aufmerksamkeit zu schenken, sondern dass diese Methoden sie auch dabei unterstützen müssen, sich darüber bewusst zu werden, wie effektive Arten von Informationen über Technologien Einfluss auf ihre Gestaltung haben könnten. Zusätzlich zeigten die empirischen Studien, dass es in Kommunikationssituationen verschiedene Barrieren zwischen Designern und Ingenieuren gibt, wie beispielsweise Wahrnehmungslücken, der Gebrauch verschiedener Fachsprachen und ein Mangel an Hilfsmitteln, um das Zusammenspiel von Materialattributen, Formungstechniken und Formaspekten zu beschreiben. Schwierigkeiten wie diese müssen in jedem Fall überwunden werden.

Im Verlauf der Arbeit werden verschiedene Methoden und Verfahren vorgestellt, die den Designer unterstützen sollen. So wurden beispielsweise analytische Verfahren entwickelt, um die technischen Möglichkeiten hinsichtlich der unterschiedlichen Designziele zu erklären und zu verfeinern. Des Weiteren werden Syntheseverfahren vorgestellt, die verdeutlichen, wie die Wahrnehmung von Produkteigenschaften verbessert werden kann, indem bestimmte Arten von Informationen, die aus Technologien abgeleitet werden können, herangezogen werden. Die anderen Verfahren sollen dabei helfen, neue Kommunikationskanäle zu öffnen, um so die Zusammenarbeit zwischen Designern und den Ingenieuren zu verbessern.

Als wesentlichen Beitrag zum Design schlägt diese Arbeit schließlich auf Basis dieser Methoden und Verfahren einen Ansatz vor, ein Modell zu entwickeln, das den Designprozess unterstützt. Dieser beschreibt ein Verfahren, mit dessen Hilfe Designer ihre Fähigkeiten dahingehend verbessern können, jene Möglichkeiten, die neue Technologien bieten, in einer frühen Phase des Designprozesses anzuwenden.

Abstract

This dissertation is concerned with opportunities and challenges for design arising in the context of technological possibilities with a focus on new materials and production techniques. The main goal has been to provide a better understanding of combinations of design and technological aspects. As a consequence, the aim is to support the design process so that it can lead designers towards becoming more skilled in making use of these possibilities early in their activities. The investigation has been carried out in the field of furniture in which new materials and production techniques are considered as an integral element throughout the design process and which develops design solutions that are adapted to these possibilities.

The research project is based on the idea that nowadays, technologies suggest the use of new materials with improved properties and shaping techniques which can constantly expand the range of possible solutions. They offer an enormous potential to think about the concepts of form anew, resulting in the fact that the product does not only meet the functional requirements but also triggers emotional and intellectual pleasure. At the same time, these possibilities can create a complex and multifaceted set of decisions for designers.

The concern of this dissertation is three-fold. Firstly, it is concerned with a new understanding of technological possibilities in relation to different aspects of design in order to improve the designers' access to information about these available possibilities at an early stage of the design process. Secondly, it aims at examining the designers' point of view with the objective to expand their understanding of the design process and to alter their methods of designing by incorporating new types of information into their design processes. In this respect, it is finally important to study the nature of

cooperation between designers and engineers when introducing new materials or techniques into the design process.

Two types of research activities have been carried out to understand these tasks which are quite manifold: On the one hand, theoretical research activities have been carried out, based on a review of publications to study the state-of-the-art of the existing technologies. This overview of recent publications on this topic reveals the enormous range of options related to different aspects of furniture design. On the other hand, empirical research activities aim at gathering 'external' knowledge about design processes that benefit from these possibilities. To carry out the empirical studies, three main methods of inquiry were used: questionnaire surveys, in-depth interviews and action research. The results of both approaches revealed, for instance, that although there are several sources of information on technologies few of them appeal to designers. As a consequence, they do not regard new technologies as being interesting or useful. They also indicated that designers need supportive methods that enable them to capture effective types of information offered by technologies which can have an influence on their designs. Additionally, the empirical studies revealed that there are different barriers which emerge in communication situations between designers and engineers, such as perceptual gaps, the use of different languages, and the lack of tools to describe the interplay between material attributes, shaping techniques, and form aspects. Barriers like these need to be overcome at any rate.

In the course of this thesis, different methods and procedures for supporting designers will be proposed: An analytical procedure has been developed to explain and refine the possibilities offered by technologies related to different design goals. Furthermore, synthesis methods are provided which display how the perception of product attributes can be enhanced due to certain types of information resulting form technologies. The other procedures help to establish channels for improving communication, with the attempt to expand cooperative efforts between design and engineering disciplines.

As the main contribution to design, this thesis finally proposes an approach to build a model supporting the design process which is based on these methods and procedures. This model describes a process with the help of which designers shall become more skilled in making use of the possibilities offered by new technologies early in the design process.

Das Problem zu erkennen ist wichtiger als die Lösung zu erkennen,
denn die genaue Darstellung des Problems führt zur Lösung.

Albert Einstein

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Chapter 1

Introduction

1 Introduction

As technology advances, both the complexity of products and the number of goals achieved are steadily increasing. This leads to more opportunities for the products as well as to new challenges for designers. The subject of this dissertation is the design opportunities and challenges offered by new technological possibilities with a specific focus on new materials and production techniques related to furniture design process. These possibilities have always brought design a good step further and an understanding of the uniqueness of their integration in the design process makes new forms available. Over the ages, designers – with their overwhelming imagination and creativity – have always been looking for new materials and techniques and in their design processes they have been supported by new technologies.

In the nineteen twenties and thirties designers such as Marcel Breuer and Alvar Aalto struggled to understand and make sense of the new machine-driven world, and experimented with new materials and manufacturing processes to create new furniture forms. Breuer used tubular-steel to find new ways of producing furniture, creating the first examples of modular tubular steel furniture. Aalto developed a language of curvilinear and organic forms based on his experimental flowing plywood furniture. In the nineteen fifties, a new generation of designers evolved. It was Charles and Ray Eames who used revolutionary new materials and techniques not only to fulfill new functions or for producing low-cost furniture but also for adding new aesthetic values to furniture products.

Nowadays, design is undergoing a phase of change, witnessing an unprecedented explosion of developments of new materials and innovative techniques available to designers. Consequently, there are enormous opportunities of ideas engendered by the advances in technology. In her recent publication, *Mutant Materials in Contemporary Design*, Paola Antonelli

[1995] indicates that “new technologies are being used to customize, extend, and modify the physical properties of materials, and to invent new ones. Materials are being transformed from adjusts in passive roles to active interpreters of the goals of engineers and designers" [p. 9]. Furthermore, every traditional material can become a “new” material through the adoption of advanced shaping and production processes.

The present technologies are not limited any more. Not only the range of materials has become much greater, designers can also choose from a number of materials to combine the best features of two or more materials into a single new one called alloy or composite. On the one side, these possibilities can expand the range of creative potentials to reconsider the concept of form and the expression of an object, while on the other side they might reduce the range of potential developments, creating a complex and multifaceted set of decision points for designers. From a different point of view, without the awareness of new technological constraints, we can only fantasize and flounder along as we are not able to put our ideas into practice. Today, each new material or process is developed by new technologies to provide a sustainable future. In this context, designers have the responsibility to contribute to the future of modern society. They and other professions might guide technologies towards a harmony of means and goals and thus towards perfection in design [Antonelli, 1995 and Stattman, 2000 and 2003].

At this point, it is important to bear in mind a fundamental fact: Despite the increasing influences of new technologies on design aspects, designers do not have adequate support to consider them during the design process. Therefore, most designers avoid making use of them or make a conscious effort to escape from using technology. Rames [1983a] asserts that designers are often faced with adverse criticism which includes confronting them with new available technological possibilities. This results in a technology shock which sometimes occurs even in our own scientifically aware generation [cited in Cornish, 1987, p.10]. For the designers of today and the future, the situation will become more complex if they intend to work in the field of possibilities made available by technologies. New or improved materials and better processes are the result of an “underpinning technology” which can stimulate innovation and improve product qualities. This refers to the huge issues that design can master. Therefore, in the future, there will be ever-increasing challenges and opportunities at same time.

To face these, not only an orientation among the numerous options offered by technologies must be found, but the designers must also expand their understanding of the design process and alter the methods of design in order to incorporate them effectively in new products. One of the questions which first arise in this context is of course: WHO can achieve a better understanding of why certain constraints exist due to technology? Who can look for innovative methods of overcoming these constraints? The contention of this thesis is to investigate whether designers are able to overcome these constraints. This leads to another vital question concerning the HOW – the way that designers will proceed to filter new technologies, fitting them appropriately to what people actually want and need. This dissertation seeks to provide answers to those questions and also to many of the other questions used in the investigation to validate the assumptions of this thesis.

The overall research approach considered in this thesis is illustrated in Figure 1.

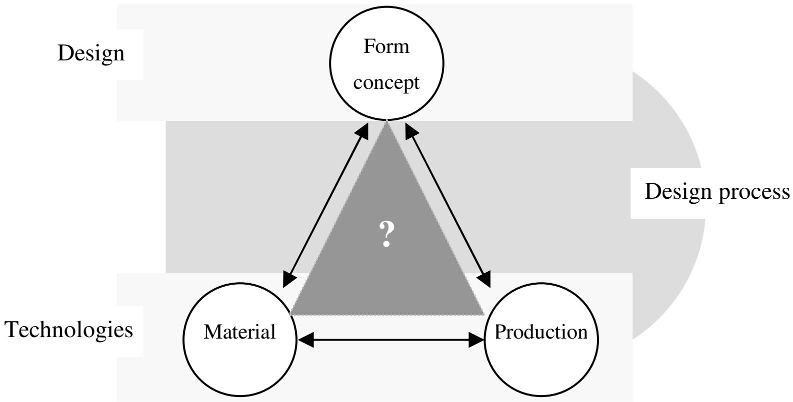


Figure 1. Reasoning scheme for the hypothesis on which this thesis is based. It adopts an expanding approach to the design process which includes the elements of interaction between the two fields of design and technology. Here the question mark in center of the scheme represents the questions WHO? and HOW? That are used to validate the assumptions of this research project in the field of furniture as the subject matter of this thesis.

1.1 Incentives for the research project

This research project[1] was carried due to a number of incentives, which have contributed to developing an approach supporting the design process. A wide range of personal experiences in the course of working in design education and from the world of practice have contributed to the identification of needs to be addressed. Some of the incentives for this research project are described in the following.

The need to know

All designers, regardless of their discipline, need to be aware of new possibilities offered by technologies which are relevant to their particular field to be able to incorporate them into their designs [Lawson, 1990 and Oakley, 1984]. Being aware of and understanding the enormous potential offered by new technologies today, provides a huge amount of opportunities functioning as a catalyst for inspiration and innovation in design. Related to the possibility of stimulating creative thinking with the help of new technologies focusing on materials and manufacturing processes Ashby and Johnson [2002] state: “New developments in materials and processes are sources of inspiration for product designers, suggesting novel visual, tactile, sculpture and spatial solutions to product design” [p.2]. Furthermore, they can help designers to create a “strong concept”. A strong concept, which is considered as a real-world understanding of materials and manufacturing processes, allows the designers to settle any questions and problems that may arise in the development phases of the idea. Thus, innovative ideas can be realized. Additionally, keeping up to date with the technologies available enables the designers to define appropriate materials in order to improve projects and their phases. They can ask critical questions concerning the integration of new technologies in design. With a good basic knowledge they can discuss problems more effectively, and, even more importantly, they can, as Cornish [1987] points out, understand the answers they receive from other experts [p.9]. In other words, with a good knowledge about the development and the availability of technologies, designers can be inspired and their role in the cooperative design process can be enhanced.

In this thesis, the guiding idea consisted of the following hypothesis: Improving the designers’ access to the information about available possibilities

[1] The research project was supported by a doctorate scholarship from the Ministry for Higher Education, Cairo, Egypt.

resulting from technologies at an earlier phase of the design process has various benefits for the designers.

The need for considering "good design" as a process based on constraints

Although good design is almost impossible to define, Zec [2000] points out that "it expresses a distinction from mere design. Good design is better than just design. Good design, then, stands for a quality which rises above the normal" [p.10]. The benefits of good design are seen in products which are clearly different from others concerning their appearance. Differentiation can be gained by satisfying user benefits in new ways, by delivering excellence in one of the product's physical attributes or by imparting "soft" and immaterial attributes onto the product [Kotler et al., 1996]. However, today, all advanced materials and the techniques of its manufacture have been invented to meet the user needs practically and sensitively. They can help to create good products which have two overlapping roles: products with technical functionality and products with personality.

Yet, creating a good design despite the limits of the capabilities of the technologies available cannot be considered an accident. It is not just a drawing or a set of blueprints, but rather a process that begins with imposing constraints on the idea concerning what is feasible within the parameters of a particular technique or a group of techniques. The form or design of the product is the result of this process. However, for a long time, designers have been facing the challenge of defining its new multifaceted skills. They use different constraints as a key to the design process. For example, Charles and Ray Eames frequently accepted the challenge of furniture design to work within the technological constraints of certain materials and techniques imposed on them. Their works proved that designers are not only able to exploit the technical limitations of their creativity for their designs, but they also identified a "recognition of need", as indicated by Charles Eames himself [cited in: Eames Demetrios, 2001]. Contemporary designers have also begun to adopt various processes with the help of which many good product designs are created despite technical constraints.

A major incentive for this thesis is the conviction that a need exists to support the design process, in order to be able to exploit new technological constraints which contribute to the creation of good design. This conviction has grown stronger during the research project.

The need for a transformation of technologies into the "soft" and immaterial aspects of design

Engineers and technicians transform science into technology. Yet, the role of designers is to transform the technology into usable products [Sommerfeldt, 2002]. During the design process, designers attempt to meet real needs [Papanek, 1984]. They bring technology to the users in a way that is good in more than just a technical way. Their ideas, which are transformed into products, will influence how technology is experienced by the users. As Ashby [1999] points out "successful industrial design tells you what the product is and how to use it, and it gives pleasure" [p. 352].

Nowadays, users of industrial products are looking for more than just function and technical capacity. Users are increasingly looking for emotional fulfillment and they are seeking products that they can identify with [Jensen, 1999]. The emotional factor is particularly important as concerns furniture products. Relating to chairs Fiell [1997] states for instance that emotional persuasion can be derived from both physical contact with the chair and from the active contemplation of it before, during and after its use [p. 13]. The chair is designed to communicate with its users, to expound wealth and style, and to determine the essence of function for human needs. However, some types of knowledge about new materials with improved surface properties and innovative shaping techniques can enable designers to play with these variables in order to create aesthetically pleasing designs that also possess commercial advantages.

Bearing all this in mind, the intention of this thesis is to guide designers towards how they can transform the results of new technologies into concepts that impart "soft" attributes onto their products.

The need for expanding mutual efforts of design and engineering disciplines

Design and engineering are different disciplines that traditionally comprise different bodies of knowledge. Due to the separation of thought and labor in the product design process during the 20th century, designers and engineers are considered as different groups with different objectives and priorities. For the designers, creating aesthetically appealing forms and satisfaction determine the design task. For the engineers, the limitations of production and cost have an impact on the process [Cagan and Vogel, 2002]. If “new” materials or techniques are intended to create a “new” design, the designers and engineers should both be involved in an early phase of the design process. This means that professionals with different bodies of knowledge define a problem, each providing their own expertise by means of communication between both disciplines. In this situation, designers should take the opportunity to cooperate with other disciplines. At the same time, they should prepare themselves for new challenges.

In this context, it is supposed that finding methods to expand the cooperation between designers and engineers could have many positive effects on the design process.

The need for a holistic approach to the design process

As illustrated in the previous section, one of the main challenges which designers will face is how to incorporate possibilities and how to cope with constraints caused by technologies in their designs. Principally, this is the first step towards a holistic approach to the design process. It includes considering effective types of knowledge about technologies related to the form concepts from the viewpoint of appeal, appearance, and performance. In the field of design methodology, there are holistic perspectives originating from the engineering disciplines. They generally put little emphasis on the interaction between form, materials and manufacturing methods from the point of view of design.

In this thesis, an interdisciplinary understanding and a mutual approach towards form concepts and the possibilities offered by technologies of materials and shaping techniques is crucial. It has been stressed that both are complementary. This reveals the necessity of a holistic approach in which utilitarian and aesthetic benefits are merged. A generic approach to the design process is suggested to enhance the ability of designers to comprehensively explain and define the design solutions determined by new technologies. As illustrated in Figure 1, a holistic approach to the design process is supposed to be formulated to form a trinity consisting of form, material, and production. This can provide growing opportunities for creative and innovative designs.

The intention is that the findings presented in this thesis will contribute to fostering a holistic approach to the design process, and that the proposed methods will support designers to be able to add values to their concepts from the technical as well as the aesthetical point of view.

1.2 What is a design process?

First of all, design is a process. The verb design describes a process of thought and planning [Friedman, 2000]. Design is considered as the process that is required for the attainment of goals across a wide range of domains. In this process, the role of the designer includes attempting to transform an existing situation into a desired new situation through identifying a need or problem, analyzing it and finding a solution to that problem [Simon, 1982].

In several studies on design Nigel Cross [1984 and 1999] explains that design processes have some similarities and consistent patterns in three areas: how designers formulate problems, how they generate solutions, and concerning the cognitive strategies they employ. Referring to problem formulation, Cross points out that rather than conquering design problems by first attempting to define them, designers explore the problem and its solution together, using the languages of drawing and modeling. Designers solve the problem by generating alternative solutions as a means of exploring the problem. In the generation of a solution, Cross found that designers impose additional constraints on their work based on their information from different fields. These narrow the solution space and help to generate design concepts which provide the possibility of a solution to the design problem. Designers change their goals and adjust constraints during the design process. The third area is the use of cognitive strategies during the design process which include forms or ways of reasoning that are particular to design thinking.

However, design is not only a process of designing to find a solution to the problem. Design is often classified by its outcome. According to Friedman [2000], the outcome of the design process may be a product or a service, it may be an artifact or a structure. The final product is something that is formed by the design process and exists after the design process is completed. Lawson [1990] indicates that the reason for this type of design classification is actually a reflection of “increasing specialized technologies”. The knowledge about technologies has an important impact on the understanding of the design process. Lawson further states that designers adopt different approaches to different design situations and they require expert knowledge to reach a good solution to the problem. He explains that designers must have a good understanding of the technology in their field, a well-developed aesthetic appreciation, and an understanding of the users' needs. Above all, they must be able to establish a connection between them during the process of design.

Although these two authors have a different approach to the question of what the design process is, they agree that adopting constraints during the process of design affects the designers' work in a positive way. Cross analyzed the characteristics of different design processes and found out that designers impose constraints on their work to narrow the solution space and to generate concepts which helped them to find answers to the design problem. Lawson explains the process as being purely individual, yet it is influenced by the different impacts on designers that derive from technology and other factors related to the final result of the design process.

This thesis focuses on supporting the process of design so that designers can arrive at a better understanding of constraints presently offered by new technologies. The purpose of a better understanding is not only to guide designers towards being aware of these constraints to some extent, but also to look for methods of design to overcome these constraints. These will be applied during the process of furniture design.

1.3 Furniture design

It seems that nearly all designers are attracted by the idea of designing a piece of furniture. Architects are convinced that a chair is architecture on a smaller scale; industrial designers are intrigued by the problem of combining mass-manufacture, modern materials, new technologies, and good looks [Dormer, 1987]. The extraordinary diversity of furniture designs, which is particularly inherent in a chair's design, can be considered as a reflection and explanation of the developments in technology. As George Nelson pointed out in 1953, "every truly original idea – every innovation in design, every new application of materials, every technical invention for furniture – seems to find its most important expression in a chair" [e.g., Fiell, 1997].

The reactions towards the progress of technology and its effects on the furniture design process have really changed over the years. For example, during the forties and fifties radical modern furniture embraced a wide range of new technological possibilities. Due to the conditions of war, many American and Scandinavian designers were initially prompted to create simple products that could be produced quickly without the necessity of investing huge amounts of money. Later they were genuinely interested in and curious to seek new ways of design with the help of new technologies. A good example is the Panton-chair designed by Verner Panton. This absolutely timeless creation reveals an understanding of the enormous potential of composite materials and their techniques. Panton succeeded not only in designing a chair shaped and molded from a single piece of plastics but also without legs. He wanted to eliminate the "forest of legs" which was needed to support conventional chairs. He separated the concept of sitting from the stereotypical concept and he sought to simplify the production process aiming at making it easier and more cost-effective. The chair would be also easier to stack, thus increasing its practical appeal to consumers [Bucquoye, 2003], see Figure 2. On the whole, the typical properties of the materials and new shaping techniques constituted the basics for the rise of new trends as well as unique and new furniture designs during the last fifty years.

Figure 2. Since 1967 the Panton chair has been produced of four different materials. Figure 2 shows the latest version (1999) made of polypropylene. With the new materials, the methods of production changed. Both had an impact on the formal appearance of the chair. Since 1967 the chair has been produced by Vitra.

The present situation is noticeably similar to the period after World War II. Furniture design is passing through a phase marked by new attention to developments due to the abundance of new materials and production technologies. This and many other reasons, for example the economy and sensibilities that develop in the world of today as well as the environment and the strong political consciousness worldwide have lead to a lot of changes. Design trends can generally be considered as an accurate reflection of some of these changes. Therefore, a sustainable future of design can be achieved by considering more possibilities and the continuous evolution. “More possibilities” as Paola Antonelli points out is today’s motto [cited in Nichols 2000, p. 186]

In the context of new technologies, design experience is often required at an early stage to make use of these developments. Designers should be aware that a large body of expertise is available in several forms. It is in their best interest to use this when considering designing with new materials or techniques. Designers with good knowledge based on the new developments in the technological field can re-design conventional forms sometimes leading to a breakthrough. In this way, many forms may be re-created using new materials with improved attributes – structural and tactile – as well as the new ways of processing. In general, the technological advances can motivate the designers of today to create radically novel shapes for furniture which are similar to those furniture breakthroughs of the last century. They can offer designers a new freedom not only to create objects with new functions but also objects that are more honest and include “soft” aspects.

In this research project the aim was to study the influences of new technological possibilities on furniture design. This included an approach towards how furniture designers can be supported to reconsider new functions, aesthetics, and, above all, how new concepts can be achieved by the use new technologies.

1.4 Scope of the research

1.4.1 Objectives of the research

The primary objective of this research approach is to develop design methods that will take into account the new possibilities offered by new technologies in early design stages. The progress of new materials and techniques is more advanced than our level of understanding. It goes hand in hand with critical questions in analyzing or incorporating them into the products. Therefore, the aim of the methods is to support the design process in order to utilize these new possibilities and to facilitate their use for the designers, in particular within the furniture field. Thus, the purpose of the research has been to:

- gain insight into the new technological possibilities of materials and manufacturing processes in relation to the aspects of design,
- examine the designers' points of view to incorporate new types of information about new technologies into their designs,
- increase the understanding of the nature of cooperation between designers and engineers during the design process,
- provide methods, which will support the design process to achieve a better understanding of new technological possibilities. Thus, designers will become more skilled in using them effectively as early as possible.

The overall objective of this thesis is twofold:

1. Attempting to close the gap between theoretical and practical knowledge which is crucial during the realization of the product form.
2. To contribute to the knowledge used in the design process with methods or models which can help designers to expand the range of solution variants, to evaluate a range of possibilities, and to have more choices available while designing.

1.4.2 Assumptions and research questions

Assumptions

This thesis is based on two assumptions, which indicate the perspective and viewpoint taken in the research project:

- A1. Paying attention to new technologies will expand the understanding of the design process, thus the chance for creating new and good ideas will potentially be increased.

- A2. Establishing better channels of communication between designers and engineers in an early phase will have benefits for the design process.

The first assumption made in this thesis establishes a link between two aspects: paying attention to new possibilities provided by technologies, and new and good ideas as a result of expanding the understanding of the design process. It implies that the exploration of technologies is enhanced when designers are more aware about designing due to the parameters set by these. Therefore, they can create successful ideas because of their knowledge about new possibilities. The second assumption is connected to the approach that designers, who have found ways for cooperation with engineers in the course of a series of contacts and communicative exchanges, will have the opportunity to be supported in their activities. They will furthermore develop skills and competences that they will use directly or indirectly in their own design process and in the interaction with engineers.

Research questions

The incentives described in section 1.1 as well as the aims and assumptions of this thesis which have been described above, provide the basis for the formulation of research questions. The first two relevant questions are related to the state-of-the-art of knowledge in the context of new technologies and the design process:

- Q1. What different kinds of information offered by new technologies need to be taken into account and can contribute to creating good and new products?

- Q2. How can successful communication be established particularly with the engineers at an early stage of the design process?

These two questions are investigated with different methods, which were applied throughout the different research activities. Through this investigation, a basic understanding is developed which naturally leads to the second set of questions, which is related to the potential support of the design process in relation to existing practices:

- Q3. How can the design process make use of possibilities offered by technologies as early and as effectively as possible?

- Q4. What is the nature of methods or models that may be used to support the design process, incorporating new knowledge about technologies into the design process at an earlier stage?

The intention is to build a model that shall support the designer in considering knowledge of both possibilities and constraints due to materials and manufacturing techniques. The type of model may be "process oriented", which means that it aims at improving the designers' skills to capture certain types of information. On the one hand, designers consider technologies as being integral elements throughout their work. On the other hand, they will be able to establish communication with engineers. Both approaches can indirectly lead towards supporting the design process in order to use opportunities and to face challenges offered by new technologies.

1.4.3 Limitations

In the beginning, this research project was relatively free from restrictions. However, in order to make the problem tangible and to remain within the framework regarding time and resources set for this research, the following limitations have been made:

- During the development of methods and the use and creation of the examples, the focus has been placed on the new technological possibilities with a great deal of the materials and manufacturing processes as integral aspects of designers' works. The cultural background of the context of the designers' work or the design process is not relevant within the scope of this research project.

- Due to the importance of the conceptual phases and their impact on all subsequent stages of the design process, the focus is set on its early phases. Detailed design, production and assembly are not treated.

- The development and investigation of the scope of methods concentrate on how they can support designers whether working alone or in a team, particularly with engineers interested in the furniture area. The investigation of the dynamics of groups, i.e. the relations between its members, or any psychological effect is outside the scope of this research.

1.4.4 Structure of the thesis

This thesis is divided into the seven chapters listed below. **Chapter 1** provides an introduction which covers the following topics: the research area, the problem which the research project is based upon, the incentives, objectives, and the assumptions of the project, the questions which this thesis focuses on, and finally the delimitation of the research project.

Chapter 2 presents a review of different approaches and concepts referring to the design process in general. It contains different sections which are concerned with the various approaches to design methods, the concepts of the theory of communication, and other approaches related to the design process. It provides an overview of those assumptions that form the background for the following chapters.

Chapter 3 provides an outline and a discussion of the research approach in general, and the specific research methods that were used in the thesis. This chapter presents the different activities that were used to gather data. These are divided into theoretical and empirical research activities. This division serves as a means of differentiating the different sources of the data. The theoretical activities of this research project include reviews of various publications with the aim of studying the state-of-the-art in relevant research areas. The empirical research activities have been carried out with the help of qualitative methods. These included questionnaires, in-depth interviews, and action research with designers, engineers, and managers from the furniture area.

Chapter 4 contains an outline of the results obtained in the course of this research project. It briefly summarizes the results of the survey of publications on technologies and the outcome of the empirical studies.

Chapter 5 presents an analysis and discussion of the results of the research project. This chapter combines the results of both the theoretical and the empirical activities of the research and is divided into three subchapters.

- **Subchapter 5.1** gives insight into the new possibilities which are presently offered by technologies and how they can make a wide range of opportunities available to design. Additionally, it provides various sources of information about new technologies in different forms.

- **Subchapter 5.2** describes a structural approach to the different phases of the design process, which helps to capture effective types of information related to the different aspects of design with a special focus on furniture products.

- **Subchapter 5.3** explains the role of communication aiming at expanding cooperative efforts between designers and other specialists in the field of technology, particularly engineers, who are interested in the application of new materials and techniques.

Chapter 6 describes an approach to building a model which might support the design process. This is intended to help designers to make use of the new possibilities offered by new technologies. Furthermore, this chapter describes the application of the model process with the help of specific case studies from the field of furniture.

Chapter 7 provides a summary of the results. It also contains some final reflections on the research project as well as some final conclusions. Additionally, this chapter gives recommendations with a view to further studies in this field.

Chapter 2

Theories and Concepts on the “Process” of Design

2 Theories and concepts on the “process” of design

This chapter presents theories and concepts which form a background for the analysis of the results in chapter 5, as well as for building the model presented in chapter 6. As described in chapter 1, the objective of the research project was to investigate the interaction between two fields of knowledge in design and technologies, including new materials and shaping techniques which are relevant during the design process. Therefore, the point of view taken in this thesis includes the assumption that it does not make much sense to isolate, focus on or look at just the one field or the other. However, a broader approach towards investigating influential elements and factors of both fields is necessary. To achieve this broader approach of understanding, it was necessary to refer to different theories and concepts including their contributions to the design process which helped to constitute design, both theoretically and professionally. In this chapter the most relevant theories and concepts for this thesis are presented.

2.1 Design methods

To enable designers to use their knowledge effectively and to recapture design decision-making activities, different methods and approaches have been developed during the last fifty years. Referring to the design of products, one could argue that there have traditionally been two major schools determining the approach to the design process. The first school regarded the “process” as the key towards understanding the creativity and mystery of design and what is going on in the designer’s head when they set out to create a product. According to Stoltermann [1994], this school is called “the aesthetic approach”. It is primarily based on intuition, i.e. personal experience: During the design process designers can only be supported by their own ideals and values. It focuses on the formulation of properties primarily concerning the appearance of the products. This description can be related to the school that Jones [1981] refers to as describing the design process as a 'black box', which cannot be understood rationally. This school originally has its background in and is based on the fields of art, handcraft design, and industrial design.

The second school has used the term "process" to identify the effort that lies behind a good product design. This is what Stoltermann [1994] called "the guideline approach". According to this school, the design process can be described rationally. It is possible to formulate the guidelines as generic design principles without focusing on a specific designer or design situation. Stoltermann points out: "It is thus possible to externalize the rationality of the design work, which means that the secret of a skilful designer could be formulated as guidelines and transferred to an inexperienced designer." [p. 450]. This description can be related to the school that Jones [1981] describes as viewing the design process as a 'glass box', with a set of clear and well-defined tasks and steps along the way. This school originally has its background and is based on engineering design.

Both of these ways of understanding the design process have strongly influenced and helped designers from different disciplines. For the purposes of the research presented in this thesis, some of the process methods deriving from both approaches will be presented in the following. The ultimate goal of this presentation is to establish a link between the existing as well as the applied theories and concepts for developing methods which can support the design process. These methods will make use of effective types of knowledge offered by technologies in the field of materials and shaping techniques.

2.1.1 The aesthetic approach to the design process

In the effort to improve the perception skills of the designer as a mediator of a *Zeitgeist*, or the designer as the user's advocate who can create products with aspects connected to the user's sensibilities, there are developments towards a more aesthetically oriented design. Some of these are presented in the following.

On the process of *gestalt* perception

McKim [1980] suggests the terms form, shape, configuration, pattern, or 'organizational essence' for describing the meaning of *gestalt*. The term *gestalt* refers to theories of visual perception developed by German psychologists in the 1920s. These theories attempt to describe how people tend to organize visual elements into groups or unified wholes when certain rules and principles are applied. McKim continues that, according to *gestalt* psychology, every perceptual image typically involves further processing of sensory input. In practice, sensation and perception are virtually impossible to separate, because they are part of one continuous process. The perception of *gestalt* is a communication process which implies the transmission of a message from one system to another, such as from a designer to a user. It involves that every thing which we perceive can be discerned as a whole that constitutes a *gestalt*, including colors, haptic, auditory, and olfactory sensations [Monö, 1997].

The perception of a *gestalt* is central as concerns the attractiveness of visual appearances in product design in general. Monö considers it as the definition of design aesthetics which can be related to everything we see, hear, feel, taste, and smell. The process of perception allows us to interpret information and reconcile multiple viewpoints about the same topic in different ways. Klöcker [1980] defines this process which occurs during the design work as a creation of visual perception based on our act of seeing. In the process of seeing, the first step in the perception is to observe the overall pattern without details. The second step, which is based on the personal needs and interests, is the analysis of the overall pattern and attributes in detail. In relation to the perception process, Ashby and Johnson [2002] argue that through observation two men are looking at a motorcycle differently. Relating to this example, they found out that two observers of the same product will perceive it in different ways. These derive from their reaction to the physical object they see and the experiences they carry with them. Additionally, they indicate the importance of the role of materials and their techniques connected to elements and patterns such as sight, touch, happiness, etc., which help to create perceived attributes.

Some rules of *gestalt* perception related to furniture design

Many authors have described the factors or rules, which improve the perception of designers, such as Tjalve [1979], Cheatham [1983], Klöcker [1989], McKim [1980], Baxter [1995], and Monö [1997]. Some of the factors which help creating *gestalt* in relation to the process of furniture design will be shortly reviewed in the following.

- The *similarity* factor: Similarity among parts in a form with the same properties helps hold the form together and it can be an effective way to create meaning. It is also called ‘the principle of common properties’ [Monö, 1997]. In furniture design, similarity is mostly a matter of trying to achieve a balance on two axes – from side to side and from top to bottom. The balance from side to side of a vertical centerline is usually the most important as concerns the visual aspect.

- The *proximity* factor: Proximity refers to distance between the parts comprising a form. The parts are individual units which are next to or near one another [Cheatham, 1983]. The proximity factor is essential in furniture design to achieve visual grouping or one form unity. Even if individual units are not similar or identical in color and size, visually they still form a group. This helps to create unity, consistency, and integration.

- The *geometric* rule: A simple or complex geometric shape allows us to perceive the form and mass of an object [Baxter, 1995]. It is often the first thing we notice in furniture. It can communicate information about the form of the product that appeals to us when we interact with it.

- The *texture* factor: It can separate, combine or define elements, areas and forms, and create character [Cheatham, 1983]. The role of texture in furniture calls attention to the form and makes a functional element more visually dominant.

- The *continuation* rule: Continuance occurs when a part of a form overlaps with itself or an adjacent form. It is also defined as ‘the line direction’ [McKim, 1980]. Continuation is a way to create visual logic in furniture to which we unconsciously respond. Furniture designs with continuance in line and form seem comfortable and create visual tension.

The rules and factors mentioned above as well as the combinations of them are the basic properties by which the designers can manipulate design on the one hand and by which they can create designs with different types of visual effects on the other hand. In addition to these *gestalt* rules, there are other rules. Klöcker [1980] for instance suggests a number of ‘secondary *gestalt* phenomena’, including:

- *Optical illusion* such as the 'impossible figure',
- The *tensioned line* or the dynamic curve according to Monö [1997], and
- The *ambiguous figure*, allowing different interpretations of seeing the object.

Klöcker's approach is based on the use of a certain methodology and analytical tools in the development of a product form according to the semantic, syntactic, and pragmatic dimension [cited in Warell, 2001].

The basic assumption of this thesis is that the new technologies that have been developed recently possess attributes which can contribute to the visual sensitivity concerning form and pattern, creating furniture ideas with a sense of conceptual appropriateness rooted in a profound sense of reality. The process by which appropriateness is revealed is not the result of the perception of *gestalt*. It is an integrated process in which all discoverable and relevant influences on the form are considered. This important aspect, which is connected with the effective use of elements and patterns directly deriving from technologies in the design of furniture as industrial products, will be investigated and discussed more thoroughly in chapter 5.

2.1.2 The rational approach to the design process

The "glass box" approach, which can be related to the school of Jones [1981], analyzes design based on its logical process and the sequence of decision-making. Jones and many other authors regard the design process as a sequence of events or phases[2], which include the generation of ideas (identification or briefing), analysis, synthesis, and evaluation [e.g. Archer 1965; Cross 1984, 1994; Lawson 1990; Bürdek 1991].

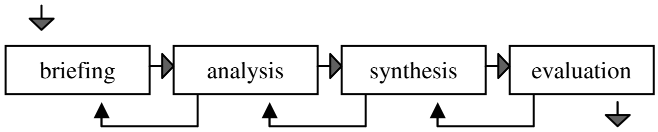


Figure 3. The figure depicts the widespread agreement on the main phases of the design process while developing product ideas or concepts, according to Lawson [1990]. Generally, the basic process in industrial design requires the implementation of a number of phases. Our thesis focuses on the initial phase in the course of which the concept or the idea of the design can be generated, analyzed, synthesized, and evaluated. The phases are interrelated and need to be accessible by return loops.

The rational model of the design process starts with a briefing or a need that is analyzed. The next step involves synthesis which is finally followed by the

[2] Different names or designations are often given to the various conceptual design phases such as problem identification, task clarification, and ideation. See Archer [1965].

step of evaluation and decision-making. Additionally, there will be some iterative loops, see Figure 3.

Apparently, the process has its limitations in the linearity and its emphasis on iterations, and furthermore, during the product creation or development, designers or teams develop their own unique problem solving style based on these models. In the context of methodology in a linear sequence, Ulrich and Eppinger [1995] state that "the concept generation is almost always iterative" [p. 80]. They do not refer to how a concept of the product can be created or how designers or teams develop such a unique problem solving style, and they do not give concrete examples concerning how this is done, i.e. indicating that a "black box" exists within or beside the "glass box".

In relation to the rational and linear design methods, it is possible to formulate guidelines as generic design principles, and therefore, they do not depend upon a specific designer or design situation. Roozenburg and Eekels [1995] underline this in the following statement: "The form of the design process appears to be hardly dependent upon the content of the problem, nor of the type of object being designed. On the whole, the same procedure is followed in all design processes, and consequently comparable methodological problems occur" [p.32].

Roozenburg and Eekels also describe a basic design cycle, which they claim to be fundamental for all designing, with its linearity and step by step procedure as well as the iterative loops: "We consider the basic design cycle the most fundamental model of designing. Someone who claims to have solved a design problem has gone through this cycle at least once. The basic design cycle also appears to be a useful scheme to classify the body of rules and methods (the 'methodics') of designing." [p. 89]. In general these rational, step-by-step methods consist of three major steps: Analysis, synthesis and evaluation in exactly this order.

The rational approach of the design process can be transformed in different ways related to the specific design problem. For example, Gregory [1966] and Jones [1981] point out that after the definition of a design problem, it may be broken down into smaller problems, each of which may again be broken down, until finally each sub-problem has a simple solution. Combination of such solutions should yield a number of solutions which help to solve the design problem. The form of this approach is called the “game tree”, which is illustrated in Figure 4.

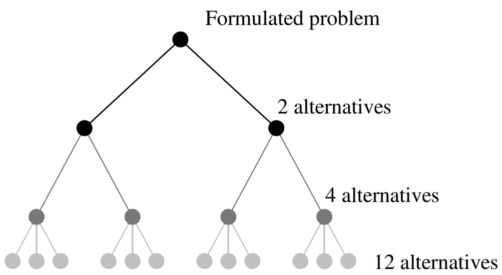


Figure 4. Design tree according to the rational methods of design by Gregory [1966] and Jones [1981].

To put it in general terms, the aim of rationality and improvement in the course of the design process with the use of methodology or analytical tools is focused on predictability in the design process. This serves as a documentation of the choices and solutions the designers have presented to their clients or the participants in the process of design. In this way, the process of creating “good form” can be explored.

The way that these rational methods are presented may lead towards the assumption that they give little room for experience, subjectivity, and the use of intuition to create new ideas. These aspects can without doubt be regarded as something irrational which is difficult to grasp. Therefore, in many cases, they are not part of the rational methods, as also indicated by Roozenburg and Eekels. Contrary to this approach, this thesis aims at rationalizing the process of intuition and experience to define the needs of design and find alternatives, as well as solutions. These solutions aim to improve the design process, with the help of new types of information offered by technologies. The sequential steps to transform a piece of information or an activity into an altered one include taking over the output from the pervious step and also becoming input for the next one. Such steps are considered as a central part of the suggested design process presented in chapter 5.

2.2 Communication theory

An important aspect of industrial design is that designers are assumed to have the total responsibility for creating products which can communicate with the users [Nelson, 1957]. In this way, the designers can be considered as an interface between consumers, manufacturers, techniques, cultures, products and environment. A general definition of communication refers to being the "social interaction through the messages" [Fiske 1990, p.2]. There are two main schools in the theory of communication: the 'process school' which sees communication as the transmission of messages and the 'semantic school' which regards communication as the production and exchange of meanings.

In the context of this thesis, both schools seem to be relevant: The 'process school', on the one hand, is one of the central elements in teamwork, especially between designers and engineers when they introduce new materials or techniques into the design processes. The 'semiotic school', on other hand, presents an essential background which can help to understand the way of using specific types of information offered by new technologies to describe and create perceived attributes.

2.2.1 The 'process school'

The 'communication process school' is concerned with how senders and receivers encode, decode and see communication as a process by which one person affects the behavior or state of mind of another. Figure 5 presents a simple illustration of a model of communication by Buur and Andreasen [1989] which is based on the original theory of Shannon and Weaver [1949]. In this linear model, the information is transferred from a sender and to a receiver in the form of a signal by using a medium of some sort (e.g. talking, symbols, writing, or a cardboard model). According to the model, when sending the information, there will be a loss of information and noise will affect the understanding.

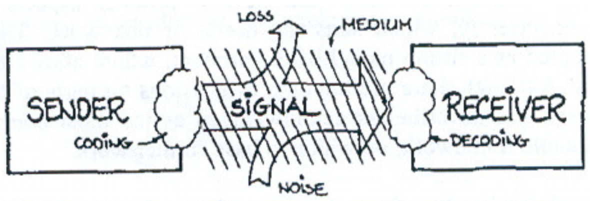


Figure 5. Model for communication, adapted from Shannon and Weaver [Buur and Andreasen, 1989]

Relating to this thesis, there might be different persons in the cooperative design process sending and receiving messages. These messages will be encoded and decoded. According to the theory, there might be a loss of information in teamwork situations, especially with designers and engineers, while transferring information. Additionally, noise will ‘distort’ the message even more. The failure of communication that might occur, according to this theory, will lead to misunderstanding and this will easily worsen the cooperation.

2.2.2 The ‘semiotic school’

The semiotic school considers communication as the production and exchange of meanings. For any type of communication a message has to be created out of signs. This message stimulates the receiver to create a meaning himself that relates in some ways to the meaning that was generated in the first place. The more the sender and receiver share the same codes, the more they use the same sign systems, the closer the two ‘meanings’ of the message will approximate each other [Fiske 1990, p. 39]. A sign is not a thing or an object, but a relation, as illustrated in Figure 6. According to Peirce[3] [1931-58], a sign or representamen is something which to somebody stands for something in some respect or capacity. According to this definition, any product has to be considered as a sign that carries a message about the product’s purpose, use, properties, functions, who made it, and so on [Monö, 1997]. The sign denotes, or describes, and indicates something such as the purpose of the product, but it also connotes, or implies something, like the social status of the product owner.

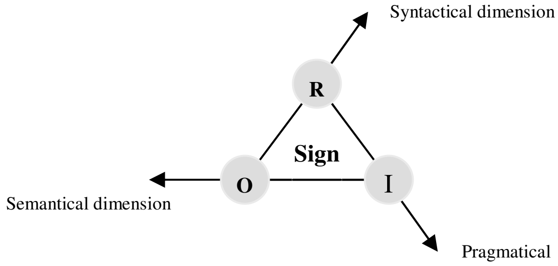


Figure 6. The semiotic concept adapted by Lange [2001] from Peirce’s model [1931-58]. The three dimensions of semiotics include the semantical, the syntactical, and the pragmatical dimensions of the sign. The three aspects of the sign are the representamen R, the object O, and the interpretant I.

[3] Peirce’s model [1931-58] is one of the main models within the semiotic school. It consists of three terms: the sign, the object and the interpretant. A *sign* refers to something other than itself, the *object*, and is understood by somebody; it has an effect on the mind of the user, the *interpretant*. The interpretant is not the user of the sign; it is a mental concept produced both by the sign and the user’s experience of the object.

Communication of meaning or messages through the form of a product can be established by the accepted “vocabulary” which designers or people outside the field of design use to describe the form of the product. Furniture is closely associated with elements of the visual vocabulary. These elements can be incorporated in the form structure, such as the line weight, positive/negative space and animation, or in the elements of composition and proportion. Finally, it can also be inherent in the elements of surface treatment, texture, and ornamentation. Elements like these associate furniture closely with and build links with its user or owners. These present, above all, the object of our senses and put us in direct and close contact with the functional and structural intentions of the designers. Furthermore, as Pile [1990] points out, the elements that indicate meanings are a way of organizing the form which makes individual communication strong and forceful.

Relating to the overall aim of this thesis which includes contributing to a holistic approach to the design process, product semantics considers an important aspect which is an established field in the context of industrial design, as proposed by, e.g. Vihma [1995] and Monö [1997]. The basic assumption of this research project is that creating a specific interplay between new materials with improved properties, shaping techniques, and form may lead designers, on the one hand, towards contributing to the creation of products which are more self-evident. On the other hand, it may also lead towards developing a number of semantic properties describing the perceived attributes of products, in this case furniture. Additionally, concepts from the semiotic school also seem to be relevant. This is because in design teams, the different members are approaching the product form from different perspectives, roles and viewpoints.

2.3 Other approaches to the design process

Against the background of and as a reaction to these step-by-step process methods, there are approaches which assume that design only slowly emerges from formerly tacit knowledge. Designing is learned by watching and working with an expert. Consequently, designers can acquire and reflect on knowledge in order to produce a reasonable solution within the inescapable restrictions imposed early on the design process. Some of these approaches are presented in the following.

2.3.1 Reflective practice

Donald Schön [1983; 1987] studied the behavior of professional practitioners, particularly designers, for more than twenty years. In his work, Schön describes design as an activity involving “reflective practice”. He stresses the uniqueness of every design problem, and identifies the core skill of designers as their ability to determine how each single problem should be approached. According to Schön, the designer, as a reflective practitioner, interactively defines the frame of the problem and names the things his or her attention is drawn to within this frame. Then, the designer generates ‘moves’ towards a solution and reflects upon the outcomes of these moves. In this process, the designer has the role of an explorer, a creator, developing a solution, and an experimenter trying to understand the situation he is creating. Schön describes this process as a ‘reflective conversation with the situation’. Through this kind of interaction with the situation, “his [the designer’s] inquiry is a transaction with the situation in which knowing and doing are inseparable” [Schön 1987, p. 78].

In particular, Schön differentiates between three types of reflection: reflection-in-action, reflection-on-action, and reflection-on-practice. For the purposes of this research, we will consider the reflection-in-action approach. For Schön, the act of reflection-in-action can help to understand the flow of skilled, practiced performance and improve the designers’ skills, so that they can become more conscious during the analysis phase.

In relation to this thesis, the intention is to arrive at an understanding of how designers can use knowledge about technologies to formulate goals and ideas during the design process. Another aim is to reveal how designers can contribute either to structuring or solving the problem of establishing a connection between the knowledge of two fields, namely design and engineering. This is carried out by a series of empirical methods applied in the actual design processes related to the area of furniture design.

2.3.2 Events in the design process

In the mutual design process, events are replicable social activities organized around a common core of procedures. These activities help the participants to develop a common language for sharing experiences that lead to a greater mutual understanding [Horgen, 1999]. Binder et al [1998] argue that such events aim at a shift from task orientation to an orientation which is more focused on the event in cooperative design. They point out: “As we hereby replace activities with events, we will also argue for the replacement of the successive decomposition of problem-solving with a more open understanding of design problems as being continuously re-constructed and re-formed”. To put it simple, according to Binder et al. [1998], events in the design process represent people with different interests, competences, and a different professional language. Within such events, different tools are used like samples, rapid mock-ups, images, or real products to facilitate the cooperation.

In relation to this thesis, it is intended to investigate difficulties of the two disciplines – design and engineering – which arise in cooperation situations due to new technologies in the context of the furniture industry.

2.3.3 Information required for designing

A well-known definition of the design process in different design areas is that the designers’ immediate objective to make use of all their knowledge of the past and present, combine it with the new technologies in a balanced and compatible manner and thus produce a result that can meet the needs [Jones, 1981]. In the design process information is needed as early as possible to help producing a design. However, there will be a large body of information from many areas including human factors, materials, business, and manufacturing etc. that they can call upon and use during the design process. At every stage of the design process, the need for a wide range of information with more details increases.

Therefore, the first problem is the availability of information, and how it will afterwards be incorporated into the process of design. Zeisel’s [1981] model for the design process suggests that the designers’ approval or rejection of ideas is based on an analysis of information included in images which they have or produce. Zeisel’s design model is formed like a spiral which explores the process of using information in design as a series of ‘conceptual shift’ and ‘looping’ structures moving through the creative process. Although Zeisel’s model does not explicitly describe how designers use sources of information within the design process, he suggests that sources of information are used as a means of refuting the focus of the design brief [cited in Rhodes, 1998].

As mentioned earlier in the description of the incentives of this research project, above all, designers need to get acquainted with new information about technologies that have become available today. In the field of technologies related to new materials and shaping techniques, engineers have ready access to information of the sort they need which is constantly being updated and augmented. In contrast to the engineers, designers lack an adequate number of fundamental information sources on these technologies. This can be related to the findings of Ashby and Johnson [2002], who stated that: "Industrial designers express frustration, both in print and in interviews, that they do not have equivalent support" [p. 2].

The purpose of this research project includes attempting to compensate the designers' lack of knowledge with the help of sources on new technologies and to investigate the following question: Which sources of information about technology do designers consult and why are those resources consulted whilst others are rejected? Moreover, how can designers be supported to integrate information about technologies into the design process with furniture design being the focus of this thesis?

Chapter 3

Research Approach and Methods

3 Research approach and methods

Although this research has interdisciplinary features, it is primarily based on the perspectives of design. The final results of the research are intended to support designers, when introducing new technologies concerned with new materials or shaping processes into design activities.

Due to the fact that design research is a fairly young discipline and due to the resulting lack of research traditions within this field, this thesis makes use of research methods from different disciplines to understand the problem and to provide new knowledge supporting designers. This project combines different research methods for building new knowledge so that new experiences can be made use of during the design process. The intention of this chapter is to provide an insight into the approaches of the research. Furthermore, the activities used to gather data related to the specific point of view and the scientific methods applied in the research of this thesis will be presented.

3.1 Research approach

The research approach of this thesis is to investigate the opportunities and challenges for design offered by new technological possibilities of materials and shaping processes. The influences of these new possibilities on design can be regarded from three different points of view which involve a decreasing level of abstraction: new challenges for designers, opportunities for cooperation in the design team, and opportunities for product design.

On the level of the *designers*, who intend to make use of the possibilities offered by new technologies, the thesis focuses on supporting designers to become more skilled in interpreting and using new technologies during the design process. The use of these new possibilities forces designers to expand their understanding of the design process and alter their methods of designing.

Downton [2003] underlines the same idea stating that: "New or revised legislation, a new material, changes to the availability of a product or material, an economic or political shift, or any of a wide range of variants might affect and alter the originally intended path of a design" [p. 22]. Based on technological knowledge, this dissertation presents the framework of a model, which enhances the designers' skills so that they can look for innovative methods of finding solutions for these constraints. The intention is that the results presented in this thesis will contribute to improving designers' work. This shall guarantee a better understanding of the new information resulting from technological developments on the one hand. On the other hand it shall ensure that the proposed methods will assist designers to capture effective types of information about them which are successful from the technical as well as the aesthetical points of view during the design process.

On the level of the *design team*, this approach considers the cooperation between design and engineering disciplines during the design process. In a rapidly changing technological environment it is required to expand the interdisciplinary cooperation efforts among different disciplines [Stattmann, 2000]. In this new atmosphere designers and engineers need to shoulder new burdens. They are continually forced to utilize new technologies in order to make their products faster, cheaper, aesthetically more appealing, smaller, etc. In this accelerating race and within this complex system, it seems necessary for designers to be able to interact with engineers effectively. This cooperation provides exciting new opportunities for both professions, but it also includes a number of challenges for the design teams. Thus, it seems to be important to examine the cooperation from different perspectives in order to develop tools and methods, applicable during the design process, which assist designers in situations in which cooperation is necessary.

On the level of furniture *products*, the focus is on presenting and discussing how new technologies make new forms possible and may even require new forms to make them usable in new ways. The intention of this is to analyze successful examples combining innovation and creativity with new materials and techniques, describing products not only concerning functional issues but also concerning aspects which add pleasure to the user's senses.

3.2 Approaches in design research

In the context of design, research is quite a young discipline and consensus about methods and research paradigms have not been formed yet [Andreasen, 1998a]. The relationship between research and design have been discussed by different authors like Cross [1995]; Friedman [2000] and Downton [2003]. They discussed this relationship from two points of view: On the one hand, there is a notion that design should conform to established ideas about science and research. On the other hand, there is the idea of design staying something unique that should develop its own research agenda. In this context, Friedman [2000] remarks that all professional fields carry out a transformation from practical experiences to the scientific discussion, and now it is design's turn to do this. For example, fields of study such as medicine, technology, and law all began with a craft-related type of knowledge which later was successively developed into a science.

According to Cross [1995], there are three forms of design research that are useful in the effort of acquiring different types of knowledge, which have been widely used:

- Research *into* design, such as empirical studies of design activities
- Research *for* design, to create tools and methods for different phases in the design process
- Research *through* design, such as abstractions from experiences of designing, hypothesizing and testing

All three areas of research are presented in this work. Yet, as the ultimate goal of this thesis is to contribute to supporting the designers' work with the help of these methods, it principally belongs to and focuses on the approach of research *for* design.

Research *for* design

The term research *for* design, according to Downton [2003], "is understood to mean research that is carried out during the overall design process to support designing in whatever way the designer(s) regard as useful and this includes research intended to provide information and data that is necessary to successfully conclude the undertaking in question" [p.17]. Due to the broad sense of this definition, Downton explains it with a number of ideas included within this general concept. Some of these will be summarized in the following:

- Research *for* design enables the individual's way of designing in a general sense. It is a way of learning about or reflecting on design.
- Research *for* design is directed towards a specific project to be undertaken. This research mostly informs about the designers' ability to choose – perhaps between directions or specific items such as materials.
- Research *for* design is a kind of research hat occurs at many points within a design process and is of varying complexity with considerably differing ranges of application.
- Research *for* design undertaken in a general and not project-specific framework is aimed at the improvement of an aspect of design or of design in a particular realm.
- Research *for* design is intended to enable design or designing in the sense of improving the processes or outcomes [Downton 2003, p. 17-18].

For each of the categories above, it is obvious that the wide scope of this type of research and its importance for the production of new information both contribute to defining new ideas as a process. Therefore, this thesis considers it to be important to gain knowledge about design processes when designers confront new types of information concerning new technologies.

3.3 Activities of gathering data

Due to the multidisciplinary nature of the research in this thesis, two parallel approaches to the research are used. The aim of this is to gather and to explore adequate data related to the research questions. The research in this thesis can be divided into theoretical and empirical activities:

- The theoretical activities include attaining knowledge about the theory of design processes on the one hand, and to capture facts on available information related to new technological developments in the field of materials and manufacturing methods on the other hand.

- The empirical activities are carried out using scientific methods to find paths which support the designers' work by incorporating new knowledge offered by technologies.

Both theoretical and empirical research activities represent a procedure to clarify the design opportunities which help to consider knowledge of new technologies early in the design processes. An outline of the research activities, which were applied throughout the thesis, is illustrated in Figure 7. Detailed information about the theoretical and empirical activities which were applied is presented in the following.

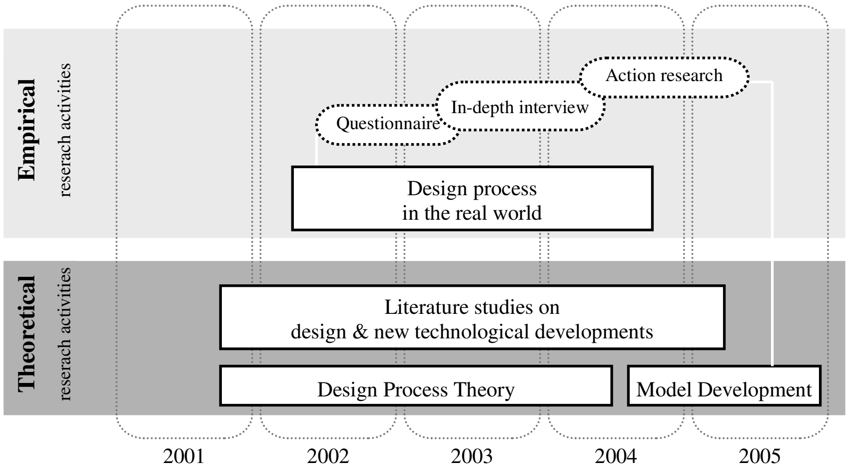


Figure 7. Diagram of research activities carried out during the research project, divided into theoretical and empirical studies.

3.3.1 The theoretical research activities

The theoretical activities of this thesis include surveys of publications in order to examine the state-of-the-art in relevant research areas related to the research approach. This involves:

- Surveys of publications which consider the theory of the design process in general. These allow obtaining a wide-ranging idea of their developments. The surveys included monographies, journals, periodicals, and essays in the design and the engineering field, for example: Jones [1980], Cross [1984; 1995]; Eder, [1990]; Lawson, [1990]; Roozenburg and Eekels, [1995]; Friedman, [2000]; etc.

- Survey of publications with the aim of studying the state-of-the-art in product design on the one hand and in the technological field concerning new materials and manufacturing processes on the other hand. Due to the variety of as well as the differences in existing publications related to both, they can be classified into two categories:

    1. Interesting publications written for and by professional designers and engineers using the language of design with illustrations of furniture products as examples which are clearly affected by new technological developments. These include monographies, magazines, and catalogues.

    2. Specialized technical publications attempting to attain more awareness and understanding of this information in detail. This includes different types such as technical monographies, magazines, journals, and websites.

This classification was essential because such information exists in vast amounts and various forms. It makes it possible to establish simple indexes on two levels. The first contains visual information about attributes of materials and their techniques. It is an abstract index of the possibilities based on the aesthetical and functional dimensions. For example, Polypropylene is formable, transparent, multicolored, and stabile, whereas aluminum is light, strong, resilient, clean, and reflective. A higher level of indexing based on describing materials and production techniques underlines the scientific information which can be collected and gathered from specific technical publications. Consider the following example: Polypropylene (PP) is a member of the polymer family. It is a thermoplastic. In its pure form polypropylene is flammable and degrades in sunlight. It can easily be molded with different methods such as blow, rotation, and injection-molding. It provides excellent resistance to chemicals and is recyclable etc. Linking the information obtained on these two levels to the existing furniture products during the indexing process enabled us to find out what types of information to look for and to select during the research process.

3.3.2 Empirical research activities

Empirical studies seek to create knowledge that serves the design profession and others as well [Poggenpohl and Sato, 2003]. The empirical research method implemented in this thesis is of a qualitative nature and uses qualitative methods. On the one hand, it aims at evaluating and validating the research hypothesis. On the other hand, it seeks to gather 'external' knowledge from design processes in the real world, which serves as a basis to capture knowledge required in design work. For carrying out the empirical studies in this thesis, three main methods of inquiry have been used. These are questionnaire surveys, in-depth interviews and action research.

3.3.2.1 Qualitative research methods

This section present the qualitative research methods used in the thesis. It presents an outline and a description of the field that the empirical material is collected from. The reasons for choosing different people and companies for research are presented and discussed.

Qualitative methodology

The phrase "qualitative methodology" refers in the broadest sense to research that produces descriptive data – people's own written or spoken words and their observable behavior [Taylor and Bogdan, 1998]. Qualitative research may be viewed as interdisciplinary with many different and multi-method approaches. As Nelson at al. [1992] state: "Qualitative research is many things at the same time. It is multiparadigmatic in focus. Its practitioners are sensitive to the value of the multimethod approach. They are committed to the naturalistic perspective, and to the interpretative understanding of human experience" [p.4].

The position taken in this thesis uses the qualitative methods to make an in-depth study of the influences of technological possibilities on designers' work during the design process. In other words, it shall reveal how designers handle information from two areas which are coming increasingly closer to each other while both reflect different expertise.

3.3.2.2 Methods of inquiry

In this thesis, three main methods of inquiry of qualitative research have been used, namely questionnaire surveys, in-depth interviews and action research. In this section a description and an explanation for this choice of methods is given.

Questionnaire survey

A questionnaire is a list of questions which allows data to be collected from a large number of people and makes it possible to compare respondents' answers to questions [Langley, 1988]. In relation to the subject of this thesis, a questionnaire survey was conducted with a large group of designers in Germany and Egypt who implement furniture design in different contexts. The aim was to first of all test the research hypotheses, to prove the importance of the research topic statistically and finally to gather information about research questions and topics. Some background knowledge related to the research topic found in different publications, helped to structure the questionnaire. The questionnaire included several open questions and others of structured response categories. After finishing the structure of the questionnaire form, a pre-test was submitted to small groups of designers in order to test the validity of the questions, and to make sure that the categories included all possible answers of the respondents. The questionnaire was anonymous and carried out during personal meetings or sent by mail.

In-depth Interview

The phrase *in-depth interviewing* refers to the qualitative research method. By in-depth qualitative interviewing social scientists mean repeated face-to-face encounters between the researcher and informants directed towards understanding informants' perspectives on their lives, experiences, or situations expressed in their own words [Taylor and Bogdan 1998, p. 88]. The choice of using in-depth interviews is closely linked to the main research questions and focus. The intention was to gather different designers' points of view and experiences of design specifically directed towards the aspects of material properties and production techniques in furniture design. Another aim was to personally encounter the different participants involved in the design process within the industrial world that have different perspectives on the design process, especially engineers. An in-depth interview is more like a 'chat' with the interviewer encouraging the respondent to give detailed answers and to explore his or her views [Langley 1988, p. 23]. Therefore, it is viewed as the right approach for this type of investigation. It is a method that is widely used within social sciences, so there were publications to build on.

Selection of interviewees and the companies for the interviews

In the following a description of people chosen for the interviews as well as an outline of the choice of companies for the in-depth interview investigation will be presented.

Selection of interviewees

In the process of the interviews, three categories of people were chosen:

- Freelance designers who work as consultants with companies.
- Designers employed in the company.
- Engineers from the production or the technical division.

The main reason for choosing the categories mentioned above lies in the basic focus of the thesis. It aims at better understanding how the design process is affected by new types of information about new materials and production techniques, along with focusing on the designers' reaction to these developments during the different phases of design process. This helps to understand the positive and negative influences caused while designers integrate these developments in different situations. Additionally, it was necessary to understand the engineers' perspective, since they are the designers' main partners and play an essential role during and after the design process.

(a) Freelance designers and design consultants

The freelance designers chosen for the interviews have their own design offices and have worked with one or many of the furniture companies. Most of them are industrial designers interested in using or experimenting with new materials or new ways of design through new production techniques.

(b) Designers employed in the company

The interviewed designers employed in the company were in close contact to the product development division and were cooperating with people working there. Most interviews there were not only carried out with designers but also with persons from the product development or the technical division.

(c) Engineers from the production or the technical division

The interviewed engineers from the production or the technical division had contact with the external design consultants or were involved in the product development process. In-depth interview studies with engineers from the production or the technical division who worked in the companies as consultants or employees were conducted from March 2004 to February 2005 during and after the interviews with the designers. The aim was not to investigate the methods developed in the engineering area, but to focus on the cooperation between designers and engineers during the design process.

Selection of companies

The companies selected for in-depth interviews deal with design consultants or have their own design sections. The selection was made with the focus of doing interviews with companies working in the furniture production where factors such as new materials, new production techniques of traditional materials, and design aspects are acknowledged as being important. The choice was also influenced by the range of products the different companies produced. These should not be similar to each other. However, the people interviewed in the companies should have a similar working context so that it would be easier to find general factors as well as factors they have in common in relation to the design process.

The contact with the Egyptian furniture companies was established through an official letter issued by the office of the cultural attaché and the head of the educational mission in Berlin addressed to the relevant industrial establishments. In Germany, the contact was established through an official and direct correspondence from Duisburg-Essen University to such establishments. The content of the message included the subject and the aim of the thesis in general. It was underlined that the aim of these meetings would lead, after all, to suggestions which would contribute to improving the designers' skills during the design process related to the real world in order to close the gap between theory and practice. These interviews were conducted from November 2003 to August 2004.

Coding of interview respondents

In qualitative research, coding is a way of developing and refining the interpretation of data. The coding process involves bringing together and analyzing all data referring to major topics, ideas, concepts, interpretations, and propositions. The main question in this context is: Which of these were general insights or vague ideas initially and which hunches are refined, expanded, discarded, or fully developed during this process [Taylor and Bogdan 1998, p. 150-151]. The coding categories in this thesis derive from sorting the respondents' data. The interviewed freelance designers and design consultants were given the code 'designers'. The designers working in companies were coded 'CD-employees', and the engineers from the production or the technical division were coded 'PE'. The coding categories helped us to have a master list of data which included a great amount of comments and quotations related to the main question of research. In this way, it was easy to analyze data and to reveal relationships between perspectives.

The in-depth interview studies with freelance designers and design consultants were run from February to November 2004. Seven respondents who are experts in furniture and products design were interviewed. A specific focus was the need for methods to capture more knowledge and various interpretations of technological possibilities provided by new materials and production techniques within the design area.

In-depth interview procedure

Because of the particular role of in-depth interviews in capturing knowledge, experiences, and perspectives in this thesis, it is reviewed and discussed in this section. The intention behind the interviews, how they were prepared, carried out, and analyzed will be highlighted.

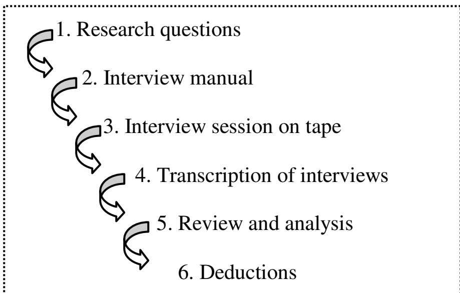


Figure 8. Diagram illustrating the phases of the interview process which were adopted from previous experiences gathered and provided by Lerdahl [2001].

Phases of the interview process

Figure 8 illustrates the different phases of the in-depth interviews. Based on the research questions, an interview manual was made. Afterwards the interview session was held and recorded on tape, usually at the design studio or at the company. The next step was the transcription of the interview material. After all the interviews were carried out, they were reviewed and analyzed which was finally followed by some deductions from the interview material.

Focus of the interview

The core of the interviews consisted of the research questions (see chapter 1). Throughout the interview process, the focus was on the following points which were considered as the main parts of the interviews.

Knowledge about new technologies as inputs in the design process

The intention was to concentrate on the characteristics of knowledge about new materials and production techniques which designers require. These types of knowledge about new technologies are available through various sources which can be considered as new inputs in the design process. The idea behind interviewing different groups of designers was that it would be possible to reveal and to arrive at a new understanding of designers' opportunities and challenges offered by new technological possibilities during the design process.

Experience of practitioners

In the interviews, the aim was not only to ask questions and to arrive at an understanding of the influences of technical knowledge about furniture design done today, but also to unveil and shed a light on the rich experience and knowledge of the respondents in relation to the design process. The choice was made to avoid asking questions about given cases in specific design studios or companies, and to look for the general reflections, experiences and viewpoints of the respondents in connection with various interpretations of these new possibilities during the design process.

Reality and wishes

In the interviews, it was essential to observe the overall picture of the design process in reality and to examine the crucial factors which support designers during the design process. Therefore, the aim was to stimulate the respondents to reflect upon and come up with propositions concerning, what might be a more optimal way of supporting designers to overcome the lack of knowledge about new developments in the field of materials and how they can navigate through this 'sea' of information, as these propositions should derive from their own experiences. The idea behind this was that it would be easier for the respondents – designers or engineers – to connect to the present case if it was related to their desires.

Principles around making the interview

At the beginning of each interview, a short presentation of the motivation and the topic of the research should allow the respondents to acquire a general vision of the research approach. In addition to this, open and nondirective questions were asked from time to time in order to enable the respondents to tell something about their own perspectives and experiences. Such questions have been aptly named "grand-tour" questions [Spradley 1979, p.86-87]. Questions would be as follows:

> "What is your view of the relation between design and new available technologies?"
>
> "What are your experiences with new materials and production techniques in the design process?"

The aim was to focus on and to explore the research topic with the help of concrete examples to clarify and elaborate it. In some cases, follow-up questions were necessary to arrive at a deeper understanding of the topics referred to by the respondent. Later in the interviews, near the end of each question, this changed towards a more "proactive" and obtrusive position. Questions like: "Do you confine your creativity by considering knowledge about materials and their production techniques in early phases of the design process? If so, why? Why not?" were asked.

Preparation for the interview

Questionnaire and manual

In the context of this thesis, after developing all possible questions of the interviews, the questionnaire covered eight pages. Later it was diminished to three pages with different types of questions which were formulated in the form of keywords and short phrases. The questionnaire was written in both German and Arabic.

The interview session

With the designers, most interviews were made at a design studio or at the company. Only three interviews with design consultants who also work as lecturers were made at universities. Additionally, one of the interviews was done by telephone. A tape recorder was used as a logging technique. The reason for having the interviews at the design studio, at the company or at universities was mostly time pressure on the respondents' side. The effects of making the interviews at the places where the respondents work could be positive. It was positive in the sense that the respondents felt they were in a known setting and were close to the problems occurring in real life. They had the opportunity to use their visual memory and give some concrete examples of projects.

Before beginning the interview I introduced myself and talked about my personal background. This was followed by a brief summary of the research focus and an explanation why I specifically wanted to interview them. Finally, the designers were provided with an overview of the main points of the interview.

The start of the interview

Each interview began with asking some general questions about the respondent and the nature of his work. In some interviews, which were made in famous companies, I asked some questions about the history of the company. The reason for asking such questions was to create an atmosphere in which the respondents could present themselves and their world.

The end of the interview

The interviews were always ended by asking open-questions about some pieces of advice which can help novice designers. Before turning off the tape recorder, the respondents were asked if they felt that there were any topics they wanted to talk about or if anything had not been covered yet. In some interviews, the respondents asked about the final result of the thesis and its presumable consequences. Hence, this created an informative discussion during which the respondents sometimes came up with new points of view. Such conversations had started after turning off the tape recorder, so that it was necessary to write them down later or sometimes the designers were asked if this conversation could also be recorded.

Transcription of the interviews

Each interview was recorded with an audio tape recorder. The formal duration of an interview averaged between 45 and 90 minutes. It was important to transcribe the interviews without changing the actual words of the respondent. The transcription of the interview would generally average between 8 and 20 pages. Transcribing the interview materials was very important, as it took so much time. Yet, it had the effect of ensuring a deeper understanding of the material and it was an effective way to get into it [Kvale 1996].

Analysis of interviews

The object of the analysis of interviews is to determine the categories, relationships, and assumptions that reveal the respondents' view of the world in general and their view of the topic in particular [McCracken 1988, p. 41]. The analysis of the qualitative data that resulted from interviews was divided into two phases:

(A) Picking out relevant quotes

After all the interviews were transcribed, comments and statements that seemed to be interesting in relation to the topic were collected. Quotes from each interview were picked out. Each quote was translated form German into English. In the analysis, the quotes that were used were generally longer in those cases in which the respondents told about their own experience from their points of view.

(B) Grouping quotes

The idea is to let the material speak and find its own structure, rather than putting it right away into categories that fit your own mind-set [see KJ-methods in Kawakita 1982]. Based on this process, the quotes were all given codes with the title and the source. The title would be related to the topic handled in the quote. After this, connections between those which fully seemed to fit into the same group were made and they were arranged. Each group then got another code or title. The grouping into general topics and categories helped structuring the chapters of this thesis.

3.3.2.3 Action research

There are numerous approaches of action research. However, within the context of action research there are three main approaches: co-operative inquiry, participatory action research and action inquiry [Reason, 1994]. All three perspectives or approaches are based on the idea that experiential knowledge arises through participation. Action research has some characteristics that differ from most other qualitative methods. For example, it is cyclic, participative, and reflective [Torbert, 1991]. The reflective characteristic of action research has been emphasized in this thesis.

Action research procedure

Based on the research inquiry and the initial conclusions deriving from a number of the in-depth interviews, some suggestions to support designers during the design process and the relation between the design process and new technical developments were tested and discussed with different groups of experts.

Two different procedures were used in the action research in this thesis, deriving from the fact that the researcher takes on the role of an active participant:

- The first one includes taking the opportunity of finding out the differences between approaches and ways of thinking related to existing examples from the furniture area during some interview sessions, especially at the end of them, as there were different people with different points of view including designers, engineers, and managers. The aim was to explore not only the designers' points of view but also engineers' approaches regarding famous furniture examples incorporating a successful application of new materials and manufacturing processes. The results and observations were recorded and noted down during the sessions.

- Secondly, in an innovative course for engineering students[4], the perspectives of a group of engineering students related to technologies of new materials and manufacturing processes were observed. This was done by presenting product examples from the furniture area applying these new technologies as well as a discussion of these. In this course,

[4] The course title was „Integrierte Produktentwicklung",held in the Fachhochschule Osnabrück.

the students were also given the task to fill in a questionnaire including similar furniture examples presented early in the simulation process in order to write a feedback. The latter represented an individual evaluation of such products from their perspectives. All questions included a list of certain words related to specific furniture products. The aim was that students should express their sensory as well as their perceived experiences about soft and hard attributes of the material and its techniques related to examples of furniture products which were attached as graphic figures within each questionnaire. Out of 31 students of Products Design Engineering participating in the action research, 22 students filled in the questionnaires. Some of them added interesting comments at the end of the questionnaires.

Chapter 4

Results

4 Results

4.1 Outline of the results

The results obtained in the course of this research project consist of findings from theoretical and empirical research activities. The theoretical activities include publications survey with the aim of studying the state-of-the-art in the technological field with a focus on new developments of material properties and shaping techniques. The empirical activities served for gathering information about real world knowledge of the design process which makes use of contemporary technologies. Three types of research methods were used to achieve this: questionnaire surveys, in-depth interviews, and action research. A summary and a short discussion of both types of research methods are provided in chapter 3.

Further outcomes of this research project can be divided into descriptive and prescriptive results. On the one hand, in the context of descriptive results, an exploration of the role of new technologies within the design area is presented, describing the relationships between technical possibilities and different proposals of design. On the other hand, in the context of prescriptive results, tools and methods will be presented and analyzed. These may be helpful for considering effective types of information offered by new technologies in the design process. Obviously, these two types of results are largely intertwined and overlapping, which is evident during the presentation and the analysis of the results in chapter 5.

In chapter 6, an approach to build a model supporting the design process based on the primary research findings is presented, evaluated, and discussed. This chapter is central in relation to the main question of the research project as stated in chapter 1: What types of models, methods, or tools may be used to enhance designers when they confront new technologies during the design process?

All results are summarized in Figure 9.

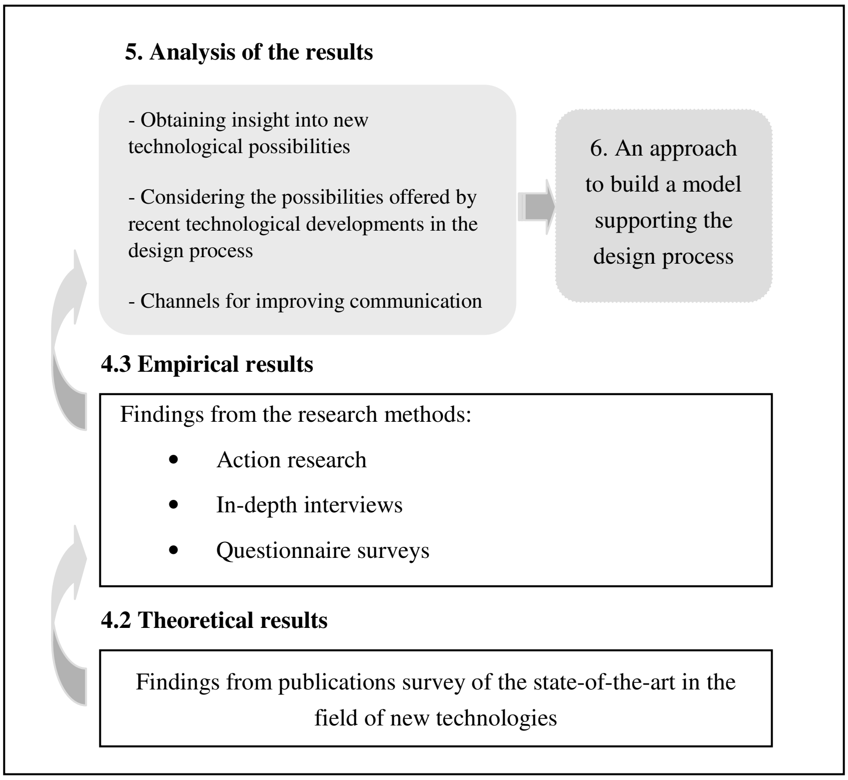


Figure 9. A summary of the results which contributed to this research project. The arrows show how the results have influenced one another.

4.2 Findings from the publications survey on technologies

The publications survey was carried out to assist designers in finding information about new technological possibilities. This guide attempts to fill the gap between designers and technology by focusing on new developments of materials and shaping techniques as well as the various sources available at present.

One of the results was that although there are several sources of information on new technologies, few of them appeal to designers in a way that they get an idea of new technologies as being interesting and useful. On the one hand, most of the existing publications on technologies show the reader how to identify potential solutions that may be adapted to solve technical tasks at hand. They also present specific details and methods for analyzing technological parameters of material behavior or for making strength calculations etc. Specialized texts like these may sometimes prove too complex for designers. On the other hand, most of the interesting publications use the language of design to explain impacts of technologies on design through e.g. samples or illustrated product examples, images, etc. that do not include adequate information about technologies. These two forms of sources of information are important and not always easy to locate. It is useful to know what types of information and publications to look for as well as the titles of the most helpful ones.

These results lead to the conclusion that it could be advantageous for designers to formally acquire some basic knowledge about technology. To do so, the designers must have some idea of what this knowledge includes and how to find it. To stress this, section 5.1 describes the need for more knowledge and for precise information about currently available technologies. As a consequence, designers have to become aware of the fact that they need to look for different types of publications which provide knowledge related to design and technical aspects. Furthermore, this section focuses on technologies in relation to material properties and shaping techniques which are needed to realize a form concept particularly in the furniture area.

4.3 Findings from the empirical studies

The outcomes of the empirical studies have provided essential background information for the concepts and methods developed in this thesis. They confirm the need for suitable methods to support designers in incorporating different types of knowledge offered by new technologies into the design process and suggest ideas for such procedures.

4.3.1 Questionnaire survey

The questionnaire survey was carried out with a number of designers who are interested in the furniture design area. The study dealt with the importance of the research topic from different points of view: the designers' attention to new technical developments, the use of methods or formal procedures during the design process, and the cooperation with other professions focusing on the design area – i.e. interaction between engineering and design. Figure 10 shows a summary of the quantity of responses.

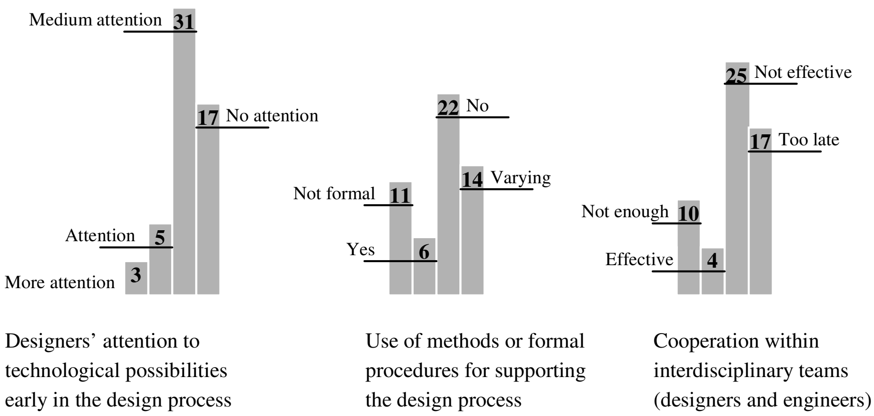


Figure 10. Results from questionnaire surveys show the designers' approaches related to three areas of investigation.

The questionnaire survey reveals that most designers give little attention to the possibilities offered by technologies early in the design process. In many cases, they are faced with a lot of different problems such as being aware of what is technically feasible and the constraints which need to be taken into account at an early stage. In the industrial world, different aspects concerning the consideration of new materials or production techniques are more frequently dealt with by engineers than by designers. The results also show that almost more than half of the designers do not have any methods of exploring or integrating this knowledge into their designs. They indicated that the use of formal methods was rather limited. Moreover, most of the designers thought that although there is the opportunity to learn about new technologies by expanding the cooperation with engineers, they expressed concerns about difficulties in achieving this.

4.3.2 In-depth interview study

Different persons who recently made use of new technologies in their designs were investigated. They were chosen from the branches of furniture design and furniture industry. Three different categories of persons were interviewed: freelance designers, designers employed in companies, and engineers from the production or technical division. Additionally, two interviews were carried out with managers or entrepreneurs.

The interviews revealed that none of the investigated designers or companies have a clearly defined and documented procedure for explaining how the early stages of the design process can be supported by making use of new technological possibilities. However, designers had different views as concerns the significance of considering knowledge about technologies as integral elements in design activities. This is may depend on differences in the nature of their work and their experiences. Some examples shall illustrate this problem:

- There are designers, either working in companies or as consultants, who frequently face constraints imposed by the technologies they are working with. Therefore, their degree of awareness concerning how these constraints should be overcome to provide the desired forms is higher. Before starting the process of design, some of them are going through a process of consciously analyzing the knowledge about what is technically feasible and the possibilities or constraints which need to be taken into account.

- On the other hand, there are designers, e.g. freelancers, who create ideas or develop visions and then search for the knowledge about existing possibilities with the use of which these visions can be realized.

There were for instance two designers from the furniture industry who mentioned that they create checklists including questions to be asked when identifying the new materials or techniques to be selected. Such lists provide them with information on different aspects of material properties which are technically and aesthetically relevant as well as the background knowledge about shaping methods. Other designers expressed that they get ideas by analyzing other designs which incorporate a successful interaction between new technologies and design aspects. However, they do not point out how these ideas can be developed or created by the analysis of other designs.

Almost all the interviewed engineers and also the managers are aware of designers' ability to interpret information about technologies effectively in their designs which have an influence on their clients or the users. At the same time, some of them expressed concerns about different barriers emerging when designers are asked to consider new materials or techniques early in their design process. They mentioned, for example, a lack of understanding concerning this knowledge, difficulties in communication, and above all unawareness of a specific sort of information that they intend to extract.

The designers also noted that the use of formal methods which integrate new aspects related to materials or shaping processes is rather limited. None of the interviewed designers regularly use formal methods at an early stage of the design process to analyze or to combine different types of information concerning available resources. On the other hand, some designers relied on the information they had gathered in the course of old projects that was already out of date. Two designers mentioned that they try to obtain recent information about new technologies by establishing contacts with material suppliers and engineers. However, they mentioned problems in achieving these contacts due to difficulties in communication.

The interviews also revealed that in the furniture area, huge opportunities can be provided by new technologies and that these lead to a freedom of design beyond which more solutions can be achieved than with traditional materials or techniques. At the same time, it is the designers' task to match their designs with the right materials for the process and vice versa. However, in those cases in which new possibilities exist it is relevant to develop methods supporting designers so that they can make use of them.

A complete summary of the outcomes of the interview studies is provided in table 1. For details, further reading, and analysis of the respondents' comments, see sections 5.2 and 5.3 of this thesis.

Integrating knowledge about and experiences with new technologies into the design process	**Designers (F)**	**Designers (E)**	**Engineers**	**Managers**
Awareness about the technological possibilities early in the design process	●●●●● (5) Varying	●● (2) Needed	●●●●● (5) Favorite	●● (2) Favorite
The philosophy of designing with technical information, that is, working within parameters	●●●●● (5) Extreme	●●●● (4) Needed	●●●●● (5) Essential	●● (2) Varying
Available sources of information on technologies at hand	●●●●● (5) not understandable	●●●● (4)	●●●● (4) Too scientific	●● (2)
Attributes offered by technologies contribute to giving a certain form	●●●● (4) Tactile and visual attributes	●●●●● (5)	●●●●● (5) Structural	● (1) Semantic
Formal procedure for considering attributes resulting from technologies into designs	●●●●●● (6) No	●● (2) Checklists	●●● (3) Needed	●● (2) No
Difficulties in researching new materials or innovative shaping techniques	To extract the relevant information can affect designs		To define new needs through parameters available	
Types of information offered by technologies connected to the user	●●●●●●●●●●● (11) Related to form perception		●●● (3) Performance	●● (2) Surface
Difficulties hindering cooperation within inter-disciplinary teams, particularly among designers and engineers	Communication "Lack of: suitable tools, language, time, lack of organization, etc."			
Constraints imposed by specific materials or shaping methods can restrict the creative nature of designers	●●● (3) Yes	●●●●● (5) Varying	●●●● (4) No	●● (2) No
Special form of organization of knowledge in general during the design process	● (1) Needed	●● (2) Needed	●●●●● (5) Needed	●● (2) Needed
Properties offered by technologies that have advantages concerning the use within furniture products	Advantages in terms of appearance, e.g. form flexibility, textured surfaces, self coloring, etc.		Advantages in terms of economics, e.g. material usage, durability, recycling, etc.	

Table (1). Summary of results from the interview study. (F): Freelance & (E): Employed designer

4.3.3 Findings provided by action research

Action research was used to test some of the methods as well as to provide a means of improving the designers' skills in interpreting different types of knowledge offered by new technologies throughout the design process. Based on the research questions, on the surveys of publications in this context, and the preliminary outcomes of the in-depth interviews, two procedures reflecting the approach of action research were applied. These were supported by samples from the furniture area which successfully make use of new technological possibilities. (See the procedures in detail in section 3.3.2.3). However, a number of key results have emerged:

- Designers have the ability to choose effective types of properties offered by technologies, if the information about these is presented in a form that is acceptable and understandable to designers.
- Designers can explain technologies to themselves by taking into account ideas from previous projects or an existing design which includes specific material properties or techniques, and combining them to come up with a new concept.
- Designers attempt to narrow the range of possible solutions or to isolate some details from the vast amount of technical data. In cases like these, they try to figure out what seems to have an influence on the look of the piece of furniture. Consequently, designers are faced with, a great number of technical problems which can arise, and then they need to find a compromise which takes all these problems into account.
- Designers' tools to describe the interaction between materials, shaping techniques, and form concepts are likely to appear in one of the following forms: quick sketches, drawings, models, or verbal expression to provide results despite the given constraints. Sometimes information externalized by some of these procedures causes the deficient communication between designers and engineers.
- One of the main problems that appeared in communication situations between designers and engineers is that there are noticeable differences in the language used by each of them to describe influences of technical aspects on the product properties and vice versa. Based on the

> differences in knowledge and cultural background, designers used "soft vocabulary" to describe aesthetical and semantic properties, yet engineers used "hard terminology" to describe facts and rules concerning technologies.

The findings of the action research are combined with the results of the in-depth interview study and presented in a detailed way as well as analyzed in sections 5.2 and 5.3 of this thesis.

Chapter 5

Analysis of the Results

5 Analysis of the results

5.1 Obtaining insight into the world of technological possibilities

The purpose of this subchapter is to help designers to become more aware of the possibilities offered by technologies. It is an attempt to extend the designers' knowledge about the enormous range of existing possibilities offered by material properties and manufacturing processes. Furthermore, this subchapter shall guide designers towards what they need to know and assist them in finding information which treats aspects that appeal to product designers in general and furniture designers specifically as the subject matter of this thesis. It seeks to fill the designers' lack of knowledge by focusing on the various sources of technological information. This subchapter shall give a simple overview of such information available at present. However, the reader has to bear in mind that this is primarily an overview and a simplification of a complex subject, since it is not the aim to provide all of the information required for a full understanding.

5.1.1 Materials properties

The developments in new branches of science resulted in an increased use of old and new materials with different properties. According to Antonelli [1995] "Scientists have discovered how to rearrange the molecules of matter into materials that not only appear different from those of the past but also have personalities and behaviours that are distinctly new. Solid metals are being replaced by ceramics and sheet metal by carbon fibres; wood can be as soft as upholstery" [p. 9]. The new, changeable character of material properties, as expressive as it is functional, has generated new forms as well as a more experimental approach towards design.

Usually, the most technically oriented publications categorize the material as families describing the physical, mechanical, thermal, electrical and chemical properties. This organization is derived directly from the atomic and electronic structure of the materials. Each family embraces classes and sub-classes and members. This classification is based on the physical aspects of the materials.

Figure 11 shows the material families: polymers, metals, ceramics, glasses, natural materials, and composites that can be synthesized by combining these [Ashby and Cebon, 2003]. Each one of them has its own structures and attributes: its properties. It is not a material per se that designers seek. It rather is a specific combination of these attributes: a property-profile. The material name is the identifier for a particular property-profile [Ashby 2001, p.22].

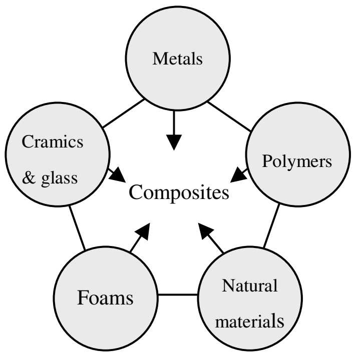


Figure 11. The world of materials, after Ashby and Cebon [2003].

In the following it is intended to gain knowledge about these properties which is relevant to design aspects. Therefore, we will consider this classification as a starting point to explore some of the new developments in material properties form the design point of view. This exploration will focus on the properties which clearly have effects on furniture design as the subject matter of this thesis. Additionally, sources for further information related to material properties will be presented.

The new metallurgy offers a very wide range of properties for metals nowadays. There is a strategy in the field of innovation that is attempting to halt the advances of plastics right in their strongest area – cheapness of transformation and easy formability combined with lightness. Even cast iron, the oldest industrial material, is acquiring new vitality through processes that provide the possibility of forming cast iron into complex geometrical forms which are much thinner than previously, resulting in products that are much lighter than those that traditional methods were capable of creating [Manzini, 1986]. However, metals used in manufacturing are usually *alloys,* which are composed of two or more elements, one of which is at least a metallic element. Scientists divide metals into two basic groups – ferrous and nonferrous[5]. Ferrous metals are based on iron compounds; the group includes steel and cast iron. The nonferrous metals include the pure metals and alloys of aluminum, copper, gold, magnesium, nickel, silver, tin, titanium, zinc, and other metals [Groover, 2002].

Metal used for furniture usually comes in the form of sheets, bars, and tubes or small "structural sections" similar in form to heavy steel sections but miniature in scale. Each one of these elements belongs to a group of metals or metal alloys – ferrous and nonferrous – which have own properties that make them more suitable for one than for another purpose. Basically, all types of ferrous metals contain carbon of various percentages which have an important influence on the properties of ferrous metals. For example, low carbon steels are relatively soft, easily rolled to plates and they are the cheapest of all structural metals. High carbon steels are specified for still higher strength applications which require stiffness and hardness. Most metals for furniture are made of low carbon steel. For outdoor site furniture applications, stainless steels offer durability and weatherability. They also provide a modern and attractive appearance. Nonferrous metals offer a wide variety of mechanical and physical properties. They have a wide range of melting temperatures, and differ greatly in cost and performance [Lesko, 1999].

Today, the most common nonferrous metal which is used for furniture is aluminum. It can be cast, extruded, stamped, anodized and printed; it can also be used in alloys and ceramic composites. Consequently, it plays a significant role in a wide spectrum of applications. Aluminum, one of the lightest and most attractive metals, can be treated in several ways to produce practical, inexpensive, and attractive furniture. However, aluminum alloys can be classified as follows: (a) wrought alloys, which can be cold worked without being remelted and (b) casting alloys, which have to be remelted and subsequently cast [Mazzolani, 1985]. Each category has its own numerical

[5] "Ferrous" comes from the Greek word ferro, which means iron [Groover, 2002].

designation. The designation system for aluminum alloys is a four-digit code number. The system has two sub-groups: one for wrought aluminums and the other for cast aluminums[6]. Generally, aluminum when used in sheet, coil or extruded form has a number of advantages compared to other metals and materials. Its many advantageous properties include softness, malleability, light weight (it is three times lighter than iron), good resistance to corrosion, and it has an attractive appearance. It can be colored and its surface will accept print. Aluminum is a completely recyclable material, since it can be remelted easily.

Due to this wide range of properties, aluminum created several possibilities for furniture designers in the past and nowadays. The pioneer who started to use these possibilities in furniture, as Edwards [1994] states, "was Marcel Breuer who seriously started to design aluminium chairs from mid-1932. […] A little later, in 1983, Hans Coray designed a lightweight aluminum chair for the Swiss National Exhibition, which was however primarily for outdoor use. Technically it was interesting as it used a tempered aluminium alloy into which was stamped the chair shapes, which were then punched with holes to give a distinctive proto high-tech look" [p. 42]. After that, Charles Eames used aluminum in developing a series of chair system designs because it can be easily manufactured, it is smooth, and it provides the opportunity of organic shaping.

In the recent years, a clear idea of the form character of a product could be established by considering aluminum as a source of inspiration. This can be seen in designs created by designers such as Roan Arad, Alberto Meda, and Christoph Böninger, see Figure 42. They produce objects that are more honest and relevant, based on the properties implied by aluminum. For example, Meda developed a form in his design called the "Longframe" *chaise longue*, which may be considered as more of an engineering accomplishment based on the effective use of aluminum properties than an aesthetic one. Figure 12.

[6] Details and analytical example of the numerical designation of aluminum and how it is coded , see Groover (2002, p. 111) and Lesko (1999, p. 19-20)

Figure 12. A combination of visual and physical lightness has been incorporated into a lounge seat appropriate for indoor or outdoor use. The form structure is based on extruded and bent aluminum frames with channels for netting insertion. The “Longframe” *chaise longue* was designed by Alberto Meda in 1993.

Different properties of aluminum have been used at different times. This will continue to be so. It still connotes lightness as well as purity and it is regarded as the metal of the future. Because of its multifaceted nature it is applied more than ever. A good introduction to these properties in relation to design is provided by a general research called *Aluminum by Design* [2000]. It is a publication based on an exhibition organized by the Carnegi Museum of Art that traced the history of aluminum from its first use as a precious metal in the nineteenth century to its evolving and enduring role in everyday life. Furthermore, the publication *Metall: Material – Herstellung – Produkte* [2004] offers a detailed description of the respective properties of metal materials in general and examples of their applications in various design areas. Further information is provided in the appendix of this book. For more in-depth information about metal properties, there are classified lists of suppliers of materials or services in general. Among the titles of abstracts covering metal properties, two interesting topics are for instance *Metals Abstracts* and *Metal Finishing*.

Plastics: The multi-purpose properties of plastics today are an optimal answer to fulfill designers’ wishes. Plastics have become sturdy, resistant, and aesthetically appealing. They can have various shapes, from the most straightforward to the most articulated. A good example in the context of plastics created by the brilliant designer Luigi Colani is illustrated in Figure 13. Colani is famous for creating streamlined furniture whose form arises from plastics properties.

The polymer family comprises natural polymers (cellulose, celluloid, casein, cellophane, ebonite, rubber). Yet, most polymers are part of a wide range of synthetic polymers, commonly known as resins, plastics and rubbers.

According to their processing techniques and properties they are classified as thermosets, thermoplastics and rubbers [Colling, 1995]. However, the first step towards making use of polymers is to know the differences between these categories that cover polymers as a technical subject. There are two basic groups of resins: thermoplastics (TP) and thermosets (TS). Both belong to the family of polymeric materials. However, the most important difference between them is that thermoplastics soften and melt when heated and harden when cooled. Because of this behavior these resins can be re-reformed or left to return to their original shape. Thermosets cannot be re-formed but have greater dimensional stability than thermoplastics [Lesko, 1999]. Elastomers are polymers with extreme elastic extensibility when subjected to relatively low mechanical stress. Elastomers are easy to foam, giving them the comfort of cushions and increasing their ability to conform to whatever is pressed against them even further [Groover, 2002]. In the context of polymers, designers must focus on some of these properties which may have an impact on the form structure and surfaces. Therefore, in the following, we will present some of these properties and some of the important members of these groups which had an impact on the structure of furniture form and its surfaces**.**

Figure 13. A swiveling armchair, designed by Luigi Colani around 1969. Colani selected a white plastic seat shell with protruding armrests and a freely suspendable back to stress the intrinsic expressive qualities of plastics properties.

Most design opportunities based on thermoplastics properties rely on the possibility of shaping the plastic into the desired form while still being in the soft state. For example, molded complex shapes can be achieved and most accept coloring agents and fillers. Many can be blended to achieve a wide range of physical, visual and tactile effects [Ashby and Johnson, 2002]. The common thermoplastics used in furniture design are: polypropylene, polystyrenes, acrylics, and polyesters. The thermoplastics tend to be tougher but less rigid and fragile than thermosetting plastics. The hardness of thermosetting plastics is however a particularly desirable property in the context of surfaces. In order to benefit from this and to simultaneously overcome the problem of brittleness, thermosetting plastics are frequently reinforced with fibrous materials, e.g. polyester resin with glass fiber to create polyester/glass fiber (GRP); melamine and phenolic resins are combined with paper to develop decorative and structure laminates. Generally, thermosets have greater dimensional stability than thermoplastics. They are used where there is a requirement for high temperature resistance and little or no creep. Most are hard and rigid; nevertheless, they can be soft and flexible [Groover, 2002; Ashby and Johnson, 2002]. However, the differences in properties of thermoplastics and thermosetting plastics have lead to various forms and shapes related to furniture products. Some of these are presented in the following.

Polyester/Glass fiber plastics (GRP) development was of great significance for the furniture designers after World War II. GRP has attractive properties for the furniture designer which make them more versatile and applicable for various utilities. It is strong, lightweight, and can be molded easily into free form shapes. In 1948 the Eames's DAR chair, the first self-supporting one-piece glass reinforced plastic chair shell, won the second prize in the Low Cost Furniture Competition in New York. Even though, it was innovative. According to Edwards [1994] "this was the first chair to have a moulded fibreglass seat in which the natural surface of its materials was exposed" [p. 28]. Later on, the awareness of the enormous potential of these new material properties revealed the true benefit of GRP, when Verner Panton produced his famous staking chair. Further developments in GRP as a thermoplastic with improved properties are widely used for specialized upholstered and shell furniture for hotels, offices and homes. For example, embedding formed of woven or felted glass fabric in a plastic resin allowed the material to combine the best attributes of both. The strength of glass fibers in the plastic makes the material rigid and the resin offers a smooth impermeable surface. Furthermore, the appearance of GRP components can be very pleasing and the gel coat surface will faithfully reproduce the mold surface whether this is a high gloss or matt finish. It has good weather and scratch resistance and thus has been favored for garden and street furniture where the low maintenance costs of GRP are fully appreciated.

Polypropylene (PP) is the one of the thermoplastics which is mostly used nowadays. According to Lefteri [2001] "it is the material of the moment" [p.25]. PP has become one of the major plastics, especially for the injection molding process. It is light, ductile and inexpensive. It offers excellent chemical resistance at higher temperatures. Reinforced plastics products make excellent use of polypropylene. It can be transparent and it accepts a wider, more vivid range of colors. PP is often laminated on other materials and used as a film. The best plastics furniture takes advantage of and uses these qualities. For example, the polypropylene chair shell makes use of the inherent toughness and resistance of polypropylene, enabling the chair to be used and flexed many hundred thousand times without distortion or failure. In addition to this, polypropylene properties are not only ideal for molding complex curvatures and providing free flowing forms, creating possible lightweight structures. Yet, also as sheets they provide new opportunities for plastics products in general. A good example for using PP properties in furniture is the "Soft Egg" chair designed by Philip Starck in section 5.2.2.1, Figure 22.

ABS consists of three chemicals: acrylonitrile, butadiene and styrene. They are combined to make the ABS plastics. It is called an engineering plastic due to its excellent combination of mechanical properties. It can be compounded with a high degree of hardness, or with great flexibility and toughness, and it is commonly described as tough, hard and rigid. It is usually translucent, yet it can also be opaque. Additionally, it is extremely resistant to most acids as well as alkalis and it can easily be molded [Ashby and Johnson, 2002]. ABS is used mainly in molded furniture requiring high surface luster and aesthetic appeal combined with rigidity and strength, e.g. in chairs, tables, shelving, and light fittings.

In addition to this, many other members of the plastics family offer useful properties for furniture products. An example for this is Polyamide (PA) which is suitable for the special application in furniture components where strength and resistance of the covering are prime requirements. Polymethylmethacrylate (PMMA), acrylic, also is a rigid plastic with a high degree of transparency. It is hard, stiff and easy to polish but sensitive to stress concentrations. Acrylic is available as a clear or as a colored material, in sheets of various thickness, rods, tubes and can be shaped by casting or extrusion. It scratches much more easily than glass, but this can be partially overcome with coatings [Ashby and Johnson, 2002].

Many good publications, catalogues and websites are designed to provide useful and interesting information about plastics properties. For example, *Fundamentals of Modern Manufacturing* [2002] concentrates on specific data and summarizes the different properties of plastics from the technical point of view. The *Handbuch Material Technologie* [2003] is an extremely helpful compendium which introduces material properties in an outstanding and easy-to-understand way. *Kunststoff: Material – Herstellung – Produkte* [2001] offers a detailed description of the respective properties of materials and examples of application. The publication *Design Guides for Plastics* [2004] presents current insights into plastics properties. Finally, websites such as www.plaslink.com, www.plasticsinfo.org, www.plasticmaterials.com, www.americanplasticscouncile.org, etc. include more information about plastics properties illustrated by numerous examples.

Wood as an advanced material: New technologies modified the physical properties of wood to become an advanced material. However, wood is not only one of the most beautiful and versatile natural material, it is also one of the most variable. It varies from species to species and within a species, from region to region, from site to site and even from one part of a tree to another [Johnston 1994. p.22]. Wood is one of the most popular materials used in furniture production because of its rich appearance, durability, and easy construction. In the course of the centuries, wood has continued to be a point of reference, a synthesis of what nature can teach mankind about design. Because of the developments in the wood technology, wood properties experienced a revolution in the 1960s with the enormous influx of particleboard panels, for which wood was ground and recomposed forming a more homogenous and isotropic material. Today, the researches on wood based composites (wood/wood composites) are being used to a greater extent than in the past years. Traditional wood based composites will continue to be used for many structural and decorative components. These include plywood, hardboard, oriented stand board and various types of particleboards. Many of these include veneers and/or paper-overlaid products for the surface.

One of the basic elements for composite wood products may be the fiber according to the foundation of the Forest Product Laboratory, as it is in paper, but it can also be large wood particles composed of many fibers varying in size and geometry. Currently, the term wood-based composite is being used to describe any wooden material adhesively bonded together. This product combines ranges from fiberboard with laminated beams and components. However, the most common types of wood-based composite materials used for furniture applications are: plywood, MDF (medium density fiberboard), and veneers [Edwards, 1994]. Today, there is a general trend towards using the results of research on wood-based composites in the field of furniture to create new innovative designs because of the different varieties of form, sizes and shapes offered by such new properties. For example, the new and rapidly developing generation of WPCs, ‘wood-based composites’, offered furniture products good mechanical properties, high dimensional stability and they can be used to produce furniture with complex shapes. They are tough, stable and can be extruded to high dimensional tolerances. WPCs are weather, water, and mold resistant for outdoor furniture applications for which untreated timber products are unsuitable.

In the context of plywood, one major development in the use of this material for furniture was the creation of three-dimensional forms introduced by Charles Eames and Eero Saarinen in 1940. The historian Edwards [1994] stated: "The Museum of Modern Art (New York) competition of Organic Design awarded these chairs the first prize. The team went on to develop plywood structures bent in two directions and it was soon declared that Eames had, 'with one stroke underlined the design decadence and the technical obsolescence of Grand Rapids', a clear reference to the old-fashioned design and production ideas of one of the prime American furniture-making centers" [p.12-13]. However, history books tell us that the development of plywood during the war was to have far-reaching effects on the furniture industry. During World War II, major developments such as the work of Eames as well as sandwich or stressed-skin plywood were made [Edwards, 1994].

This developing use of plywood caused changes in the furniture construction. Plywood panels encouraged flush surfaces in cabinet design, and the supply of pre-formed molded shapes could be used for chair and seat parts. Nowadays, molded plywood has also started a new phase of technology with the innovation research of the German company Reholz. With the proprietary technology developed in 2001, Reholz has been able to mold veneer into three-dimensional shapes that were impossible until now. Before this "3-D Form" technology, deep molded forms required precise patterns to be made before the veneer assembly was glued and pressed, like the Eames plywood splint. Reholz's technology now allows unprepped sheets of veneer to be molded without any mechanical preparation [Ngo and Pfeiffer 2003, p.73], as demonstrated by Peter Karpf's chair, see section 6.3.

MDF is another wood based composite and was originally developed exclusively for furniture because of its weight, strength and aesthetics. MDF lends itself well as a substitute for clear lumber, and while it does not have a grain structure, finishes and overlays can be used effectively to provide a furniture product that looks like wood. Furthermore, the lacquering properties, strength and ability to maintain shape are well suited to MDF which offers the advantage for furniture to become always trendy.

Summarizing the previous paragraphs, it seems to be crucial that WPCs properties provide designers with an excellent alternative for creating new products that possess a quality appearance, a range of visual effects and that may look good for many years.

More detailed and current information on the development of wood properties is generally available in handbooks such as *Wood Handbook – Wood as an Engineering Material* [Forest Product Laboratory, 1999] which covers types, standards, uses, defects and general descriptions of wood properties. Another useful publication about the different characteristics of wood composite materials is *The Family of Wood Composite Materials* [1996]. A good source of information which offers an inspiring overview over many types of wood in general and their derivatives is *Wood, Materials for Inspirational Design* [2003]. It presents a range of furniture products and other projects considering a diverse sample of wood in various forms. It also includes technical information and a website directory of key timber associations, suppliers and environmental groups as a guide to recent types of wood use. A comprehensive source dealing with plywood furniture is *Bent Ply: The Art of Plywood Furniture* [2003], which present the history of plywood from it first use and techniques based on the skills of the craftsperson to the new technological possibilities recently available. The newer editions of some magazines might be of interest for designers, such as *Magazine for Architecture, Designers and Engineers* [2005], which includes information about recent innovations concerning new properties of wood.

Rubber and foam: The softness and flexibility of rubber and foam make them particularly useful for objects engineered to adapt comfortably to the human body. Rubber and foam is a wide-ranging category that encompasses various materials and technologies including natural and synthetic rubbers, gels, foams, and air- or gas-filled bladders . In the context of furniture, polyurethane (structure foams) represents an important recent breakthrough in the creation of new furniture designs. Even though thermoplastic polyurethane (TPEs) has been available since the 1950s and many TPEs since the 1970s, advanced materials were not always as easily accessible to designers as they are today [Antonelli, 1995]. They are soft, stretchy, and they can also be leathery or rigid. Because of these versatile properties of the polyurethane family, they appear to provide an endless source of innovation in the field of furniture. In the beginning, they were used as a rigid material for the production of chair shells. After the successful use of rigid polyurethane foams in chair shells, further development led to integrally skinned polyurethane foams, now commonly referred to as 'polyurethane structural foam'. Rigid polyurethane foams are renowned for their ability to bond strongly to most materials and this has been exploited in combining *in situ* reinforcement and anchorage fixtures for legs and covers [Antonelli, 1995]. Today, flexible polyurethane foam has remarkable versatility. It can easily be cut and shaped to serve an almost unlimited number of designers' purposes. It offers a number of benefits for designers and users of flexible polyurethane foam as demonstrated by Jasper Morrison' s sofa, see Figure 14.

An effective new application with new polyurethane foam for upholstered furniture has been developed by Bayer Material Science. This organization is one of the leading manufacturers of polyurethane materials with different physical properties. It produces for instance an extremely light polyurethane foam used for covering upholstered furniture. This highly elastic material known as HyperNova is dimensionally more stable than the polyester fiber fleece and other materials traditionally used for this purpose. Another benefit of this very soft polyurethane foam is its exceptional breathability: It is extremely permeable to air and can absorb up to ten percent of its weight in moisture and emit it again later [The Bayer Press, 2004].

Figure 14. The "Three sofa" system designed by Jasper Morrison (1992) made use of the flexible molded foam. The foam properties provide the possibility to combine spectacular shapes with a high degree of functionality, reconciling maximum comfort with top quality.

The transparency and invisibility of glass make it the most naturally beautiful of all materials. Simply molded, colored, and unadorned, it provides a fascinating study in its very essence [Lefteri, 2002]. Through the centuries, this material, made from mixed sands treated to achieve a state of rigid liquidity, has been the magical obsession of alchemists, chemists, and engineers and has developed extraordinary mutant qualities. The qualities associated with glass are pure form-transparency, fluidity, and sparkle. Much

Figure 15. "Aura" coffee table, 1990, designed by Karim Rashid. The table is designed to be configured into approximately twenty-seven different compositions made possible by different colors and shapes of glass on three levels [Antonelli, 1995].

glass, rather than being transparent, is merely translucent or even opaque; some has no noticeable sparkle, and many special types are as hard and durable as steel. In relation to furniture production, glass most commonly takes the form of cast or rolled sheets in various sizes and thicknesses. Today, with special tempering systems, glass can be produced in multi layer panels (the number of layers depends on the ultimate application) that have a special transparent or opaque plastic film of exceptional strength inserted between the layers. In other words, it can be laminated to great organic forms. In addition to coatings on glass sheets and additives to the fusion process, other glass products are created by the insertion of a second material between the two sheets of glass [Antonelli, 1995].

With this way of production, new aesthetical aspects for furniture products can be created. A significant example in this context is Karim Rashid's coffee table made of beautifully colored PMMA (polymethyl-methacrylate) film. It is a spontaneous exploration of the potentialities of the laminated glass technology. Rashid used PMMA film in this project, yet one of any number of other films could have been used to other polarizing, refractive, and optical effects, see Figure 15.

Designers can be inspired by the shaping possibilities of glass objects which usually derive directly from the forming methods. Furthermore, the colors and texture qualities are incorporated in its surfaces. Interesting information related to glass forming by pressing, blow molding, centrifugal casting, drawing or rolling is provided by the following publication: *Industrial Design: Materials and Manufacturing Guide* [1999]. *Glass: Materials for Inspirational Design* [2004] is another unique and stylish, but also highly informative source for product designers. It describes glass in all its applications including architecture, furniture, lighting and domestic products, and in all its forms – mosaic, sandblasted, etched, colored, texturized and molded.

Composites: The lightness and resistance of composite materials can tread on sensitive toes regarding the contest between techniques and aesthetics, form and function. However, a useful definition for the term composite is two or more materials brought together to make a new product "better" than the individual components. Better may mean improved properties or performance, or in some cases, improved economics [Harper, 2001]. The concept of composites was not invented by human beings; it can be found in nature, too.

An example for this is wood, which is a composite of cellulose fibers in a matrix of natural glue called lignin [Sanjay, 2002]. Imitating nature, scientists came to find out that the combination of a matrix (polymer, metals, ceramics) with reinforced fibers (jute, flax, glass, carbon, etc.), generates a new class of materials: the composites. From the engineering point of view, the greatest advantages of composite materials are strength and stiffness combined with lightness. By choosing an appropriate combination of reinforcement and matrix material, manufacturers can achieve properties that meet exactly those requirements that are needed for a particular structure and for a certain purpose. Modern aviation, both military and civil, is a key example in this context. It would be much less efficient without composites. In the modern days of composite materials, many new composites have been developed, some with very valuable properties. By carefully choosing the reinforcement, the matrix, and the manufacturing process that brings them together, engineers can influence the properties to meet specific requirements. They can, for example, make the composite sheet very strong on the one side by aligning the fibers in a certain way, but weaker on the other side for cases in which strength is not that important. They can also select properties such as resistance to heat, chemicals, and weathering by choosing an appropriate matrix material. For the matrix, many modern composites use thermosetting or thermosofting plastics. The use of plastics in the matrix explains the name which is commonly attributed to these composites: 'reinforced plastics'. Some of the properties that designers generally find attractive in fiber reinforced plastics include: textured surfaces, self coloring, low density, durability, etc. Another advantage of composite materials is that they provide the design with lightness. Along with these excellent properties, the real breakthrough in the field of composite materials was caused by the processing techniques which transform the shape of materials. There are various types of composites processing techniques available to process the different types of reinforcements [Mayer 1993, p. 2-4]. The basic principle of these techniques is the molding process. Some types of processes are described in the following section 5.1.2.

Figure 16. The "Air Chair", designed by Morrison, is a successful design which derives from the properties of composite "polypropylene" and the gas-injection technology that is used to manufacture it. The properties of the composite alone are too flexible to create the chair, so, before molding it, it is mixed with fiberglass to add strength. Morrison relates this highly technological process to natural principles by describing the chairs as being 'like a bone' [Morrison, 2002].

More and more furniture designers were impressed by the freedom of shape offered by composites. They were tempted by the ease of combining a flexible reinforcing phase with a liquid resin to produce a rigid structure [Bucquoye 2003, p. 41]. Moreover, composites' properties are highly relevant for the furniture industry. The efficient application of composite technology offers new designs freedom for new potentials. On a more mundane level, composites can be used to replace metals and wood in applications like the inner structural sections of lounges and other soft furnishing, as well as in the structure sections of office furnishing. The advantages and opportunities of advanced composite materials combined with new process technologies will lead to a completely new attitude towards furniture, space and the possibilities of design. Beside the examples presented earlier in the context of plastics properties which belong to the group of composites, there is another effective and efficient example using the possibilities of composites: the "Air Chair" presented in Figure 16.

A variety of sources about composite materials is vital for designers as these enable them to have a pool of expertise. Those likely to be of interest to designers are for example: *From Bakelite to Composite: Design in New Materials* [2003] which presents very interesting data about different composite materials. It introduces different types of composites, examples and the names of designers who are famous for using the possibilities of composite materials. Another publication, *Design with Reinforced Plastics is an Effective Guide for Engineers and Designers* [1993], discusses the integration of reinforced plastics in the design process, starting with the design brief and progressing through the various stages of design to manufacturing and testing. *Composites Manufacturing: Materials, Product, and Process Engineering* [2002] offers a comprehensive overview and includes in-depth information about composite materials and their application as engineering materials. Not only texts, but also films and video-cassettes originate from many sources, for example from suppliers of materials. Nowadays, conferences concerning plastics products emphasize news of composite material developments. These are sources of information reflecting selected facets of the current state of science and technology. An outstanding example in this context is "Material Vision", which is the result of an interdisciplinary conference and a company trade fair. It was established as a new platform that focuses exclusively on new materials, their properties, and their future potential. Furthermore, there are some useful websites providing a data-based information service created especially to meet the needs of designers. For example, www.composite.about.com provides a general introduction to composite materials. www.materialwork.com offers examples of all materials which are listed in the database that can be ordered. www.compinst.asn.au/industry.html. presents a brief summary of composites and their manufacturing advantages.

5.1.2 Shaping processes

The new possibilities of manufacturing processes and the uses of newly developed materials continue to stimulate the creativity of designers. The growing variety of shaping techniques of materials is associated with an increase in the material properties. Most shaping-processes apply heat or mechanical force or a combination of these to cause a change in the geometry of the working material. There are various ways to classify these shaping processes. Technical literature generally classifies the shaping processes based on the state of the starting material such as a liquid, plastic, or solid state [Groover. 2002]. This classification depends on the material properties and the ways of forming. However, every traditional material can become “new” through the adoption of advanced shaping/forming and production processes. The possibilities of shaping processes are various, as these are based on specialized equipment used for converting materials into finished items. The more important of these, as far as they relate to the field of furniture, are: bending, casting and molding processes. In this section, some of the possibilities related these three essential processes and their sources are shortly presented.

Binding

Since the 1841, when Michael Thonet, the Austrian furniture inventor and manufacturer, obtained patents on his method of making complete pieces of furniture from bent wood parts [Pile, 1990], manufacturers and designers have explored the design and the economic advantages of “bentwood”. The process of wood bending in the course of which solid wood can be made flexible by steam heating has long been known. With growing worldwide interest in contemporary furniture based on wood bending (bending process), research has been carried out in order to find other and better methods for the industrial bending of solid wood. The decisive breakthrough was initiated by a compression machine which allows to bent wood with high shape quality. The compressed wood can be subjected to extensive changes in shape. It can be bent in all directions and has a low waste rate. Furthermore, bending can be done by means of simple tools and jigs, whose handling is easy to learn [Buchter et al., 1993]. Some conditions determine how much the compressed wood can be bent, such as the wood species, quality, dimensions, and rate of compression as well as the shape of the component and the applied tools and jigs. The principle of the patented process is based on steaming the wood to soften it. Afterwards it can be compressed longitudinally in the direction of the fibers with the help of special tools. After the plank has been bent into the desired shape, it must be fixed in a certain form and be allowed to dry. During the drying, the wood "sets" in the desired shape [Xylon international, 2002]. This new technology offers the unique opportunity of using pliable veneer, flexible wooden materials and easy bendable solid wood. Moreover, it offers furniture designers not only the possibility of creating multiply curved furniture components for chairs, tables or beds etc., but also the possibility of re-interpretation of the original Thonet designs, see Figure 17. However, with the new process of bending (solid, soft or laminated wood), structure and material have now freed bentwood furniture from its former heaviness and rigidity. It is possible to make bentwood furniture that is pliable, springy and light[7], as Gehry [1992] revealed in his reflection on building the "Cross Check" Armchair (see this chair as example in Figure 32 in section 5.3.2). In this chair Gehry, who was first inspired by the qualities of autonomous structures of bushel baskets, used the recently developed technology of bentwood and assembly in the development of a new bentwood product system.

Figure 17. The "Friday Chair" is an interpretation of bending possibilities by Stefan Diez [2003]. The chair consists of an innovative re-proposal of a type of tub and wood bending technology [Polster, 2005].

The unique opportunities for furniture products based on the advantages of the technology for bending do not only refer to wood, but also the tube, rod, and sheets of metals. However, the bending of metals is generally important for designers because of its ability to create a great attractiveness and efficiency in industrial production. Tubing (round, square, etc.) and solid rod can be bent to shape over hard steel dies to produce a wide range of furniture parts. Tube and rod metals are used for the production of chairs. Three types of machines are used for tube bending: manual-human-powered forming which is suitable for tubes up to one inch diameter; semi-automatic hydraulically or electrically powered equipment, some with advanced features; CNC-computer controlled equipment that accurately performs 3 axis bends [Miller, 2002]. Bending sheet metal along one plane is normally a fairly inexpensive operation that creates simple shapes and gives that sheet some rigidity and strength. In the process of bending sheet metal, the material tends to be flexible in the use of sheet-

[7] 'Frank Gehry re-invents the chair', Blueprint (September 1992), and Domus, 739 (1992).

forming machines. These machines are controlled by computers and they are capable of complex forming, however, only along one axis for each bend. Conceptually, it may be useful to think of one-axis sheet bending as being somewhat similar to bending paper [Lesko, 1999]. However, making use of the potentials offered by metal bending, furniture designers have always demonstrated the aesthetic possibilities of transparents, textures, and curved plans resulting from a linear movement.

A source of detailed information dealing with bending wood in general (its history and new developments) are *The Story of a Chair: The Steam Bent Vienna Chair and its Designer Michael Thonet* [1979] and the *Wood Bending Handbook* [1970]. These publications are quite old, but they still represent a useful resource. They focus on the principles of the solid and plywood bending process and the historical background of bending wood. A more recent publication is *Introduction to Compressed Wood*, [2001] which introduces new innovative applications of bending based on compression machines. In relation to the bending process of metals Greg Miller, discusses and investigates some of the more popular options available for tube bending, its benefits, limitations, and applications in the publication *Justifying, Selecting and Implementing Tube Bending Methods* [2001]. Furthermore, *Industrial Design, Materials and Manufacturing* [1999], presents a useful summary of metal bending possibilities. Another very useful source which might help to draw the designers' attention on the potentials of metals is a publication with the title *Metals: Materials for Inspirational Design* [2004]. Greatly visual and easily accessible, even to those with no prior knowledge about the material, this book introduces each application with a comment by the author as well as interviews with designers and manufacturers. Examples from different areas are featured. This is complemented with detailed technical specification tables, an internal index which points the way to linked pages of interest, as well as an extended glossary and resources section for more in-depth study.

Casting

Casting is a manufacturing process capable of producing fully shaped components in any size of practically any metal or alloy. Casting users are placing increasing demands on the foundry industry to produce castings of improved quality. This is reflected by the demands for improved dimensional accuracy and consistency, improved surface finish and improved metallurgical integrity [Clegg, 1991]. The process plays an important role in the furniture component production which are usually used in practical ways and shaped with a modern look. Prominent examples for casting are frames, legs, pulls, knobs, shelf supports, connections or other components which help to reduce the structural parts to minimum size and to produce lightweight components. Generally, casting is the name used for metals. The different casting techniques offer a variety of possible sizes, shapes, and a spectrum of castable metals. However, metal casting processes can be divided into three main categories according to the type of mold: sand casting, other expendable-mold-casting processes, and permanent-mold-casting processes. There are many different variables between them. Each one can change the final product. Therefore, it is vital for designers to select the correct casting process to prevent problems at a later stage. In the following different casting processes will be presented.

In the green sand casting process, a mixture of sand and clay is compacted in the spilt mold around a pattern that has the shape of the desired casting. The pattern is removed to leave the cavity in which the metal is poured [Ashby and Johnson 2002, p.247]. In this process, very complex furniture shapes and components are achievable. Another casting process has been developed to produce castings of improved quality with precision surface details which meet special needs. The difference between these is that techniques in the composition of the mold materials or in the way the pattern is made vary. For example, *shell molding* is a casting process in which the mold is formed like a thin shell made of sand held together by a thermosetting resin binder [Groover, 2002]. Some big advantages are: the excellent casting surface finishing, the increased productivity and the closer tolerances. Nevertheless, the size and weight range of the castings is limited. The *investment casting process*, which is known as the wax process, has several advantages, such as the superior surface finishing, the great freedom of form, and greater dimensional accuracy. Another casting process is the *plaster mold casting process*. It is a specialized process used for the production of non-ferrous alloy casting with smoother surfaces resulting in a finer reproduction of details and greater dimensional accuracy than in the products obtained from sand molds. Finally, in *permanent-mold casting*, the mold is reused many times. Permanent molds are often cast in iron or are machined in various metals. Cores can consist of metal, sand, or sand shell [Lesko 1999, p. 25-37]. It has several advantages compared to other processes which include a good grain structure, a high degree of uniformity, a high degree of dimensional accuracy, and a consistent quality finish.

In general terms, it is important for designers to consider some principles of casting processes which can have an impact on the final form created by this process. The designer must for instance be aware of how the solidification is affected by the geometry of the parts and changes in the cross-section area. This affects the appearance of the product. Furthermore, sharp corners, angles, and flat areas should be avoided because they have a tendency to warp and often result in poor surfaces [Lesko, 1999]. Bearing this in mind, for designers it seems to be important to understand more about the different types of processes in order to achieve the best final product appearance. Unfortunately, there are very little sources which treat the aspects which are relevant for designers related to casting processes. Therefore, designers should seek to capture further information from the trade foundations of surface finishing metals, for example from the *Cast Metals Federation* [8]which has a web site that is daily updated. Its website provides insight into the different processes used when casting metal. Moreover, most publications which deal with new developments concerning metals generally include information related to casting. Good examples are publications like *Industrial Design, Materials and Manufacturing* [1999] and *Metals: Materials for Inspirational Design* [2004]. Both include basics and elementary principles designers must be aware of and some ideas which can incite their imagination.

Molding

As opposed to casting referring to metals, molding is the term commonly used for plastics. Plastics can be melted or treated at relatively low temperatures and are thus easier to handle and require less energy to process them than many other manufacturing processes [Groover, 2002]. Among a variety of plastics processes, molding processes have had a great impact on the plastics furniture industry from its beginning[9]. The plastics molding process usually refers to shaping plastic products in a mold cavity or through the opening of a die. Today, a huge number of plastics materials are available along with many highly sophisticated plastics-processing machines to turn these materials into

[8] http://www.castmetalsfederation.com/home.asp , Cast Metals *Federation*.
[9] Concerning the historical background, see "Plastics+Design": Die Neue Sammlung, Staatliches Museum für angewandte Kunst, München“, Arnoldsche, 1997.

an increasing number of plastic furniture products which have become an essential part of our daily life. There is a variety of different processing methods used to convert plastics into finished products. Molding processes are the most common methods of converting plastics from the raw material to an article of use. Common materials for molding, which have more impact on furniture manufacturing, are thermoplastics and thermosetting plastics. Principal methods of processing thermoplastics include “extrusion”, “blow molding”, “rotational molding”, “thermoforming” and “injection molding”; but also for thermosetting plastics, “compression”, “transfer” and “reaction injection” molding are frequently used. However, in the following it is intended to define some of these processes and the various sources related to them.

Extrusion occurs in any process in which a material is forced through a shaped orifice with the material solidifying immediately to produce a continuous length of a constant cross section. Squeezing toothpaste from a tube is a similar and highly familiar example [Levy, 1990]. Extrusion is one of the most important shaping processes for the reason that pellets, which are used for many other molding processes, are normally produced with the help of this process. The process produces continuous two dimensional shapes like sheets, pipes, films, tubes, hoses, rods and also structural or profile shapes. However, extrusion basically is a process which uses a machine to extrude a material; it is called *an extruder*. Many different materials can be extruded, such as clays, ceramics, metals, and of course, plastics. The main function of an extruder is to develop sufficient pressure in the material to force the material through the die. The publication *Understanding Extrusion* [1998] includes an illustrated drawing of the main components of an extruder machine and the several functions of each component. The principle of this operation is the same as that of a meat mincer but with heaters added in the wall of the extruder. The extrusion process permits a wider range of possibilities to produce several items incorporated in furniture which fit most conveniently into the components’ field. A good example for this are extruded sections in PVC used as edgings on wood and wood chipboard. More recently rigid extruded sections in expanded or foamed PVC have proved particularly suitable for edgings on wooden furniture. Extruded sections are used for lining runner slots in drawers for the purpose of proving smooth, silent action. Extruded sections may also be used for edging glass or their sheet materials can be used as a protective measure. Extruded panelling in polystyrene and PVC can be met as decorative in-fill panels, particularly in the cabinet field. Generally, a wide variety of standard profiles is now available for form extruders and for many applications involving extrusions for component use in furniture.

Blow molding is the forming of a hollow object by “blowing” a thermoplastic molten tube called a parison in the shape of a mold cavity [Lee, 1990]. It is an important industrial process for making one-piece hollow plastic parts with thin walls, such as bottles and similar containers. Since many of these items are used for consumer beverages for mass market, production is typically organized for very high quantities [Groover, 2002]. Recently, blow molding has become the most prominent method for the manufacture of plastic items with reentrant curves providing technical, aesthetical and cost advantages [Rosato, 1989]. The basic process is described in interesting texts in the *Plastic Blow Molding Handbook* [1989] which presents the fundamental phases of the processes. Furthermore, the *Fundamentals of Modern Manufacturing* [2002] classifies the process into two major categories: extrusion blow molding and injection blow molding. Above all, a blow molding process is intended for manufacturing hollow plastics products and its principal advantage is its ability to produce hollow shapes without having to join two or more separately molded parts. Generally, several successful items of furniture, particularly in the seating area, have been made by blow molding. An example for this are the famous “Ball seats” designed during the sixties as unusual shapes which were made in one piece.

Injection molding is the most important process used to manufacture plastic products. Today, more than one third of all thermoplastic materials are injection molded and more than half of all polymer-processing equipment is used for injection molding [Trurng, 2002]. It is a process which offers a high degree of latitude to designers. The recent developments of the injection molding process have allowed furniture designers near-total design freedom with new design quality. However, the injection molding process is a high speed, automated process that can be used to produce plastic parts with very complex geometries. The process can produce either very small or very large parts using virtually any plastic material [Malloy, 1994]. Basically, in injection molding, plastic granules are heated and “injected” under pressure into metal molds, where the molten plastic hardens into a designated shape. The mold then opens and the newly formed part is removed and inspected, ready for shipment or secondary manufacturing operations. Essentially, the most common equipment for molding thermoplastics is the reciprocating screw machine. An interesting schematic and descriptive essay helping to understand the process of injection molding is included in *Material and Design: The Art and Science of Material Selection in Product Design* by Ashby and Johnson [2002].

The central element in an injection molding machine is the mold. The mold distributes polymer melt into and throughout the cavities, shapes the parts, cools the melt, and ejects the finished product [Trurng, 2002]. Mold design is in itself an extremely diverse and complicated subject. However, it is useful to understand the basic features and the construction of simple injection molding tools. The *Injection Molding Handbook* [2002] and *Fundamentals of Modern Manufacturing* [2002, p.287-291] present a precise and comprehensive overview over data about mold parts and mold construction. Authors like Ashby and Johnson [2002] referred to injection molding as being the best way to mass-produce small, precise polymer components with complex three-dimensional shapes. The surface finish is good; texture and pattern can easily be altered in the tool, and fine details are reproduced well [p. 240].

If, in furniture design, plastic items shall be made by injection molding, it is essential to be aware of the inherent properties of the envisaged materials and to relate these to the item which shall be made. By this approach a successful use of the plastics, for example in chairs, storage furniture and others items can be created. Injection molded plastics furniture can achieve most success in designs which incorporate components such as curves, complex shapes and sections and free forms. This process conforms to a modernist fantasy of designers to create perfectly formed products with an aesthetically fascinating appearance ejected from a machine.

Rotational molding is like blow molding used to produce hollow plastic articles, though the principles in each method differ a lot. Rotational molding uses gravity inside a rotating machine to produce a hollow form. Also called rotomolding, it is an alternative to blow molding for manufacturing large, hollow shapes. The process is exemplified by an interesting illustration in *Materials and Design: The Art and Science of Material Selection in Product Design* [Ashby and Johnson 2002, p. 241]. The process is simple, versatile, and inexpensive and it is one of the few processes which is able to manufacture hollow products. Good knowledge about this process combined with some creative ideas, can create a fascinating variety of furniture by rotational molding. Rotationally molded chair units and similar pieces of furniture seem ideal for the use in public places such as swimming pools and hotels. Other than chair units, rationally molded polyethylene bins used as components of intuitional furniture have been successfully marketed; some items of 'chunky' nursery furniture have been made like this.

The thermoforming process is ideal for flat parts and rigid sheets which can be used to produce innovative furniture items. Applying these flat sheet processes designers can easily create furniture with surface quality and stylish appearance. Thermoforming uses heat and pressure to form thermoplastic sheets [Lesko, 1999]. In this process the rigid sheets can be softened to a rubbery condition by heating them up to a particular and relatively low temperature. Such sheets can be molded in three-dimensional shapes at their particular shaping temperature. The publication *Fundamentals of Modern Manufacturing* [2002, p.292-296] presents three types of thermoforming processes in a detailed way: vacuum molding, air pressure molding, and mechanical molding. However, the thermoforming potentials include producing good surface sheets in two or three dimensional shapes and the possibility of being applied to any thermoplastic sheet. Therefore, the process has some relevance to specific applications in certain areas of furniture production. For example, acrylic sheets, which are known under the trade-name of 'Perspex', are one of the more commonly used sheet materials in furniture. They have a hard surface of glass-like quality and can be obtained in wide range of transparent, translucent and opaque colors. Furthermore, based on the thermoforming process, polystyrene sheets can easily be shaped into deep complex forms and produced in a range of colors. In relation to furniture, such sheets are used in bathroom cabinets as well as for some settees and for chair forming. Rigid PVC sheets are also tough and resistant to the spread of flame render. PVC is especially suited for some items of public furniture. These possibilities allow designers to adopt an attractive range of colors and various surfaces which help designers to create forms having the same material but incorporating different shaping characteristics.

Foam molding or polymer foam is a polymer-and-gas mixture, which gives the material a porous or cellular structure. Other terms used for polymer foams include cellular polymer, blown polymer, and expanded polymer. The most common polymers used to make foam are natural rubber ("foamed rubber") and polyvinylchloride (PVC) [Groover, 2002]. The characteristic properties of foamed polymers for plastics in furniture are growing steadily. Recently, techniques for molding foamed thermoplastics have become available, these being based on the injection molding principle. However, the more important techniques now available for processing the main types of structure foams which are effectively applied in the construction of furniture are expanded polystyrene and polyurethane foams. Interesting descriptions which are illustrated with figures are available in *Materials and Design: The Art and Science of Material Selection in Product Design* [Ashby and Johnson, 2002]. The possibilities which the foam molding process allows to designers are the following: complex profiles can be molded, the material is light in weight, and has visual as well as tactile properties that are interesting.

The process of polyurethane foams or structure foam process offers foam with properties which are suitable for the most common cushioning materials used in upholstered furniture. The flexible properties of polyurethane foam give furniture designers more freedom to develop new ideas and to make specific designs work. Polyurethane foam products are made in a one-step process in which the two liquid ingredients (polyol and isocyanate) are mixed and immediately fed into a mold or other form, so that the polymer is synthesized and the geometrical part is created at the same time. The shaping process for polyurethane foam is presented in a detailed way in *Fundamentals of Modern Manufacturing* [Groover 2002, p. 299] which divides them into two basic types: spraying and pouring. The main difference between both processes, from the design point of view, is the final result of the target surface. Generally, with the polyurethane foam molding process, which is now supported by efficient and reliable items, it is expected that polyurethane structure foams will achieve a significant breakthrough in the furniture field.

This was a short introduction and simplified summary of some molding processes and their advantages related to the design area, in this case furniture. Deeper understanding and further information can be obtained with the help of the sources which are included in the previous paragraphs. Additionally, illustrative examples describing the possibilities of shaping processes in general will be presented in the following sections.

5.2 Considering the possibilities offered by recently developed technologies in the design process

This subchapter provides approaches to consider the possibilities offered by new technologies concerning with materials and shaping techniques early in the design process. The suggested approaches respond the need for methods that include suitable procedures for supporting the design process by which designers will be able to take into account effective types of information offered by recently developed technologies throughout their activities. The idea behind this is that these methods lead designers towards exploring the design opportunities provided by technologies.

The results presented and analysis in this section combines findings from both theoretical and empirical research methods which have been applied in this thesis.

5.2.1 Ideas generated based on new technologies

The term ‘idea’ is defined as "the conception existing in the mind as a result of mental understanding, awareness, or activity" [Cambridge Dictionary 1989, p.706]. According to Baxter [2002] "idea generation is at the heart of creative thinking. The ideas produced are the lifeblood of the creative process. They are what put the ‘creative’ into creative thinking" [p.73]. This reflects that the new idea is the main process in any innovation. Without the idea it is impossible to enter the next stages. It is the starting point of design [Ashby and Johnson, 2002]. In other words, there is an almost magical quality to any new idea. It seems to appear from nowhere. Nevertheless, ideas or solutions cannot emerge from a genuine vacuum. Unconsciously, our minds generate ideas from different experiences stored in the mind either consciously or subconsciously. In the context of the technological possibilities of the new materials and shaping techniques, it is supposed that an innovative idea may be handled with the help of the designers’ special awareness of these. In so doing, the designers can enhance their creativity and find new sources of inspiration. Moreover, such possibilities can help designers to generate effective solutions or concepts related to the design brief which is surely based on the product requirements.

Our investigation in this area is focussed on the question: Can technological possibilities offered by the properties of materials help to generate ideas or are they themselves the reason for starting a design? Answers to this question from experienced designers indicate that:

- Many designers [over 42 %] do not see the significance of information that materials and their techniques provide at an early stage of their design processes. They emphasised that bearing technical issues in mind would constrain the creativity process that is required in the beginning of the design phases.

- Some designers [11 %] are apprehensive about becoming aware of more technical information, particularly because it might reduce the number of alternatives of the generated design solutions. However, they cannot ignore that some qualities of the material concerning function or usability can assist to define the users' needs or a problem statement. They point out that some information about the characteristics of materials or their production techniques can help designers to interpret them effectively in order to perform certain functions or to elicit certain forms. For instance, according to one designer from this group, some properties of composite materials can ensure the durability of furniture pieces and at the same time impart lightness on the form. Both properties can trigger ideas at the beginning of the design concept related to use and aesthetic problems. Another subgroup of these designers believes that superior design concepts can be created on the basis of the technical information and their relationship to the problem statement. This can be fulfilled if designers make the effort to balance their own creative thinking skills on the one hand and relevant types of the available knowledge on the other hand.

- Furthermore, some designers (nearly 4 %) stress the importance of the deep understanding of technical knowledge and its role in creating 'new' design ideas. They believe that the designers' interpretation of this knowledge is based on observation and perception skills. Designers perceive this knowledge in a different way than others do. Therefore, they are able to select certain suitable types of this knowledge in order to stimulate their creativity earlier in the conceptual phase for further interpretation of their concepts. This depends on early access to inspirational sources of new materials and their techniques in a form that is acceptable to designers. They pointed out that some of these sources can be found, for instance, in design magazines, in material sample collections, in mood boards[10], in product samples, in experimental forms with new materials, etc.

Definitely, the ability to generate innovative ideas primarily depends on the domains of knowledge which are available and thus on the designers' experiences to interpret them in different ways. The designers' interpretation of the possibilities offered by technical knowledge is normally based on experiences gained through observation and perception of a physical object. It is in the hands of the designer to make such experiences in finding out about characteristics and opportunities provided by the available components. However, it observed that certain material properties or production methods are mostly interpreted based on the designers' intuition[11]. In any case, designers must have sufficient experience of the field in which they can be intuitive. Due to the designers' lack of information and experience in the area of technology, the suggested ideas or solutions have to be rejected. The reason for this is feedback concerning the impossibility of the technical realization of the first idea.

In practical design work, the generation of ideas is affected by certain types of constraints that are imposed on the intended design or related to briefing. One of those constraints involves certain material properties or techniques. In this situation, these constraints are early defined and they must be taken into account by designers at the beginning of the design process. Therefore, the realization of the proposed idea can continue.

As a general principle, designers need background information about the possibilities provided by material properties and techniques in order to be able to interpret them. This interpretation can be done either in the way of "free thinking" or in the way of exploring the constraints imposed on the design idea due to such possibilities. Hence, it is supposed that certain kinds of useful information about material properties or their techniques should be considered by designers. This can help to develop new ideas. We argue as follows:

[10] "mood board" as a personalized, project-focused image collection, enhanced by a collection of material samples, [Ashby and Johnson 2002]
[11] Intuition is called an "exact fantasy" or "the spontaneous, free agreement of the imagination with the laws of understanding", [Goeth and Kant] in Jones [1992].

- The use of the numerous options offered by technical innovations to generate ideas will facilitate the designers' interpretation of such possibilities in new forms. For instance, in the context of furniture designers created organic designs and free forms inspired by the suggestive laminated fibreglass layers shaped three-dimensionally in a way that resembles elements of Salvador Dali's surrealist pictures [see La Chaise by Charles and Ray Eames, or new developments in composite properties]. Moreover, the process of injection moulding with minimal material usage and great technical precision can create aesthetically fascinating forms. Therefore, many furniture designers were impressed by the freedom of form offered by material properties and manufacturing processes that inspire their imagination. (See examples of analysis in section 5.2.2)

- From a different point of view, imposing constraints on the intended product through material or production methods during the idea generation phase can help specifying what the product might look like and how it might function. This means that designers are not obliged to consider a wider range of technical knowledge. By thinking logically and systematically about available material properties and the subsequent analysis of its limits related to the problem statement or the users' need can open up a range of possibilities for designers. For example, a polymer material is proposed to design a chair. The material itself and its limitations could dictate strong new forms and functions for a chair or the modification of a conventional chair. That is, some properties of polymer and the technical processes which are implied by this material give the desired chair a light weight, stability, a modern look, a soft seat, the flexibility of the material simplifies the production, etc. Generally speaking, considering different possibilities provided by technologies from a logical and analytical point of view can stimulate the designer to start developing ideas according to ergonomics, economics, and other pertinent information.

- Sources of inspiration for new ideas regarding technological possibilities are required and must also be presented in a way that appeals to designers. According to Ashby and Johnson [2002] some of these sources are:

- Design magazines that illustrate innovative ideas and sometimes lists attached to these that describe materials and production methods.
- Material sample collections which are the key point for new ideas and inspiration. There are material information services that provide a large sample collection and offer web-based access to images and suppliers.
- Product samples which are the favourite tool of designers. They often present information about possibilities of materials and their techniques in an appealing way. They stimulate creative thinking of designers by appealing to their observation and perception skills and the inclination to explore successful applications and practical solutions related to them. Furthermore, they directly and visually describe the interaction between design and technical aspects in which functions, structures, and forms have already been interpreted.

The short discussion above reveals that some information related to the technological possibilities offered by materials and production methods can help to discover how the intended concept of design can take shape during the first phase of the design process. Such possibilities are not necessarily the only way to create a new idea, but using effective and suitable ways to explore information about them can put forward the ideas.

5.2.2 Exploration of technological possibilities through analysis

This section proposes an analytical approach in which design opportunities through technological possibilities can be identified. Beginning with the definition of issues of analysis in design this section will afterwards present a summary of designers' comments on their consideration of technological knowledge in the analytic phase of the design process. Finally, suggestions which might support designers during the analysis phase of the design process to explain design opportunities provided by technologies will be presented.

Issues of analysis

As the initial concepts, which are created during the idea generation or problem definition phase, are crude and problem-prone, designers have to refine their concepts by paying more attention to the problem statement in detail. Thus it is essential that refining and winnowing ideas begins with the process of analysis. According to Lawson [1990] “analysis involves the exploration of relationships, looking for patterns in the information available, and the classification of the problem” [p.27]. Generally, during the analysis phase the designers handle information from different areas related to design problems. Therefore, they set up lists of all factors consisting of statements that are relevant for the problem or its solution. These should include considerations concerning the basic function to be fulfilled, the possibilities and limitations of technologies, the customer, the user, etc. [Jones, 1981; Heufler, 2004]. A lot of information about these factors or requirements has to be related to each other to point out that the whole design problem has been defined. Our suggestion that new relationships regarding the problems of design can be explained and identified if the possibilities offered by technologies are taken into account during the analysis phase of the design process. Consequently, new interactions with other factors could be identified.

Designers’ points of view regarding the assumption above are as follows:

- Some designers (over 15 %) indicate that various design elements can be driven by the possibilities of the materials and shaping methods of its manufactures. According to these designers:

Some characteristics of information concerning materials and techniques can help the designers to analyse the suggested forms logically during the process of design. They argue that in the course of analysis some types of material properties can be selected to provide new aspects related to functions, use and aesthetics. For instance, in the context of furniture design better materials for lightweight structures, plastic films or sheets can stimulate designers to convert them into interesting convertible and portable forms. The radical innovations in the field of flexible cellular foams, ‘soft materials’, enable designers to analyse the function based on the performance of materials, etc. Generally speaking, for these designers, the attributes of the materials possess different dimensions such as use, function, and engineering. These can suggest different appropriate solutions and alternatives which satisfy the user. Furthermore, this group of designers indicated that it might be useful to begin the analysis phase with the establishment of relationships between product function and effective properties of materials which in turn have a positive effect on the desired performance and appearance of product.

- Other designers (37 %) are worried about the abundance of information which is required for the analysis throughout the design process. Therefore, they use speculations while analysing the materials and their technical information depending on their own experiences from pervious designs. According to these designers there are two reasons for this act of conjecture. The first reason is the lack of time, whereas the second reason is the lack of resources, which hinders them from selecting effective properties or techniques during the analysis of their proposals. At the same time, they indicated, however, that it might be important to search for the appropriate types of information resulting from technologies and then analyse them according to the problems earlier identified in the design process. For instance, in some cases the environmental problems require the analysis of certain characteristics of materials that make products recyclable. In other cases the analysis of tactile attributes of materials such as softness or hardness is essential to stress certain functional and safety dimensions.

- Other designers (48 %) confront various difficulties either in the analysis of materials or their technical potentials related to design proposals. The reason for this is that they are not able to distinguish between the relevant or irrelevant information concerning material properties or their techniques which are required for the analysis. Consequently, they cannot perceive to which extent and which types of information about technologies can affect the designs they create.

The designers' comments above indicate that the analysis of some types of information related to material properties and manufacturing processes enables them to find new relations to design. But, due to the fact that most designers are not aware of what information should be analyzed and how information could be gained through analysis regarding the design objectives they totally avoid considering such types information. However, any analysis, as mentioned previously by Lawson, involves the exploration of relationships and the classification of objectives. Therefore, it is suggested that the analysis of some types of information offered by materials properties and by the techniques of its manufacture can contribute to the design process. This will help the designer to pay more attention to a clarification of some design objectives provided by these technologies.

In this context, Ashby and Johnson [2002] demand an analysis of information concerning technological possibilities which arise due to new materials under four different dimensions. These involve that multi-dimensional information affects engineering, use, the environment and perceptions. Therefore, it is suggested that the analysis of possibilities offered by technologies under multi-dimensional aspects can help designers to become more aware about capturing effective types of information. This enables designers to achieve a new relationship to design problems.

In the following, designers shall be guided concerning how to analysis technological possibilities within furniture design. The analysis will be structured according to the four dimensions suggested by Ashby and Johnson [2002].

5.2.2.1 Multi-dimensional possibilities offered by technologies

In this section, a strong interaction between the design and technological aspects will be explored. Based on the results of the research investigation, this interaction put out multi-dimensional possibilities based on new technologies. The intention is to show precisely how much a good technological approach can enhance a design product and vice versa, in this case furniture. It also demonstrates that the designers' creativity is visible in the ingenious use of material properties and new production methods. This section is structured according to the four dimensions of possibilities: engineering, use, the environment and aesthetics. Vital links between multiplicity parameters and immateriality which designers must deal in order to utilize new potentials will be explained, see Figure 18.

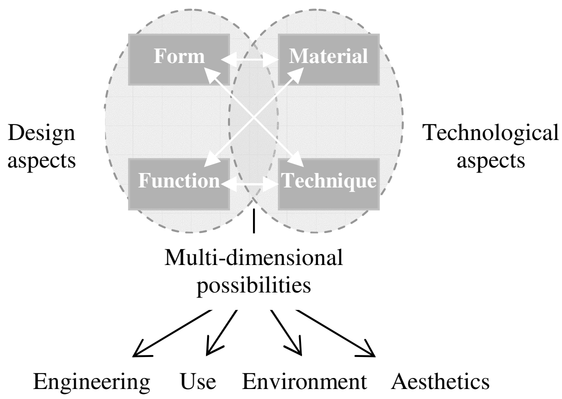


Figure 18. Exploration of interaction between design and technological aspects offers multi-dimensional possibilities contributed to the design process.

Engineering dimensions consist of the technical data about available material properties or its manufacture. On the one hand, they derive from the atomic and electronic structure of the material: among these are density, stiffness, optical transparency and many others [Ashby and Johnson, 2002]. One the other hand they are the application of processes to alter the geometry and/or the appearance of given starting materials to make parts or products [Groover, 2002].

Although different types of information about technical data[12] which are needed for technical design to assist engineers to select or to distinguish one property from others are available, few of them treat the aspect of product designer's operations specifically. Therefore, designers ignore this type of information during the design process. Basically, designers' expertise, for example in the calculation of safe loads or temperatures, is not required, but it is necessary to consider the consequences of such information and their influences on the formulation of the concept design. Some successful designers profit from the results of the technical data in creating new innovative forms with high quality performance and appearance. Some of the contributions of engineering data to furniture design, which have been interpreted effectively by different designers, are presented in the following.

Durability is related to the intended use of the product and its expected life length. Materials are the most important factor in determining product durability and life [Hodgson and Harper, 2004]. Evidently, furniture is so diverse in its uses and its materials that it is required from designers to consider some of the engineering approaches which provide exceptionally good durability. Some of the most important factors concerning indoor and outdoor durability of furniture are stability and strength. They are an important feature in the engineering design of furniture and must be discussed with production engineers as early in the design process as possible. Today, new developments of composite materials with improved properties give designers complete freedom to achieve certain design objectives based on capabilities of materials such as strength, rigidity, specific gravity (or density) and also lightness. Such properties allow an increased use of garden, sport, and leisure furniture. In such cases, the question of outdoor durability of materials must be

[12] Types of technical information are usually presented in numeric form, in maps or in charts. For more information see Ashby and Johnson [2002, p51-55]

considered by designers. Additionally, some issues such as corrosion resistance of metal furniture are particularly important considerations which need to be highlighted. In this context Harper and Hodgson [2004] point out that "frequently designers face a choice between achieving improvements in durability through changing materials or by protecting them in some way, perhaps by cooling, or coating. Informed decisions of this type require the impact across all relevant attributes (perhaps cost, impression, performance) to be considered" [p.6].

Lightness properties are usually presented as engineering aspects. As a matter of fact, engineers develop methods to solve problems concerning lightness of construction. Their effort is to meet the demands of the industry which includes lightness as a consequence of a reduction in the material used. This already seems to have reached the limits of functional acceptability [Manzini, 1989]. However, lightness is a delicate matter regarding the harmony between material, form and the production process [Beukers and Hinte, 1999]. Tubular aluminum chairs, for example, can be made lighter by applying materials with new composite properties and with the help of the injection molding process. Hence, form, material and the production process form a trinity. It is self-evident that if the construction weighs less, the balance between the three elements becomes more critical [Bucquoye, 2003]. In the context of furniture design, lightness properties are important in two respects: aesthetics and functionality. The first aspect is the preference regarding aesthetic lightness. Many furniture designers were impressed by the new possibilities of lightness.

Figure 19. The "Go" chair is made of injection-molded magnesium, which makes it light-weighted but strong. Designed by Ross Lovegrove [2001]

A good example is the "Go" chair, for the creation of which the capabilities of magnesium properties and injection-molding techniques were used efficiently creating a light-weight chair, Figure 19. It is a curvaceously streamlined, sculptural construction that mimics the physiology of the human form. The carved-out voids serve both material and weight. The first version of the chair, made of aluminum, weighed over 12.71 kg: too heavy for its solid metal construction. After looking for new materials and manufacturing methods, magnesium material and the injection-molding technology were selected. The advantages of using the optimal properties of magnesium material in the frame of the chair and the great technical precision provided by the injection-molding process provided the opportunity to produce a chair which weighs about 6.81 kg and is aesthetically fascinating [Onna, 2003]. The second advantage of lightness can be expressed in terms of an increase of the functions incorporated. According to Manzini [1989] "An intelligent object is not light only in terms of its weight in absolute terms, but also – and chiefly – in terms of the range of functions performed." [p. 114]. For example, aluminum and plastic folding chairs are light enough to carry and the economic efficiency outweighs its appearance and level of comfort by far.

Generally speaking, multiple degrees of performances can be achieved by considering the engineering dimension of materials and their techniques. Furthermore, it can change the characteristic structure of the form to achieve various design requirements.

The dimension of use of a product has three broad aspects: The first is concerned with adjusting the product to the properties of the human body; the second refers to adapting it to the reasoning of the human mind; and the last is to adjust it to the surroundings in which the human lives and works. Together these are known as human factors and their study is called ergonomics, interface design, or human-factor engineering [Ashby and Johnson 2002, p. 56-57]. However, some contributions of materials and techniques play an important role regarding the aspect of the use of furniture. These will be explained in the following paragraphs**:**

Comfort and convenience are determined by the quality of material properties which are used in upholstered furniture today. However, the "elastomechanic nature of upholstery", the "support of body" (ergonomics) and the "microclimatic contact with the body" are the substantial aspects of comfort, and thus of quality, which are of basic importance across all consumer groups [Devantier and Gelhard, 2004]. There have been various solutions to the problem of finding a sufficient level of comfort in a seat. Some derived from the shape of parts involved, others from softness by using suitable materials to achieve these. In the Sixties and in the Seventies the new possibilities offered by plastics, encouraged designers to experiment. They went beyond the system of old forms in an attempt to create a new system with the aim of living with new comfort quality. In relation to this, Manzini [1989] states: "Not only did the new 'padded furniture' have a different form, but it called for a new concept of sitting down, of communicating with others, and, in the final analysis, a new concept of the home"[p.154]. Today, the versatility of different polyurethane foam grades which was offered by new potentials of material properties gives furniture designers more freedom to develop new ideas and to make specific designs which have fulfilled the ideal combination between aesthetics and comfort. For example, the right foam specification allows the designer to use a thin-profile cushion and still provide comfortable seating. The right foam might also allow a designer to create a very plus- but durable-seat which minimizes the change of dimension and loss of firmness during use. Furthermore, polymer gel properties allow soft tactile surfaces, woven and non-woven fabrics to adapt to the body shape. Generally, new possibilities provided by technologies such as infinite flexibility, softness, and cutting quality of foam stimulate designers to experiment with new upholstery forms. See the “Three Sofa” in Figure 14.

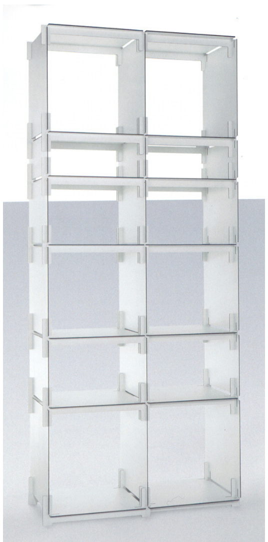


Figure 20. The shelving system is designed using a lightweight construction to keep it flexible: it is adjustable in all aspects and directions, and it can be built on, built up and rebuilt. The individual shelf components slot together without the use of tools. In order to use the same material for both the shelves and the connecting parts, the design has made the most of the possibilities of CNC-machine technology [Polster, 2005]

Systems based on modular elements ensure variability with the aim of individual design. System design involves the recognition of an unimaginable multitude of objects by means of systematization that goes hand in hand with simplification[13] [Wigand, 2002]. However, material properties and their production techniques can be considered as one of the driving forces behind the development of furniture design systems for several reasons. For example, the result of new developments in the panel industry produced different surfaces, textures, sizes, strengths, colors, with some level of visual privacy, acoustical control and light weight. Based on some of these possibilities the idea of modularity became the basis for many seating systems that allow curvature in arrangements which are simply convex or concave curves or combinations of straight runs and curves [Pile, 1990]. In addition to this, flexible connections and joining vertical and horizontal surfaces produced from different materials provide designers with ideas resulting in fantastic performance and appearance. For example, interchangeable frames, top and storage units, which are used in office furniture, are based on system concepts. Generally speaking, results of technological developments provide a wide range of possibilities for enhancing the multifunctional designs at home and in the office. As a result, a piece of furniture can become generic enough to suggest a multitude of activities that provide multiple choices for users and allow functions to be situationally contingent. Moreover, the aspect of “self” in the individual furnishing of one’s living space plays an important role. Furniture has become a means to include in one’s own lifestyle. A good example in this context is the “platten_bau” assembly shelving system. It

[13] For scientific background of system design see Introduction of Hans Gugelot's *System Design* by Hans Wichmann, Munich 1984, p.8-12.

satisfies the demand for a highly personal piece of furniture by offering interesting possibilities and interpretations, see Figure 20.

Surface innovation has been associated with advances in technology**.** The latest technological developments have provided many new surface possibilities, allowing surprising (and often humorous) combinations of materials and applications [Martin, 2005]. Digital technology is increasingly influential in the design of many finishes. Additionally, texture, structure, and the visual aspect have been completely redefined. Manufacturing techniques have also provided protection and aesthetic or sensory qualities to surfaces. With regard to furniture products, the range of performances which the surface can provide is quite broad and grows continuously. It extends from the most traditional and obvious performances such as creating various shapes and giving durability. Qualities like these transform the surface into a medium for static and dynamic communication.

Today, most materials can be produced in sheet, foil or film form and it is possible to create sheet products with a wide range of properties. With the help of these possibilities, surfaces can lead design towards achieving new goals. For instance, laminates in their various forms provide new surfaces for flat boards. These laminate surfaces incorporate the required pattern and color, they are hardwearing and durable, are easy to clean or self-cleaning and can be veneered with new gluing systems that can now offer great acoustic and lighting potential. Moreover, based on the continuously growing range of adhesive films with a wide variety of properties, surfaces provide several functions ranging from a simple protective aesthetic covering function to filter functions as well as mirrored and retro-reflective surfaces. Thus, bear in mind that new surfaces with improved properties can offer the product new qualities concerning shape, structure, sensation, color, touch, reactive and communicative aspects.

Safety is a fundamental responsibility of designers. They have to predict and diminish the potential of a product to cause harm especially during use. In many cases the materials used define this effectively. It is important to consider both acute and chronic effects. Acute effects such as a physical trauma are typically linked with deformation and fracture or failure behavior of materials used, while chronic effects are often defined by the chemical nature of materials (toxicity) [Hodgson and Harper, 2004]. The design of furniture for children or elderly people is a good example in this context: Some properties providing high rigidity of materials coupled with lightness, enhance the performance as concerns mobility, attractive forms and colors.

Most overturnings of furniture or accidents usually occur in situations of unexpected types of use. Materials and manufacturing techniques can be used to actively enhance the safety of products. For instance, the use of new furniture edging from polyurethane elastomers, which have smooth rounded corners or new molded shapes, can avoid the risk of accidents. Additionally, most new materials are developed with special properties that can reduce the flammability, but they should be tested regarding fire safety characteristics.

The environmental dimension in product design is an increasingly significant consideration in the design process [Tischner et al., 2000]. This is closely linked with new developments in the technological field especially new materials and production methods. Therefore, the designers' work can have a major influence on the things produced concerning the materials that are used; how they are constructed; their ease of maintenances and even their recycling or reuse potential [Luke, 2002]. This means that adopting the principles of new materials or techniques to achieve "ecodesign" will force the designers to think in new terms such as reliability, economic use of materials, service, and later recycling. Consequently, in the process of ecodesign, designers must chiefly find alternatives in order to define appropriate materials. Moreover, new relationships between the product and the material, production, and economy must be taken into account so that the effects on the environment can be identified. An example for this is a, chair called "Picto" which is shown in Figure 21.

Figure 21. The Picto chair [1991] is the first office chair in the world to have been designed consistently to fulfil with environmental criteria. It is designed to be repaired easily, for easy disassembly and take back. It combines ergonomic, material innovation, and ecological intelligence with unmistakable individualistic aesthetics.

It is an office chair designed to have a long life. The number of parts and the amount of materials have been reduced to a minimum. The product is made for easy repairs, disassembly and reuse. The chair is made from polypropylene, higher-pressure secondary aluminium, PUR-foam produced without CFCs, and beach wood from renewable sources. The pigments do not contain heavy metals. The cloth covers are detachable for cleaning, repair or replacement [Godau, 2003].

The aesthetic dimensions provided by new materials and techniques have the possibilities to expand the values of a product. Indeed, the technological contribution in the past and today, appeal to the human senses in the form of non-verbal communication. Sigfried Giedion [1941] describes the influence of Eiffel's early construction, the Galérie des Machines of the Paris International Exhibition of 1897, as follows: "In all sorts of ways – by the extensive use of new materials, by the employment of new devices like the elevator, by the provision of walks along the transparent glass surfaces of the 'promenoirs' – the public was introduced not only to the new technical achievements but also to completely new aesthetic values". Today, new materials and processes also tend to stimulate the designers to develop sensibility through new structural forms, touch, sight, etc. Some of these values related to furniture products are presented in the following.

Form structure refers to the internal parts of a form that support and define its appearance and contribute to conveying its message. Structure holds components and ideas together and is generally necessary to create meaning and sense of continuity [Bowers, 1999]. Form can be given in a number of ways. It can be suggested by the function matter being explored, it can take the shape of the material structure, and it can be conveyed by the communication of messages or through the creation of pleasurable experiences. In any case, 'having structure' presumes the presence of structural features in the product form [Muller, 2001]. In relation to the potentials of material properties and shaping processes, designers' creativity can be enhanced to develop structural forms with new aesthetical elements. These elements can be new types of lines, shape or volume. This establishes different ways of communication between the designer and the user. For instance, specific properties of composite materials as well as injection molding force designers to create free-flowing curves like curvilinear shapes and volumes which are frequently found in nature. All these ambitions can be realized today. Such forms, sometimes,

Figure 22. The 'Egg armchair' is made of glass fibre polypropylene. It is a stylish, stackable rounded form resulting from the ideal use of polypropylene material properties and the injection-molding process. The chair was designed by Philippe Stark (2002)

meet the mental model of users which are occasionally affected by the visual impressions offered by the natural forms. Additionally, they directly evoke a feeling of pleasure due to the adoption of decorative forms which are offered by the properties of composites. Many designers make use of such potentials to create streamlined structural forms that possess intrinsic expressive qualities, see as example Figures 22 and 42.

Touch is the most analytic of all senses, the sense which is furthest from sight [Manzini, 1989]. Results of technological innovation nowadays offer materials with characteristics that emphasize tactile qualities and highlight the contrast of different surfaces. For instance, hard materials used in furniture such as steel and glass can be made "soft" by forming shapes with bends or twists. Moreover, their impression of "coldness" evoked by touching the material can be transformed into an impression of "warmth" by a heating process [Ashby and Johnson, 2002]. In the same way, new tactile qualities with new semantic aspects can arise due to processes such "3-D" paints; velveted paints which are "paints that are soft to the touch"; laminates with surface in relief form, translucent skin warps, etc. Such expressions indicate the form of a surface and designers must try to imagine a tactile sensation to accompany them.

Sight involves aspects such as transparency, translucency, opaqueness, matte surfaces, reflection, etc. These are new qualities among an even greater range of possibilities offered by new technologies. They represent not only certain performances, but also aesthetic and emotional aspects. For instance, transparent ceramics possess the mechanical properties of ceramics and also transparency comparable to glass [Stattmann, 2003]. However, integrating transparency in furniture cabinets for example allows not only to see the contents but also creates aesthetic effects caused by this special invisible and glowing materiality. Furthermore, digital fabrication techniques are used nowadays to generate a new sensibility provided by reactive and expressive surfaces. These surfaces carry different messages in two-dimensional components offering a great variety of combinations of functional logic and emotion values, see Figure 23.

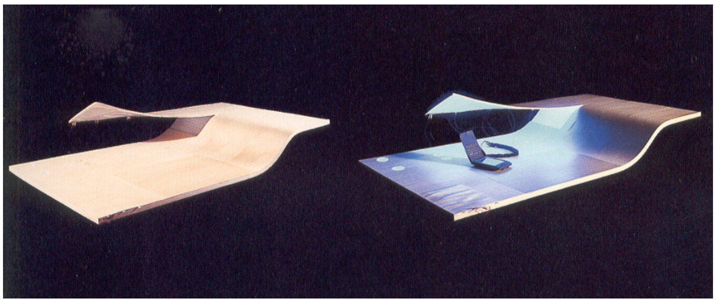


Figure 23. The Electric Plywood Desk is an interactive wood surface. Ultra-thin polymer films are layered between the plywood laminations. Digital fabrication techniques are used to form the plywood in a way that light can flow across its surface. A Memory Blotter reacts to the changes in illumination. The Memory Blotter has been impregnated with a luminous phosphor which then absorbs and recycles the light. Digital tools can be embedded into the desk, where they are activated by touch via a springy, resilient wood veneer [Lupton, 2002].

To conclude, during the design process it is worth bearing in mind that knowledge about technologies possesses multiple dimensions of possibilities such as engineering, usage, the environment and perceptions. It is evident from the previous analysis that such different dimensions of possibilities give, in general, a great variety of items of different style and form, offered by setting limits to the wide application of its main technologies in order to satisfy what is essentially a fashion market. It is incumbent on designers to match their designs to the right options and alternatives offered by technologies nowadays to meet the demands of the market. Within this broad notion however, there is an essential need for a procedure by which designers can give more consideration to the new technological possibilities in regard to the aspects of design. Therefore, an analytical procedure is proposed in the following can orient designers towards expanding solutions arising from the material and its techniques according to specific design elements.

5.2.2.2 Analytical procedure

The method of analysis has great strengths. It is systematic, it is based on a deep ("fundamental") understanding of the underlying phenomena, and it is robust – provided that the inputs are precisely defined and the rules on which the modelling is based are sound [Ashby and Johnson 2002, p.126]. Analysis methods to make use of possibilities offered by materials and processes concerned with design requirements already exist, such as those suggested by Ashby and Johnson [2002]. Their contribution includes the act of selection by analysis. This method is – as a general feature of their approach – summarized in Figure 24.

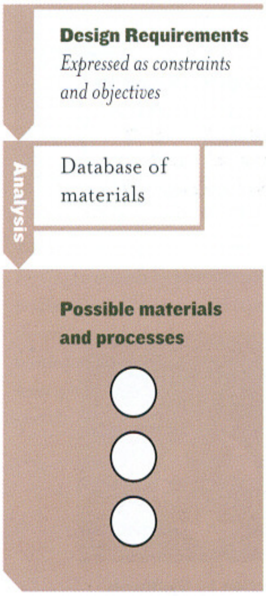


Figure 24. Method of analysis is to help in selection of materials and their processes according to Ashby and Johnson [2002, p. 125].

As presented in Figure 24 the act of material and process selection by analysis according to Ashby and Johnson [2002] includes an analytical procedure in four steps: (1) The translation of requirements, initially often expressed in non-technical terms, into a statement of the objectives and constraints the design must meet. (2) The analysis of the components for which a material is sought, identifying performance metrics and expressing these as equations that measure performance. (3) The identification of the material properties that determine performance which is derived from the earlier equations. (4) The screening of a database of materials and their properties eliminating those that fail to meet the constraints and ranking those that remain according to their ability to maximize the performance metrics. Related to the figure the process requires the selection of material from a database of materials and material attributes. Here, the white circles represent solutions that meet all the constraints and maximize the objective.

In design is sometimes necessary to conduct a procedure systematically so that it leads towards defining and clarifying relationships between different aspects involved in the design process. Therefore, based on the multiple dimensions of technological possibilities explained in the last section under design consideration, the suggestion here is to provide an analytical procedure for these. Thereby the designers' awareness of capturing effective types of information offered by technologies related to design goals will be increased. The procedure is presented in Figure 25. Its main objective is to refine the possibilities offered by materials and processes concerning two types of information. One of them is to give direct information related to the appearance of the product; the second is to give indirect information related to the performance of the product. Both share the same goal: the explanation of the interaction between design and technological aspects contributed to the furniture products as the subject matter of this thesis.

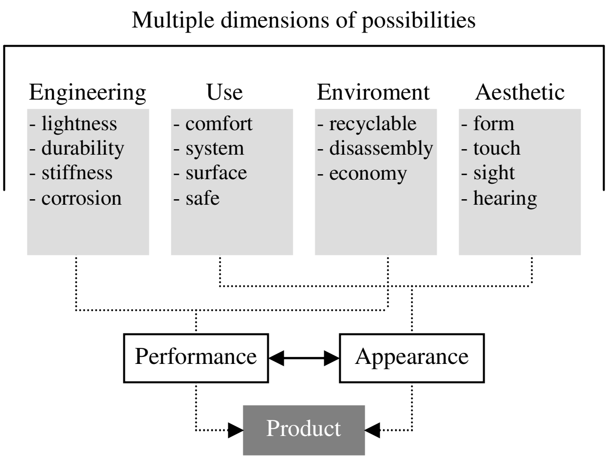


Figure 25. Analytical procedure to explore and refine the possibilities offered by technologies contributed to the design aspects.

On the one hand, materials and finishing processes can determine the appearance aspect of a product. They give pleasure which can derive from form, texture, feeling, perception and associations [Jordan 2000, p.101-107].

On the other hand, they also contribute to the product performance. Performance deals with functions, which are actions or activities that a product should perform. New materials and processes with improved properties help to create furniture products with a better performance in some sense, such as being more durable, lighter, easier to handle and to use. Hence, largely mutual qualities of both types of information related to appearance and performance can impart different qualities on the desired product by combining on with another quality.

Methodical procedure

The main objective of the method is to identify and analyse the contributions of new technologies related to product design, in this case furniture. The starting point for the procedure is the analysis of the multiple dimensions of possibilities offered by technologies. As presented previously, this analysis covers various aspects related to product design including engineering, use, environment, and perception. These aspects refer to the headlines in Figure 25. It is proposed that the procedure for analysis be formalized into the following steps:

1. The analysis starts with the search for possibilities offered by material properties and production techniques under the four dimensions of engineering, use, environment, and aesthetics.

2. By breaking down these dimensions into components, a great deal of information related design aspects can be gained.

3. Combinations of the resulting aspects aim at clarifying two types of information regarding the performance and appearance of a product. On the one hand, links between aspects of engineering and environment dimensions help to gain indirect information which can contribute to the product performance. On the other hand, links between aspects of use and aesthetical dimensions help to gain direct information which contributes to the product appearance.

4. The resulting information related to performance and appearance is now refined and can be transformed into a statement of product requirements by establishing mutual relationships between them. For instance, some indirect information regarding the performance of material properties like molding and density can add information about the appearance such as form, surface, texture, and vice versa.

5. The procedure from step 1 to 4 is repeated for the clarification of the capabilities of materials and their techniques according to the pertinent design information until the product is satisfactorily analyzed[14].

The basic assumption of the procedure is that all design opportunities provided by technological knowledge are explored and structured by analysis. Consequently, the relative importance of product information can be assessed by designers in order to meet some of the design requirements as well as to lead them to discover later gaps, if there are any.

[14] The analytical procedure, including an illustrated example from the furniture area is presented in section 6.3.

5.2.3 New technologies incorporating values by means of synthesis

The analytical approach presented previously allowed us to clarify the different potentials offered by new technologies regarding the performance and appearance of the furniture product in general. In this section, we aim to stress the elements and components concerned with new technological possibilities by which the perception of product attributes could be enhanced. Generally, aspects which describe the feeling of shape, touch, proportion, personality, and style help products to be more attractive. These emotional aspects are also linked with the user's experience as well as the manufacturers' benefit [Norman, 2004]. It is expected that new materials with improved properties and their technologies can contribute to these aspects.

It is proposed to establish a combination of elements and components that result from new materials and shaping techniques. This combination could lead towards imparting "soft" attributes to the concept of the product. This will firstly be granted by focussing on the characteristics of synthesis in the design processes. Afterwards, an investigation of how designers use these characteristics during the design process for creating concepts which have certain values concerning the possibilities offered by new technologies will be presented. Furthermore, a description of some combinations which can help to explain new design qualities through certain types of knowledge about given innovative technologies to designers will be provided.

Synthesis in the design process

Many researchers described synthesis as the core of concept design and the most important and creative part of the design process. Muller [2001] stated that synthesis is in fact a process of visual thinking in which the designer is able to imagine a solution for functional problems. He points out that "during this process, the designer has a certain goal in mind. This goal is often described in terms of the function or functions the product has to fulfil" [p. 29-30]. Therefore, a multitude of forms can be imagined for a function that shall be realized based on a combination of visual relationships. Furthermore, Lawson [1990] indicates that "synthesis is characterised by an attempt to move forward and create a response to the problem. Essentially, synthesis is the generating of solutions" [p. 27]. From the engineering point of view, Roozenburg and Eekels [1995] defined synthesis as a basic step in the circle of design to generate a design proposal. They state that “the word ‘synthesis’ means the combining of separate things, ideas, etc., into a complete whole. Since a design is a new ordering in space of already known materials, parts and components, this is what the step is called” [p. 90].

Principally, while developing the concept of a product, synthesis aims at fulfilling the overall requirements of the product. In relation to the idea of Ashby and Johnson [2002] this means, first of all, it ensures that a product works properly and contains the functions necessary to perform the tasks for which it is intended. Having appropriate functionality alone is not enough. The product must also be easy to use, understand and operate. This is the answer to the question of usability. Finally, synthesis can also lead towards providing satisfaction, bringing not only functional benefits but also emotional ones. These are three hierarchical levels: functionality, usability, and pleasure which reflect the way in which the contribution of human factors to product design might be seen and considered [Jordan, 2000]. In this context Ashby and Johnson [2003] take a closer look at the synthesis requirements for products and present “the requirements pyramid” which is illustrated in Figure 26.

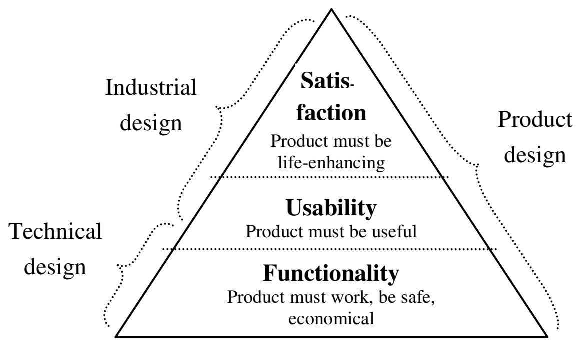


Figure 26. The requirements pyramid. The lower part of the pyramid tends to be labelled ‘Technical design’, the upper part ‘Industrial design’; it is perhaps better, to think of all three tiers as part of a single process that Ashby and Johnson call ‘Product design’ [Ashby and Johnson, 2003].

At present, users of industrial products are looking for more than just the function and technical capacity of a product. Product users are increasingly looking for emotional fulfilment and experience in the interaction with the product [Jensen, 1999]. Hence, the heart of our assumption is that some characteristics of information related to new materials and their techniques can help to extend the synthesis of solutions which appeal to the users' senses. In so doing, we suggest that some collected elements and components resulting from new technologies could be combined in order to impart a perceptual character on the product. As a result they might offer emotionality.

Our suggestion will firstly be based on designers' approaches. Information about these was gathered with the help of questionnaires and interview studies. Afterwards, it will be supported by publications providing examples in this field.

The general question to designers which is investigated in this area is: Might materials with improved properties and new shaping processes provide opportunities for designers to enhance the attractiveness of furniture products? However, the results of the questionnaires and interview studies focus on sensory elements and components resulting from technological possibilities that were addressed by experienced designers. Designers' points of view with regard to these aspects indicate that:

- Some designers (21 %) see that properties provided by new materials and their shaping techniques have an enormous influence on the perceptual aspects of a product, although they actually concentrated on supplying the physical needs of the product. They believe, for example, that a process like injection molding of polymers redefines the relationships between the part and the whole in the construction of a chair. Based on this process, it is possible to envisage that a connection between vertical and horizontal lines included in the chair structure is no longer relevant. This process creates a harmonious union between the individual elements and the whole. Moreover, by injection molding the non-welded structure of metal helps to create objects with a physical expressiveness and provides freedom from variations in non angular-geometry. Two designers from this group used examples of existing products that included new technological applications in the course of their argumentation and for the clarification of their approaches. These two designers pointed out that there are strong concepts depending essentially on the synthesis of new properties or shaping potentials of materials and elements of visual tension which are often used to create compositional interests. For instance, properties such as brightly colored PC "polycarbonate", translucent PP "polypropylene", and molded elastomer surfaces can be combined with elements of form to stress them or redefine them. This is applied in furniture design to enhance the attractiveness of the product.

- Some designers (14 %) emphasized that it is important to consider new surface properties related to coating and the transparency of materials as a new style and language which substantially contributes to the visual quality of the design. One designer points out that ”awareness of information about new coating possibilities enable designers to combine structure and surface to form an integral whole, while adding novelty to the design, in which elicit associations can be created.” Another designer expressed that “combinations of certain kinds of new decorative or communicative surface potentials and furniture components determine how the product can be perceived. That’s because they have a character of their own”.

In addition to the comments mentioned above, table 2, summarizes the variations in vocabulary used by the interviewed designers to describe impacts of new materials and their techniques on sensory elements of furniture products. This vocabulary has been classified into two groups in order to understand their relationship to possibilities offered by new technologies.

Table 2. Exemplifies some vocabulary and expressions used by designers especially during the interview sessions to describe sensory elements of products affected by new technologies

Sensory elements resulting from technological possibilities related to furniture design
Form structure, joints and connections: clarity, unity, harmony, repetition, framelessness, perfection, simplicity, flexibility, versatility, minimalism, coherence, carving, playfulness, dominance.
Surface expression: softness, decorativeness, layers, contrast, elegance, dynamic, honesty, asymmetry, purity, reflectiveness, hardness, naturalness.

Two approaches considered by designers for emotional fulfillment through technologies

Obviously, new technologies provide a wide range of potential combinations enabling them to fulfill emotional needs. It was observed that designers have two different approaches in attempting to achieve this:

- Form follows structure
- Form follows surface

The first approach is based on changing the traditional form with the help of new potentials of material as a structuring principle. This can be related to Eames' concept. He did not only use new materials in new ways because of their structural and tactile qualities, but also created a form with a distinctive visual and artistic personality [Nelson, 1953]. Eames applied recent developments to mold plywood for creating new structural furniture forms. Today, this concept is extended due to the combination of new processing methods available. With a new expression of forms resulting in a unified design, sensory elements, due to which furniture forms are perceived or portrayed, can perhaps be redefined. For instance, through various molding processes the form of a chair can be created without joint and connection to suggest visual tension and adding a sculptural look. It is perfect, playful and has implicit cues relating to the human body. (See Figure 22 as an example).

The second approach is, the recognition of a form based on the qualities incorporated by the surface such as touch or color. These help to reveal that all sensory activities take place at a different level than the recognition of a shape. Today, you can rely upon the fact that surfaces with improved properties tell us directly about the perceived value of the form. Is it warm or is it soft? Is it hard and cold? Does it indicate to us how heavy the form is? Would it be difficult to move or would it be stable? Surfaces can allow us to perceive the form. Surface properties can also help the form to appear with multi-dimensional looks and tactile qualities. Following this approach helps designers to recognize trends and styles.

Some of these sensory elements within the field of furniture, according to the designers' interpretations provided by the investigation, are described with the meaning implied by the vocabulary in table 2.

5.2.3.1 The role of new technologies related to the product character

Aesthetic perceptions play a significant role in the actual and perceived experience of products [Norman, 2004., Jordan, 2002., Desmet, 2002]. They are the emotional factors which describe feelings of shape and form. They represent the part of perception that is connected to personal experiences and how we interpret these, while the intellectual factors are connected with our logical understanding of the product and its qualities [Aubry and Vavik, 1992]. This means that, when products are perceived, we are affected by their character, feeling, and richness of style. However, the increasing knowledge in the technological field and their varieties can help designers to create products with a character or personality that elicits the desired experiences.

Snelders [1995] argues in his doctoral thesis on the consumer's judgment of products that our perception of products is twofold. It consists of rational judgments based on concrete product attributes and emotional judgments based on the more abstract ones. On the one hand, a concrete product attribute describes something that is understandable and meaningful to everyone. On the other hand, an abstract attribute refers to the product qualities that are perceived in a more individual way depending on a person's private associations. Both of these, objective and subjective properties share and change the roles in which the products are perceived. Therefore, during the design process, designers have to balance them and at the same time combine different types of information related to each one in order to evoke pleasure with the products.

In this context, it is necessary to refer to our earlier assumption again which indicated that new developments in the field of technology include elements and components which can contribute to the fact that soft product attributes are perceived emotionally and subjectively. To prove this assumption it is first important to dissect product character in general.

Figure 27 shows a way of dissecting the product character according to Ashby and Johnson [2003]. They supposed that product character can derive from the dissection of a product under the conditions of a certain context. Product character can be divided into two areas:

- The physiological or physically determined aspect of product character, which implies that a product needs knowledge and skill for its realization, mainly concerning materials and manufacturing processes.
- The psychological or sensorially determined aspect of product character, which involves 'non-physically' stimulated interaction between the human and the product, such as cognition, aesthetic and semantic communication between the product and the user, concerning usability and personality.

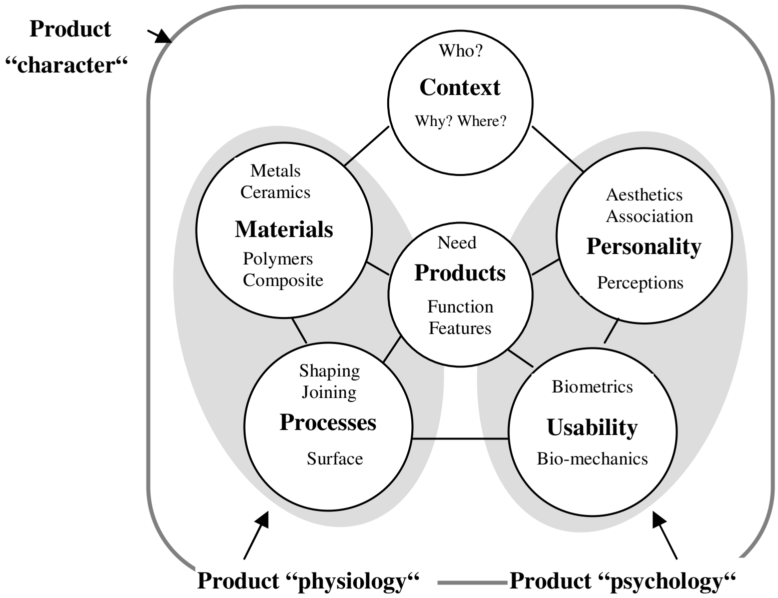


Figure 27. The dissection of the product character. The context defines the intentions or the 'mood'; the materials and processes to shape, join, and finish them in order to create the "flesh and bones" as Ashby and Johnson put it. Ergonomics determine usability; aesthetics, associations, and the perception of the product to create its personality [Ashby and Johnson, 2003].

Figure 27 illustrates a scheme of organizing information in order to handle the dissection of the product character according to Ashby and Johnson. They set the information about the product itself such as the basic design requirements, its functions, and features in the center. These attributes of the product are certainly based on the conditions provided by the context, which are shown in the circle above it. The context is set by the answers to different questions: who?, where?, when?, and why? The first of these: who? can be explained as follows: The designer seeking to create a product which is attractive to different target groups will make choices that fit each one. The question where? points to the following: For instance, furniture designed for the use at home requires different materials and forms than furniture designed to be used in a school or hospital. The question why? indicates that a product that is primarily utilitarian involves different design decisions than one that is largely a lifestyle statement.

On the left, there is a circle representing information about the materials and processes used to shape, join, and finish the product. Each represents the resources, from which the choice can be made, and the attributes that each choice offers. Ashby and Johnson stress that the primary step of selecting both material and process can meet the constraints imposed by the primary design requirements – the essential functions and features of the central circle. They pointed out that "Material and process give the product its tangible form, its flesh and bones so to speak; they create the product physiology" [p.28]. On the right side of Figure 27 there are two further fields of information. The lower one – usability – represents the ways in which the product communicates with the user: the interaction with their senses, cognition, and functions. This is necessary for products that require a mode of operation.

One circle in the figure remains: the one labeled personality. Product personality is one of the aspects that is determined by how a product looks and how it is perceived. This contributes to product experiences. Desmet [2002] defines product personality as the product appearance and how the user's senses react on this appearance. According to Govers [2004], product personality refers to the profile of characteristics that people use to describe a specific product. Hence, the results of technological possibilities concerned with material properties and shaping processes can play a vital role in the experiences of people who interact with the product. They have a huge influence on all three of these variables – aesthetics, associations and perceptions.

According to Arabe [2004] that is because, materials – even before they are shaped into something recognizable – have a character of their own. While this intrinsic personality can be masked or disguised, when suitably manipulated, it conveys its qualities to the design. Arabe explains this using an example concerned with wooden material. She states "wood's embedded personality evokes craftsmanship – a quality that is hidden when wood is used in packing cases where it connotes low-cost utility, but is brought out when the material is used for fine furniture". Ashby and Johnson [2002 and 2003] also indicate that materials and their processes can affect the perceptions of a product e.g. futuristic, nostalgic, classic or trendy; feminine or masculine; youthful or mature; etc. They can also have an impact on the associations the product evokes such as flowery, homey, of military origin, streamlining, honeycomb, etc. The reason for this are their renewable qualities. In other words, they can contribute to the description of the perceived attributes of a furniture product through vocabulary with which it can be described. Thus, they may undertake an interesting role in the semiotic aspects of the furniture language. Monö [1997] indicated that in product design, semiotics maintains that we place meaning in what our senses (visual, olfactory, haptic, auditory, kinaesthetic, and taste) perceive. Related to the theory of product language, these meanings are constructed through signs. See details related to this context in chapter 2.

If this scheme is applied to the combination of material properties, their shaping processes and form elements and used to obtain specific product attributes and human responses, we will find out that products have incorporated meanings related to their technological qualities. For example, fluid lines and an organic feeling can be evoked by taking advantage of the flowing shapes formed or structured by composites and injection molding, the warmth and softness of textures, the quality of surface and differences in transparency and colors of plastic and glass. In addition to this, the perfection of the finish reveals something about the quality of a product, its user or about its manufacturers. This is certainly dependent on product itself, and, more importantly, the context and the time in which it is used. An example of this was provided earlier pointing out how some of these emotional factors related to furniture products are influenced by new technological possibilities related to materials and processes (see section 5.2.2.2).

Another communicative example in this context is the "Sinterchair" shown in Figure 28. The principle idea of the chair is based on two types of technology: stereo-lithography and selective laser sintering which is also applied in the automobile and aircraft industries.

Figure 28 illustrates an application of new technologies based on new materials and processes in structuring a chair. Specific form elements result from new material properties and innovative processes which are reflected in the futuristic, aesthetic qualities of the chair. Its honeycomb structure makes it lightweight, strong, trendy, elegant, and perfect. It is also appropriate to apply this process for designing a chair, as chairs serve as design icons that often illustrate the current status of society and its technological achievements. It combines technological know-how with materials and aesthetic sentiments to form a seating sculpture linked to man's cultural history like no other item. Examples of such chairs include Thonet's bentwood chair, a chair, whose manufacturing process was, at the time, ground-breaking, or the tubular steel furniture of the Bauhaus era, or the Panton chair, the one-piece plastic chair that became a symbol of the 1960s, this was emphasized by the Vogt+Weizengger GmbH, at the fair "Tendence 2002".

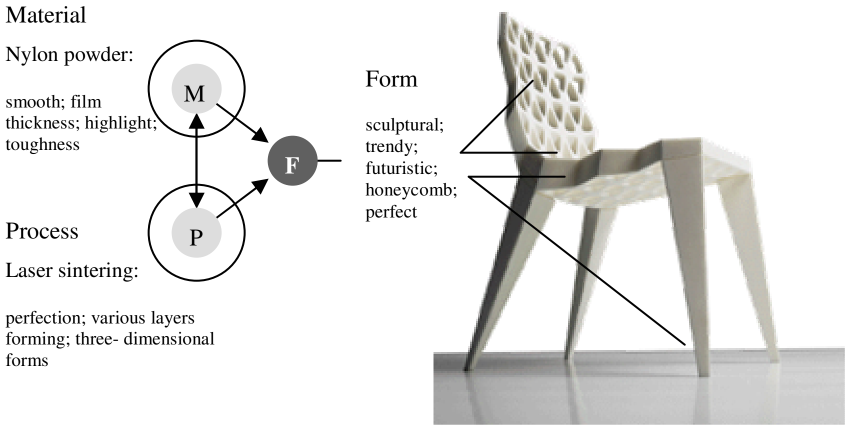


Figure 28. Sinterchair is an futuristic vision is become reality through using new materials "nylon powder" and with help 3D system sintermachine. It is designed by Vogt+Weizengger [Vegesack, 2003]

Indeed, considering results from new technologies related to new material properties or shaping processes can affect more than the aesthetics of a product. They can impart their personality onto the product if they are appropriately interpreted by designers.

5.2.3.2 Perceptual combination resulting from technologies

The following aims at suggesting a synthesis of properties resulting from interaction between certain types of information about new technological possibilities and design elements. Consequently, soft attributes can be imparted onto the desired product concept. In other words, we will describe a perceptual synthesis of a product, in this case furniture, based on combining the form elements with the possibilities offered by materials and shaping processes. This can guide designers to realize such possibilities in products which can appeal to and evoke sensation of the human senses in the form of non-verbal communication.

Based on the results of empirical studies and the review of authors' opinions presented previously, we tried to find relations between information resulting from new technologies and design qualities. Obviously, some characteristics of this information have a wide range of potential combinations enabling them to fulfill not only functional but also emotional needs. Therefore, it is intended to display some of the connections between both possibilities offered by material properties and shaping processes on the one hand, and information about features of form on the other hand. This can help designers to incorporate certain types of information in their products and put the focus on new ways in which sensory elements of the desired product can be synthesized. However, the main principle of displaying these connections is to combine the attractive characteristics of materials and processes with the form concepts. This can include visual, tactile, and structural features which incorporate a look and feeling of sensory experience related to the user of the product. This is illustrated in Figure 29. The circles in the center of the figure represent a synthesis of these features which should derive from the mutual connections between material properties, shaping processes, and the form elements.

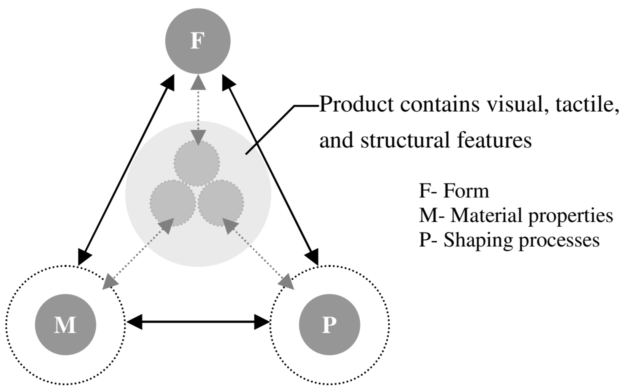


Figure 29. The combinations of form, material properties, and shaping processes help to impart sensory elements onto the desired product. These can be achieved by a synthesis of visual, tactile, and structural features resulting from these combinations. The three circles in the center of the figure indicate this.

This can be illustrated by using a specific example. Consider the following: A furniture manufacturer asks a designer to develop a concept of children's furniture that is it trendy and humorous. In this case, it is recommended to make use of the properties of composite materials as well as their shaping capabilities. After the designer has identified the multi-dimensional possibilities offered by composite materials and their shaping processes by means of analysis, he suggests to use polypropylene. The possibility of shaping it by injection molding leads to a new form or the modification of conventional forms. As presented in the last section (5.2.2), this process can be explored by consciously analyzing these possibilities and their contributions to both appearance and performance of the product. However, connections and interactions between properties focusing on the soft attributes gained as well as taking advantage of these qualities, must be taken into account. For example, polypropylene is ideal for molding complex curvatures and providing free flowing forms, resulting in lightweight structures. High surface gloss, translucency and coloring can also be achieved. Combinations of these with the concept of form will set features which affect perceptions. They can contribute to establishing visual and structural lines which may appear in carton series based on injection molded forms with reference to animal and human forms. Furthermore, rounded corners with tactile cues provide the possibility that our sense of touch helps to confirm what we see. Equally, we might see a surface and perceive it to be smooth, but if we touch it, we will find unseen irregularities and inconsistency. Our fingers glide over the surface and make confirmatory judgments to what we have seen. This is a quality of a surface which is offered by the interaction between polypropylene and the perfection of their shaping process. Thereby, the piece of furniture tells us what furniture for children should be like. Generally speaking, this is a synthesis of visual, tactile, and structural features which results from the fusion of possibilities offered technologies and form concepts. This seems to be the best possible way of evoking emotional participation in children's furniture.

At this point, a further development of the approach might help to gain new insights by displaying some mutual connections between possibilities offered by materials and processes as well as the form concept. Figure 30 shows three types of combinations. Each one combines certain characteristics of information which contribute to the way the perceptual character of a product can be described.

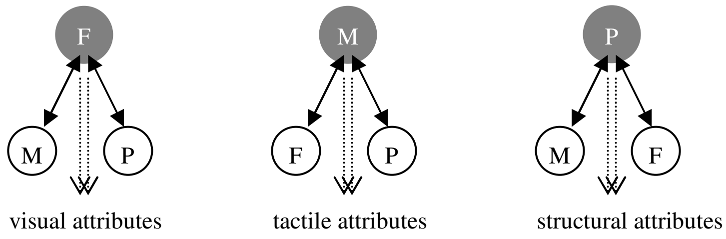


Figure 30. Displaying three mutual connections between possibilities offered by materials (M) and production methods or processes (P) as well as the form concept (F).

The first combination aims at the visual elements of a product form, which most people accept and feel comfortable with. All forms generally require attention to composition and proportion. Composition refers to the arrangement of forms within an object or the arrangement of elements within a form. Proportion describes the relationship of parts to each other or to the whole [Cheatham et al., 1983]. In this context, materials with variable properties such as thickness, density, edges, colors and transparency have the potential to help developing visual tensions between elements and parts. Visual vocabulary is often used to describe compositional interests. Thereby, variable properties like these can enhance the form in order to create harmony between the width and height of parts incorporated either in a two-dimensional or in a three-dimensional form. In addition to this, processing techniques with great precision enable the form to convey specific information and meaning which is incorporated in its surface or shape. They represent the non-visual proportions incorporated in the appearance and the feeling of the form in order to make it 'look right'.

The second combination aims at developing a tactile medium that confirms to us what we see. All materials have their own particular texture, and it is this texture that helps us to identify them. Texture properties can be combined with form features and elements in order to stress some of these more than others. For instance, a material which has smooth, warm, and soft attributes requires certain types of lines, weight or size that differ from other materials that have hard, cold, and rough attributes. Technical processes can also help to make a surface for example be perceived in a comfortable way in direct contact with the human body. There are different technical options like the assembly of systems of springs, wire nets, or elastic fabrics which support materials to impart tactile attributes onto the upholstered furniture such as softness or flexibility.

The third combination uses processes of shaping not only with a view to efficiency, but also with a focus on their new opportunities including structural qualities. Due to this, shaping processes seem to be able to represent "possibilities". New processes such as injection molding, casting, or bending with the help of special properties offered by new or traditional materials provide the possibility of creating new structures in furniture. These structures appear to have a new character; they can for instance be pliable, springy and light. Additionally, when form elements are combined with new surface finish potentials, the product appearance can be redefined as a channel for self-expression. Joining processes with their purity and simplicity conceived through visual inspection seem to provide new ideas for forms. These represent the potentials implicit in the joints, as for instance the efficiency of the digitally produced wood joints in self-assembly furniture. Deliberately highlighted joints are also used for a decorative reason, as their functionality contributes to creating form associations. By so doing, the designer can meet new structural systems for the form construction and for connections of various parts included in the form which help to convey his messages.

The connections mentioned above, related to existing examples in the field of furniture, are presented in a more detailed way in section 6.3.

5.3 Challenges of communication

Today, a designer who intends to use the possibilities provided by technical innovations must be able to establish channels of communication with different persons, mainly engineers. Communication is of course an effective way of acquiring knowledge about several parameters which designers must deal with in order to make use of new options. However, problems arising due to failed communication have been documented in many areas of industry. Within technology based companies, benefits gained from improved communication between the engineers working in research and development and the marketing departments have frequently been highlighted [Gupta et al 1986, Souder 1988, Song et al 1996]. Problems can also be noted in the course of investigating the role of the industrial designer within the process of R&D [Walsh, 1995].

Within this thesis, we found out that problems of communication occur in two situations: Either, if designers are brought into the process just before the realization of a product starts and are asked to provide a good-looking facade for the given technology, or if designers themselves suggest design opportunities including possibilities offered by new properties of material or by the techniques of its manufacture. In both situations, it is supposed that the effective use of these technological possibilities during the design processes depends on how designers communicate with engineers at the earliest possible stage. This helps designers to acquire information and experiences, as well as stimulating them to use the technological possibilities in a creative way. Above all, it can ensure that their proposals are achievable. In this context, Ashby and Johnson [2002] refer to the importance of communication for designers. They stated that "Channels of communication are imperfect, making it difficult for designers to find the information they want. And early in life, a new material is expensive – the development costs must be paid for – and availability can be restricted." [p. 158].

Hence, in this subchapter, we will investigate the communication between designers and engineers especially when introducing new materials or techniques into the design processes. This approach attempts to consider some of the barriers preventing progress and some of the options being considered. In other words, it is intended to establish a dialogue between designers and engineers about where communicational problems have appeared, where obstacles hindered the communication and also concerning solutions to improve communication. The investigation carried out in this context is chiefly dependent on empirical studies. These are based on action research methods as well as in-depth interviews with designers and engineers interested in the application of new materials and processes related to furniture products. Within the investigation, examples from furniture products clearly affected by applications of new technical possibilities were used.

5.3.1 The perceptual gaps between two disciplines

John Ruskin identified the separation between thought and labor, between thinkers and workers as the root of modern failure in the working world [Wilson, 1991]. The division of labor meant that each of the disciplines involved in the design and manufacturing of products has become very specialized. This fragmentation of labor into various groups with different objectives has led to each having a very narrow set of priorities. This has caused differences in cultural respects arising between the disciplines, most importantly those between designers and engineers. These differences cause gaps in the communication between designers and engineers. The two disciplines clash because there are fundamental differences in their approach. From the designers' point of view, shape and aesthetics are the most important aims and these determine the process. From the engineers' point of view, costs and complexity determine the process. Cagan and Vogel [2002] refer to these differences as "*perceptual gaps*", a model of which is shown in Figure 31.

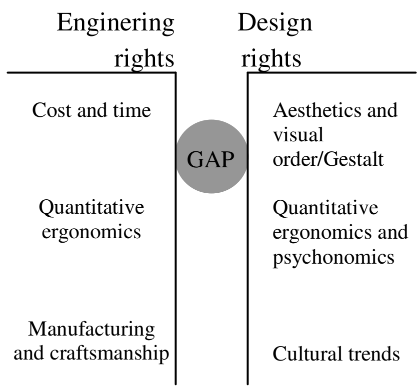


Figure 31. Illustration of the perceptual gaps model according to Cagan and Vogel [2002]. Perceptual gaps are defined as the differences in perspectives that engineers and designers have. These derive from a way of thinking that is specific to a certain discipline.

They pointed out that perceptual gaps derive from several sources. One of these is for instance caused by differences in education. Engineers are trained to know what is "right". They recognize what can be done and what cannot be done, based on their understanding of how the world works. They focus on performance, quality, and manufacturing. Designers, on the other hand, are primarily visual thinkers, trained to explore and think about what should be, not about what is given. They think of quality as aesthetical and emotional impact. Another source of perceptual gaps are the inherent personalities of engineers and designers. Engineers tend to think of things as being either black or white – right or wrong. They feel comfortable with mathematics and use statistics to reach consensus and conclusions. Designers feel more comfortable with uncertainty. They see the world around them as being evolving and indecisive. Engineers like to get specific information early while designers like to leave options open until a late stage in the process of development [Cagan and Vogel 2002, p.144-145].

When looking at the multiplicity of chances and options offered by new and current manufacturing techniques, it is at any rate necessary to shrink these gaps. In other words, designers and engineers must establish channels of communication, a reciprocal awareness of each other's field of expertise – of what each discipline knows and what he can do. However, in an attempt to achieve this objective, presented in the following are the viewpoints of the interviewed engineers and designers concerning communicational problems within the design process of furniture. They named some reasons and made suggestions which may help to shrink perceptual gaps in the interaction of engineers and designers.

Communication – the engineers' point of view

Engineers, working as consultants or in technical divisions in furniture companies, were questioned as to why it would be important to improve communication with the designers, which barriers they had encountered in the past and what they perceived to be difficult at present. They enumerated several reasons why they found it difficult to achieve adequate ways of communication with designers: One problem consisted of the lack of understanding about materials and production processes. Another problem consisted of the lack of attention which has lately been given to the use of innovative engineering properties of materials to enhance the cost-effectiveness, environmental sustainability, durability, structure flexibilities, lightness, etc. In their opinion, possibilities like these are of primary importance, as they are related to new applications within the field of furniture. These have to be discussed with designers at an early stage of the design process. Relevant remarks revealing the engineers' point of view will be provided within the following quotations:

"Schools definitely make design students develop the idea that engineers are their enemies instead of teaching them to be interactive."

"New materials with improved properties and shaping techniques really add qualities to furniture products, but designers lack interest in knowledge about some of these rules of what can and cannot be done when they are confronted with the different perspectives of engineers"

"Designers are not required to have a comprehensive understanding of new innovations in the field of materials and processes; it is rather required to ask the correct questions which are appropriate to the reality on the basis of which they will then organize their exploration."

"To avoid a breakdown in communication, designers must be willing to learn the underlying principles of technology and develop a competence in using the appropriate terminology".

Despite the above mentioned critical remarks, some engineers have a positive view of designers. They expressed that designers play a very important role as concerns some techniques such as the injection molding process. Yet, it is essential that they cooperate with plastics engineers. Spark [2004] also mentions the importance of their role related to this process because the aesthetic limitations imposed by the production methods are crucial to this particular process. An emphasis on curves, the compositional role of the 'parting line', color and size are crucial visual components of plastic design – the technical information which the designer has to discuss carefully with the engineer before design can begin [p. 135].

However, it was pointed out that establishing ways of communication depends on the project and its complexity. In the case of injection-molded furniture for example, a model for an interdisciplinary design process must be established. The main task of the engineer then is to define and simplify the information which possesses vital impacts on the form structure and aesthetics. For instance, the success of injection-molded chairs normally relies on the addition of thickness and ribs to stress-bearing elements of design to give the chair structural stability. In many cases, furniture designers considered the structure ribs as a virtue incorporating new aesthetic values in the object. One engineer stated that it could therefore be helpful to use visual and graphic illustrations exemplifying existing cases in which this information has been applied. In this way, designers might have some confidence in developing forms despite technical limitations.

Communication – the designers' point of view

Those persons representing the designers' side, whether as freelance designers or designers employed in furniture companies, have equally strong views about engineers they have worked with in the past. They have a negative idea of engineers as being patronizing, unimaginative and inflexible. The most common statement is that engineers regard technology itself as being invariable. They have no interest in anything having a more cultural nature and sometimes try to restrict the creativity of designers. This occurs especially in those cases in which designers choose a new material property or technique and attempt to gain more information about this option through interaction with engineers to ensure that their idea is going to be viable. Relevant remarks revealing the designers' views will be provided within the following quotations:

"In many cases our enthusiasm to transfer new applications of materials or techniques from fields such as cars or the sports industry to the field of furniture, is broken because of engineers not being willing to cooperate."

"Hindering the sharing of knowledge is caused by the fact that engineers tend to use a language and models which are not clear to us, e.g. concerning strength, function, analysis and costs, as well as two-dimensional technical drawings."

"It is difficult to talk with engineers early in the design process because they don't understand the process of our work."

"Narrow and uncreative, he is a highly trained mechanic, skeptically unable to look at a product in any context larger than the working of its parts."

Beside the designers' comments and their frustration about their relationship to engineers, they expressed concerns about difficulties in researching new material properties and techniques. By so doing, some designers stressed their awareness about the need for a close cooperation with engineers during which ideas can evolve. These difficulties occur in two situations: Even though they have learnt something new about particular materials and processes from project to project, new challenges might arise which they need to discover and discuss early in the design process. Another difficult situation refers to the problem that sources of information are available but are too complex and detailed for designers. However, it can be difficult to extract the relevant details and predict their effects on the designs they create.

Shrinking the gap

First of all, to overcome some of the problems mentioned by designers and engineers, it is most important to understand the significant differences between them, which determine the way that each discipline proceeds to solve problems. The British engineer G.F.C. Rogers [1999] points out that engineering refers to the practice of organizing the design, construction and operation of any artifice which transforms the physical world around us to meet some recognized need[15]. Therefore, the goals of engineers are in most cases determined by functional aspects and they undertake the process in a relatively linear manner in accordance with a desired timeline. This way of thinking moves from the known to the unknown by analysis based on acquired rules and logic. In direct contrast to this, design often implies an uncertainty or open-endedness. According to Wallace [1991] it creates the unknown from the known by synthesis – by dissecting and recombining ideas and images. In relation to the process of design, Wallace also indicates that there is no linear path from the initial "design brief" to the final "product specification", instead of this there are many paths – in the form of bubbles – linking the thousands of bubbles that lie between them. Hence, because of the differences between the two processes of thinking, engineers are inspired by different things which are not similar to the inspiration of designers. Therefore, those things that seem to

[15] Here Vincenti [1990] uses the term "organize" in the sense of "bring into being" or "get together" or "arrange". The first end, "design" has to do with the plans from which the artifice is built. "Construction" denotes the process by which the artifice is translated into a concrete object. "Operation" deals with the use of the artifice in meeting the recognized need [p.6].

be exciting and innovative to designers may hold no interest for the engineers and vice versa.

As in all extreme cases, these differences in the ways of thinking should not result in any problems. One of the two professionals should accept the decision of the other. The clash however occurs in the majority of cases, that is, if designers know more about new material properties or their techniques. What we can conclude from this is that these two professionals not only have different kinds of minds and, hence, different approaches to the same problem, but they also have a real problem as concerns communication: They speak different languages and do not understand each other. This is understandable, since the designer is expected to have studied technology, but the engineer is not expected to know anything about design. However, we find that it is important to provide suggestions that might help shrinking some of theses gaps.

Requirements for engineers

As mentioned previously, it seems to be obvious that designers are not going to fully understand all the different technologies available to them. Moreover, technological information is often presented in a way that does not appeal to the designers. Therefore, it is necessary to develop filters for this information which can help designers to choose certain types of information that meet their needs. In other words, it is suggested that when interacting with designers, engineers could present the relevant information in a way that designers will find interesting and useful. It has been found that talking directly about the basic science underlying a technology or mathematics does not work. The information must be provided in a form that is acceptable to designers using a language they can understand. From a different point of view, it is crucial to understand that the nature of a designers work requires it to be creative, in order to create new designs with the support of the innovations provided by technologies. Therefore, the engineers should make the effort to enhance the designers' creativity by providing broad and variegated approaches to the possibility of using technologies as an understandable means of stimulation for designers. This can help them to increase their imagination to define a problem related to using a new property or technique. However, the idea of filters is quite common. This can be related to Manzini [1989], who points out that "any approach to reality that intends to make it understandable must involve the use of a filter, a way of organizing raw information according to a model appropriate to the specific sort of information that one intends to extract" [56].

That is, engineers should separate and refine results of technological innovations in order to gain those types of knowledge which meet the mental images of designers before starting the communicational process. For instance, simple maps, illustrated examples, or comparisons in the form of visual graphics revealing links between different properties or techniques, are productive. They represent a way of communication that designers can understand. Additionally, such filters should include the organization of various options and functions offered by material properties and their techniques, based on the user's needs. Thereby, designers can find answers and suggest crucial questions to engineers.

Requirements for designers

In the course of the design process, it has to be noted that designers face frustration when they adopt traditional models of product representation to communicate with engineers. These models mostly include superficial knowledge and involve a blend of information including technical and aesthetic functions. They create, for example, three-dimensional portraits by using surface modeling software or hand in sketches and samples to explain certain properties of materials or connections between parts, etc. The models represent either the technical functions or the interactive functions [Svengren, 1997], but there is no way of representing both perspectives simultaneously [Persson, 2002]. This causes difficulty in recognizing how the aesthetical solutions work in relation to the technical solution of the product. Hence, Hill et al. [2001] suggest that a shared design understanding is often manifested in the use of a similar jargon in documentation because differences in the vocabulary used can create problems while communicating [cited in Persson and Warell, 2002].

It seems to be obvious that if the intention is to create products out of new materials or by applying new processes, the problem of appearance is inevitably enormous and requires the close cooperation of the engineers and the designers in order to find new and viable solutions. In doing so, it is suggested that designers:

- should classify the information related to their proposals into two separated types when communicating with engineers: The first includes information related to aesthetics. This reveals something that did not exist earlier or predicts new elements and chances for product appearance. The second refers to the comprehensiveness of information regarding the possible functions offered by certain materials or techniques. The latter implies a technical way of thinking such as analysis, sequence, and arrangement based on the principles of logic.
- should organize the representation of each type of information separately for engineers.
- should establish new channels of communication between different fields of design and technical areas by using technical terms they both understand and find a language they both have in common.
- should stimulate their mental images by exploring the information in the real world, whether that consists of time spent visiting factories and laboratories or reading books and journals or chatting with engineers.

The following example should be taken into account: An early stage of furniture design process, designers with some basic technical knowledge and experience must predict the major problems they might face, if they are supposed to develop ideas under some technical constraints related to a specific material or a manufacturing process. They have to communicate with engineers to point out these limits. Consider the example of plastic arm-rests: at the very beginning of the design process, a meeting with plastics engineers is necessary in order to ascertain if the armrests will support part of the body weight through good physical properties, if the armrests may be provided for comfort due to satisfactory strength and stability, etc. and above all, which shaping techniques are being made available to ensure a good surface and their influence on the quality of complex forms for moulding. Otherwise, if the design process has proceeded so far that it cannot be changed any more, industry will find a way of producing design without considering all wishes the designers expressed earlier. Therefore, engineers are asked to provide the necessary information in a form which is understandable for designers. The best possibility of presenting this information is by providing samples of earlier projects. Moreover, before the beginning of the design process, it might be useful to visit the engineer who is the partner in the project, in order to find out what types of examples, material samples, or machines exist.

To conclude, it is a fact that most designers, in this case furniture designers, are surprised about how quickly they can pick up the basics of another discipline that will be fit for their purposes. Yet, designers must first of all be willing to learn the underlying principles of new types of knowledge and new ways of thinking. This should be ensured by developing self-organizing methods for designers and engineers. This aims at shrinking the perceptual gaps or at least at diminishing the differences in perception. Finally, it is the design process which benefits from this cooperation. According to Cagan and Vogel [2002], these differences help to provide the trade-offs that make products innovative and yet affordable as well as being produced on time [p. 146].

5.3.2 Different vocabulary and terminology

In relation to the Communication theory, communication involves a sender and a receiver, a message, a medium, and a shared understanding of basic elements, including words and symbols [see review of the theory in chapter 2]. However, recent studies indicate that in the communicational process between the two disciplines of engineers and designers, engineers do not understand the "fuzzy" vocabulary used by designers. Equally, designers find it difficult to understand how this influences design solutions [Persson, 2002, Warell, 2002]. This semantic disturbance is considered one of the important types of problems leading to misunderstandings in the communication situation [Fiske, 1990]. As mentioned previously, this derives from a different background knowledge, different ways of thinking, and the cultural background.

In the course of using the possibilities offered by materials and their manufacturing techniques, different vocabulary and terminology continually appears among individuals who are concerned with the same design in different ways. They serve as a means of communication regarding the description of the product during the design process. Vocabulary and terminology transfer facts concerning the content of the message as well as meanings which are used to identify interaction between materials, techniques, and the product form. The message as such is understood, but understanding the underlying reasons for the message requires an interpretation of the content of such vocabulary and terminology. Unawareness of the differences between them can lead towards communication being prevented in the early phase of the design process. For instance, they can either prevent designers from searching for existing solutions with desired properties or they can hinder them from sharing their knowledge with other persons involved in the design process.

Previous studies by Johnson [2003] as well as by Lenau and Boelskifte [2003] attempted to describe vocabulary and terminology which are particular to the interaction between material, manufacturing, form and other properties of the specific products. The main objective of these studies was to identify the semantic properties behind these interactions by describing *soft* attributes of certain products. They worked with an interdisciplinary group from different areas such as design, engineering, and business areas to find out about these differences.

With a similar objective but with using different research methods[16] as well as referring to a different area of design, it is intended to investigate the differences between vocabulary and terminology used by two disciplines: design and engineering. Two disciplines - design and engineering - were asked to describe in their own words, influences of possibilities offered by materials and manufacturing processes related to certain selected examples of furniture products. In this investigation, we considered a selection of groups from products possessing a number of different attributes which can be deduced by each discipline. However, the purpose was that each discipline should express these influences based on their own experiences.

Figure 32 illustrates the four products used in the questionnaire and in the interview sessions with interacting participants. Furthermore, the figure contains a summary of the significant interpretations in vocabulary and terminology by each discipline, which is divided into two categories: The left column reveals the *soft* vocabulary which was used by designers to describe the number of semantic properties associated with the interaction between material, process, and product form. The right column shows the *hard* terminology which was used by engineers for the same purpose.

[16] See “action research methods” presented in chapter 3.

Figure 32. Vocabulary and terminology used by designers and engineers to describe influences of material properties and their shaping techniques on a group of furniture products. The words in the left column refer to the soft attributes of the product which are explained previously section. The words in the right column were used by a significant number of participating engineers in order to describe the products in the figure. These are shown in bold.

Soft vocabulary		Hard terminology	
Warm, organic, flexible, classical, ornamental, handmade, expensive, formal, cultural	1	**Bonding**, **elasticity**, **laminated**, veneered, thin, twisted, framing, recyclable, bonded	Group (1)
Minimal, simple, light, futuristic, elegant, clear dynamic, clever, mature versatile, youthful	2	Economical, bended, molded, **extruded**, elastic, **light**, live-hinge, practical, fit	Group (2)
Rounded, decorative, open, heavy, soft	3	**Reinforced**, **molded**, stress-resistant, **layered**	Group (3)
Trendy, smooth, organic, bright, glittery, perfect, colourfast, feminine	4	**Molded**, **mono**, composite, stable, stiff, durable	Group (4)

The results of our investigation, as illustrated in Figure 32, indicate that there is a very clear difference in language between the two disciplines concerning the words used to describe influences of materials and processes on the product properties. The designers use "soft" vocabulary based on their aesthetic experiences in order to describe these influences on the product properties. The engineers used hard terminology based on their technical experiences in order to indicate facts and rules. This difference, as mentioned earlier, logically derives from differences in knowledge and is influenced by the cultural background considered in each discipline.

It seems to be impossible to create a language that both sides can understand. Yet, it is possible to prevent the struggle of each discipline to understand the underlying "intentions" of this type of vocabulary and terminology. In other words, it is required and necessary for the designers to learn some of the terminology used by engineers to identify specific basic technical knowledge which is needed for the product realization. This terminology includes different types of knowledge implying a specialized set of properties. Yet, this terminology remains incomprehensible to the designer. Due to this, difficulties in communication arise. Hence, in this context it is suggested to guide designers towards interpreting some of this terminology in relation to existing products, including new applications of technologies. This is supposed to stimulate designers to extend their knowledge as well as to open new channels of communication with the engineering discipline.

The words shown in the right column, in Figure 32, shall be interpreted in the following. They have been used by engineers to describe the potentials offered by new technologies incorporated in modern designs from the field of furniture. Each of them implies the concise terminology that is well known in relation to certain material properties or shaping processes used in engineering. Some of these can be interpreted as follows in relation to the selected product samples:

- **Group (1)** includes the following words referring to the "Cross Check"[17] armchair: "laminated", "bonding", "elasticity". These words do not only indicate certain techniques, but also possibilities resulting from applying new techniques. However, the word "laminated" refers to an assembly technique of layers of wood. Generally, laminated assemblies benefit partially from the strength of a buildup of layers [Nago and Pfeiffer, 2003]. The use of the recently developed thermoset assembly glue allows strips to be laminated while still providing facilities of movement and flexibility. This quality can be achieved, due to the high-bonding-urea glue used to make all wood grain run in the same direction for resilience. Thermoset assembly glue provides a sound and springy structure without the need of metal connectors.

- **Group (2)** includes the following words to describe the "FPE"[18] chair: "sinuous", "extruded", "molded", and "light". These words reveal the potentials implied by the initials of the name of this chair: fantastic, plastic, elastic. The chair has a soft and sinuous form. It is not only a design incorporating a great form, but also a product that reflects new chair production methods. This reflects the underlying meaning of the terminology "extruded" and molded". These words explain that this chair is made from two components: an extruded aluminum frame and a molded polypropylene seat. The seat is produced as an injection-molded flat sheet which slots into the frame. The word "light" implies

[17] "Cross Check" Armchair, 1992, designed by Frank O' Gehry, Manufactured by Knoll Group.
[18] "FPE" fantastic plastic elastic, designed by Ron Arad, 1998

that not only does the material used cause the light characteristics, but that it also provides a strong joint at the point of contact with the frame [Lefteri, 2001]. Thus, the properties of the chair emphasize the suitability of the product for different spaces. It is, so to say, "practical".

- **Group (3)** refers to the seating element "Osorom"[19]. Words like "reinforced", "molded", and "layered" indicate a material with special properties in relation to the form structure: hard, capabilities of a multi-layer structure, and composite. Considering only the word "reinforced" designers can be guided towards reaching a great variety of properties including the advantages of fiber reinforced plastics. Examples of these properties are: low density, high strength, high rigidity, textured surfaces, self coloring, durability, and lifelong attractiveness. This is a range of attractive properties which are implied by reinforced plastics and can be combined in numerous ways. One of the materials resulting from such a combination is a material called "Hirek" used in the seating element which is illustrated in Figure 32. It is a composite multi-layer techno-polymer which is composed of various layers. The components made of Hirek can be relatively voluminous, yet very light. They can be injection molded, and are very hard yet still flexible.

- **Group (4)** is an example of five chair studies with the typical Colani[20] look. Terms used by engineers related to this chair such as "mono" and "molded" imply that the product is manufactured in one single step with minimum material use. The main characteristics refer to the fact that the chair conforms to a modernist fantasy in which perfectly formed identical products are ejected from a machine continuously. There are no parts which need to be assembled; each chair emerges complete and whole. There is no original model; each is an exact replica of the other chairs that were produced before and those that will succeed. At the moment of extraction from the mold, each is unblemished, harmonized, and timeless. From a different point of view, these terms imply economical aspects related to low-cost, fast and efficient production.

[19] K. Grcic's Osorom is currently being produced for Moroso (www.moroso.it), using Hirek materials. Hirek is a composite multi-layer-polymer made of polyolefines and polyester.
[20] The chairs are designed by Colani design Germany, 2004. The models are based on a design concept from the 1970s.

The previous analysis results in the following suggestion: Listing vocabulary[21] and terminology used in communicational situations and following the underling intentions of each, will reveal links between them and the desired attributes of the product. Furthermore, lists like these can be used as a facility of searching about new possibilities by which the designers' knowledge can be extended and new relationships can be established. Above all, by using words involved in these lists, designers can promote channels of communication with persons involved in the design processes.

5.3.3 Tools for enabling communication

Innovative new forms based on the process of using new materials and technologies indicate that designers need to have tools which enable them to communicate with their own ideas and to share these ideas with others involved in the design process. Tools have to be found which help to record the transitory thoughts and to exchange knowledge between different professions. However, the purpose of this section is to present existing tools used to capture those fleeting thoughts of the designers. In this way, the designer can thoroughly evaluate them, applying all the relevant criteria. Furthermore, such tools can improve the communication between designers and engineers, especially when they try to consider new forms or existing conventional forms resulting from new material properties or shaping technologies during the design processes. This presentation will be based on information gathered from empirical studies and from recent publications referring to the tools of both professions. The aim of this approach is to investigate how tools for communication can be applied in the design process, enhancing designers in the best possible way. Eventually, designers can make useful experiences and ensure a better exchange of knowledge among all persons participating in the design process, in this case within the field of furniture design.

Various tools used by designers

Figure 33 illustrates tools mentioned by the interviewed designers which help them to visualize their ideas as well as to transform their thoughts into a language which can be easily understood by other persons participating in the design process. Additionally, a summary of designers' comments on which

[21] "soft vocabulary" related to examples from furniture area, is explained in detail in section 5.2.2.1.

tools they prefer to others is provided in Figure 34. However, it seems to be obvious that variation between designers inevitably occurs, concerning the use of tools for communication. This does not seem to be strange because of the differences in the nature of their working environments and skills. However, in the following, some of these tools shall be defined. At the same time, we will describe which tools facilitate the communication between designers and their ideas on the one hand and designers and engineers on the other hand, when they introduce new materials or technologies into the furniture design process, as the subject matter of this thesis.

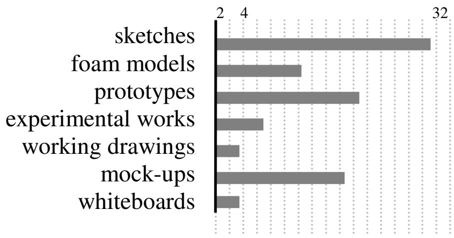


Figure 33. Differences in tools for communication which are used by designers during the design process.

Figure 34. Short illustration of reasons for the variety of favored tools used by designers for the communication of their own ideas and with persons involved in the design process.

Variation in the preference of tools for communication during the design process

Sketches: the quickest and simplest way of converting, made freehand, need not be in scale

Foam models: an ideal way of creating accurate three dimensional forms and of having a good surface definition.

Prototypes: a means of stimulation and the best possible record of a designer's intention, the key step to define the link between form and manufacturing norms.

Experimental works: lead to an unpredictable solution, evoke curiosity, expand imagination, open a channel for communication with engineers, methods to develop new forms

Working drawings: serve to allow a realization, formality, logical, minimize errors, ideal for communication with engineers.

Mock-ups: encourage easy alteration; present the overall form without details.

Whiteboards: better opportunities for cooperation, ideal for exchanging knowledge and concept presentation.

Sketches and drawings

A sketch is usually the first external visualization of a design idea. Sketching allows the designer to record and represent the ideas and images which he has in mind [Cross, 1999; Goldschmidt, 1994]. Yet, these represent only one of the advantages of sketches. Designers are accustomed to using a sketch as the quickest and simplest way of converting a mental image into a tangible reality that can be viewed, retained, and shown to others. Sketches function as the building blocks of design and production. Henderson [1999] points out: “They are developed and used in interaction, their visual representations act as the means for organizing the design to the production process and hence serve as a glue both between individuals and between groups” [p.6]. Drawing can also be regarded as the most fundamental activity of designers, a selection of lines made after great consideration or very spontaneously. They can produce form, structure, solutions, inventions, and provide a starting point to a whole range of developments [Butterworth, 1999]. In others words, the drawings and sketches themselves structure the working process as well as its product. According to Henderson [1999] “they are the basic components of communication; words are built around them” [p. 1]. Visual representations such as sketches and drawings are, besides being devices for a communal sharing of ideas, also a ground for design conflicts. They help to make the best decision about design.

With regard to this thesis, it seems to be useful to relate to these tools used particularly by designers while attempting to close the gap between design and technology. However, in the course of our investigation it became apparent that drawings especially can contribute to closing this gap because of their ability to provide specific technical information. The way in which both sketches and drawings can indicate technical information is illustrated by the example of Kinsman's table legs in Figure 35. His sketch and drawing present cast-aluminum legs for a table. Strongly splayed and finned, the cast-aluminum legs which support glass or wooden tops in various sizes are bolted to a pressed steel beam. The cross-section thus had to work for a number of different scales: for a standard two-meter long table, for a bigger conference table, and for small, round café tables. The drawing indicates the development of a geometry based on bolting the legs to a boss. For small tables there would be just one central boss; for larger tables there would be a boss at each end, connected by the box section pressed steel beam [Manser,1992].

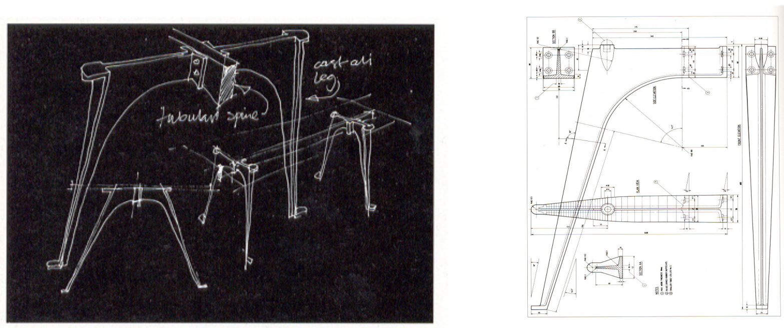


Figure 35. The representation of the cast-aluminum leg designed by Rodney Kinsman indicates the major difference between sketch and drawing. The sketch of the legs involves the crucial three-dimensional form at an early stage of the design development. However, the drawing shows the final form of the leg. It refers to a more formal, finished representation of a design. Both include technical information leading to a realization of the designer's exact intent.

There are many different types of drawings that designers might use. The first drawing might be more like a sketch. Most designers use it as a tool for collecting and analyzing information, a source for further research. From the initial sketch, designers create a conceptual drawing which can be called "presentation drawing". It is a formal drawing made to present the design to a client [Pile, 1990]. It may include written notes, diagrams and measurements.

Another type of drawing are construction drawings or working drawings which include all the information about the material that each part will be made of as well as details of tooling equipment needed for its manufacture. Creating construction drawings is part of the role of production engineers. A decision which is made during the phase of construction drawing can cause problems that can lead to radical changes of the designers' earlier proposals. This is caused by the fact that the designers' drawings include incorrect information related to materials or their shaping methods on the one hand, and that the engineering principles such as assembly of different parts are not reconsidered on the other hand. Hence, it is very important that designers ensure that the solutions which are recorded in their drawings provide the correct information so that production drawings can be made from these. An ideal way of handling this problem would then be that designers provide a channel of communication with the construction engineers as early as possible to capture information which will serve to permit a realization of the designers' exact intention. Moreover, the designers must be able to understand some basics in the field of technical drawings. Often, these represent the best way of providing a general view of the complete design in full size. At the same time, designers can for example add details that point out crucial intersections, special situations that may present problems or irregular shapes that might be distorted in the process of enlargement to full size.

An engineering drawing becomes an essential part of the design process and it is the basis of the eventual design which can ensure a correct interpretation of the designers' intention. Therefore, if complex forms, irregular curves, and obscure details are involved in the design, the designer must take the general rule of engineering drawings into account. According to Pile [1990], furniture working drawings were traditionally made in full size. In modern practice this is still done when complex forms, irregular curves, and obscure details are present. When forms are simple and geometric, smaller scales are satisfactory and avoid the inconvenience of large boards and large tracings as well as prints that are difficult to handle and store. Full size drawings are frequently required for chairs, where complex shapes are common. Surprisingly, chairs are not normally large enough to lead to an inconveniently large sheet. It is customary to draw any possible symmetrical view (usually front, back, top, or bottom views) to show only one symmetrical half of the view. Sofas may be extended versions of chairs and require only a scale drawing to show overall size and any modifications that the development of a sofa from the corresponding chair may require. Tables, desks, other storage furniture, and beds can often be shown in smaller scale with any critical detail in full size [p. 119-126]. Furthermore, while making the drawings, the designer must take into account all the conditions defining the ability to operate the machine, assembly and disassembly as well as the attachment of adjacent parts; he also has to choose the correct materials for the main components[22]. In all these cases, it is essential that engineers, manufacturers and operators are consulted.

Experimental works

In many cases, the new form is the outcome of an experimental work. The latter provides an opportunity to identify the key factors that affect form based on a unification of shape, function, material, and production techniques. A breakthrough as concerns improvement can then be made. This can be shown clearly considering the works of Panton and other experimental designers of the 1960s and 1970s. They experimented with a wide range of industrially produced materials in an attempt to transform furniture design into industrial design. They tested new materials and technologies that were unconventional

[22] See some examples for engineering drawings related to furniture products according to Pile [1990, p. 118-129]

at the time: plastics, fiberglass, plexiglass, steel, foam rubber, etc. In this context, Stattmann [2000] states that designers have always tended to explore, invent and experiment. In order to provide the latest design, it has been necessary to develop new innovations, which not only refer to the products, their appearance and their function, but again and again involve the use of new materials and production techniques. For instance, the designer couple Charles and Ray Eames experimented in this way, using fiber glass and layered wood to develop new possibilities for the future of furniture production [p. 7].

Today, there are designers who follow this tradition. In their opinion, experimental work with materials that appear to be quite different in properties, behavior, composition, and workmanship, will nonetheless find applications in furniture design. Their innovation is the outcome of technical research which was pushed to the furthest limits of the expressive capacity of materials, producing formal, functional, or even tactile results of great harmony.

However, according to most designers experimental work can be described as a learning process. In this process, designers make experiences not only by "doing" but also by "interacting". Today, as a fact one can achieve this in companies that need "renewal" and "change" in the form of their products is needed. Here, experimental work is greatly appreciated, as it provides the opportunity to discover the innovations associated with technological progress. In the manufacturing context, experimental work means creating a "multidisciplinary team" to foster innovative thinking by focusing on different professional perspectives of a problem or a project. This approach is the core of the process of experimental work, focusing on the collaboration between different disciplines. The difficulty, which designers and engineers in these multidisciplinary teams face during their experimental work, is that companies concentrate only on the formal ways of cooperation: instructions forms and reports to the management and the handing over of information between the design department and various other departments. This can be related to what Squires and Byrne [2002] found out with regard to "multidisciplinary teams": Companies do not teach the teams working together how to communicate with each other. They stated: "Each group has its own concerns, priorities, and issues that it is attempting to communicate, and often they speak different languages as well" [p. 163].

Ideally, experimental work should include a close cooperation between designers and engineers, especially at early stages of the process when the new material or technique needs to be identified or ideas based on them need to be refined. In the experimental work it is required that designers and engineers work hand in hand from the beginning when material characteristics are identified by laboratories until their realization. They make compromises, exchange knowledge, and establish a language they have in common. Therefore, during the experimental work, designers must be a master in the field of fabrication techniques, not persistent, not arrogant, not superficial, and above all cooperative.

A good example in this context results from experimentation with carbon fiber in the field of furniture products created by Alberto Meda. He carried out studies in close cooperation with laboratories where carbon fiber is produced and experimented with. "Light Light", Meda’s first lightweight chair, was built with a Momex-honeycomb core. The surface consists of carbon fiber embedded in epoxy resin. It weighs only about 1 kg [Antonelli, 1995], see Figure 36.

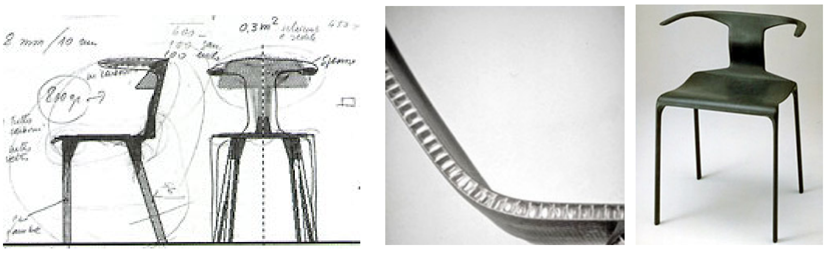


Figure 36. Results from experimentation with carbon fiber. (left) Sketches; image courtesy of Alberto Meda. (middle) Nomex honeycomb. (right) “Light Light” chair by Alberto Meda, 1987, molded carbon fiber in an epoxy-resin matrix and Momex honeycomb.

Furniture designs resulting from experimentation reveal a harmonious relationship between their various individual elements regarding the structure, the material, and the function in a way that adds unique attractions to the idea. In the experimental stage, designers have to look for a bright idea that will make the new project somehow innovative and discover more opportunities to meet the world of design.

Models

A model has been defined in the most fundamental manner as „a way of making a trial that minimises the penalties for error” [Judson 1980, p. 112].

Generally, in the case of any product it is more difficult to experience the spatial shape and the interactive concept on paper than in spatial models which can be seized, turned, moved and used. Models[23] allow the designer to explore and test interactions, to evaluate and develop aesthetic aspects of design, and to determine manufacturing and marketing aspects [Hummels et al., 1997]. There is a wide range of modeling tools and materials which help to obtain this diversity in models. Designers use different tools to create simple paper models (e.g. a pair of scissors and glue), clay models (e.g. scrapers, spatulas and tape) or refined prototypes from MDF, aluminum or synthetic material (e.g. a turning lathe, a milling and drilling machine and a sanding machine). However, there are two types of models called "mock-ups" and "prototypes". These two terms overlap to some extent, yet they can be described as follows.

Mock-ups are full size models that reproduce certain aspects of a design in full and realistic detail, but omit other aspects of realism with a view to easy construction and revision, resulting in economical use of time and costs. A mock-up chair, for example, might present seat and back surfaces in full size and at the intended angles, including the final seating construction, yet they might be made of rough materials without any effort to incorporate the final appearance [Pile, 1990]. In other words, the advantages of using mock-ups are that designers can see the piece of furniture develop three dimensionally and in full scale. Nevertheless, materials are wasted.

Prototypes are generally defined as "an approximation of the product along one or more dimensions of interest" [Ulrich and Eppinger, 2004]. A prototype is – like a mock-up – a full size model; yet it is made as accurately and perfectly as possible, including all materials and finishes that will be used for the final product [Pile, 1990]. In other words, it is a full-size working model of a physical system. According to these definitions, a prototype is in fact a type of model; in design terms it is regarded as a suitable tool for careful evaluation of relationships between surfaces and structural elements. However, it offers the possibility of revision that may improve the subsequent production. An ideal furniture prototype is, as Pile [1990] indicates, indistinguishable from the production units it simulates and it is often considered to be a possible record of a designer's intention. Thus, it is frequently proposed as a good alternative

[23] Few publications refer to models produced by industrial designers: Studies have largely focused on engineering design such as Emori [1977].

to drawings. This view is shared by a number of designers who prefer to move directly from the sketch concept to the production of a prototype.

Nowadays, digital technology can provide designers with three-dimensional models. All the important aspects are integrated in those models. Some modifications can include the addition of color, the rounding of edges, movement as well as the integration of different types of materials. It is even possible to virtually modify some smaller details inside an object. These new techniques are used to visualize complex furniture models and for the conception of the final idea. Complex furniture prototypes can be created with the help of rapid prototyping techniques in a much faster and effective way. They could even enhance the creative process by helping designers and engineers during the design process in generating and animating solutions quickly. 3D prototypes permit better communication and interaction between associates.

Producing models generally requires the investment of large amounts of money. Bearing in mind new material properties or new shaping processes, it is obvious that design and production errors must be corrected at the earliest possible stage. Therefore, it is required to translate ideas into three dimensional forms as quickly as possible. In order to put this into practice, furniture designers use different tools to produce models which allow them to 'see' and 'touch' the surface as well as to observe the 'sizes' of realistic details. Models functioning as tools of communication with engineers can also support designers. They can incorporate realistic touch and haptic aspects related to materials and form structure. This is what distinguishes finished models from a sketch model, as the first attempts to imitate the final product in a visible way. Furthermore, the finished model is an ideal way to open channels of communication with engineers in order to show the impacts of different properties of materials and their shaping techniques in relation to the appearance of the product. Often, engineers point towards elements of reality in the models. These are hints for designers which help to solve critical problems. Yet, it is not possible to represent all aspects of the product. Nevertheless, the designer needs to ensure that the model contains and reveals interactions.

Whiteboards and visualization as tools for better communication

In any process in a group, it is important to have a shared space to communicate and to exchange knowledge. Suchman [1988] characterizes the whiteboard as structuring "shared interactional spaces" [p. 319] and a "second interactional floor which is coextensive and sequentially interlocked with talk" [p. 322]. According to Henderson [1999], "both the drawing and the whiteboards may be delineated into owned territories or inhabited jointly" [p. 201]. The merging allows visual representations and whiteboards the flexibility to become "an arena for the introduction, manipulation, and resolution of design dilemmas". Easily accessible, whiteboards or shared work surfaces (IT tools) based on visualization may thus be regarded as a means of support for communication during the design process.

Generally, some areas of the furniture industry use IT-supported methods for furniture design at present. Facilities such as computer interfaces for example, can support designers in their design decisions during the sketching stage. Tools like these are applied, aiming at establishing closer contacts among designers and engineers. They simplify the cooperation between designers and engineers, if it is suggested to integrate materials with new properties or shaping technologies into furniture form structures. An example for this is the Swedish Furniture Association (SMI) and the Studio of Design at the Chalmers University of Technology. Based on IT, they developed graphical interfaces as a tool which helps designers and engineers to discuss and establish some kind of language they have in common. With the help of the interfaces, designers can modify the appearance of the product in the interface in critical situations such as concerning armchair forms. At the same time they can check their response to the engineers' proposals and vice versa. New tools based on computer programs such as a sketchpad can enable persons with a different background to communicate effectively and reflect upon the knowledge and insights they gain as a group[24].

As a matter of fact, all the tools mentioned above which are used for communication, are important. They help designers to communicate in a verbal and visual way in order to establish consensus and a general understanding of the problems, issues, ideas and contextual assessment.

[24] The information presented here is based on a project at the Chalmers University of Technology, 2003. The project was established with the aim of developing an approach allowing experts in material science, structure mechanics, aesthetics and manufacturing to combine their efforts with the use of IT support in the design of new furniture.

In relation to the technologies involved in material properties and processes, they trigger reactions to concepts on the engineers', the manufacturers', or other general stakeholders' side with whom the 'product' interacts. Thus, it is very important to emphasize that the digital design tools are advantageous. They link different visualization techniques and phases in the design process and also help to select the advantages of different techniques as well as to combine these within new tools or visualization techniques. For example, sketch-mapping preserves the expressiveness of sketches, whilst simultaneously profiting from the possibilities of interaction with the model. Moreover, digital technology can also provide new possibilities which were impossible to obtain with traditional techniques. They support the designer in the process of altering design solutions quickly, without having to recreate them entirely and to save these alternatives separately, thus facilitating comparison and evaluation. The tools can exploit the absence of physical laws, such as the absence of material resistance and gravity, which can physically facilitate modeling and increase the expressive range, if applied properly. Furthermore, the ins and outs of the appearance and the functions of the design can be demonstrated with the help of simulation techniques [Hummels, 2000].

To take full advantage of the ongoing developments in these technologies, it is necessary for designers to have the ability to work with these. Their original skills for visual communication such as drawing with traditional tools such as pencil and paper to create an image can be enhanced by the use of computer skills. For instance, CAD and CAM tools have provided more freedom for designers and have also given them more control enabling them to design products of better quality. Tools like these help designers to translate and express their ideas into three dimensional forms. Thus, by contributing to both the quality of designer's visual thinking and to the simplification of the communication with engineers, judgments can be made determining which design or idea should be developed further. Generally speaking, the tools for creating as well as working with three-dimensional design and models are used in communication in an effective way. They offer the potential to revolutionize computer-supported design by moving away from the 'desk-top box' scenario to more fluid and flexible forms. Haptic devices can provide a sensation of touch related to materials and their physical properties.

Furthermore, new computer tools support the designers’ capability to imagine objects in complex geometric forms. Finally, tools in general can enhance designers’ skills to conceive of an idea for a product and then provide the possibility of sharing the idea with others.

Chapter 6

An Approach to Build a Model Supporting the Design Process

6 An approach to build a model supporting the design process

This chapter proposes an approach to build a model supporting the design process. It describes a process with the help of which designers can become more skilled in making use of the possibilities offered by new technologies early in the design process. The chapter is central in relation to the main research question stated in chapter 1: What types of models, methods, or tools may be used to enhance designers when they are confronted new technologies during the design process?

The approach to the model proposed in this chapter is intended to expand the understanding of the design process by focusing on the design opportunities which result from new technologies. The model is based on the hypothesis that the information about new technologies can be used to provide paths towards an expanded range of creative solutions, thus potentially generating new products. The model will also indicate channels of communication among members of teams from diverse disciplines, mainly designers and engineers. These objectives, which will be incorporated in the model, are based on the results of the research which were presented, analyzed, and discussed in chapter 4 and 5 of this thesis.

6.1 Background for model building

6.1.1 Definition of a model[25]

In the Wordsmyth dictionary [www1] a model is defined as “a representation or copy, often smaller than the original and used as a guide to making a thing

[25] There are some words containing aspects of a ‚model’ such as a frame, guide, outline, rule, picture, type, etc. As well as functions of models related to early words can contain various meaning such as order, interpret, simulate, suggest, evaluate, explain, explore, transform, translate, describe, etc. [see more aspects and functions of models by Gregory, 1966, p. 144]

in full size". Webster's dictionary [www 2] defines a model as "a usually miniature representation of something". Another definition in the Webster's dictionary is that a model is "a description or analogy used to help visualize something that cannot be directly observed". A model is often a fairly abstract, declarative representation of real world entities that can be used for reasoning and can therefore give room for many different interpretations.

The approach of using a model as proposed in the context of this thesis may be described as a *"transformation and simplification of the knowledge"* during the designers' work. With the help of the transformation, the model will guide designers towards transforming knowledge about technologies from the "concrete" or "hard" state into the "abstract" or "soft" state so that they will be able to interpret it effectively during the design process of the product, in this case furniture. By means of simplification of knowledge concerning technologies, the model endeavours to filter this information, emphasizing some types and neglecting others. In other words, the model will display relations that are important for a new understanding of how an overlapping between two types of knowledge – design and technology – is possible and how designers make use of it. The model can furthermore function as a basis and a framework for reflection and discussion among different professions. Through discussions like these, a new understanding may be developed.

6.1.2 Suitable instruments for enhancing designers' ways of thinking

The act of creation in a design process is linked to different ways of thinking. Based on the publications of authors like McKim [1980] and Edwards [1979], discussing ways in which the brain manipulates information, they distinguish between two modes of thinking: the right and the left mode. The right mode is for instance holistic, intuitive, spatial, and synthetic, while the left mode is essentially linear, a sequential path, logical, and analytic[26]. Tovey [1991] points out the difference between the two ways of thinking in a study of typical visually thinking designers. Observing them simultaneously produce and develop ideas during synthesis, he concludes that this kind of designer is a typical right-hemisphere thinker. However, during analysis, evaluation, and assessment of those ideas, the process is serial, a property of left-hemisphere

[26] Differences in ways of thinking between design and engineering disciplines are presented and discussed in a detailed way in section 5.3.2.

thinking. In what he calls a "dual processing model", Tovey argues that there is a parallel course of both modalities during the design process [cited in Muller 2002, p. 26-31]. However, according to his approach, which follows McKim's and Edwards's hypothesis, Figure 37 gives an overview in which the various modes of thought and behavior are distinguished in relation to knowledge acquisition.

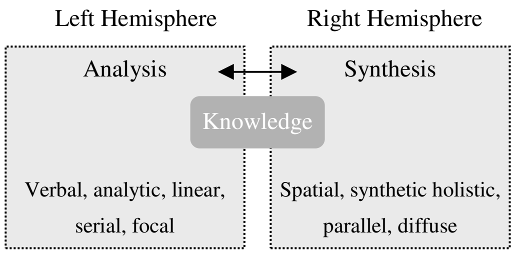


Figure 37. Summary of approaches related to Edwards [1979], McKim [1980], and Tovey [1991]. It shows two modes of thinking, resulting from the ways in which the human brain manipulates information. The first seeks solutions by analysis and logic, the second seeks solutions by synthesizing elements. During the design these two modes of thinking should be combined.

As mentioned previously, knowledge generally plays a key role during design processes, especially in conceptual design. Designers gather information from different areas such as ergonomics, aesthetics, functions, technology, users etc. and they apply it throughout the design process. However, all designers, regardless of their discipline, require expert knowledge to reach a good solution to the design problem. In addition to this, they need to be aware of technological possibilities offered by new materials and processes relevant to their particular field to be able to incorporate them into their designs [Lawson, 1990 and Oakley, 1984]. Yet, as this research project revealed, even if information about technologies is available, it is often presented in a way that does not appeal to the designers. In other words, the knowledge about technology is presented in a way deemed irrelevant or too scientific by designers. Designers encounter such a diverse range of materials and processes during their various projects that it would be impractical to expect them to retain detailed knowledge about the different available techniques [Lawson, 1990].

It is obvious that there are conflicts between the two types of knowledge – design and technology. Therefore, it is suggested that beside the importance of providing suitable sources of technological information to designers, it is also necessary to transform this knowledge in an effective way that is acceptable, namely better understandable for designers. Because of this, it is suggested to use "product samples" which incorporate a successful overlapping between design and technical aspects, as a medium of transmitting knowledge about technological possibilities. These will be defined and reflected upon in the following.

Using good product samples to communicate knowledge

Product samples are examples from existing concepts which include a successful integration of design and technical aspects. The approach of using product samples as a medium of transmitting technological knowledge is based on two ideas: First, existing examples summarize results and efforts that have features worthwhile recognizing and they are presented in a format that is easy to understand for designers. This can be related to what both Powel's [1987] and Durling's [1997] studies revealed: that designers have a preference for product samples because they have the same 'language' that is used by the designers themselves. The second idea is that such samples include and represent information about materials and manufacturing processes in a very concentrated way. This can be related to Lenau [2001] pointing out that "Using good product examples makes it possible to communicate central information about materials and manufacturing processes in a very concentrated way" [p.5]. Furthermore, they are worth investing time in exploring.

Previous studies by Haudrum [1993] and Lenau [1993 and 2001] revealed that designers often limit their selection of materials and processes to a few well-known ones. According to Lenau, this is unfortunate, if new and innovative products are desired. He gives two reasons for this. One of them is that designers could avoid risks. Another simple and very important reason is that the existence of other materials or manufacturing processes is not known or that they are mistakenly believed not to be suitable. Only little help can be found in the existing literature to facilitate solving this problem. The structure of common sources requires that the material or process sought after has to be known in the first place [Lenau, 2001, p. 2].

The investigation within the furniture design area agrees with the results above and it also revealed that most designers can expand the range of possible solutions by considering knowledge offered by materials and processes, if this information is presented to the designers in an appealing way. To put this into practice, product samples are often used to transfer this information as well as to convince the designers that these materials and production methods have been used before. Additionally, the results of the investigation pointed to the fact that some designers use samples of existing products to defend the rationale for a proposed design. In other words, using good product samples including the successful application of technologies gives the designer the opportunity to learn about materials and processes, and how to incorporate these into their designs in order to achieve innovative design solutions. Furniture designers are inspired by the interpretations of other designers who successfully made use of technological possibilities in good products. These provoke them to think creatively. This can be related to Ashby and Johnson [2002] stating that designers get most of their ideas from other designers (past as well as present) and from their environment [p. 128]. An incidental encounter of these examples of good designs can inspire designers. Inspiration can be incited by materials or processes, particularly if these are new or used in unusual ways.

Therefore, good product samples shall communicate information on technologies supporting the structure of the intended model. The proposed model will guide designers towards exploring and interpreting possibilities offered by technologies in existing samples. Then they may be able to transform the gained knowledge and apply it effectively in creating a desired concept of the product early in the design process.

6.1.3 Existing concepts and models

In the context of design methodology, there are many concepts and models originating from engineering disciplines regarding materials and processes within the field of technology.

On the one side, they generally give guidance for engineers and designers to select from the vast amount of materials and processes which are best suited to their tasks. Such methods are based on providing a strong interaction between design (shape and function), material, and the process in order to achieve excellent service and to optimize the balance between performance and cost, see Figure 38 (left).

On the other side, due to the increasing knowledge concerning the field of technology, manufacturers nowadays face the problem of depending on the technical functions or performances alone. A Dutch newspaper stated for example: “Manufacturers more and more cater to emotion, now technique is no longer distinguishing”[27] [Van Ammelrooy 2005, p.7]. Therefore, concepts have been developed which attempt to adopt a holistic approach towards the integration of materials into design. This process, as illustrated schematically in Figure 38 (right), involves considering the materials as the heart of the design process, as the integrating element permeating all aspects of the design [Hodgson and Harper, 2004]. This approach is much more compatible with the typical practice of most product designers, and is in effect a “material specific” mirror of the widely advocated process of formulating a conventional product design specification [Pugh, 1991]. The concept tries to balance the engineering property requirements and design needs which are subservient to the user and the producer [cited in Hodgson and Harper 2004, p. 3].

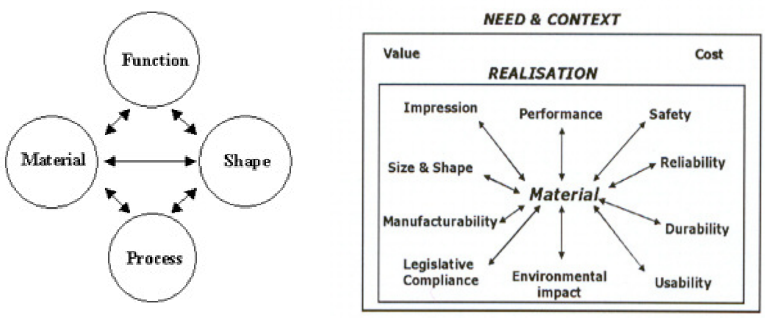


Figure 38 (left). How function, material, process, and shape interact, according to Ashby [1999]. **(right)** Relationships between materials and the elements of design, according to Hodgson and Harper [2004].

There are only a few models that emphasize the use of material properties and their manufacturing processes to generate new interactions which can help designers to create products which guarantee emotional fulfillment and a personality that elicits the desired experiences. One of these few models is presented in Figure 39. It illustrates an integrated model of design considerations that includes materials among other elements of design. The model clarifies the complexity of interactions between function, use, product personality, materials, shape, and manufacturing processes. The model was developed in order to contribute to the product designers’ understanding of

[27] De Volkskrant, February 19th, 2005, Economie, p. 7. Amsterdam: PCM Uitgevers NV.

design and the selection of materials to create product personality [Kesteren, Stappers, and Knadachar, 2005].

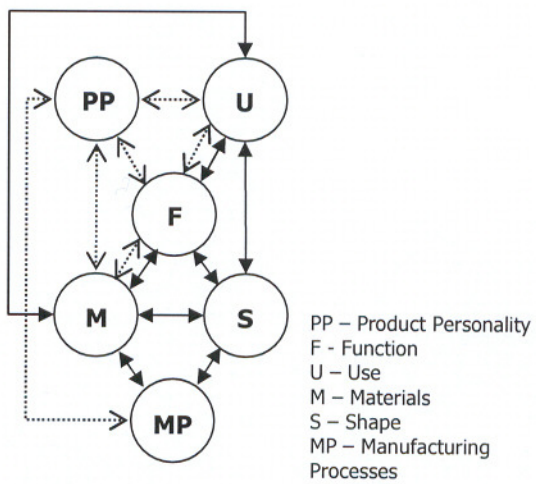


Figure 39. Integrated model of design considering the interaction of function, materials, shape, use product personality, and manufacturing processes. This model results form a combination of different models in design and technical parts. The dotted arrows in the model represent the interaction found in the part describing materials and product personality and the normal arrows represent the interactions found in the part describing materials in product design, [Kesteren et al., 2005].

6.1.4 Other principles and objectives supporting designers

Each of the previous studies is based on building interactions between aspects related to design and technologies. None of the studies above refers to how the knowledge about technological possibilities can be explored and combined with the designers' proposals. In other words, with the increasing knowledge in the field of new technologies, it is essential to guide designers towards finding out how they can be able to capture effective types of knowledge about technologies. They also need to become aware of how they can build connections between those effective types of knowledge generating new opportunities for design. This is one of the main problems which designers confront.

However, the studies mentioned above try to describe the circumstances under which good design is to be created or they try to enhance the designer's understanding of the selection of materials and their techniques during the design process. They affirm that such relations offer growing opportunities for innovative design with the help of technologies. In fact, the first deduction is that the approaches involved in these studies are inadequate. Furthermore, overemphasizing certain links between different kinds of information aiming at a certain goal to be realized could hinder the emergence of new or unexpected forms and could lead to critical design errors in the worst case [Hodgson and Harper, 2004]. From another point of view, there is the dangerous chance that this kind of thinking may make designers become formulae-bound easily. Perhaps, approaches like these may well be accepted to support the systematic thinking of engineers in making adjustments or compromises in order to achieve a so-called optimum overall solution. In the design of most products the 'optimum' is not necessarily a unique or ideal solution, as indicated by Gregory [1966].

For those designers who promise new outcomes to satisfy the user and to find what might be called "answers" which are suited to humans, it will be difficult to suggest an act of systematic thinking which could enable them to create new concepts. In dealing with human requirements, it may be more profitable and acceptable to provide procedures for enhancing the experiences accepted and adopted by designers so that they treat not only functional benefits offered by technologies but also emotional ones. This is the new challenge that designers are faced with today. Their task is to "domesticate" the new technologies and make them not only available for human use but also to add values to the product and the user [Katz, 1997 and Jordan, 2000].

Hence, the main principle of the model proposed in this thesis is to support the interpretive behavior of designers in order to transform the outcomes of the "hard" attributes of technologies into "soft" attributes to fulfill emotion needs and to appeal to the users' senses. Another principle of the model is to encourage the communication between designers and engineers and to provide insights into "how other disciplines – engineers – think and talk". The reason for this idea is that the field of possibilities, as Manzani [1989] indicated, is a complex system, because it is extensive and changeable. Therefore, designers cannot depend on their own knowledge or personal perspectives in this system. In this new atmosphere, according to Manzani, "it is necessary for the designer to know or intuit how and with whom he must communicate" [1989, p. 56].

In this sense, information about technologies can enhance design, if designers achieve an understanding of these early in the design processes. That means that the aim is not only to explore or find relevant information related to their proposals, but also to combine certain information in which underlying values, intentions, and "softer" aspects of the product can be created. Hence, to achieve these objectives, the approach towards building a model to support the design process in this thesis may be regarded as a contribution to:

- paying attention to technical knowledge which has recently been developed or found on a scientific basis.
- describing instruments to enhance the capability of designers to better understand the possibilities provided by materials and manufacturing processes connected to the "soft" aspects of design.
- indicating modes of communication between designers and engineers so that the designers' access to reliable and effective information at an earlier stage of the design process can be ensured.

The approach of model building can be implemented in several products; yet, here the approach focuses on furniture products as the subject matter of this thesis.

6.2 Model building

This subchapter proposes an approach towards building a model supporting the design process which helps to enhance the capabilities of designers to make use of possibilities offered by new technologies. The following sections present the structure of the model and the requirements to put it into practice. This will be based on the results of the research presented and analyzed in the previous chapter 5.

6.2.1 Description of the frame structure of the model

Figure 40 presents an approach towards building a model which supports the design process. Above all, the model should contribute to the design process as its intention is to make use of the possibilities offered by new technologies. However, the structure of the model suggests that knowledge about technical possibilities of materials and manufacturing processes as well as the concept of the form are mutually indispensable conditions during the design process. The frame of the model is similar to the structure of a triangle. It is wide at the bottom and narrow at the top, which represents an increased complexity towards the goal state. The primary level of the model requires a basic knowledge and sources to acquire knowledge about new technologies. With a good basic knowledge the designers can not only propose an array of possible design solutions but they also have the opportunity to transform the knowledge from the "hard" state into the "soft" state, connected to the aspects of design. The intended concept of the form is situated at the top of the triangle. It should involve "soft" and immaterial attributes of design.

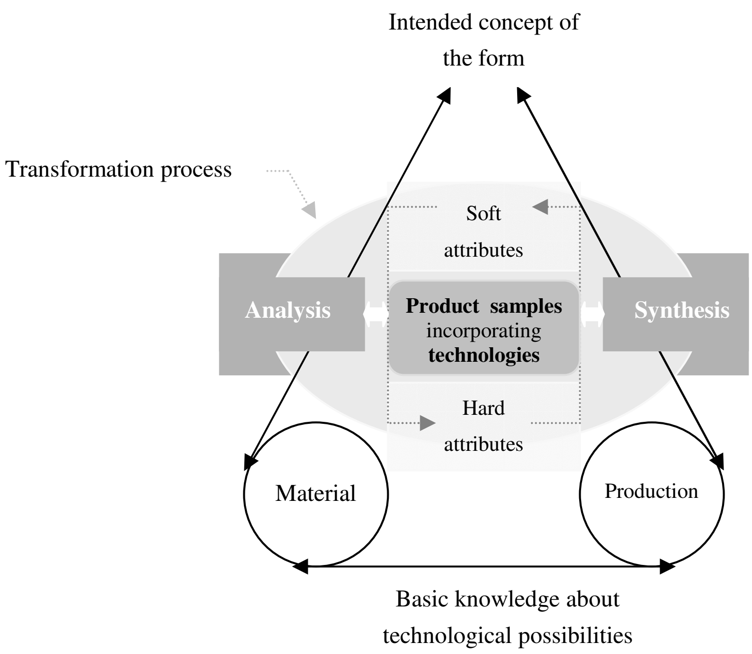


Figure 40. The framework of the model describes its main components and the process of transformation. The transformation is supposed to take place starting with the basic level including information about technological possibilities in the field of materials and production techniques so that "hard attributes" will be transformed into "soft attributes" that represent the level of the design goal.

A process of transformation is supposed to take place from one level to the other, from the initial state to the requirement-matching goal state. Related to the approach of the model, this process consists of two overlapping stages: One aims at exploring where the opportunities for design can be found with the help of technologies. This can be achieved by an analysis of the possibilities offered by these. Based on issues of analysis, designers can discover useful types of information related to design objectives in general. The other stage makes use of features of synthesis in order to combine certain types of information gained by analysis describing the soft attributes of a product. This will allow a potential solution to be synthesized, which is connected to design goals.

In these two stages, the process of transformation is based on an operation of "coupling"[28] between two types of information, hard and soft. The hard aspects of information are those that can be articulated and captured. These result from an interaction between the form of the product, the material, and the processes which help to describe a number of technical (hard) attributes like stiffness, density, lightness, etc. The soft aspects of information are those that can hardly be externalized. These include the perceivable properties of a product which result from a combination of the soft attributes associated with materials and processes such as the shape and the quality of the surface on one hand and the form elements included in the product on the other hand. Both hard and soft information interact to provide designers with elements that enable them to create the whole concept of the product. However, the whole process of the model is described in section 6.2.3.

In the centre of the model, there are existing product samples which are intended to communicate knowledge of new technologies effectively. The chosen samples should involve successful applications of new technologies resulting from materials and their production processes. As mentioned previously, good product samples can be used as a medium of transmitting knowledge which is intended to convey information about new technologies in a form that is acceptable and understandable to designers.

6.2.2 Fundamental requirements for the process of the model

As indicated in the description of the model structure, the process is based on the knowledge about technologies and also on samples of successful products

[28] "Coupling" is a common phenomenon in design. It can generally be defined as the conflicting interdependence of two or more functions which is based on the concept of transmission paths [Condoor and Burger; 1998, Heufler ,2004]. According to this theory, any design can be regarded as a system that interacts with its environment by means of inputs and outputs. The routes, through which the inputs are processed by the design to create the outputs, are called transmission paths. Therefore, the word "process" is used in the definition of transmission paths to include the meanings of transfer, transmit, transform.

whose form represents this knowledge. The general requirements which are essential for the application of the model are presented in the following.

A basis of knowledge can ensure that designers are chiefly able to realize the variety of available possibilities in which differences between characteristics of materials and technologies related to them are identified. For example, composite materials provide more possibilities and more special characteristics than homogeneous or traditional materials. Furthermore, the manufacturing methods and the techniques of both are totally different. Therefore, an adequate knowledge about scientific facts that result from technology is essential for model building. However, some basic knowledge and useful resources available at present are briefly presented in section 5.1. It summarizes knowledge about material properties and shaping methods. Referring to these two topics in relation to their application within the field of furniture design, this subchapter presents a simplified overview of these. Moreover, it guides designers towards obtaining in-depth information about new technologies by providing various sources related to new developments in this field.

Good product samples should be selected bearing in mind that they should involve innovative forms and shapes resulting directly from new material properties or new ways of shaping. In relation to this, Lenau [2001] points out that: "In order to get a good product the designer should not only select a suitable material but also think about the special properties of the material and of the possibilities that the manufacturing of it gives" [p. 3]. In the context of furniture, there are many works which show the designers' enthusiasm in using new possibilities offered by materials and manufacturing processes. For instance, products such as "La Chaise" chair by Charles & Ray Eames, the "Egg" chair by Arne Jacobsen, and the "Panton chair" by Verner Panton belong to the works of pioneers. Recently, products such as the "Air" chair by Jasper Marison, the "Soft Egg" armchair by Philippe Starck, and Ron Arad's designs have played a similar role in furniture design. However, it is important to mention that it is not intended to select or to consider certain samples; it is rather intended to use these samples for the exploration of different ways towards creating design solutions which result from new technologies. They can also be a valuable source of inspiration for the improvement of existing products by means of re-creation [Lenau, 2001].

6.2.3 Two transformation cycles within the stages of analysis and synthesis

Figure 41 presents and elaborates the process of the model. This process can be regarded as an instrument enhancing the designers at an early stage of design processes which are intended to make use of possibilities offered by technologies. Therefore, the objectives of this process can be:

- Providing the designers with a guide by which they can capture better insights into such possibilities. Then, they can become more aware of how they can create their concepts according to these possibilities early in the design process.
- Helping designers to open channels of communication with different participants in the design process, mainly referring to engineers.

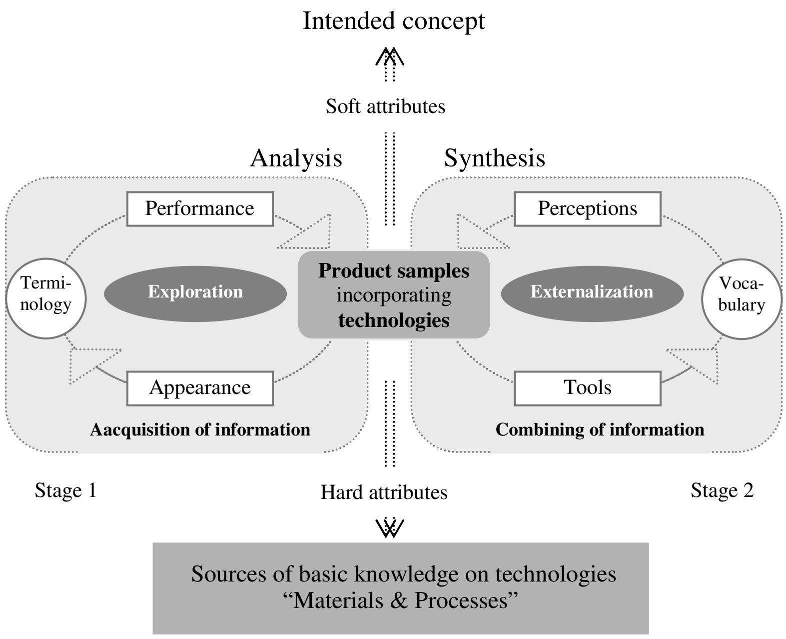


Figure 41. Scheme for the acquisition and the combination of effective types of information concerned with the possibilities offered by recent technical developments in the field of materials and manufacturing processes. The main goal of the model process is to support designers so that they can become more skilled in making use of these possibilities early in the design process. In general, the process is similar to the concept of left and right mode thinking which different fields of research in design refer to. It seems to be similar to the model for using and accumulating knowledge in general which has recently been presented by Owen [1998]. Yet, different terms have been used in the process model, referring to the specific context of this thesis

As mentioned in section 6.2.2, sources of knowledge basics of new technologies and also good product samples including specific properties related to materials and manufacturing techniques are essential for the process of this model. These will help designers to observe the impacts of materials and processes on the whole form of the product. Afterwards, they have to look at the actual details in sources of information on technologies. As illustrated in Figure 41, the product samples incorporating new technologies represent a kind of bridge, linking the process of exploration and externalization of information which can contribute to different aspects of design. This process can be performed in two types of transformation cycles proceeding parallel to the analysis and synthesis stages during the design process. The first cycle is based on analysis, aiming at the acquisition of a wide range of possibilities offered by technology regarding existing products. The other is based on synthesis features in order to enhance the designers' ability to externalize and describe links between certain information imparting soft aspects to the intended product form. These aspects refer to the emotional fulfillment and experience in the interaction with the products.

The operation of these two cycles within two essential stages of the design process, which is based on the outcome of the research and the discussions presented in chapter 4 and 5 of this thesis, can be elaborated as follows:

Cycle 1 within the stage of analysis

As mentioned in section 5.2.2.1 the information about new technologies related to materials and their shaping processes involves multiple dimensions. In this context, we explained four dimensions in relation to furniture products: engineering, use, the environment, and aesthetics. Based on the analytical procedure presented in section 5.2.2.2, two different types of information can be captured by observing how these dimensions are incorporated in the product samples and by refining the information related to them. One of these might point toward direct information related to the appearance of the product, the other might indicate indirect information related to the performance of the product. Both can explain the impacts of technologies on the product in general. Furthermore, during this process of exploration, certain terminology appears implying a specialized set of properties and shaping processes such as laminated, molded, extruded, reinforced, elastic, etc. Listing such terminology and linking it to the product attributes can enable designers to search for in-depth information regarding new potentials offered by technologies. Lists like these can also help to establish channels of communication with engineers early in the design process.

The complete analytical procedure is presented and discussed in section 5.2.2.2. Furthermore, section 5.3.2 presents ways that the terminology referring to materials and shaping processes can be used as a search facility for obtaining more information about new technologies. This section indicates how such terminology can help designers to find out how and with whom they should communicate.

Cycle 2 within the stage of synthesis

The second cycle begins with a combination of certain types of information gained by analysis aiming at perceptive properties. According to the approach of the model, the selected product samples can guide designers again. They give designers the opportunity to observe and interpret how specific types of information are matched in order to add soft attributes to the product. Information like this can be related to a specific material, process, user, context, or time of use. In section 5.2.3 three perceptive combinations are presented and displayed in order to lead designers toward imparting soft attributes onto the product through new technologies. They describe the mutual connections between possibilities offered by material properties and shaping processes as well as the form elements. The first combination aims at the visual elements of a product form. The second focuses on developing a tactile medium based on the material texture. The third uses processes of shaping to describe new qualities regarding the form structure. Each one combines certain characteristics of information which contribute to the way the perceptual character of a product can be described. These three combinations related to furniture products are shown in section 5.2.3.2 in a detailed way.

Afterwards, it is helpful to list vocabulary which describes the soft attributes associated with the selected product samples. This points towards the specific interplay between materials, shaping processes, the form, and other properties of the specific product. From lists including certain soft words related to specific products, designers can learn to express their "intentions"[29] implying the concept of design more clearly. Moreover, according to Lenau and Boelskifte [2003], lists involving semantic properties help designers to make the product more self-evident as well as giving the product a distinct character. An example of lists of vocabulary gathered from interviewed designers regarding furniture products is presented in section 5.3.2.

[29] According to Ashby and Johnson [2002], the word "intention" describes what the product is *meant* to be – the priorities in the mind of the designer [p.122].

Finally, the moment of using the tools not only to transform the initial and abstract ideas into concrete products, but also to visualize and evaluate them, has come. Tools such as sketches, drawings, models, etc. help designers to communicate with their own ideas and to share these ideas with other persons involved in the design process. Various tools for communication and sharing of ideas used during the design process are presented and discussed in section 5.3.3.

Designers should bear in mind that during those two cycles a connection between the selected samples and sources of information about new technologies should be made simultaneously.

6.3 Application of the methods involved in the model

The intention of this section is to illustrate how the methods involved in the model can be used to support the design process. These methods should help designers to incorporate effective types of information offered by technologies into their activities. As presented in the description of the process model in Figure 41, the first stage is to explore design opportunities resulting from technological possibilities. The purpose of the second stage is to combine these elements based on the relations found in the previous stage by means of externalization. These two stages propose feasible procedures to enhance designers' skills in considering interaction between design and technological aspects during the analysis and synthesis phases of design work.

In relation to the model building presented earlier in section 6.2 and the subject matter of this thesis, chairs are used as examples of furniture illustrating how two main procedures of the methods can be used related to the model approach. The chair has been chosen due to different perspectives including technical, functional, semantic, and aesthetic aspects, which are relevant in every application of materials and every technical innovation in the field of furniture to create modern products. According to Nelson [1953], all these aspects seem to be important while designing a chair.

As shown in Figure 42, four existing samples of chairs were selected to reveal information about new technologies. They cover a wide range of various possibilities offered by material properties and manufacturing processes.

The following discussion aims at illustrating the two procedures in order to summarize and join the potentials of interaction between design and technical aspects which can be used early in the design process.

(1) (2) (3) (4)

Figure 42. Four selected chairs, incorporating a successful interaction between design and technological aspects. According to the model approach, it is supposed that samples like these can communicate information about new technologies in an effective way that is understandable to designers. Chair (1) presents the latest development in thermoplastic "airmold" technology, by Bartoli Design. Chair (2) with a seat and back made from extruded aluminum sections. Chair (3) shows the possibility to draw the seemingly "undistortable" aluminum panels extremely far, designed by Christoph Boeniger. Chair (4) is made from a single piece of molded beech plywood, by Voxia.

6.3.1 Procedures in the analysis stage

After obtaining general background information about each of the samples above, sources of information about the materials and techniques applied should be gathered and then more detailed aspects should be recorded. Access to these is vital for the first definition of the basic information related to the technologies that were applied. Afterwards, the following procedures must be considered, in order to explore the relative interaction between materials, techniques, and the form concept.

Analytical procedures

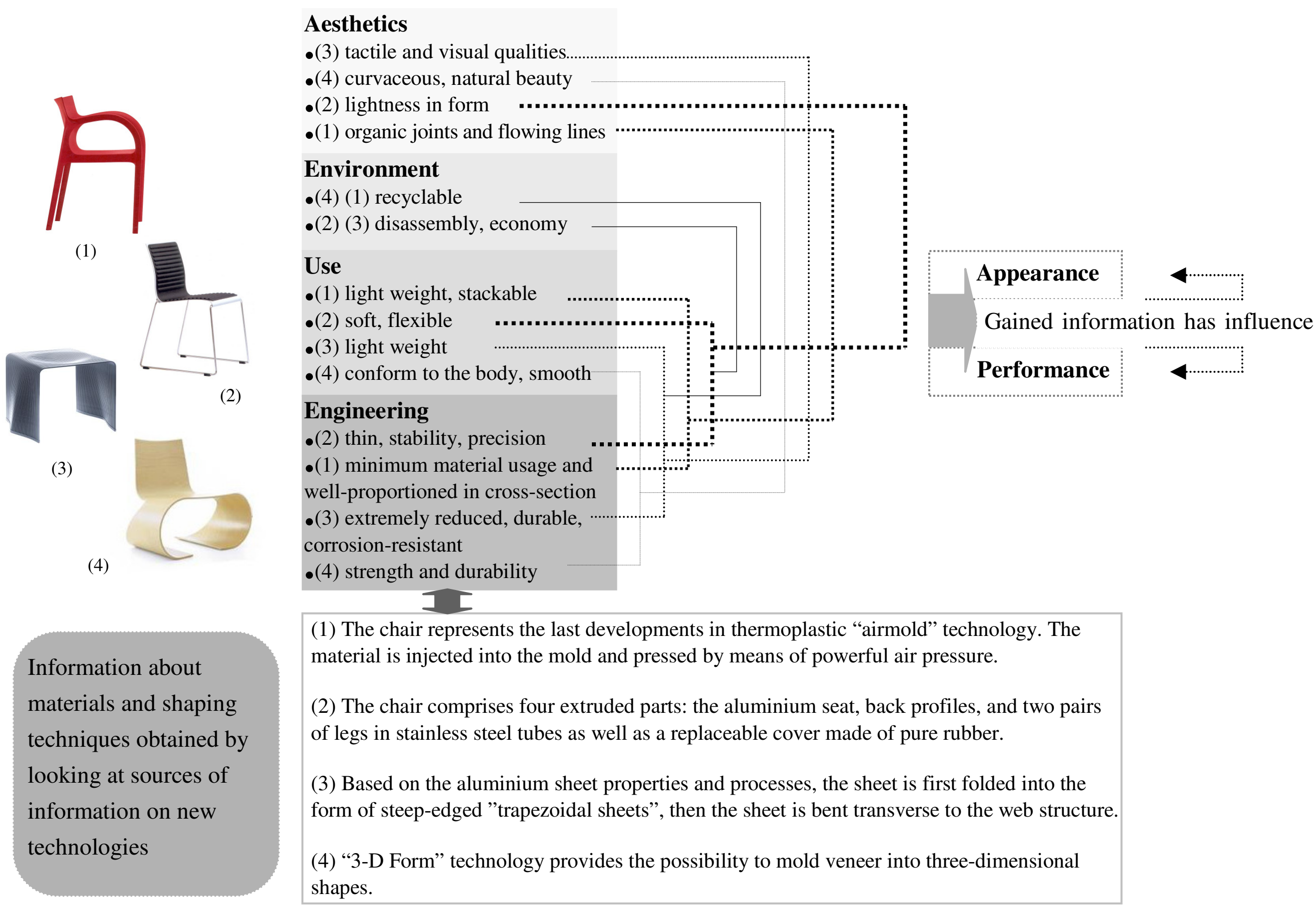
Based on the analytical procedures described in section 5.2.2.2, the multi-dimensional possibilities can be explored and refined. These include: the engineering dimension, the dimension of use, the environmental dimension, and aesthetical dimension. Figure 43 shows a way of examining the interaction between design and technological aspects related to the example above. Finding combinations between elements and details will lead towards gaining two types of information which can have an influence on the appearance and performance of the products. A complete description of the analytical procedure is presented in section 5.2.2.2.

Listing terminology

- During the analytical procedure, different terminology is used which points towards the potentials offered by new technologies incorporated in the selected samples. For instance, those technologies that were used in the chairs presented in Figure 42, can be described with the following terminology which relates to each of these chairs:

- Chair (1): airmolded; stiff; monoblock; injected; pressed
- Chair (2): extruded; bended; stabilized, roll forming
- Chair (3): folded; steep-edged "trapezoidal"; elasticity
- Chair (4): laminated; bonded; veneered; molded; layered

Figure 43. Reasoning scheme for the analytical procedure within the analysis stage of the process model, which is structured according to the four suggested samples form the furniture area.



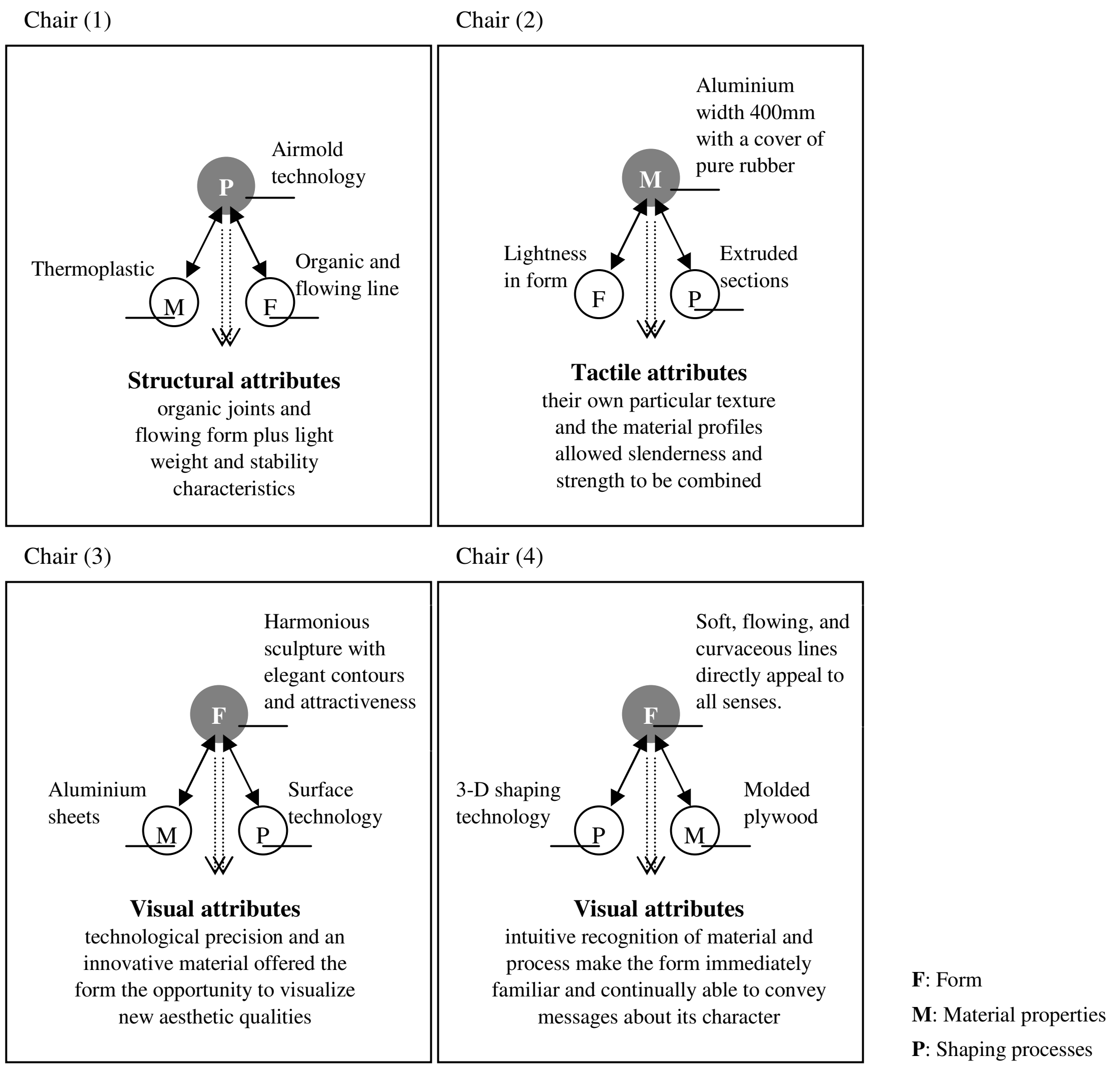
Listing terminologies like these has two benefits: On the one hand, they help designers to obtain in-depth information about new technologies if they follow the underlying intentions of each one. In other words, such lists can be used as a search facility. Additionally, awareness about and the use of these technological terms in interaction with engineers, can help designers to open channels of communication and to establish a better cooperation. More details about these benefits are presented in section 5.3.2.

6.3.2 Procedures in the synthesis stage

The methods applied in the synthesis stage aim at combining specific types of information identified early in the analysis stage, emphasizing the "soft" and immaterial aspects of design. This will guide designers towards describing and externalizing their concepts or ideas in the context of the 'form language' of design. Moreover, it is intended to indicate how the communication with engineers can be improved at this stage.

Perceptual combinations

In relation to the approach presented in section 5.2.3.1, some types of information offered by new technologies can contribute to adding values to products. These are based on creating mutual connections between certain types of attributes of materials and shaping techniques and the form elements. This approach can be applied to the selected chairs in Figure 42, as follows:



The suggested approaches for a combination of form, material, and process and how each one has an influence on the other are described in a detailed way in section 5.2.3.2.

Listing vocabulary

Based on the results presented in section 5.3.2, it was observed that designers use certain "words" to describe the specific interplay between form concepts, materials, and manufacturing processes. These words represent the accepted vocabulary used for a wide range of attributes associated with meanings, which help designers and other people outside the design area to recognize the intrinsic character of a piece of furniture.

Hence, it is recommended that listing vocabulary like this can assist designers to explain some form attributes which would otherwise be confused, ambiguous, and non-communicative. According to the model approach, designers can formulate lists of vocabulary which are concerned with semantic properties with the help of good furniture samples. Significant words and terms which can help to establish such lists related to the four selected chairs are illustrated in Figure 42,

Chair (1): elegant, fluent, organic, trendy, and strong

Chair (2): easy, minimal, formal, chic, slender, and youthful

Chair (3): opaque, lightweight, futuristic, sculptural, and remarkable

Chair (4): historical, smooth, natural, warm, curvaceous, and familiar

Two complete lists including "soft" vocabulary and "hard" terminology related to other examples from the furniture area are presented in section 5.3.2.

Tools

It is well known that each designer has his or her own tools for externalizing the transitory thoughts which they have in mind while creating a product and for transferring an idea to others. Tools like sketches, drawings, models, experimental works, etc., which are presented in a detailed way in section 5.3.3 enable designers to describe their concepts as well as to communicate with others, particularly with engineers during the design process. Therefore, using appropriate tools during the synthesis stage is one of the most important procedures which help to translate ideas or concepts into two- or three-dimensional forms.

The results of the interviews with designers revealed that some of these tools enhance designers to achieve a more controlled way of reflection while considering specific material properties or shaping methods, especially during the design of irregular forms. Moreover, they help designers to reflect on their own intention and enable them to communicate the details of the design to others – engineers or craftsmen – so that they know what they will have to do. Therefore, it is recommended that the suggested approach to build a model for supporting the design process must emphasize the improvement of the designers' skills to use tools like:

- Drawings which initially show how an idea or concept will be realized and which also depict how the proportion and the details of each element will interact on a visual level. Especially technical drawings enable designers to communicate ideas on paper and to explore these with a focus on their full potential concerning which types of materials are required and which methods of construction can be applied. Drawings include all the information about the material and how each part will be made as well as the impacts that these have on the final form of the product. Additionally, it is commonly believed that technical drawings help designers to evolve and to improve their focus on details of material properties and elements as well as to establish a common language in order to discus these with engineers.
- Extra skills to use CAD and CAM which give designers more freedom, enabling them to design products of better quality. These tools, for example, enable designers to create a rough, conceptual physical model which can quickly be refined and produced. Moreover, they simplify the production of objects encased in complex geometric structures and they are more flexible, so that they enhance designers in combining specific material properties and complex shaping techniques expressing forms both in terms of the interaction with the users and aesthetics.
- Experimental work with materials or new shaping techniques which leads designers towards discovering unpredictable solutions, as Mede[30] [2003] pointed out. It is a tool that is used to create pieces of furniture combining thought and practical work in one single process. In this process, as mentioned by expert designers, experience can be identified

[30] Picchi, f. [2003]: "Alberto Mede", Abitare Segesta, Milan.

> by focusing on the relationship between individual form elements regarding the structure, the material, and the function. Furthermore, experimental works can foster communication between design and engineering disciplines so that the chance of exploring all the different possibilities for creating an unusual shape is increased.

The four selected furniture samples presented in Figure 42 can guide designers towards studying the interaction of specific material properties or techniques and also towards thinking about solutions anew. These solutions will be recorded in technical sketches or drawings. Designers can also obtain a great deal of technical information involved in these samples by using computer software which can provide more rapid access to more information. Afterwards, the designers make use of the important factors – overall shapes, structural investigations, functional requirements, and basic manufacturing processes that may be used for new interpretations as well as for new experimental works.

To conclude, improving of the designers' skills to use tools like those mentioned above is vital in order to establish visual connections in the ingenious use of materials and the production systems which have an impact on the appearance of furniture designs. Additionally, visual techniques help designers to share their ideas with others effectively.

Various tools which are used by designers to communicate with their own ideas and to share their proposals with other persons involved in the design process are presented and discussed in a detailed way in section 5.3.3.

Chapter 7

Conclusion

7 Conclusion

After summarizing the content of the previous chapters, this conclusion aims at discussing the results of the research referring to the main questions that were formulated at the starting point of this research project. In addition to this, it gives an outlook on topics that might be addressed by further research.

7.1 Summary

The purpose of this thesis was to investigate the various opportunities for design arising from new technologies that provide new materials and shaping techniques, focusing on the furniture area. These specialized, complex possibilities originating from new techniques present new challenges for the design process. Therefore, the main goal was to explore the state-of-the-art in the field of technological possibilities which have an impact on different aspects of design. Another aim was to study the designers' points of view concerning the consideration of these new possibilities during their design processes. In the context of the emerging new technologies, it was also important to examine the nature of the cooperation between design and engineering disciplines in order to find out how better ways of communication can be established.

To prove the main assumptions of this thesis as presented in chapter 1, that new insights into technological possibilities can support designers at early stages of the design process and improve the cooperation with engineering disciplines, thus adding significant values to furniture products, two ways of achieving a better understanding were pursued:

- One way was to obtain insight into the world of technological possibilities by reviewing publications with the aim to study the state-of-the-art in this field.

- Another way was to identify the specific types of information resulting from technologies that designers intend to extract and by which they can also be stimulated.

This background knowledge led towards the following approaches:

- A development of an analytical procedure to explain and to refine the multiple dimensions of technological possibilities contributing to the different aspects of design,
- A display of perceptual combinations which emphasize the “soft” attributes of products resulting from the mutual interaction between the form elements and aspects offered by new materials and techniques,
- A description of new channels of communication that can diminish the different communicational gaps between design and engineering disciplines in order to improve the cooperation during the design process,
- A demonstration of the effectiveness of using these possibilities by developing a model with the help of which designers can become more skilled in incorporating new technologies into their design activities at an early stage of the design process.

7.2 Discussion of the results

Throughout the thesis, there is a permanent attention to the duality of possibilities offered by technologies on the one hand and of the different aspects of design on the other hand. The results of the research project provide evidence for the relevance of considering this duality as one of the most effective keys to expanding the insights into the design process. If this is the case, several challenges need to be addressed. First of all, sources of information about many areas of new technologies are relatively difficult to find, due to the fact that this information is often presented in a way deemed irrelevant or too complex and detailed by designers. Therefore, most existing publications fail to motivate designers to consider new design solutions resulting from technological innovation, especially in relation to new materials and shaping techniques. Secondly, the empirical studies reveal that most designers do not have any formal methods to explore this knowledge or to transfer it into their design activities. Additionally, there is an essential need for methods and procedures, which help to learn about new materials and shaping techniques as well as to incorporate these new possibilities into the design process. Yet, even more importantly, the results confirm that cooperation between designers and engineers is essential to describe the interplay between material attributes, shaping techniques, and form aspects effectively. The outcome of the studies also indicates that various barriers such as perceptual gaps, the use of different languages, and the lack of using similar tools to externalize the design proposals, all of which are based on the differences in knowledge and cultural background, hinder both of them from achieving effective contacts and communicative exchanges.

Thus, there is a great need for enhancing the design process in order to be able to face various challenges, due to the continuing technological progress. As a reaction to part of this need, the research presented in this thesis reflects the current situation in the knowledge about and the understanding of the impacts of technologies on furniture design, as the subject matter of this thesis.

The research project is characterized by an integrative approach. Different types of information are intermingled with the different perspectives of different persons, aiming at a holistic approach to the design process. A basic question was: Which types of knowledge about technologies can contribute to the different aspects of design? The question focuses on identifying relevant types of information and their potential contributions to the concepts included in the product form.

In order to study the state-of-the-art in the product design area on the one hand and the recent technological developments of materials and manufacturing processes on the other hand, a survey of publications in the two areas was carried out. It needs to be emphasized that the overlapping of technological and design aspects can be described in two different ways: The first way is concerned with the "soft" or abstract types of information connected to the underlying values and emotions. The second one refers to the "hard" or concrete types of information covering specific details which are related to technical subjects. Linking these two types of information with the existing examples of products enables the designer to look for and to select specific knowledge which can then be used to explain the interaction between these two aspects. Therefore, sources of information on new technologies, which might support designers in identifying new solutions or in being more aware of these possibilities or constraints, should not prove too complex or too detailed nor too abstract. Access to resources like these is increasingly important for the design process in order to make use of the opportunities offered by new technologies. Some of the sources of information on available technologies are proposed in section 5.1 even though some of these publications might sometimes seem to be too abstract and relatively complex.

The methods and procedures reviewed in chapter 5 are linked with the explorative approach to the design process in the course of which new types of information were found and investigated. This means that this approach puts emphasis on motivation, iterations, and procedures within the design activities in order to explain the different design opportunities provided by technologies. This approach led to the following conclusions:

- It has been argued that the idea generation phase of design can be enhanced by paying attention to certain material properties or shaping techniques. The approach behind this should for instance include inspiration and motivation. Another basic assumption consisted of the notion that imposing technological constraints on the intended concept should help designers to specify what the product might look like and how it might function. This means that designers are not obliged to consider a wide range of technical information. They should rather seek specific information to discover how the intended concept of design can take an initial shape during the first phase of the design process according to other types of pertinent information.

- One of the other initial hypotheses supposed that analysis methods, which help to make use of possibilities offered by technologies concerned with design goals, should be systematized. During the design process, it is sometimes necessary to conduct a certain procedure systematically, so that it leads towards defining and clarifying relationships between design and technological aspects contributing to the overall concept. In section 5.2.2.1 it has been argued that the exploration of the interaction between these two aspects offers multi-dimensional possibilities which can contribute to the design process. Based on an analytical procedure, these possibilities can be refined to explain two types of information: The first type is direct information which has an impact on the appearance of the product, while the second type is indirect information related to the performance of the product. Both share the same goal, yet each of them could have different effects on different types of intended goals of the design process.

- This thesis concludes with the notion that the underlying values, intentions, aesthetics, and perceptions of the product can be enhanced by providing designers with specific types of knowledge about present innovative technologies. Focusing on the combination of the elements and components that result from new materials and shaping techniques, in the course of which the detail is neglected, can lead towards imparting "soft" attributes onto the desired product form. This thesis stresses the idea that designers can describe perceptual product attributes by linking and combining the form elements with specific material properties on the one hand and the shaping techniques on the other hand, so that the concept of form determines the design process. Conclusions concerning the positive effects of such combinations and the display of mutual interaction between different aspects, as reviewed in section 5.2.3.2 support this view.

Another essential step in the research project was to investigate how new technologies offer opportunities to improve the cooperation between design and engineering disciplines during the design process. Different ideas have been proposed in this thesis that could help to overcome the barriers which arise in communication situations, such as perceptual gaps, using different languages, and a lack of tools to describe the interplay between material attributes, shaping techniques, and form aspects. These ideas are intended to promote a dialogue and to open new channels of communication between designers and engineers at an early stage of the design processes. Hence, the thesis concludes with the following suggestions:

- Designers should try to present their ideas in a way that engineers can understand and organize them based on a logical way of thinking.

- Designers should learn to use the basics of the engineers' language in order to be able to articulate their own intentions. Engineers use a different terminology to describe the impacts of technologies on the form. The use of such a terminology provides a more effective form of communication within a given technical discipline but it also creates a wall around that discipline, hindering the sharing of knowledge.

- Designers should develop skills for using new tools to externalize their design proposals. Tools such as technical drawings, 3D-CAD models and CAM should be taken into account from the very beginning, before the conditions change or problems arise either in further stages of the concept development or during the realisation of the final form. Moreover, considering some of the engineering rules during the externalization of the idea enables designers to use arguments that their colleagues can understand and accept.

As pointed out in previous sections of the thesis, to avoid a breakdown of communication in the cooperation with engineers, designers must prove their willingness to learn the underlying principles of technology and to develop the competence of using the appropriate terminology and tools.

Building a model to support the design process

In chapter 6 an approach to build a model supporting the design process has been proposed and discussed. The model describes a general process with the help of which designers can become more skilled in making use of the possibilities offered by new technologies at early stages of their activities. It integrates different procedures and methods reviewed and presented in chapter 5 of this thesis.

The main objective of the model is to provide a suitable instrument for enhancing the designers' ways of thinking so that they are able to incorporate effective types of information offered by technologies into their design processes. The model structure is based on sources of technological information on new materials and production processes and also on samples of successful products which represent this information in their form. Based on two transformation cycles within the stages of analysis and synthesis, which both proceed simultaneously, designers are intended to explore what they need to extract. Within the analysis cycle, they can arrive at a better understanding of how design and technical aspects overlap. Within the synthesis cycle, they should learn how these two aspects can be combined to identify perceptual attributes in their own products as well as to find out how such attributes can be expressed verbally. Finally, designers can look for the adequate tools to externalize their proposals. Consequently, with the help of the model approach, specific types of information can be filtered and transformed, emphasizing the "soft" and immaterial aspects of design.

The approach of the model is intended to filter specific types of information implied by two disciplines to make them understandable for designers, while it might also appeal to engineers. For instance, the first stage of the model process should support the designers in obtaining information by undergoing logical procedures and also by reflecting on terminology. The other stage aims at describing and externalizing this information in various forms or with different tools, such as in a verbal way, in sketches, technical drawings, models, etc. The function of this approach is to promote the dialogue between design and engineering disciplines.

Section 6.3 refers to the idea that the model components and stages could help designers to handle new possibilities offered by technologies and not to be dominated by any technology, if they apply the procedures and methods involved in the model.

Evaluation of the results concerning the research questions

In chapter 1 four different research questions have been presented. The first two questions that were posed are related to the state-of-the-art and the existing knowledge about the field of technologies with a focus on new materials and shaping techniques and how these are used when putting design into practice. This issue is discussed in the following.

Question 1. What different kinds of information offered by new technologies need to be taken into account, and which types of information can contribute to creating good or new products?

Recent publications revealing the state-of-the-art in the field of new technologies have been reviewed in order to explore specific types of information which relate to the different aspects of design. This is aimed at attempting to fill the designers' lack of information concerning technological aspects by focusing on new developments of materials and production techniques as well as the various sources available at present. As mentioned previously, most existing publications on new technologies are presented in a way that is either too scientific and too detailed, or they use a language that is too abstract. Therefore, in order to obtain a better insight into the field of possibilities made available by technical innovation, it was required to combine these two types of sources and to link the obtained information with certain examples from the area of product design. Additionally, some results of the empirical studies carried out with a number of expert designers helped to focus on specific technological information which can contribute to the different aspects of design. This broadened understanding helped to give new input which can be used at early stages of the design process.

Question 2. How can successful communication be established particularly with engineers at an early stage of the design process?

This question has been addressed during the in-depths interviews and action research which was carried out in different design offices and furniture companies. As mentioned in section 5.3, when designers and engineers introduce new materials or shaping techniques which shall be considered in the design process, a series of problems arises due to difficulties of communication. The problems might for instance consist of perceptual gaps between the two disciplines, the use of different languages, or a lack of similar tools to describe the interplay between material attributes, shaping techniques, and aspects of form. These barriers derive from different knowledge, different ways of thinking, and the different cultural backgrounds, hindering them from achieving successful communication and sharing their knowledge. The studies also revealed that successful communication with engineering disciplines requires learning something about their ways of thinking, awareness of their terminology, and finding common tools during the design process.

The second set of research questions posed in chapter 1 is related to the development of procedures and methods which can support the design process in order to achieve a better understanding of new possibilities offered by technologies. Thus, the work of designers could be enhanced if they became more skilled in using these possibilities at an early stage of the design process.

Question 3. How can the design process make use of possibilities offered by technologies as early and as effectively as possible?

In chapter 5 different procedures and methods that are intended to support the early stages of the design process have been proposed and reviewed. As described in chapter 1, the intention of this thesis was to focus on the conceptual phase of the design process due to its importance and its impact on the subsequent stages of the design process. Therefore, the main principle of the intended approaches to supporting designers in this early stage of their activities should be to motivate and to convince them of the need to follow the changes in the field of technology. In this way, their creativity can become visible in the ingenious use of new materials and the application of the constantly changing systems of production.

Question 4. What is the nature of methods or models that may be used to support the design process, incorporating new knowledge about new technologies into the design process at an earlier stage?

The nature of methods and procedures proposed in this thesis is determined by the theories and concepts referring to the "process" of design which have been reviewed in chapter 3, and by the need for methods which the outcome of the empirical studies revealed. The most important characteristic of the proposed procedures and methods can be identified via an "explanation-based process" in which designers attempt to exploit possibilities offered by new technologies and then incorporate these into their design activities to recreate forms or concepts.

Based on several procedures and methods presented and discussed in chapter 5, such as the analytical procedure, the methods of combination, the procedure to shrink the perceptual gap, the listings of terminology and vocabulary as well as the use of various tools to externalize the ideas, an approach to build a model which integrates all these procedures and methods supporting the design process is suggested in chapter 6. The main characteristic of the model is to function as a suitable interpretive instrument by which designers can be enhanced so that they will be able to transform the "hard" attributes of technological information into the "soft" attributes linked with the aspects or goals of design.

The framework of the model structure and an illustration of the model process are visualized in Figures 40 and 41.

The conclusions above reveal that the research questions have been studied and satisfactorily answered.

7.3 Outlook

The intention of this research project is to show how much a good technological approach can enhance the design process. Nonetheless, the outcome of the research does not rely on technology to define methods for designing, but rather on the use of its possibilities to achieve different design goals and to teach designers how they can put their ideas into practice. Based on this perspective and the other approaches presented in this thesis, the research project has elicited a number of topics that need to be investigated. The following possible research projects can be identified:

- **A big challenge for design education**. New materials with improved properties and new innovative shaping techniques will continue to cause startling changes in our lives, and design will become one of the key professions to translate these changes and advances into new products. Hence, fundamental changes must take place in design education to take advantage of the new opportunities offered by these developments.

- **New channels of communication.** The field of technological possibilities is a complex system because it changes fast and is based on individual exploration. In this new atmosphere, more studies on opening new channels of successful communication are constantly needed.

- **Methods for enhancing the transformation skills.** The most important ability of designers is that they can transform the “hard” attributes of technological information into new ways of addressing the “soft” and immaterial aspects of design. Suitable methods of enhancing designers in identifying and defining such ways, represents an area worth studying.

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