CREATIVE COMPUTER AIDED ARCHITECTURAL DESIGN

An internal approach to the design process

HARRI HAAPASALO

Department of Industrial Engineering

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To the memory of my father

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Abstract

This survey can be seen as quite multidisciplinary research. The basis for this study has been inapplicability of different CAD user interfaces in architectural design. The objective of this research is to improve architectural design from the creative problem-solving viewpoint, where the main goal is to intensify architectural design by using information technology. The research is linked to theory of methods, where an internal approach to design process means studying the actions and thinking of architects in the design process. The research approach has been inspired by hermeneutics.

The human thinking process is divided into subconscious and conscious thinking. The subconscious plays a crucial role in creative work. The opposite of creative work is systematic work, which attempts to find solutions by means of logical inference. Both creative and systematic problem solving have had periods of predominance in the history of Finnish architecture. The perceptions in the present study indicate that neither method alone can produce optimal results. Logic is one of the tools of creativity, since the analysis and implementation of creative solutions require logical thinking. The creative process cannot be controlled directly, but by creating favourable work conditions for creativity, it can be enhanced.

Present user interfaces can make draughting and the creation of alternatives quicker and more effective in the final stages of designing. Only two thirds of the architects use computers in working design, even the CAD system is being acquired in greater number of offices. User interfaces are at present inflexible in sketching. Draughting and sketching are the basic methods of creative work for architects. When working with the mouse, keyboard and screen the natural communication channel is impaired, since there is only a weak connection between the hand and the line being drawn on the screen. There is no direct correspondence between hand movements and the lines that appear on the screen, and the important items cannot be emphasized by, for example, pressing the pencil more heavily than normally. In traditional sketching the pen is a natural extension of the hand, as sketching can sometimes be controlled entirely by the unconscious. Conscious efforts in using the computer shift the attention away from the actual design process. However, some architects have reached a sufficiently high level of skill in the use of computer applications in order to be able to use them effectively in designing without any harmful effect on the creative process.

There are several possibilities in developing CAD systems aimed at architectural design, but the practical creative design process has developed during a long period of time, in which case changing it in a short period of time would be very difficult. Although CAD has had, and will have, some evolutionary influences on the design process of architects as an entity, the future CAD user interface should adopt its features from the architect's practical and creative design process, and not vice versa.

Keywords: creativity, systematicism, CAD, sketching

Preface

This study was carried out at the Department of Industrial Engineering at the University of Oulu. However, the design studios throughout the Finland are the places where this research has had its most critical discussions.

I wish to express my greatest gratitude to the supervisor of my work: Professor Pekka Kess. He has encouraged and guided this work with great expertise during its different phases. Special thanks are further due to Professor Jorma Tuomaala and Professor Jouni Koiso-Kanttila for their great assistance with specialist knowledge during the research project. The manuscript was reviewed by Professor Örjan Wikforss and Docent Tapani Savolainen. Their valuable comments and critique are gratefully acknowledged.

I thank all the personnel at the Department of Industrial Engineering for creating a favourable atmosphere for doing the research, especially mentioning Mr Marko Paananen who helped with the technical issues. Thanks are due to Mr James Nimmo for revising the language of this thesis.

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One of the greatest thanks is due to the profession of designers. This preface is too short in order to mention and thank all the architects separately who have introduced their special knowledge, without those enthusiastic discussions this research could not have been fulfilled. Also the resources provided by the mechanical engineering designers and industrial designers interviewed are also gratefully acknowledged.

I want to express my gratitude to my family and friends for their support. Also the ever-present Mr Murphy deserves acknowledgements. Finally, and most importantly, I wish to thank my lovely wife, Minna, for her support and our daughter, Henriikka, for giving me relieving moments from the work.

Oulu, August 2000 Harri Haapasalo

Abbreviations and description of key concepts

Abbreviations

2D	Two-dimensional model/modeling
3D	Three-dimensional model/modeling
6B	Thick and soft pencil
6M	Cause and effect diagram including six M’s, which are Material, Milieu, Machinery, Man, Method and Money
ANN	Artificial Neural Networks
ARK95	The scope of work in architectural design instructions in Finland
BMP	Building Product Model
BUI	Body User Interface
CAAD	Computer Aided Architectural Design
CIC	Computer Integrated Construction
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CUI	Character User Interface
DFA	Design For Assembly
DXF	Data Exchange File
EDP	Electronic Data Processing
EXPRESS	Information Modeling Language
GDL	Geometric Definition Language
GUI	Graphical User Interface
IDEGEN++	A software supporting creative thinking
IGES	Initial Graphics Exchange Specification
IPS	Information Processing System
KRISYS	Knowledge base management system
L1	Phase of first sketches in the scope of work in architectural design instructions in Finland

L2	Phase of second sketches in the scope of work in architectural design instructions in Finland
QFD	Quality Function Deployment
RYL90	General quality requirements in construction in Finland
STEP	Standard for the Exchange of Product Model Data
TOTE	Test-Operate-Test-Exit operations in design process
TQM	Total Quality Management
UI	User Interface

Description of key concepts

Creativity	It is the ability to produce new ideas and solutions, which are novel to the author. It is a normal activity of the brain and the whole human body. It is also a primary quality of every human being. Creativity presents itself on many levels, it can be an over-all holistic idea or a sudden perception on the detail level.
Systematicism	It is based on logical reasoning. Systematic design pursues the development of methods, procedures and means to design, select and outline problems. The design process is changing the defined problem to a description of a technical system. It concludes with a certain structure and hierarchy where components and problems are solved.
Design	Design is a wide concept and it can contain the appearance of the object, but also the action of designing the object. Designing consists of existing information, abilities, experiences and future actions of humans in. It is integrating knowledge and action. Information and its processing is the main problem in design. However it has been proposed that design, as a complex entity, should not even be tried to be determined in detail, because the search for a definition is much more important than finding it.
Architectural design	The purpose is to produce, from given objectives, an architectonic final solution, where functional, economic and artistic features are in balance. The finished building has to play a harmonious and enriching role in the infrastructure. From the construction process point of view the essential in design is to produce documents in order to construct the building.
CAD	The definition of CAD, computer aided design, means designing with the aid of a computer. Therefore definition contains only the means to design and process images, not all possible tools that information technology allows. E.g. traditional CAD applications and 3D modelling are used for varying purposes, not to mention other forms or possibilities of information technology.

Contents

1. Introduction

1.1. Information technology in construction and design process

The use of information technology (IT) in industry has increased a lot in recent decades. Computer aided manufacturing (CAM) and computer integrated manufacturing (CIM) have been used as a concepts in automating processes and tasks (Krajewski & Rizman 1999). In the construction industry, this term has been designated as computer integrated construction (CIC). Typical for CIC is the use of computing and all kind of applications and data transfer via a network during the construction process. In research, CIC is seen as one of the few means in the construction industry through which productivity and the quality of the final product could be increased. Construction as an information intensive and complex industry should have many preconditions in computer aided tasks, but so far, it has not been a tremendous success in the practical construction process (e.g. Björk 1995).

In CIC research the utilization of information technology is considered with intra-industrial participants (Fig. 1). Construction as a complex process and building as a large and unique product forms in total an elusive research paradigm and the computer aid even increases it. This study is a part of the research linked to the automation in construction (CIC) and more precisely concentrated on the early phases of a construction project, on the entity of architectural design. In the context of CAM and CIM, design is generally noted as computer aided design (CAD), but when focusing on CIC, computer aided architectural design is specified as CAAD. However, CAD is generally used as abbreviation also in architecture.

Usually when examining architectural design the issue has been trends or the features of the object or styles of design. This study does not concentrate on the architecture itself, but it is aimed at the design process. Architectural design has often been compared to free art. The most well known architects have had the ability to work without scientific theory just relying on their ability to create intuitively. So, is the theory of design needed? Yes it is. The need for the theory arises from the development of design and design methods. Correspondingly this is a consequence of the development and change in construction technology, the needs of interest groups in design and especially the effects of IT.

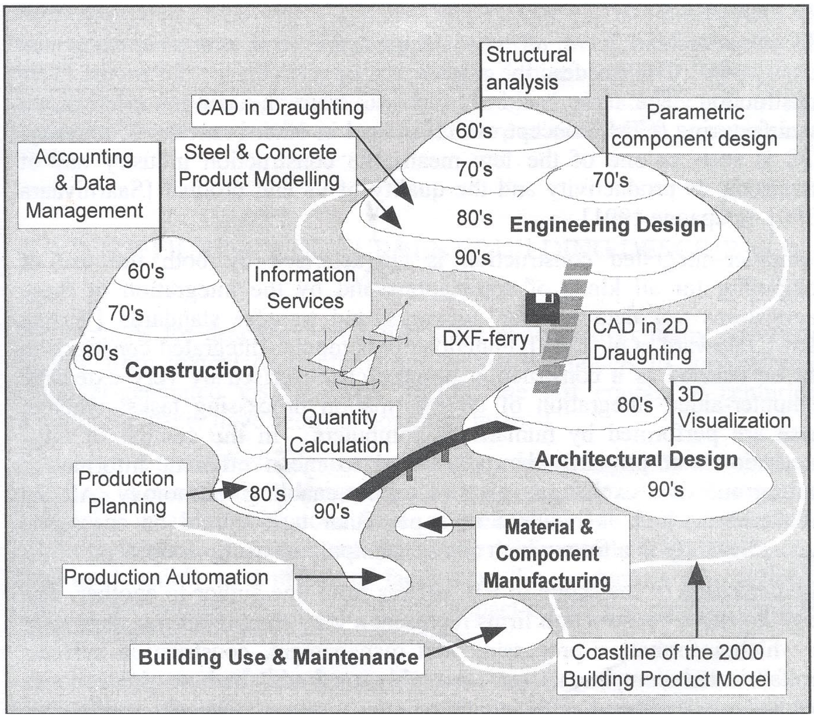


Fig. 1. The islands of automation are used to describe the distribution and proliferation of information technology use in the construction project (Björk 1995).

From the construction process point of view the essential in design is to produce documents in order to construct the building. Architects have a central role in the construction process both directly and indirectly. As a main designer, they are responsible for the design management in the whole project (Fig. 2). (Cross 1994). The purpose of architectural design is to produce, from given objectives, an architectonic final solution, where functional, economic and artistic features are in balance. The finished building has to play a harmonious and enriching role in the infrastructure. (Christopher 1974, Klercker 1996).

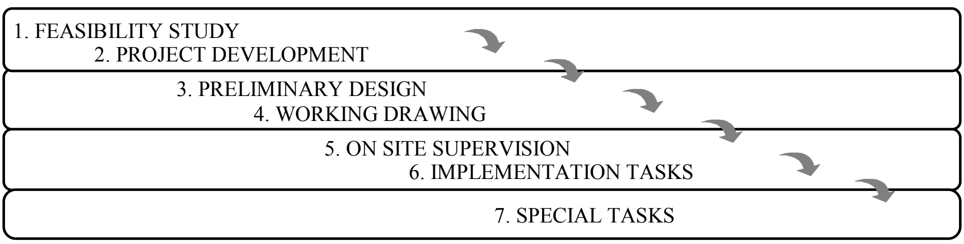


Fig. 2. The scope of work in architectural design. It is a task list of stages of operation in ARK95 and not a process specification. (National regulations and instructions in Finland RT 10-10387 1989, RT 10-10577 1995).

The most significant features of building are already determined and costs are fixed in the first sketches of architects (Fig. 3), but only a small part of total costs is used in design (Cross 1994, Ullman 1992). Therefore architectural design is a critical phase in the whole lifecycle of a building. Then inadequate and poor solutions or features in design may cause unnecessary cost during the life cycle.

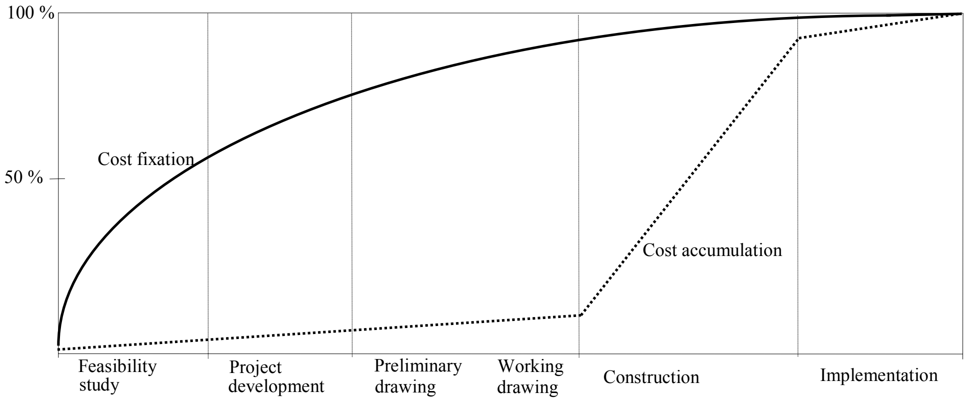


Fig. 3. The fixation and accumulation of costs during the construction project (Perttilä & Sätilä 1992, Ullman 1992).

The amount of information technology has increased in architectural design. Development has been fast, when comparing it to the research in design methods. Usually information technology has had a strong emphasis in it. (Gero and Mahler 1997). Mitchell (1977) taught already at the end of the seventies that "during the 1980's everyday use of computer aided design techniques will radically transform the practice of architecture", but the reality has been different to that expected. There are a lot of different drawing and design applications on offer, but these programs haven't been applied to traditional sketching and so there are inconsistent opinions (Achten 1996). The main problem is in the user interface, but the abilities of designers vary too. Rigidities and inconveniences in applications have caused negative attitudes towards information technology. (Heikkonen *et al.* 1995, Kiviniemi & Penttilä 1995, Negroponte 1995).

The stress from the environment has influenced the use of information technology in architectural design, because e.g. in some projects CAD documents are unconditionally required. Correspondingly, constant change in design, construction process and in business environment and the general rationalization of operations sets a lot of requirements and challenges for architectural design. Architectural offices have experienced large changes in the economic and operational respect in the recent decade. On the other hand customers for architectural design may expect some changes in the output of the design process due to CAD (Klercker 1996). In particular, the collapse of fees in Finland has set several requirements for more effective operations and the quality of design and product. Constant pursue of effectiveness contains some risk factors, because the early phases of design are the most essential and critical and the time reduction is usually aimed at these phases. (Damansio 1994, Pallasmaa 1993). From design, construction, facility management and from the environment point of views it is essential to intensify design so that these sensitive phases can be processed optimally and the changes are directed to the routine phases of design.

Computerized working has partially intensified, facilitated design data management and made finished documents more uniform. However, the field of architects has divided into two separate parts: some are in favour of and some against information technology. Some of the advocates attempt to apply computers in all possible phases except the rough sketching and the rest apply it in the final phase. However, a number of architects rely on pencil and paper. (Kiviniemi & Penttilä 1995, Scianna 1996).

In CAD, the computer takes the place of pencil, paper and drawing board, but these programs don't perform anything by themselves and still the most valuable unit in design is the designer himself. (Kiviniemi 1991). However, information technology is the greatest change in architects' work during the last centuries (Davies *et al.* 1991). Therefore, according to Schmitt (1988), the understanding of the most profound essence of architectural design is the basis for developing methods and applications. Although the media may have changed, the work itself is the same. Therefore in developing CAD the core – the creative design has to be profoundly understood.

Architectural design is creative work, but on the other hand, it processes technical entities and therefore the elements are various and may even be inconsistent. The history of design knows both creative and rational periods of ascendancy in design and developing it. The era of rationalism has pursued the end to develop methods based on logic and systematics. In contrast, the periods of creativity have relied on the ability of the creative designer also in larger tasks. (Lehti & Ristola 1990, Quantrill 1995). Creativity is seen as an irrational and inconsistent process, which is not well known or well defined. Generally, creativity is seen as a mysterious and special talent of a few people. (Pallasmaa 1993).

1.2. Research traditions of design discipline

Theories or disciplines in architectural design research can be divided according to Lehti and Ristola (1990) into two main segments: theory of methods and theory of contents. The theory of methods in architectural design illustrates the work of the architect or design process. It contains questions and problems from designing, environment and action of the designer. In architectural design information and controlled action are processed or more accurately connect knowledge and activity together. One way or the other all theories of design process this connection. (Cross 1994, Freidmann & Hudson 1974). In the theory of methods at least four research traditions can be distinguished, according to Lehti and Ristola (1990): the tradition of philosophical synthesis, the tradition of rationalism, the tradition of organization development and the tradition of empirism. These traditions follow somewhat the same line as presented in the development of ideologies in architectural design (chapter 2.2.2.).

The philosophical synthesis contains research outside other main traditions. Their influence has never the less been significant to development of design. It is typical of this research tradition that scientists have sought an integrated view of design and therefore end up in multidisciplinary research. (Freidmann & Hudson 1974). Afterwards modern western philosophy has included a hermeneutic approach, which can be seen as rehumanism, into these discussions (Lehti & Ristola 1990).

The tradition of rationalism studies the rationality of decision-making. In design rationality means that problems are well defined, logical and rational problem-solving methods are sought and the "best possible" solution is achieved. (Freidmann & Hudson 1974, Lehti & Ristola 1990). Mcloughlin (1969) tried to create the theory of system design, to which Chadwick (1978) added information technology and Faludi (1973) added a self-controlling system based on cybernetics.

The tradition of organization development concentrates on examining the means to attain desired changes in the structure and behaviour of an organization. In contrast to the tradition of rationalism, developing organizations is experiential, and developing relevant theory is more experimental learning than logical inference. (Freidmann & Hudson 1974). It is ideologically closely related to rehumanism and it can be seen as an empiric tradition (Lehti & Ristola 1990).

The school of tradition of empirism is divided into research on national and urban planning. In addition to the previous traditions a fifth viewpoint, rehumanism, can be found. It could also be included in several research traditions. Secondly, the literature of the last two decades contains mixed features of several traditions. (Lehti & Ristola 1990). There could be even additional research tradition, which is concentrated on research of creative human action (Häyrynen 1992). Therefore it could be said that there is no distinct classification into research for the design process.

The theory of contents explains the structure and operation of the building or the object to be designed (Lehti & Ristola 1990). It also contains the research of architecture - the research of how buildings are connected to the infrastructure and how individuals can experience those structures. It can be more precisely seen as research of styles on the theories of architecture (Routio 1983), but not theories of the design process. This has been the usual approach in the research history of architectural design, because the design process has been seen to be too deep or impossible to understand (Christopher 1974). Routio (1983) has classified architectural research as follows: technical - economic approach, functional approach, healthful approach, psychological approach, architecture research as communication, social approach, art history approach and so on. Other classifications can easily be made according to the trends of architecture e.g. functionalism, modernism and so on. The main point in the theory of contents is that design methods are intentionally left for lesser attention.

This research is part of the theories of methods. It is linked to the tradition of philosophical synthesis as multidisciplinary research, but it also contains features of rehumanism. Furthermore it clearly concentrates on the creativity research. The diffused theoretical field emphasizes even more the need for research of methods and theory especially in CAD.

1.3. Research strategy

1.3.1. Research problem

The basis of this study is to explain how architectural design can be intensified by using information technology and how this would be possible in practice. This standpoint connected to the background establishes a difficult and extremely complex problem, which cannot be solved with a simple model. Therefore the mode and existence of the research entity has to be first outlined and after that explained from smaller entities.

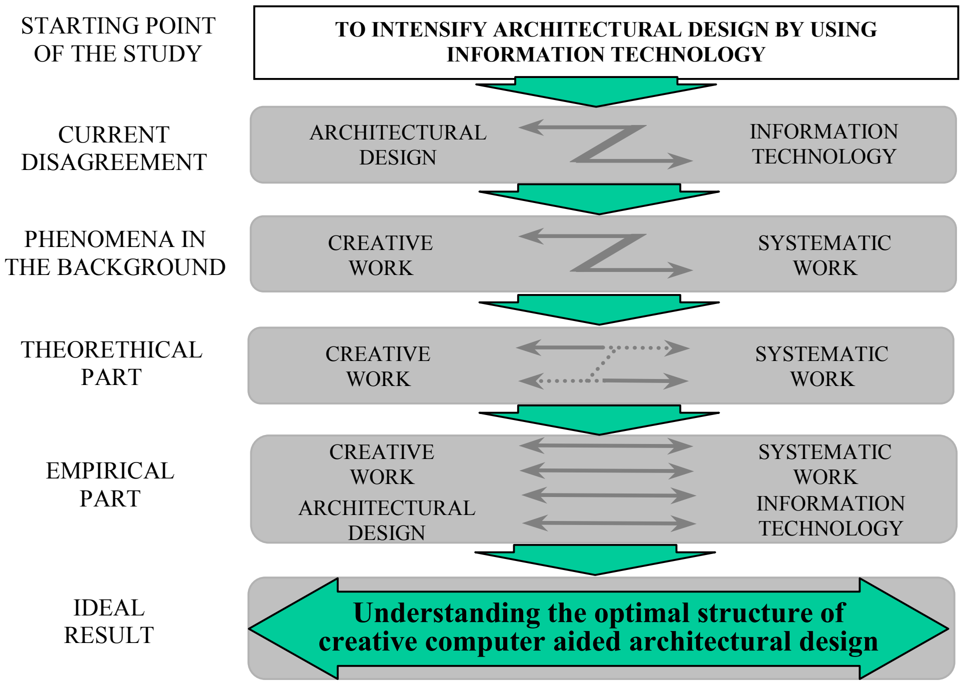


Fig. 4. Research positioning, phenomena in the background, the whole research problem and the progression of the study.

In order to outline the research problem considerable familiarity is required on the general level from architectural design, construction, building utilization and information technology. From the research point of view this starting point is linked to several sub-disciplines as presented in figure 4. During the practical and theoretical research of these disciplines a clear picture was formed from the principled discrepancy in the architectural design, which actually sets the outline for the theory needed. In the early phases architectural design is mainly creative problem-solving, where a universal architectonic solution is achieved. Especially in the early phases designing can be seen to be closely related to free art. (Aalto 1948, Damansio 1994, Pallasmaa 1993). In contrast computer aided design is dependent on the commands fed into the system, which are based on the logic in the system. These commands require a rational environment and systematic method in order to operate effectively. (Cha & Yokoyama 1995, Paulson 1995, Van Dijk 1995). Because of this antithesis the original research problem has to be extended in order to cover creative and systematic working methods and the possibilities to combine these. Without a comprehensive understanding of the creative architectural design and on the other hand the possibilities and constraints of the computer user interface, a optimal user interface cannot be developed in the creative computer aided architectural design (Gero & Mahler 1997, Gero & Yan 1993, Jun & Gero 1997, Maher *et al.* 1995). This antithesis doesn't have an unambiguous methodological solution and therefore the problem has to be approached from several points of views. This in contrast raises the need for several different tests in this research (Räsänen 1993).

Setting the research questions and reasons for research methods can be found from the original research problem; so far the applicability of computers has not been very good. This problem is very difficult to solve in any other way than to approach the practical architectural design in a natural environment. Understanding the activities and operations in architectural design and background for these sets the base for the creative process and possibilities to utilize information technology. Therefore the theoretical framework arises from developing creative design theory and verifying it empirically.

1.3.2. Objectives and research questions

The objective of this research is to improve architectural design from the creative problem-solving viewpoint. The main goal is to intensify architectural design by using information technology. This has been divided into two partial objectives, where focused and individualized research questions are:

- what is the applicability of computer aided design systems to architectural design and
- what are the most significant features of creative architectural design to be considered in developing computer user interfaces?

These objectives were the original goals at the beginning of the research, but the formulation has been a bit different. They have focused and matured during the research and the answers have been given at the end of this thesis. For the applied research approach in this study it is typical that research questions will focus and evolve during the research (Moilanen 1998).

This research does not contain an actual research hypothesis, because the problem in the hypothetic –deductive approach is the absolute verification of qualitative results. Furthermore the interpretative approach emphasizes the uniqueness and multidisciplinary nature of anthropology. The theory of creative design, constructed in chapter 3, has been verified with several surveys. The purpose has not been testing the hypothesis, but to explain the creative process and the establishment of new knowledge and understanding of the creative process. The theory concluded deductively has been verified inductively though empiric material and thereby the total balance has been achieved.

1.3.3. Research approach

The general concepts of science can be divided into positivism and hermeneutics. Positivism leans on pure experienced facts and discussed conclusions are rejected, because they are not perceived. Hermeneutics is seen as a science of interpretation, which is a philosophical tendency underlining concepts such as interpretation, meaning, historical and understanding. (Olkkonen 1993). Information technology and pure systematicism are closely related to physical science and therefore positivism. In this research the architectural design process, the phenomena in the background, connections to information technology and especially the integration of these is considered or in other words, human action in some certain operational environment is examined. (Miles & Huberman 1994). Former guides this research under hermeneutics.

Inside hermeneutics there are several classifications containing several different trends, which in contrast contain different definitions. Several scientists have tried to define hermeneutics, some succeeding better than others. It is, however, much more important to search for the content than find the final definition, as Lawson (1990) defines the entity in design. Therefore it is more relevant to concentrate on assumptions that are fundamental and related to this research (see also Kusch 1986). Koski (1995) classifies the entity of hermeneutics in conservative, Gadamer's (moderate hermeneutics), critical and radical hermeneutics. The hermeneutic approach named after Gadamer is close to this research. It doesn't offer any unambiguous methodological instructions for research. It doesn't pursue absolute objective knowledge through methods, because the interpreter and the object to be interpreted are somehow related to each other. (Koski 1995). Then a different pre-understanding may also lead to a different final result. (Moilanen 1998). In a certain sense Gadamer's hermeneutics contain an optimistic idea of the possibilities in interpretation, because initially there is always the element of producing new knowledge. (Koski 1995).

In the traditional analytic philosophy of science the interpretation of human action has had causal, agency and hermeneutic theory (Moilanen 1998, Stoutland 1989, Tuomela 1979). According to causal theories identifying intentions and beliefs means explaining the origin of action, because these intentions and beliefs are reasons for action. This differs the physical movement from action. Action is caused causally by intentions and beliefs unlike simple physical movements. In agency theory the reason for actions isn't a mental model or state, but the actor itself. The internal intention is not construed as a mental occasion, but the direction of action. Agency theory emphasizes the aims of the actor and these aims differ results of action from consequences. The action is directed to results, and not to consequences.

According to the hermeneutic approach causality of actions hasn't validity in the analysis of intentional action. Action means that people aim at something and mean something with these actions. Another significant feature is the emphasis of understanding, when the reasons for action are not the issue, but the understanding of action. Human action can be understood with meanings, rules, norms and social practices. (Miles & Huberman 1994, Stoutland 1989, Tuomela 1979). In this research the aim is to enhance understanding or to explain human action (creative architectural design) through hermeneutic theory.

Because of the multidisciplinary research problem this research applies creative, inventive and divergent thinking. In contrast convergent thinking is also included in order to follow the determined and logical or so called general formula of verification. (Olkkonen 1993). Furthermore the interpretative approach emphasizes the methodological uniqueness of anthropology, where hypotheses are not absolutely verified, but more like produced (Räsänen 1993).

Construction in chapter 3 has been deductively reasoned from the existing theory of creative mechanical engineering design, but because the original discipline is different inductive reasoning is needed from the empiric material. The features, factors and phenomena concerning population in the background are reasoned from a sample. (Olkkonen 1993). Results of this research cannot be presented as statistical factors and therefore several surveys have been made in order to gain evidence for analysis, which has been done by approaching the problem from several viewpoints. Triangulation can be seen as an act of bringing more than one source of data to bear on one single point. Data from different sources can be used to confirm, elaborate and illuminate the research problem (Marshall & Rossman 1995, Stake 1995). As Marshall and Rossman (1995) express, when designing a study in which multiple cases or informants or more than one data gathering method are used triangulation can greatly strengthen the research usefulness for other settings. Cassell and Symon (1994) have obtained good results with triangulation in studies of complex problems, e.g. in research into organizational problems. Because of the nature of the empirical material and triangulation, the research has contained several phases of analysis and synthesis (Fig. 4, 5 and 6).

The basic idea behind positivism, scientific rationality and logic, has been the guideline in structuring this research so that the construction of validation can be seen afterwards, which is one of the key concepts in evaluating hermeneutic research results (Moilanen 1998). The methodology of qualitative research has been adopted e.g. from Cassell and Symon (1994), Lee (1993), Marshall and Rossman (1995) and Stake (1995), who have specialized in solving sensitive research questions.

This research contains several interpretations in different phases. Therefore it is not absolutely certain that another researcher from a different pre-understanding would end up with same result (Olkkonen 1993). It is therefore essential to present the most significant results as they are obtained from informants (see Koski 1995, Moilanen 1998). Hermeneutic theory and the hermeneutic model leads or gives some basis for the researcher, and the research itself is considered as a scientific empiric method in order to obtain reliable results (Moilanen 1998, Stoutland 1989, Tuomela 1979).

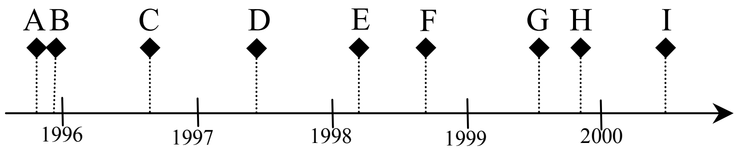
The verifiability of qualitative results remains lower than the results of a quantitative study, but using intuitive methods man can solve problems, which cannot even be determined logically (Richards 1974). To research and develop the ability to be creative we should first recognize the existence and the mode of action of our four basic human functions: conscious mind, subconsciousness, motorics and senses. These human parts are in operation with each other making our activities, thinking and doing in different tasks of life possible. Science knows the least about our mysterious subconsciousness. We cannot consciously leaf through our subconscious mind nor is the detailed investigation of its operation easy. Different practical perceptions can be made, which are at some point fictional and detailed authentication is very difficult. If they explain several perceptions coherently they can be considered as competent at least so far when some discrepancy is indicated (Harth 1993). On the other hand falsification of the results, which are based on empiric material may be as difficult as verification (Leppälä 1995). Already Popper pointed out that a theory cannot be verified, but it can be made reliable. Prognosis given by a certain theory and several test increase the reliability in science, but empirical tests never verifies the validity or truth absolutely. (Bohm & Peat 1992). In this research the reliability of simple surveys cannot be considered particularly high and therefore triangulation has been used in order to increase the reliability. Also these factors connect this research to the hermeneutic approach.

Moilanen (1998) separates the technical and philosophical level in the reliability discourse of qualitative research. On the technical level a certain commitment to opinions of the basis and purpose of the study is either consciously or unconsciously made. Then the model to evaluate reliability is developed. Philosophical perusal is explained, where the more significant factor than research methods is the definition of basis and purpose. Hermeneutics is a fertile approach to evaluate the reliability of interpretations of actions. When interpreting human action reliability evaluation is done in several phases. Also separate surveys in the same research should be, and are, evaluated separately. Therefore evaluating the whole research proper analysis for reliability and validity is required. In this research, this is done in the conclusions chapter.

Interpretations in this research are aimed at the action and thinking of architects and at the phenomena in the background. In architectural design there are congruent features with every other human action, but it is, however, easier to examine the actions of architects than human action in general. (see Moilanen 1998). One of the theoretical bases has been principles of designing. Another important standpoint has been creative mechanical engineering design. Other theoretical references have been e.g. product development. Furthermore the theory constructed in chapter 3 applies widely in design and creative work and, in some respects, to research also.

Creative architectural design and problem-solving have been the issues examined in this research. This has focused on the internal design process of one individual designer or how the individual architect designs from his own personal perspective. However, architects have a lot of cooperation and teamwork in design and even this communication plays a very significant role in the design process, it more useful to first examine the individual process in order to reveal the most significant features in the design process. It is the creative process that has been examined. Another possibility could have been the progress of design through the standardized process in the scope of architectural design (see Fig. 2). This has not been the approach, but it has been, however, noted in this research too. The section, where this research settles in the scope of architectural design (see Fig. 2) is phases 3 and 4 (preliminary design and working design).

Participating architects have mainly been members of the Finnish Association of Architects. The average object of design in surveys has been the usual building of a house, but also enriching features from any kind of project have been considered. Similarly in exploring the possibilities of information technology, traditional CAD applications (programs aimed at drawing and design) have been the main consideration. The enriching possibilities e.g. 3D applications have studied only as secondary options. Empiric surveys (Fig. 5) have been done according to the original objectives and research proposal, but also focused factors have been noted during the research. The methodology of empiric research has been explained in detail in chapter 4. Also the features of separate surveys are explained in chapter 4.



A: A interview about architectural design procedures
B: A survey about the state of art of computer aided design
C: A survey about creative architectural design
D: A interview about using different CAD programs
E: A survey about systematic design procedure in architectural design - QFD
F: A survey about systematic design procedure in mechanical engineering design - QFD
G: A case -study about the design process
H: A survey about the state of art of computer aided design
I: An interview for case study designers

Fig. 5. Empirical surveys in research process.

Because of the approach and the complexity of the research problem the literature has been processed quite extensively (see schematisation of the theory later in Fig. 8). In order to filter out less critical theory, compress relevant theory and discuss some of the perceptions in between scientists and architects international discourse has been used (Fig. 6). In addition to methodological surveys, theories and results have also been discussed widely, informally and maybe also unscientifically among practical designers, but this discourse has brought similar features up to the surface. Far more important is the support and encouragement from creative workers during this learning process, which is also significant in the hermeneutic approach. To mention some disciplines other than architects there have been mechanical engineering designers, industrial engineering designers, creativity, medicine, brain and many other researchers not to mention psychological and pedagogic.

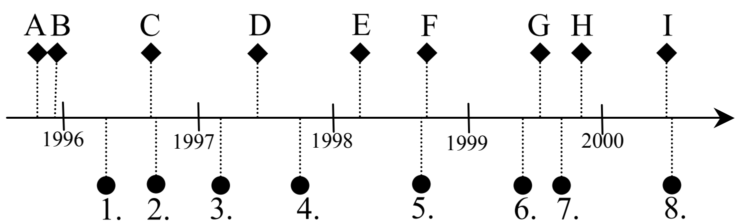


Fig. 6. International publications during the research process (1. Heikkilä *et al.* 1996, 2. Haapasalo 1996, 3. Haapasalo *et al.* 1997, 4. Haapasalo 1997, 5. Haapasalo 1998, 6. Haapasalo 1999A, 7. Haapasalo 1999B, 8. Haapasalo 2000) (see also Fig. 5).

1.4. Outline of the thesis

The background for information technology in construction and computer aided design has been presented in the first chapter (Fig. 4). Current problems and existing realities are connected to the objectives and research questions and to the research approach. They are also linked to the discourse of research traditions. (Fig. 7).

Chapter 2 and 3 contains the theory of this work. The theoretical part has three separate purposes in this research. Therefore the theoretical framework is presented at the beginning of chapter 2, in order to outline and analyse the theory. *The first* part of the theory presents related research and work (chapter 2.1). *The second* purpose is to present the theory of deign process, development of architectural design, information flows, theoretical progressing of creative and systematic design processes, user interface and usability, opportunities of information technology and the main principles and possibilities of CAD (chapters 2.2. - 2.4.). *The third* purpose and the actual contribution of this work begins from chapter 3. The creative and intuitive architectural design process is deductively concluded of existing theory from creative engineering design and features from architectural design. The theoretical comparison of creative and systematic design and applicability of computers in architectural design is also presented in chapter 3. The deductive reasoning in chapter 3 utilizes the design theory presented in chapter 2.

Chapter 4 presents the empiric framework of this study. It operationalises different surveys and contains explanations for the empiric survey settings for different surveys. Furthermore it contains the framework for empiric analysis and inductive reasoning.

Chapter 5 presents the results and analysis of this study. In the sixth chapter, the reliability and validity evaluation of the whole study is presented and then the evaluation of the answers obtained to the research questions. Finally, a summary of this study is presented.

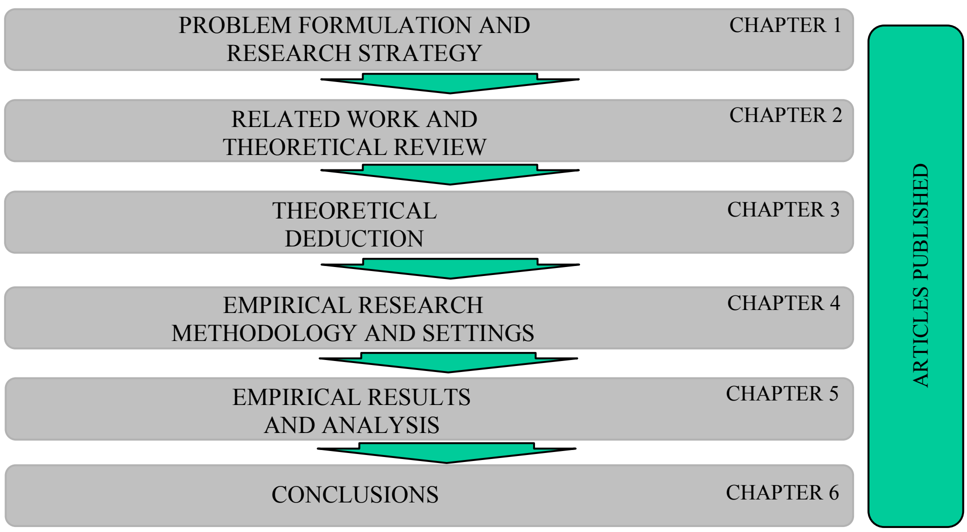


Fig. 7. Structure of the research.

2. Architectural design and information technology

Computer aided architectural design is a young discipline in science, but CAD has a significant domain in practical development. Its key issues, however, have been discussed within a number of related disciplines. These areas may be, and have been, far away from design theory, even when they should contain it. It is therefore useful to summarize those lines of research and development that have addressed computer aided architectural design. This is, in practice, an impossible task, because almost all linked disciplines have a large body of literature in the background discussing either directly or indirectly the topic of this research. It is, however, possible to point out some lines of research that have direct relevance to this research (Fig. 8). This outline may not be the only and final way to see the factors behind CAD, but the purpose of this outline is to analyse the theoretical framework, which is useful to the researcher.

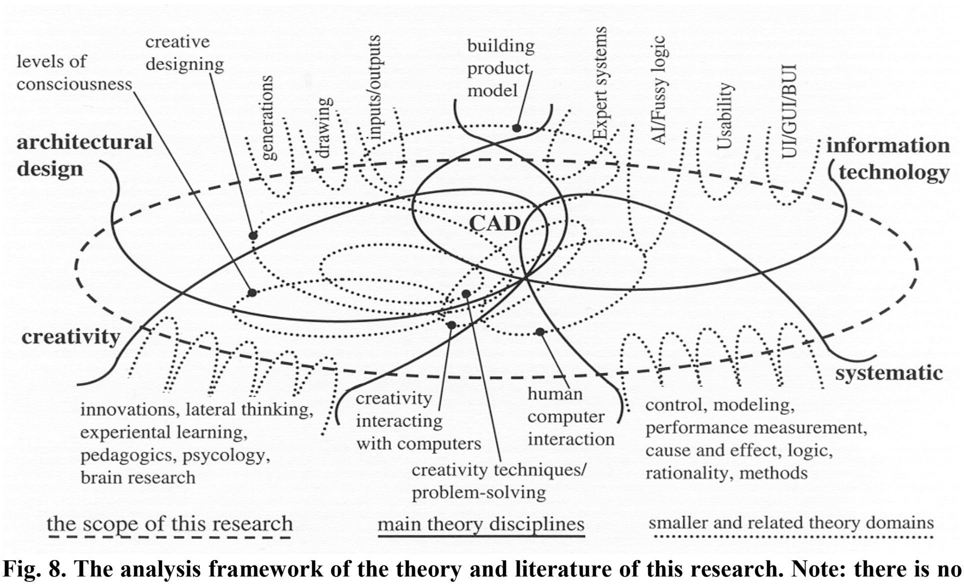


Fig. 8. The analysis framework of the theory and literature of this research. Note: there is no closed loop or area, which means that there is some theory diffusion between topics and the possibility to attain more.

Conceptually CAD can be approached from many different directions. One emphasizes the architectural design process itself and another the creativity in it. The third concerns information technology and the fourth the theory of systems and logic. This division in not a clean one and there is also some overlap. However, it also seems that these four clusters have not been integrated into a unified view that would address the various contributions provided by extant research. Additionally, within each of these clusters there are relatively independent research traditions, which have not been well recognized outside their own disciplinary boundaries. Connections behind these four disciplines related to this research are presented earlier in figure 4. The contribution of these four disciplines to this research is reviewed in chapters 2 and 3, and also a few discrepancies are indicated.

2.1. Related work

In the following both related work and related research are taken into account. This is because of the approach to the research area. There is a significant amount of effort which has been done as a development work and not so much research in the scientific sense. Related research means that is has been carried out according to scientific methods and also evaluated critically from the reliability and validity point of views. Comparably, related work has been done more as development work, which usually doesn't include the traditional verification process or more likely verification is very difficult to achieve. Furthermore related research or work includes interdisciplinary features. Therefore the title of this chapter can be considered more preferable as related work than related research. The difference between these two standpoints has been taken into account during the research process.

In this chapter the main related topics of the research area are reviewed. Supportive research in CAD research is not in balanced in all dimensions, because some disciplines are more mature and studied more than others. For instance, design methods have evolved during the centuries and e.g. human computer interaction is at the beginning. Anyhow there are no exact definitions or common unanimity for designing theory either. Creativity and the human ability to be creative has been a very popular research area on its own, but without general consensus, and therefore further research is needed. A school for systematic engineering design has been very productive in research and making publications. As mentioned earlier and explained in more detail later on, research in computer aided design has not been done on a great scale in the scientific sense. Human-computer interaction is also a relatively new scientific research area. In addition, analogies from different areas are taken into account during the research, but aren't included in this thesis. As a multidisciplinary and lateral problem bunch this research has to have understanding from all of these disciplines in order to combine and to have a compact theory in creative computer aided architectural design. Scientific research containing all these areas (dimensions of creativity, constraints of systematic and possibilities of computeratisation applied to architecture) is almost totally lacking.

2.1.1. Creativity

Creative problem-solving, its development, its applications and producing innovations have become more and more popular in recent years. Interest towards utilizing hidden resources has increased in science, art and in education, but particularly in business and industry. All possible utility and capacity should be exploited when pursuing innovations and efficiency. Some scientists have tried to combine creative and rational problem-solving in order to generate a systematic creative method as an answer to these questions. (see Savolainen *et al.* 1999, Virkkala 1991).

Phenomena can be seen similar in all disciplines, however an unambiguous definition has not been presented so far. Different research for instance in mechanical engineering design (Tuomaala 1995, 1996), architectural design (Arieti 1976, Cross 1999, Ferrare 1996, Pallasmaa 1974, 1976, 1993, Petäjä 1977, 1983, Pietilä 1987), technical problem-solving (Drabkin 1996, Virkkala 1991), product development (Rickhards 1974, 1988), creative behavior of teams (Tuomaala 1992, Virkkala 1991), psygology (Freud 1989) and pedagogics (Heikkilä 1982, 1987, Uusikylä 1994) contains congruent features.

As mentioned, the definition of the creative process is very difficult, because all relevant matters take place outside of the conscious mind. Creativity is everywhere, in all domains, but it usually has varying characters. In the following there are several definitions of creativity and creative work. General methods are usually based on solving tasks or producing ideas to certain problems. Traditional methods in exploring or defining creativity as a process map in principle have been inquiries, interviews, observing different design or problem-solving situations and experiences from personal work. Some extreme studies have been carried out under the influence of depressants (medicine) (Heikkilä 1981). Anyhow, the precise definition of the creative process has not been presented. The situation in architectural design is much more open, even if creativity itself is a familiar concept to the designers. For instance Aalto (1948) has made an excellent description of his own creative work, but representation is not concrete or easily intelligible. Tuomaala (1995, 1996, 1999) has made a comprehensible description for creative mechanical engineering design.

The history of creativity, creative thinking and creative problem-solving can be seen as a multidisciplinary review. As described in previous paragraphs several studies have been made of creative behaviour. According to Rickhards (1981) the creative process is almost the same regardless of the field of excellence, which can be seen as a surprising result. Even when ordinary people are studied, creativity has similarities with that of specialists. This may be true, as it said creativity is the ability of every human to produce new or novel ideas, which are new or novel to the author. (Drabkin 1996, Heikkilä 1987, Ruth 1984, Virkkala 1991).

Wallas (1926), one of the first; has presented a content for the creative process. His general definition was also approved on a wide scale. It contains preparation, incubation, insight and implementation phases. The significance of the unconscious concerning the solution is evident. The process in unconsciousness ends up in the insight, thereafter the implementation is done with the aid of conscious thinking. Patrick (1935) has explored poets, artists, scientists and their principles of working and recognized the phases presented by Wallas (1926). In that time the ability to be creative was seen as the ability of a few (Casson 1934). Rossman (1931) explored inventors and found the view of Wallas correct, but extended the model to discover the need or problem, analyse the need, consider the available information, gather all relevant solutions, critically analyse of these solutions through weaknesses and benefits, form a new idea – invention and finally test and select the most promising ideas and complete the selected invention to implementation through the previous phases.

The principle of Osborne (1963) doesn't differ much from Wallas. It is a bit more accurate and illustrated especially in the beginning. He noted that brainstorming is a tool to combine the unconscious resources of a team. His procedure starts from problem indication (become familiar with the problem), preparation (assemble relevant information), analysis (specify the information into primary factors), creation (generate ideas), incubation ("let it come" allure insights), synthesis (assemble pieces) and development (evaluate results). (Osborne 1963).

Guilford (1971, 1977) is highly appreciated as a creativity researcher. He distinguished not only creativity and intelligence, but also memory and thinking. His most important observation was the variation between convergent and divergent thinking, which easily can be seen in practical design. The starting point in Guilford's (1971, 1977) principles is that creativity is a learning curve, which can be distinguished from intelligence. Creativity is not a simple function it contains mental capabilities and several other elements. Intelligence is divided into memory and thinking. Thinking has significance in creativity. Thinking can be distinguished as observing, generating and evaluation. Generation is the most significant and, in creativity, it is divided into convergent and divergent thinking. Of these divergent is more significant. Divergent thinking requires fluency, flexibility and originality.

Heuristics was firstly brought to creative thinking by Wartheimer (1982). He represents heuristic design as a basic element of architectural or industrial design. A creative process proceeds structurally from an unstable or unsatisfying position S1 to position S2, which brings the solution. The abyss between positions fills up and the structure takes shape. Classifying, outlining and structuring appear in creative thinking. An entity is divided into components. Noting these separate components (without losing the general view) connected to each other is important in creativity. Some components of position S2 can be visualized in the mind and are structured into entity position S2. Then components are adjusted with applicability, not incidentally. The whole creative process can be seen as one continuous routing. (Wartheimer 1982).

Taylor (1959) specifies different levels of creativity, but accepts the principles of Wallas. He has concentrated more on product development. Revealing creativity is independent expression without connection to the quality of a product. Productive creativity is controlling the environment and producing objects. Reuse of old components is required in inventive creativity. Ingenious creativity evolves new ideas and principles. The ability to adapt general experiences and introduce novel ideas is expressive creativity. Taylor's (1959) classification begins with the creativity of children followed by common creativity. The third dimension is not real creativity; people call themselves inventors and imagine that they are creative. Political or over-smart creativity is the fourth level. The fifth level introduces the real creativity. It contains talent, exhaustive knowledge and experience. The most experienced scientists; engineers and designers are on this level. (Taylor 1959).

Preparation and learning precede the phases of Stein's (1974) creative process (forming hypothesis, testing hypothesis and analysis of results), but phases can be parallel or overlapping when one is more dominant than others. The principle of Koestler's (1964) creative process is solving the inconsistency between two features. The essential concept in creativity is biscociation. It is a mental process where two generally unsuitable structures are combined. Rickhards (1981) specifies a creative process containing preparation, incubation, insight and validation phases. Rickhard's specification can also be accumulated from the definitions presented above.

According to de Bono (1971, 1990) lateral thinking is a process and set of techniques, which demystify the creative process by providing thinking tools and a conceptual framework. His well known descriptive metaphor of problem-solving process is ”digging a hole deeper”. Formerly there was only vertical thinking and it is only through the use of lateral thinking that we can escape from the hole and ”find something else to dig”. The need for lateral thinking arises because the mind doesn't record successive data in an objective way, but produces understanding through creating patterns. New data is fitted into older patterns and also influences and reorganizes the older patterns. de Bono suggest various mechanisms for restructuring the thinking process, which are in fact techniques of lateral thinking. In *the intermediate impossible* –technique the operational procedure is to set about finding a totally outrageous idea. Then after analysing and understanding the idea and its variations, the idea has to be returned to a new and useful reality. *Random juxtaposition* forces extensions of the horizons of thinking by the deliberate introduction of evocative and random extra ideas. *Concept challenge* focuses attention on the assumptions behind assertions of fact and belief. (de Bono 1990).

Altshuller (1988), as a patent reviewer, has distilled the problems, contradictions and solutions in these patents into a theory of inventive problem solving which he named TRIZ. He directed attention to the phenomenon, that almost all patents are based on the coincidence of two opposite characters. In the wider perspective we really can find a new solution, if we are able to combine two factors, which in common sense, do not fit together. Even this notation is correct, the theory of technical creativity is based on it, but it has not reached any significant acceptance.

Another of de Bono's (1990) well-known idea is his concept of *six thinking hats*. By using those different hats he stimulates thinking. *The reversals technique* of Rickhards (1981) turns conventional logic upside down to discover something new. At the humble level many industrial breakthroughs come up by turning conventional wisdom upside down. Also Buzan (1983) brings new or original ways to think as a source of novel ideas. He developed and introduced *mind maps* to expand or stimulate creative process. It is useful to reassemble and draw the map to a preferred order after first drawing. Other similar techniques are *relevance trees* and *fishbone diagrams* (Dale 1994, Oakland 1995, Rickhards 1981). This list could continue forever, because development of different techniques has been very popular in the systematic field of product development (Heikkilä 1981, Virkkala 1991).

The first significant event in creativity research in psychology was Köhler's (1959) discovery of insight with bioassay. His findings led to research on significant variables of complicated problems, strategies concerning problem-solving and also features of personalities, which either help or restrain effective problem-solving. Capabilities of learning, understanding the nature of learning and constancy in manners of learning were the essential results. De Bono (1990) has stated that, when moving from a familiar to an unknown problem-solving situation certain principles of thinking are influencing the transformation and cause of new ideas. Campell (1960) has emphasized the meaning of "effort and mistake" already in obtaining and learning additional information.

The scientific world has been aware of the functional differences between sides of human brains already for a long time. The left part of the human brain is specialized in logical and analytical thinking and verbal expression. Typical activities are speaking, reading, writing, mathematical operations, a great deal of linguistic and numerical operations and generally processing information in a certain order at a conscious level of thinking. In contrast the right part of the human brain dominates when thinking is done in the subconscious mind and solutions are achieved intuitively. Example activities are spatial observations, holistic understanding, realizing observations, sensing, musicality, visualization and intuition. Nevertheless creative problem-solving is such a complex procedure, that it cannot be unquestionably focused to certain parts of human brains nor have dependencies between different parts been shown. (Albert 1992, Dew 1997, Isaksen 1987, Sternberg 1985). Freud (1989) separated subconscious and conscious thinking when he specified subconscious thinking as a primary process and conscious thinking a secondary process. Co-operation is required in creative work and Freud attributed that to a tertiary process, but he didn't locate or define the subconscious mind more accurately. However, studies of brain damage indicated that the front lobes of the brain are participative in planned and associative action, speech generation and understanding languages. According to present medicine, creative problem-solving is related to cognitive, neurobiological, endocrinological processes and mental development of the individual. (Albert 1992, Bohm & Peat 1992, Isaksen 1987, Sternberg 1985).

Heikkilä (1981, 1982, 1987) has studied creativity from the pedagogic point of view, especially applied to teacher training. People try to seek features from the learning and teaching environment, especially what supports and confirms the logical learning structures inside a student. This usually happens in an intensively managed, controlled and strictly standardized environment. As a of the consequence former, new things are harder to learn, when versatile divergent thinking is needed and individuals are incapable of responding to these challenges in a new environment. This can complicate, for instance, the learning process of computer aided design methods for architects. Taylor's (1959) concept of creativity supports Heikkilä's viewpoint.

Räsänen (1993) has explored the comprehensive and experiential model of learning, presented originally by Kolb. Learning is a process, where knowledge is created by the transformation of experience. Schön (1987) has also explored learning in process complex problems and he noticed the principle "reflection-in-action". It means that learning needs action. Kolb's (1984) experiential learning is the basis of many pedagogical applications in education. It is a four-stage cycle involving four adaptive learning modes; concrete experience, reflective observation, abstract conceptualisation and active experimentation. According to Kolb (1984) learning can start at any of the four stages, but for the proper learning all four stages have to be done in the cycle. The student has also to be active and to be involved with the material or skill to be learned in some kind of experience. Concrete experiences are actually happening to the students. These events may have been specifically designed for learning. They are concrete because students are actually present and participate. The reflective observation is probably the most important part of the cycle and the part where the real process of learning takes place. It is the process by which student start to think about, to question, to sort out and to classify the main events of the concrete experience. This does not necessarily occur only at the time of the event, it may happen sometime afterwards. The abstract conceptualisation is the process with which we store abstract ideas and the outcome of reflections on our experience in our minds for the future use. The reflections must be transformed into abstract ideas in order for them to be stored in our minds. The process of abstract conceptualisation is one which is gradually built up after each experience. The more powerful the experience is, the more is built from it. In active experimentation students anticipate an experience by drawing from our store of abstract knowledge the facts, ideas, skills, processes and attitudes or values, which we think will be of help to us in the experience which we are anticipating. The difference between the unconscious and conscious mind is emphasized in Kolb's (1984) model. Artistic learning is understanding and internalising the knowledge gradually, where the student continuously structures his self-comprehension and awareness with the aid of interpretations. (Räsänen 1993).

The ability to be creative or the ability to produce novel ideas has been a very famous research topic. However, there is no average creative person, although according to Casson (1934) at the beginning of the 1900 –century creativity was considered an exceptional talent and a feature of an unusual person. According to later research the behaviour of most creative architects is dominant, spontaneous and they have more self-confidence than others. In addition they are independent in their opinions, demanding, aggressive and intelligent. They are also interested in multiplicity or the possibility to reshape or reorganize entities. On the other hand creativity has also been seen as a normal quality of every man, which can be increased or restrained by the environment. (Heikkilä 1987, Pallasmaa 1976). Anyhow, according to de Bono (1990) creative individuals are people who use more time to be creative, because creativity motivates them.

Aalto (1948) has been reviewed several times. His famous article ”Taimen ja tunturipuro” (The trout and the stream), has been a basis for several studies in architectural creativity. Architects and researchers (Arieti 1976, Cross 1999, Ferrare 1996, Lehti & Ristola 1990, Pallasmaa 1974, 1975A, 1975B, 1976, 1993, Petäjä 1977, 1983) have interpreted and tried to construe a theory from his very figurative description of the architect's creative work. However, these interpretations have been more like verifying and confirming his work, but not constructing a general model. By using a scientific framework it is very difficult to approach Aalto's work, which is typical when there is artistic and abstract aspects in research. Therefore it might be more concrete and more scientific to study creativity from the design process point of view, which is especially important when concerning computer aided design.

The well-known researcher and professor of history, Ferguson (1977, 1993), has reviewed the development of innovations and technology. He noted that by using only systematic methods proper and novel solutions couldn't be found in the long run. His contribution to design science was quite original “the mind's eye”. According to Ferguson, features of the designed object cannot be reduced to unambiguous verbal descriptions; they are dealt with in the designers mind by a visual – nonverbal process. The designers mind's eye is a well developed organ that not only reviews the contents of his visual memory, but also forms such new or modified images, as his thoughts require.

Ferguson means that much of the creative designer's thoughts of the technological world are nonverbal, not easily reducible to words or numbers. The language of these creative thoughts is an object or a picture or a visual image in the mind. From the historical point of view this intellectual component is non-literary and non-scientific and has been generally unnoticed because its origins lie in art and not in science.

2.1.2. Systematic point of view

Present design science strongly concentrates on the development of different systematic theories and methods for the utilization in practical design. (see Eder 1998, Pahl & Beitz 1988, Hubka & Eder 1992). Therefore the trend towards systematic design methods and theories can be found to be determinative today in the business world and also in the world of science. The reason for this is an ambition to manage and control every activity in companies or in organizations. This is usually done when pursuing effectiveness and finally in the name of business (see Kess 1992). Designing as a slave of information technology can even increase the dependence on systems, according to Ferrare (1996). Computer-aided design systems are limited by hardware and software, and may therefore lead to an even more systematic approach.

There has also been plenty of speculation about future development and management trends also in the field of design. For instance Total Quality Management (TQM), which is currently a general management philosophy in business, pursues certain systematic and rational ways to operate. This is based on man's desire to seek for rational ways to operate. All action should be measured and controlled in TQM. It is also typical that measuring and especially controlling is aimed at the future. (Dale 1994, Oakland 1995). This easily leads to a general analysis of design, usually done from the business point of view not from designing activity, and in consequence, some models are developed and used to measure design. For instance Ojanen *et al.* (1999A, 1999B) have presented a set of measurement proposals for research and development work. According to their survey only very few of the indicators are suitable for most companies. This reflects the complexity of the research and development and design activities and the impossibility to create a common set of measures. Therefore choosing the right measures from the whole company's point of view is a real problem. In design it is also problematic to determine the objects to be measured and control the whole measurement system. According to Ojanen *et al.* (1999A, 1999B) there are no systematic ways to select research and development performance measures at the company level. This is very difficult from the design or research and development point of view, because the progress or results of design cannot be forecasted or even measured in a reasonable way.

Ullman (1992) has studied design from the systematic point of view. The reason for methodological and systematic approach was, according to Andreasen (1991), that the nature of objects to be designed was a technical system. Eder (1998) has made a list of methods, which are applicable in different phases of design (appendix 1). Correspondingly Virkkala (1991) has developed a systematic creative problem-solving framework (appendix 2). Ullman (1992), Eder (1998) and Virkkala (1991) have presented an approach which uses systematic methods in every stage of design or problem-solving to proceed in the design process. Virkkala's (1991) example is a map which attempts to illustrate the information and knowledge in design process in three different sectors. The techniques used by Ullman (1992) in the design process are e.g. Quality Function Deployment (QFD) to specification development, Pugh's method to compare available decisions, concurrent design to develop production plans simultaneously into product, Design For Assembly (DFA) to improve manufacturability and Taguchi's method for robust design.

Essential in these frameworks (e.g. Eder 1998, Ullman 1992, Virkkala 1991) is, that by using different methods in every stage of the design process, solutions can always be achieved. Taura and Yoshikawa (1994) have gone in an even more systematic direction, they have developed a mathematical framework for analysing knowledge in the design process. Although Ullman (1992) and Virkkala (1991) are proposing a systematic approach to design, they represent a bit more conservative approach than e.g. Pahl & Beitz (1988) and Hubka & Eder (1992) (their approach to design is represented more accurately later on), whose framework doesn't include any undefined matters. For instance Hubka & Eder (1992) present a note in their systematic design process (appendix 3): "thinking is not included in design hierarchy, this process takes place inside the human and is not directly observable or verifiable by documentation". In one of the latest articles Eder (1998) expresses a question even in the name of his article; "Design Modeling – A Design Science Approach (and Why Does Industry Not Use It?)". The question itself explains a practical view of developed systematic design methods.

As Andreasen (1991) remarks the development systematic theories of design has been dominant in the 1960's and 1970's, but the way in which human being think has begun to have weight in the late 1980's and 1990's in the systematic school, too. Andreasen (1991) also announced, that in developing design - practical experiences and work should be in an intensive role and researchers should leave their "ivory tower" in academia in order to attain considerable results in the future. Anyhow, this trend in systematic school has so far been only words but not actions. For comparison in the world of science the goal is to find logical connections from new truths to former truths (Horwich 1994, Niiniluoto 1984). This emphasizes the need for a systematic way of thinking and explaining processes. This attached to Ferguson's (1977, 1993) review of history shows that in designing probably the systematic methods don't give the best possible solutions, because the origins of design lie in art and not in science, according to Ferguson (1977, 1993). Both approaches presented emphasize the need for multidisciplinary research in order to attain good results in the future.

2.1.3. Computer aided architectural design

The history of computers in architecture is so far very short. It has been intensively related to the development of information technology by both hardware and software. Furthermore architects as a profession have slowly adopted the possibilities of information technology. One reason for this is the expense of the investments related to the nature of the design business. (Ekelund *et al.* 1992).

The first articles concerning computer aided design were published in 1961 and 1962. They were concerning programs intended to produce plans and layout drawings. The intention was to describe a building or a plan as one graphical object. Despite the development from 1965 to 1975 programs were very difficult and awkward to use. Besides the development was done by the programmers and not by architects. Computer aided design was first taught in Australia in 1967 at the university of Sydney. In the late 1970s architects were allowed to take part in software development and as a consequence programs were gradually taken in to the design process in large architectural offices all around the world. In the beginning of 1980s programs were good enough to aid design. Also the interest towards research and development rose. (Cross 1977, Gero 1983, Gero & Maher 1997, Mitchell 1977).

In the beginning computer aid was aimed to automate drawing and produce only simple drawings. Computer support was centered in the final phases of design. (Björk 1995, Ekelund *et al.* 1992). Therefore the first generation of CAD was nominated as electric drawing. Drawings were done only with simple lines and objects were assembled from several separate short lines. (Eastman 1991). Two-dimensional computer aided drawing can be compared to the contrast between typing and word processing (Penz 1992). Programs in the second generation contained e.g. wall drawing applications including possibilities to insert windows and doors. Graphical features in programs made working easier and more effective. (Penttilä 1989). Almost all present programs allow drawing in three dimensional co-ordinate systems, which means three-dimensional (3D) modeling.

CAD is designing where traditional tools are replaced with one system. CAD is a wide concept containing almost all features of information technology in design. (Kiviniemi & Penttilä 1995). Without effective utilization, investments are useless and working shrinks to computer aided drafting. Inadequate capabilities shifts attention from design to equipment and programs and the work itself suffers. (Heikkonen *et al.* 1995). Also the wrong basis for CAD investments have led to poor results and cause a negative attitude towards information technology also on a wider scale. Naaranoja (1997) has linked a strategic framework to support the decision-making process when evaluating CAD systems in design offices. Her decision making process consists of seven steps; setting performance objectives of CAD development, generating action plan alternatives, screening alternatives and focusing on chosen ones, analysis to alternatives chosen (related to benefit, cost and risk), post project evaluation in three layers (user, technology and business) and finally evaluating on the business level. This kind of framework is needed in architectural offices in order to the obtain optimal CAD system.

CAD research has not have a long traditional framework, which would have evolved during a long scientific work. This is obvious when talking about a new field, such as computer aided architectural design is. Also the whole industry of information technology is relatively new compared to the development of design itself, so there has not been a possibility to develop a stable research tradition. There is however development, but not always in the scientific sense. (e.g. Holvio 1993, Kiviniemi 1990, 1991, 1994, Kiviniemi & Penttilä 1995, Medland & Mullineux 1988, Paulson 1995, Penttilä 1989, Penz 1992, Schmitt 1988, Virolainen 1994). These references and the work itself are usually based on the practical experiences of the authors. The reliability and validity of these reviews are not scientifically proven and they cannot be therefore considered as a scientific fact, but these references are usually, however, experiences and observations of specialists in the field of design.

The Australian professor of design science, John Gero, has been very active and productive in the field of design theories and computing. According to Gero and Maher (1997), design computing has often been considered a subset of computer applications that assist the designer in documenting and analysing complex designs. They consider design computing as a research area, one in which the results of the research lead to more than additional computer programs and in fact lead to a better understanding of designing and computer support for designing.

Gero and Maher (1997) have found three paradigms in the design computing research. These varieties of scientific methods to attain useful and distinctive results are empirically-based research (cognitive models), axiom-based research (computational models) and conjecture-based research (computational models), which is divided into conjectures based on an analogy with cognitive processes and conjectures based on an analogy with computational processes.

Empirically based research involves the development of experimental studies of designers that result in cognitive models of designing (e.g. direct observation of the results of designing, surveys of designers' perceptions and protocol studies of individual and collaborating designers working). (Gero & Maher 1997). Axiom-based research involves the identification of a set of axioms and their consequences to derive a logic-based computational model of designing (e.g. an axiomatic logic-based shape representation allows for the uniform representation of shapes with or without curved boundaries, the consequences of which are representations of complex shapes that can be manipulated with logical implications) (Damski & Gero 1996). Conjecture-based research involves an analogy between a cognitive or computational process that leads to a computational model specific to designing (case-based design [design based on precedents; representation of cases including multimedia representations], design prototypes [knowledge chunking], graphical emergence [emergence of shapes, objects, semantics and style from drawings], design by analogy [between domain analogies in particular] and qualitative reasoning in design [qualitative representation and reasoning about shapes and spaces] (Gero & Maher 1997, Gero & Yan 1993, Jun & Gero 1997, Maher & Balachandran 1994, Maher *et al*. 1995).

Due to the short and changing history of CAD Gero and Maher (1997) have posed a question; "What directions are open for design computing research? Not so much what projects should be pursued, rather what strategic directions may yield results, which inform us about designing and produce processes of value. *As empirically based research produces more results, we should have a greater understanding of how human designers design*. Such knowledge will have implications for both how information technology can be interfaced with human designers and, perhaps more importantly, provide new conjectures for design computing research to explore in order to provide the foundation for more useful tools for designers. Similarly, as the other approaches yield insights into designing they may provide the foundation for novel tools." The former statement describes extremely well the necessity, significance and validity of this research. Analogies from and to the international world of science emphasize the need for this kind of research applied to the finished environment. In Finland this kind of research is almost totally missing.

2.1.4. Human-Computer Interaction

Human-Computer Interaction (HCI) is the study of how people design, implement and use interactive computer systems and how computers affect individuals, organizations, and society. It was adopted in the mid-1980s as a means of describing the new field of study. HCI encompasses not only ease of use, but also new interaction techniques for supporting user tasks, providing better access to information and creating more powerful forms of communication. It involves input and output devices and the interaction techniques that use them: how information is presented and requested, how the computer's actions are controlled and monitored, all forms of help, documentation and training, the tools used to design, build, test, and evaluate user interfaces and the processes that developers follow when creating interfaces. (Preece *et al.* 1994).

HCI is a discipline whose goal is to bring the power of computers and communications systems to people in ways and forms that are both accessible and useful in our working, learning and communicating (Kuivakari *et al.* 1999, Procter & Williams 1992). Toward this end, technologies such as the graphical user interface, virtual environments, speech recognition, gesture and handwriting recognition, multimedia presentation, and cognitive models of human learning and understanding are developed and applied as part of HCI research agendas (Table 1).

Table 1. Factors in designing HCI (Preece et al. 1994).

ORGANIZATIONAL FACTORS training, job design, roles, work organization		**ENVIRONMENTAL FACTORS** noise, heating, lighting, ventilation
HEALTH AND SAFETY FACTORS stress, headaches, musculo-skeletal disorders	cognitive processes and capabilities **THE USER** motivation, enjoyment, satisfaction, personality, experience level	**COMFORT FACTORS** seating, equipment layout
USER INTERFACE input devices, output displays, dialogue structures, use of colour, icons, commands, graphics, natural language, 3-D, user support materials, multi-media		
TASK FACTORS easy, complex, novel, task allocation, repetitive, monitoring, skills, components		
CONSTRAINTS costs, timescales, budgets, staff, equipment, building structure		
SYSTEM FUNCTIONALITY hardware, software, application		
PRODUCTIVITY FACTORS increase output, increase quality, decrease costs, decrease errors, decrease labour requirements, decrease production time, increase creative and innovative ideas leading to new products		

HCI is a socio-technological discipline, because it concerns how people are affected by computer systems. It draws on computer science, computer and communications engineering, graphic design, management, psychology and sociology as it endeavours to make computer and communications systems more usable in carrying out tasks as diverse as learning a foreign language, analysing the aerodynamics of a new airplane, planning surgery, playing a computer game, accessing information on the World Wide Web or programming a VCR (Table 1). (Preece *et al.* 1994, Procter & Williams 1992).

HCI itself is a wide and new research area, where only general patterns can be constructed. It contains in practice all possible solutions and products where computer aid can be utilized. Preece *et al.* (1994) have identified factors, which have to be noted in HCI planning (Table. 1). Development of a user interface will be even more complex, because of the invariable interaction between many of these factors. When approaching more exact HCI, a certain discipline must be determined. For example in computer aided architectural design, which can be seen as a small section in HCI research, user interface factors have to be considered much differently than in developing heart rate monitors. In computer aided architectural design research HCI has been, in practice, an unknown concept, these factors (Table 1) are, however, unconsciously considered, but only to a certain extent.

2.1.5. Creativity interacting with computers

Preece *et al.* (1994) defines "interaction" as the exchange that occurs between users and computers. More precisely "interactive" means that it responds to input and produces feedback, which can be reacted to by the user. In contrast "Creativity interacting with computers" mean, that how ability to create reacts when computers are considered.

Licklieder from MIT wrote in the 1960s about "human/machine symbiosis", his desire was "companionship, which thinks the way no man has ever thought". Another famous professor from MIT was Negroponte (1972); he wasn't satisfied with the computers' ability to react to operations defined beforehand. The system has to be able to monitor the operations of the user and respond to those, the computer has to be active by attaching its input to the design process. (Cross 1977). This approach was aiming to generate new intellectual dialogue between man and computer.

Much of traditional research has concentrated on routine, well-defined and stable, tasks or low level computer support for complex tasks, e.g. spell-checking for someone writing a book. Increasingly, however, interest is moving to the support of people involved in creative tasks. Savolainen has developed software (IDEGEN++) to support creative thinking. It is an application for stimulating and guiding creative thinking. Savolainen *et al.* (1999) brought the concept of computer aided creativity. To support and guide creative working actively with the aid of the computer is the definition of computer aided creativity. The software (IDEGEN++) uses the forced relationships method to support and aid creative thinking to produce ideas (Savolainen *et al.* 1999).

Writing can be seen as both routine and creative work. Norvasuo (1991) has used word processing as an example in studying creativity with computers. The work itself has been quite unchanged even with computers. If creativity is measured from the efficiency point of view, information technology can be seen as a conducive factor. But then whatever saves time should also improve creativity. More and faster can be achieved, but what is the value of the output? What are causes and what are effects? This has been and may still be an unsolved paradigm in the future.

Design and the visual arts will be used as typical examples of creative work and visions of computer futures and their cultural and social implications are explored. Creativity interacting with computers is at the beginning of its development. It is much more immature than computer aided design. This is also much more evident in the research of this paradigm. Therefore this research area as a whole can be emphasized more with questions than research answers.

Computer systems for professional workers are, according to Edmonds *et al.* (1995), often constructed in relation to a problem-solving paradigm. On the other hand, studies of professional people at work suggest that they spend much more time in problem formulation than they do in problem solving (see de Bono 1990). Problem solving requires expertise but problem finding requires creative thought. The question based on the former can be then presented: should we aspire just to automate expertise or should we aim to amplify human creativity (Edmonds *et al.* 1995)? Several similar questions, connected to this research, have been presented and discussed in an international context in several occasions (see Fig. 6).

What is stimulating to creative thought and what is inhibiting? For example software criticism, according to Savolainen *et al.* (1999) and Edmonds *et al.* (1995), is very helpful in bringing errors to the attention of the user, but the criticism knowledge can include conventional wisdom. A creative act may often involve contradicting a standard convention. So does the criticism help or restrain? What should the research agenda be for advancing support for creative thought and action?

According to Edmonds (1994) findings for computers to support human creative thinking must be able to keep up with human recognition of emergent ideas. This implies that the system is not based upon a well-ordered object set but has pattern recognition capability that can find the new objects, as they emerge, with minimum human guidance. According to Edmonds (1994) emergence is fundamental to creative thought in the sense that we find it hard to qualify an idea as creative if it is clearly implied by the preceding conditions. The creative thought introduces something new (Tuomaala 1992, 1995). In studies of design Edmonds (1994) sees reshaping as a significant creative event. In a recent study of innovative bicycle design it was shown that the designer shifted his thinking from the conventional tubular frame to the concept of a single "monologue" whole that could not have been inferred from the earlier model. As he considered smaller tubular frames he came to see the possibility of filling the enclosed space in and, then, of abandoning the traditional structure entirely. Such emergent ideas are typical of innovative thinking, but what are the implications for computing?

Computers were invented more as productivity aids, which have made them more or less useless in the creative domains. The tools of the creative actions in design are typically paper and pencil, white boards and physical objects. Ideas are initially sketched out in a rough form. (Ferrare 1996). Also Riecken recommends to employ the computer only during a design session to enumerate an exhaustive set of views representing plausible solutions to a given problem. But this would require the computer to encompass an extensive domain-specific knowledge database. (Edmonds *et al.* 1995). The computer doesn't, by itself, influence creativity much. Yet it allows views of the world, and consequently it has an impact on creative work. It has often been said that with the computer, artists, designers or architects may easily play with hundred of solutions or variations. Thereby computers may have a supportive impact on creativity. However it is only the trivial aspect of creativity. Anyhow the importance of the groundwork of creativity should not be understated. The computer may be ”the machine to think with”, as it has been said in various contexts. (Nake 1993). According to Bohm and Peat (1992) computers may represent, at their best, artificial or synthetic mechanical intellect on behalf of intelligence or insight. They don't see the possibility that computer aided design or computer language could emulate creative freedom closely enough.

Correspondingly Fischer (1994) sees the power of the unaided individual mind to be highly overrated. He claims that much of our human intelligence and creativity results from the collective memory of humankind and of the artefacts and technology surrounding us. Rather than studying humans in isolation, models of distributed cognition and new role distributions between humans and computers should be developed. To exploit artefact, group and institutional memories and to bring design concepts into unseen and untaught, yet relevant contexts, new representations are needed to serve the task at hand. Fisher (1994) sees task relevant reminding critical for creative activities. ”Artefacts do often not speak for themselves” - therefore mechanisms are needed to increase the talk back of artefacts. Human knowledge is tacit and it only surfaces in the context of specific tasks. This implies that problems are not given, requiring the integration of problem framing and problem solving. In his research Fisher (1994) has tried to create computational artefacts supporting these challenges. The domain-orientation of our design environments brings tasks to the forefront, thereby transcending ”human computer interaction” by supporting ”human problem - domain interaction”.

Spence has tried to look forward to the design office in the year 2020 by interviewing several expert designers. The possibility of the computer itself being creative was dismissed. Pencil and paper, frequently combined with face-to-face discussion with colleagues, will still be common in 2020. However computers will be facilitated in the creative process. The emergence of ideas or solutions may be facilitated by pattern recognition and/or neural networks. CAD software will be designed to allow suspension of judgment so that decisions can be made at any time. The form of computer-based tools will reflect the need to support two concurrent processes, those of problem formulation and problem solution proceeding in tandem, at any level from component to system. (Edmonds *et al.* 1995).

2.2. Theoretical background for the architectural design process

Practical design in its present form can be divided into two separate elements, design of the physical environment and functional-economic design. Designing the physical environment means preparation for an actual construction project in the physical environment. The basis for this has been the need for producing objects and designing buildings. (McLoughlin 1969). Functional-economic design is based on the theory illustrations and development of design methods through society and its operations. (Lehti & Ristola 1990).

Design consists of existing information, abilities, experiences and future actions of humans in society and the use of power with the aid of design. (Siirala 1989). Gero (1995) considers design the most complicated and intellectually most demanding activity of humans, while it is a basis for modifying our living-environment. Therefore it is surprising, that it is not known or even understood very accurately.

Dror (1971) sees design as a rational action in preparation for decision-making. Friedmann's and Hudson's (1974) definition is based on rationality. It is simple and clearly analytical, they see designing as integrating knowledge and action. Chadwick's (1978) and Falud's (1973) definitions are also based on the framework of rationality, but they attach information theory and self-controlling cybernetic system to the definition. Information and its processing is the main problem in design, according to Roos (Siirala 1989). By combining former definitions designing can be seen as preparation for decision-making in the future or making these decisions for the future. Several choices and decisions have to be made during the designing and they control the action in further processing. (Ljung 1972, Ozbekhan 1969). The former still doesn't give the answer to what designing is. One possibility to get deeper understanding is to get acquainted with the designing process from different standpoints. (Lehti & Ristola 1990). In contrast Lawson (1990) expresses that design, as a complex entity, should not even be tried to be determined in detail, because the search for a definition is much more important than finding it.

Individuality, uniqueness and the pluralistic nature of artistic features are typical for architectural design. Individual methods of working also make it difficult to give an unambiguous definition. (Korhonen 1979). Designing is activity where thinking is structured as chains. At first, this is comes from satisfying the motivation needs of man's action, and further action is caused by these needs. (Siirala 1989, Lehti & Ristola 1990). Ozbekhan (1969) deems design as a preparation for changing the physical environment and seeking the means to achieve these goals. These changes try to be as optimal as possible with the help of the design activity (Dror 1971).

Design can be described as a cyclic or iterative chain (Fig. 9). This chain is composed of consecutive activities and the influence of activities is observed and analysed in-between different activities. In Chadwik's (1978) model the analysis is done with Test-Operate-Test-Exit (TOTE) operations. The model describes the design as an onward procedure in time where interaction between the real world and information process is essential. (Chadwik 1978).

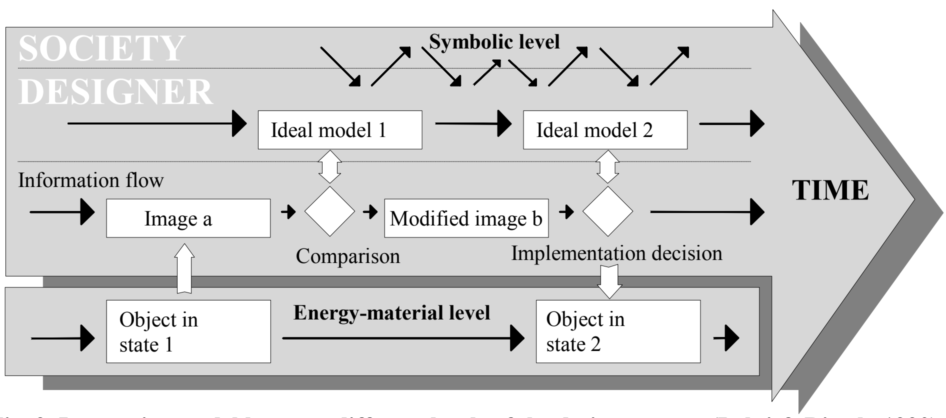


Fig. 9. Interactive model between different levels of the design process (Lehti & Ristola 1990).

Design is usually presented as a linear and straightforward process for simplicity (Fig. 9), but in practise it proceeds cyclically from level to level from phase to phase, then the process can be seen as an iterative and redoubling chain. The symbolic level can also be called an information system, where the information process progresses iteratively between participants. The system is divided into the information process between society and the designer where all information form different participants influences design. The designer's work is part of the information process where illustrations are transferred to the symbolic level. The energy-material level is a description of the real world, where the implementation of plan is fulfilled. (Lehti & Ristola 1990).

On a concrete level architectural design is an activity where project documents are generated for the actual implementation. It consists of information amassing and processing, actual work or producing plans and project documents, verification and testing. Architectural design contains both creative thinking and logical reasoning. The designer first has to gather the information, internalise and understand it, modify it and draw his or her thoughts into a generally intelligible format. Work is not done in a certain order, but in the way that all the different activities are included in the design. The entity of designing also contains the selection of design methods.

The design process can be simplified and generalised as a model (Fig. 10), where actual design work is done in the "black box". This black box is determined more accurately later on and it is the most significant element in research of design process. From an entity point of view it is not essential whether the design is done systematically or intuitively. The origin is, however, that as a result of design the project documents are produced to implement the project. The actual work is done with the available input.

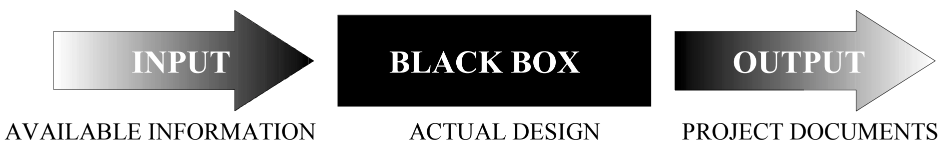


Fig. 10. The general model of design.

The content of the black box is very private and frequently an unconscious thing for most designers. The whole process of design can be understood much better by studying the phenomena in the black box. It also gives the basis for developing design and especially computer aided design. Therefore in the following inputs and outputs are presented at first. Then the history of the design development is reviewed, which leads us to two different approach to design theory – creative and systematic approach.

2.2.1. Inputs and outputs

Usually the project plan is the basis for design. According to instructions (RT 10-10387 1989) it contains information about the development of activities, capacity, building site, implementation and also building schedule, maintenance, conditions of premises, preliminary cost estimation, cost benefit analysis and the survey of environmental effects and risks. In addition, the following documents are needed as input information (Fig. 11) (Perttilä & Sätilä 1992, RT 10-10387 1989):

- different design instructions, regulations, standards and norms,
- target plan or design instruction and specifications for the project from the promoter,
- task lists and output requirements and
- general quality requirements in construction (in Finland RYL90 1989) in order to improve good designing and construction.

When considering architectural design from the methods point of view the starting point is the need for space or the empty site to be built. The actual work begins from the site views, but main functions are the first to be designed, which are, however done in order to follow the city plan and regulations from public authorities (Fig. 11). (Routio 1994).

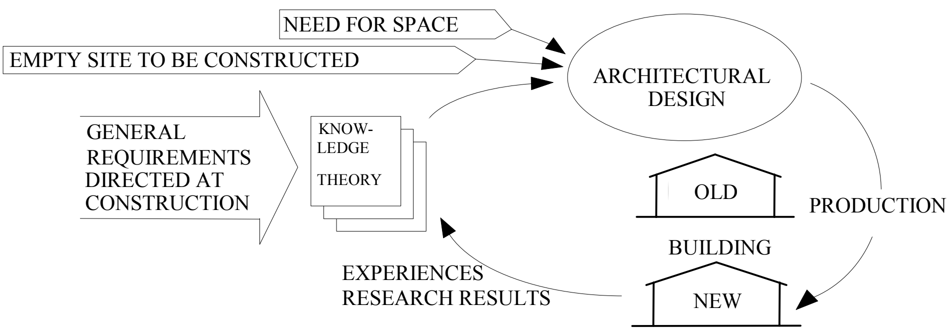


Fig. 11. Initial information and information re-circulation in design (Routio 1994).

In architectural design the number of requirements, restrictions and instructions is currently very high. Usually the amount of information will grow even so high, that it is impossible to handle it logically or systematically. Then the designer has to fall back on simplifications and intuition in generating the main solution. (Broner 1982, Routio 1994).

Phases of design can also be seen from the need for information point of view, when drafting the entity or structures of building, the customer needs are enough as information. (Aalto 1985). The architect generates the first draft from the mental image emerging from the needs. In addition to the needs of the customer the unique experiences in both skills and knowledge and even the genetic information inheritance of the designer influences the forthcoming solution (Pallasmaa 1975A, 1975B). Then the idea or sketch is developed towards the final solution and also the instructions and regulations are taken into consideration more accurately. Generally architects rely strongly on their own abilities and capabilities, because they use only less than 10% of their time in obtaining information. (Aalto 1985).

The most important source of information is the knowledge of new materials, products and components. The second most important ones are the building and design instructions and regulations and the third one is the technology and technique of construction. Official publications are not popular as an information source nor are pictured product data, design manuals, building reviews in magazines, handbooks and books considering architectural design. (Aalto 1985). This support the intuition based information acquisition.

Computer aided design doesn't necessarily decrease or increase the information needed, but the processing and form may change considerably. The format of digital information for a building site is coming into operation so that it is directly available for CAD applications. In addition dimensioning information of the conditions of premises can be changed directly to a scheme of the premises (Heikkonen *et al*. 1995). Different directories or libraries for blocks and symbols are available for almost all CAD applications, but on the other hand this increases the amount of information. Anyhow, CAD sets some requirements on information utilized (Kiviniemi 1994):

- structurally regular,
- suitable for transferring format between all utilized applications,
- content should have attribute structure, not broad statements and
- documented.

The primary goal of architectural design is to create a model in order to construct a building. After the decision to proceed to the building phase architects prepare design documents for several purposes such as the promoter, authorities, contract accounting, building and also for other designers. In figure 12 there is example of the Finnish regulations and instructions in the architectural design procedure, when different parties are involved. (national regulations and instructions in Finland; RT 16-10288 1986, RT YM1-20956 1994, RT 10-10575 1995, RT YM1-21003 1996). From the efficiency and economic point of view it is essential to produce only those documents which are necessary for any party. This should be considered in the number of documents and in the information in those documents.

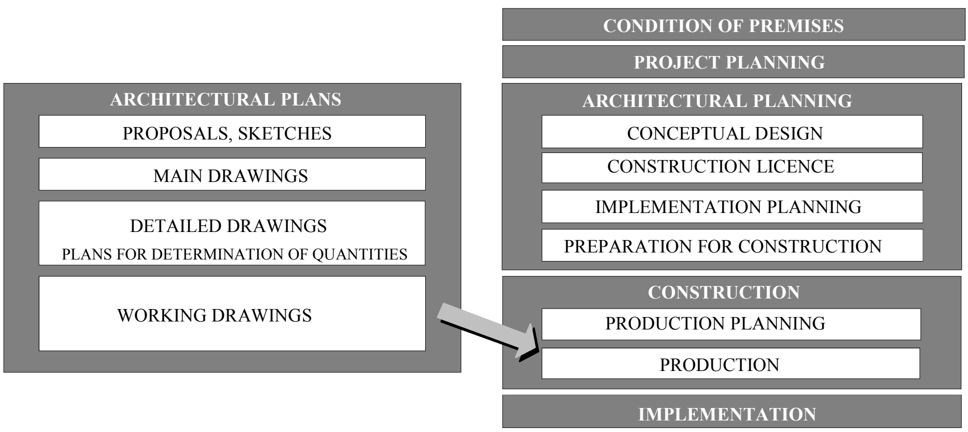


Fig. 12. The need for plans and the regeneration during the phases of designing and the construction project, see also Fig. 2 (national regulations and instructions in Finland; RT 10-10388 1989, RT 10-10575 1995).

Proposals and sketches primarily present the components, inconsistency between those components and the order of importance of the specification requirements (Lehti & Ristola 1990). The sketch is some kind of model of the solution and at the same time it is visual description of needs regulations, restrictions and compromises, which unavoidably occur in design. The architect uses the model to visualize the possibilities to attain the target and final solution. Master plans are used to present the final sketches and the main functional principles of the building. Master plans are also used to control and manage the design and building process. Detailed plans are more accurate than master plans, which are adjusted during the planning and implementation of the actual building. Detailed plans are used to promote the actual construction. (national regulations and instructions in Finland; RT 16-10288 1986, RT RakMK-A2 1991, RT YM1-20956 1994, RT 10-10575 1995, RT YM1-21003 1996). Planning the facilities management and the comprehensive functional planning during the whole life cycle of the building are also included in the architect's work. Gathering the general and detailed information for the maintenance manual from the project documents is also the duty of the architect. (KH 90-00223 1996, KH 90-00224 1996, RT 15-10441 1990).

2.2.2. Generations

Both creative and systematic problem solving have had periods of predominance in the history of Finnish architectural design. The periods differ from each other mainly in the ideology and structural changes of design. The main reasons for these changes are the increase of knowledge and the development of the society and design. (Lehti & Ristola 1990).

The first period (c 1944 - 1950) was during the reconstruction after the Second World War. Influential architects were typical of this phase, where few designers in number dominated the whole field of design. (Lehti & Ristola 1990). Too optimistic assumptions of the possibilities of creativity were also typical for this phase (Häyrynen 1992). On the other hand the methods of design cannot be considered very mature, because at that time a designer's ability to solve all problems was almost unlimitedly relied on.

Economic growth required better performance from design, both in Finland and in other countries (Quantrill 1995). Also the increasing amount of knowledge was inevitably noticed in design management and organisation. Characteristic for the development of hierarchical design systems and the breakthrough of industrial construction (c 1950 - 1975) was the pursuit of technical and economic efficiency. According to an idealistic way of thinking it was possible to gather all information about the problem thoroughly, process it systematically, deal with all possible solutions and then produce a design with logical conclusions. (Cross 1977, Häyrynen 1992, Lehti & Ristola 1990).

A rationalistic design system fulfilled the needs of an expansive society. A consequent period of uncertainty was, however, the result of rapid growth (c 1975 - 1985). During this period it was characteristic to understand the design process as a creative learning process, a cyclical event and an effort to control instability. However, the rational view of design was strong. Internal inconsistency among designers was also typical of this phase. (Häyrynen 1992).

In the mid 1980s a new way of thinking was created by structural alteration, new economic growth and the antagonism of rationalism and rehumanism (Lehti & Ristola 1990). According to Häyrynen (1992) the 1980s were architecturally tolerant, which was the opposing reaction to rules and standards. This new wave was symbolised by a rapidly changing and knowledge based society (Lehti & Ristola 1990), but creativity in design is emphasised too (Häyrynen 1992).

2.2.3. Architectural design as a creative process

Alvar Aalto is undoubtedly classified into the maestro caste of architects. He emphasises that he mentions his personal experiences without wishing to make them into some sort of method. In any case, he thought that most of his colleagues would know something of the same from their own struggles to conquer problems. He also emphasises that examples are not, of course, related in any way to the good or bad properties of the resultant building. He mentioned them only to demonstrate his own instinctive belief that architecture and the free arts have a common root, a root, which is abstract in some way but nevertheless based on knowledge and analyses stored in our subconscious. (Aalto 1948). Even Aalto was not very productive in numbers of scientific articles, but he is one of the most referred to or analysed publishers. Aalto (1948) has been referred to on many occasions and his original ideas have been developed further, but the idea of Aalto's experiences and practical work is best on view from his original texts. Besides, it could be said that newer descriptions of creative architectural work are not as good as the description of Aalto (1948) is.

"When I personally have to solve some architectural problem, I am constantly almost without exception, indeed - faced with an obstacle difficult to surmount, a kind of *courage de trois heures du matin* (three in the morning feeling). The reason seems to be the complicated, heavy burden represented by the fact that architectural design operates with innumerable elements, which often conflict. Social, human, economic and technical demands combined with psychological questions affecting both the individual and the group, together with the movements of human masses and individuals, and internal frictions - all these form a complex tangle which cannot be unravelled in a rational or mechanical way. The immense number of different demands and component problems constitute a barrier from behind which it is difficult for the basic architectural idea to emerge. I then proceed as follows - though not intentionally. I forget the entire mass of problems for a while, after the atmosphere of the job and the innumerable different requirements have sunk into my subconscious. I then move on to a method of working which is very much like abstract art. I just draw by instinct, not architectural syntheses, but what are sometimes childlike compositions, and in this way, on this abstract basis, the main idea gradually takes shape, a kind of universal substance which helps me to bring the innumerable contradictory component problems into harmony." (Aalto 1948).

A practical experience of Aalto's (1948) work, where the strongly intuitive method has been used is, when Aalto (1948) designed the Viipuri city library he used a strongly intuitive method. He had a lot of time available, a five-year period, to complete the mission. "I spent long periods getting my range, as it were, through naive drawings. I drew all kinds of fantastic mountain landscapes, with slopes lit by many suns in different positions, which gradually gave birth to the main idea of the library building. The architectural framework of the library comprises various reading and lending areas stepped at different levels, while the administrative and supervisory centre is at the peak. My childlike drawings were only linked very indirectly with the architectural idea, but in any case they led to an interweaving of the section and the plan shape, and to a kind of unity of horizontal and vertical construction." (Aalto 1948).

Aalto's (1948) well-known illustration of the meaning of the unconsciousness in creative work is in his article. The name of his article (The trout and the stream) describes the content extremely well. "Architecture and its details are in some way all part of biology. Perhaps it and they are, for instance, like some big salmon or trout. They are not born fully-grown; they are not even born in the sea or water where they normally live. They are born hundreds of miles away from their home grounds, where the rivers narrow to tiny streams, in clear rivulets between the fells, in the first drops of water from the melting ice, as remote from their normal life as human emotion and instinct is from our everyday work. Just as it takes time for a speck of fish spawn to develop into a fully-grown fish, so, too, we need time for everything that develops and crystallizes in the world of ideas. Architecture demands more of this time than other creative work. A minor example that I can mention from my own experience is that what may seem to be just playing with form may unexpectedly, over a long period, lead to the emergence of an actual architectural form." (Aalto 1948).

Architect Petäjä has studied architectural creativity and his concepts of creativity and learning are more art than science. He emphasises, as many other researchers do too, the meaning of emotional and irrational substances in the creative process and in understanding it. (Lehti & Ristola 1990). The question of the link between architecture and the free arts has always been to the fore. Usually it is mentioned as a desire for architecture to have features from sculpture and painting. Various suggestions have even been put forward for cooperation between active exponents of these –"three arts". Aalto (1948) agrees with these desires. He sees that forms in abstract art have been a great stimulus to modem architecture, indirectly admittedly, but the actual fact cannot be denied. On the other hand, architecture has also provided material for abstract art. These two spheres of the arts have influenced each other in turn. (Aalto 1948).

The quality of individual creativity is based on formative phases in life and even the genetic information behind birth (Christopher 1974, Pallasmaa 1975A, 1975B). Creativity, according to Petäjä (1983), is a connective power between individuality and community. Even the best specialists don't have complete control of the possibilities in creativity. There are no prepared solutions for any future construction project, because all architectural problems are unique, but our fundamental expectations towards an environment can be rather similar. It is essential for consequential designing that, between progressive logic and architecture is certain correspondence. (Petäjä 1977). Structures in architecture are forms of reality, and they obtain the contents from human observations and consciousness. Therefore architecture can be seen as both creative and physical design based on facts. To combine features from feelings and individual notions is the mission of creativity. Then creativity arises as ability to combine the space of feelings and reasons as balanced reality. (Lehti & Ristola 1990). Gathered from the former, Petäjä (1977, 1983) sees creativity as designing from conscience.

Academician and architect Reima Pietilä (1987) sees his working as a goal-oriented seeking of the problems rather than solving these problems. He names his sketches metaphors, which represent the references and elements in the background of solutions and not the actual final solution. Professor Aulis Blomstedt has presented a comparison using an architectural iceberg (Fig. 13), which describes the meaning of the ideas and all the factors and elements in the background. The top of the iceberg is the final solution, the project documents, which can be seen as a visual product of the design. Under the visible top, beneath in the depths are the ideas and the invisible sediment of the solution. (Pietilä 1987).

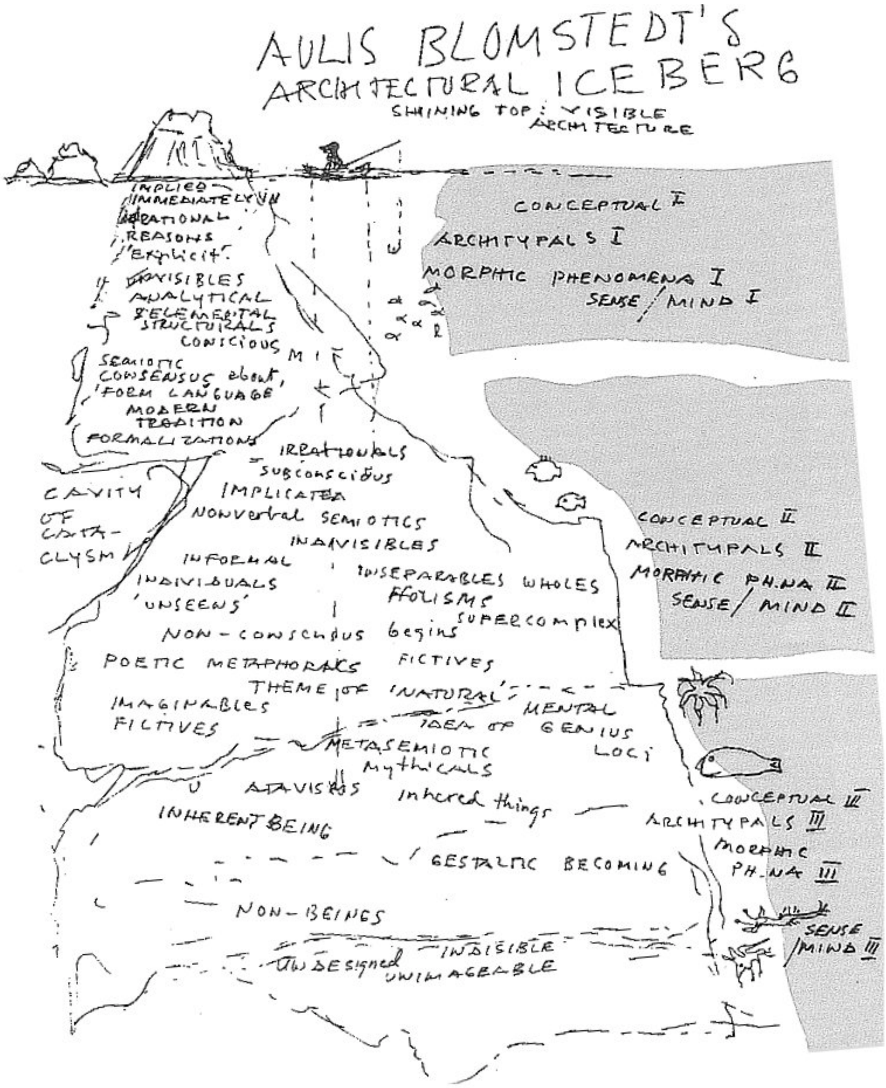


Fig. 13. The architectural iceberg by Aulis Blomstedt (Pietilä 1987).

A relevant origin for design can be found even from an unintentional or absurd concept, according to professor Juhani Pallasmaa (1974), emergence can happen elsewhere than from drawing board. Sketching and sketches can be interpreted several ways and they can be associated with other background motives of drawing. Sociality, functionality, technicality and formality should be considered, when seeking the solution from different standpoints. (Pallasmaa 1993).

Former descriptions present very well the meaning of the subconsciousness in creative design and the amount of factors in design. On the other hand it can be easily noted that the procedures used in a creative architectural design process are quite unique with different designers. Another conclusions of former could be that the creative design process is complex and extensive and therefore precise definition is very difficult to give.

2.2.4. Systematic design

Systematic design theory has tried to develop different methods to search for solutions with logical conclusions. Systematic design pursues the development of methods, procedures and means to design, select and outline complicated problems. (Pahl & Beitz 1990). The design process is, according to systematic design, changing the defined problem to a description of a technical system. It concludes with a certain structure and hierarchy where components and problems are solved. (Hubka & Eder 1992).

A certain structure and hierarchical order are part of systematic design, where entities and tasks are fulfilled. The systematic mechanical engineering design process, presented by Hubka and Eder (1992), contains five main levels (appendix 3). Several activities and a great amount of information are included at all levels. A large amount of information is typical for systematic design, which frequently makes the structures difficult and complicated. The systematic design process (Fig. 14) consists, according to Pahl and Beitz (1990), of the main system S, which is divided into subsystems S_1 - S_5. Subsystem S_2 is divided into even smaller tasks S_{21} - S_{24}. To operate properly the system also needs inputs I_1 - I_3 and output O_1 and O_2. Ullman (1992) emphasizes the meaning of functionality, when dividing a product into operating systems.

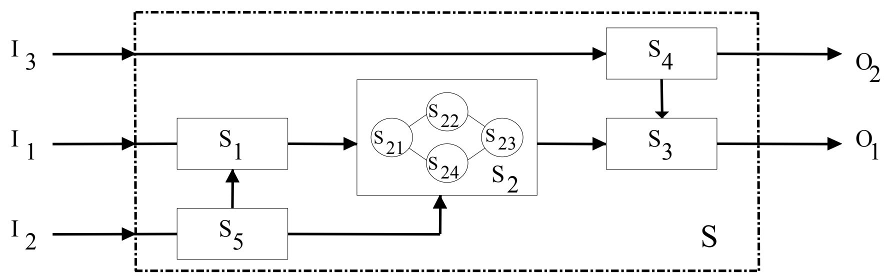


Fig. 14. The main system of the design process is divided into smaller subsystems (Pahl & Beitz 1990).

The system is composed of parts in interaction with each other, which are also independent systems. The comprehensive solution can also be seen as a part of the broader system. The main principle of the systematic design process is that the problem is first divided into sub-problems and then the forthcoming sub-solutions are a connected logical entity. (McLoughlin 1969, Pahl & Beitz 1990).

Systematic design science describes decision-making in the design process as a loop (Fig. 15). These design loops are combined in the design process as an entity, which consists of small steps both forward and backwards in progress of the design process. (Pahl & Beitz 1990).

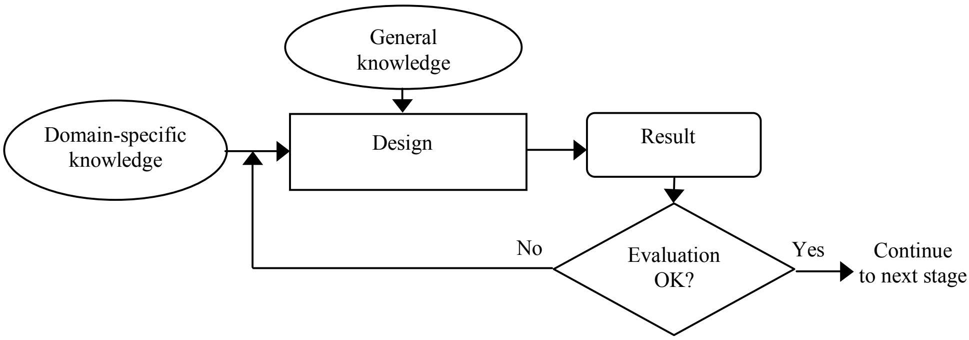


Fig. 15. The design loop (Pahl & Beitz 1990).

Another focused description of the steps in the design process, according to the systematic school, including the preliminary design loop is in figure 16 and all-inclusive process with synthesis-analysis loop is in figure 17 (Pahl & Beitz 1990) (compare to the systematic design process presented by Hubka & Eder 1992, in appendix 3). The original intention of systematic representation is to express the design process in the form of an algorithm so as to be able to automate it.

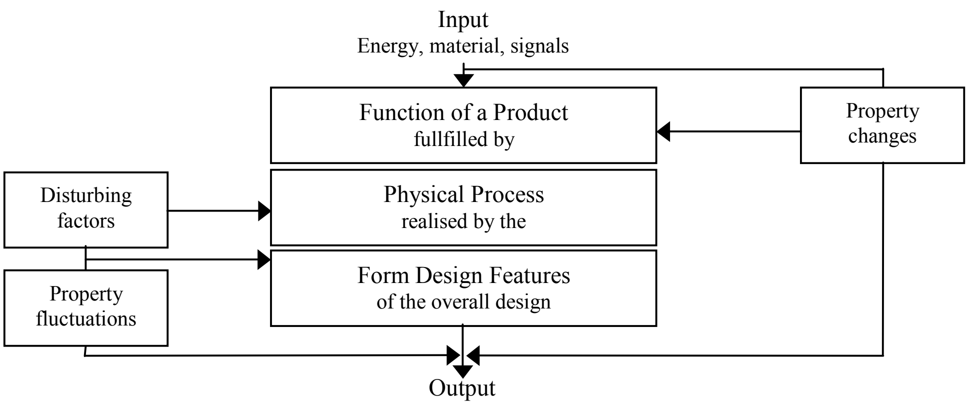


Fig. 16. The systematic presentation of design process (Pahl & Beitz 1990).

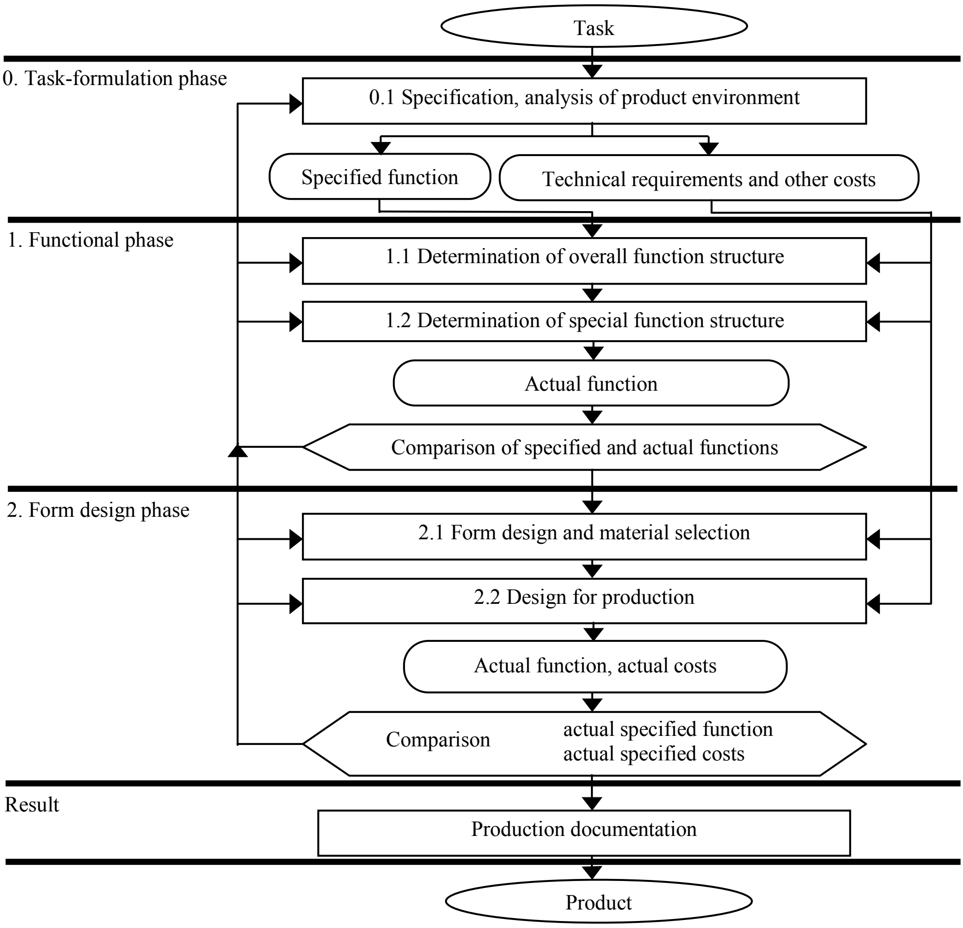


Fig. 17. The phases of the systematic design process (Pahl & Beitz 1990).

Design contains, according to Siirala (1989), several stages of analysis and synthesis. In the analytical part, information is collected and translated into a suitable format. It is a basic tool for gathering information systematically, where structures, features and their consequences of elements are examined. Analysis is a question of identifying, determining, outlining and organizing information in a certain image of a subject. In synthesis different contributory factors of available information are organized as one entity. In constructive activity it is essential that separate solutions are combined to form one active entity. Global or systematic thinking should be applied in synthesis. (Siirala 1989, Pahl & Beiz 1990).

Cross (1994) has developed a simple descriptive model of the design process based on the essential activities of the designer. The end point of Cross' (1994) process is communication of a design, which means ready for manufacturing. Prior to this the design proposal is subject to evaluation against the goals, constraints and criteria of the design brief. The proposal arises from the generation of a concept by the designer, usually after some initial exploration of the ill-defined problem space. Additional similar models can be found from several authors. These models simply describe the sequences of activities that typically may occur in designing. (Cross 1994). Furthermore some models are accurate than others and may have different angle of view or emphasis.

Different systematic methods have been developed in intensifying systematic work and producing new ideas. A few examples of these are; associations with known alternatives, remote models of thinking, brainstorming, lists of questions, double team, 635-method, idea cards, delfi and gallery methods. (Pahl & Beiz 1990, Virkkala 1991). The intention of all these numerous methods is to produce solutions with the aid of a logical and systematic process. The purpose is to produce a great amount of ideas and select the best of them for further processing.

One general way of approaching systematic design is to describe it as an activity containing several stages (as Pahl & Beiz 1990, Hubka & Eder 1992 in appendix 3). The work proceeds by the steps of a list, either straightforward or cyclically. This is very difficult, however, because from the design point of view the most important items take place in the designer's mind and therefore are invisible to outsiders. According to Korhonen (1979) these steps could be:

- analysis of object,
- classification of the features in object,
- valuation of significant features,
- classification of the outside features and relating those local features, e.g. new specification requirements, change in society values and theoretical knowledge,
- analyse of all features or actual design activity,
- testing the plan and
- implementation of the plan.

Siirala (1989) has presented a principle of design process (Table 2). In examination the problem is outlined and forecasts are proposed. Goal setting contains problem iteration and specification for external requirements. Analysing means is outlining the possibilities to achieve a solution. Solution is selecting the best alternative and defining the further processing. Action model contains all parts of the process and can be for instance an architectural design project in preparation for construction. A preparation model is, for instance, a preparation to decision making where selection is eliminated and only alternatives are produced. The mechanical model is the smallest, where means are sought for achieving goals and external requirements. (Siirala 1989).

Table 2. Process steps and form of design in the design process (Siirala 1989).

	Process steps			
Form of design	1. Examination	2. Goals	3. Means	4. Solution
Action model	●	●	●	●
Preparation model	●	●	●	
Mechanical model			●	

Newell and Simon (1972) have presented the human information processing system as a basis for a theory of human problem solving and the purpose was to present a systematic model to solve problems. Their main features of the problem solver were understand the task environment, the task itself, the knowledge about it and the solver who assembles the information for task. Virkkala (1991) has also presented a model for a systematic problem solving process (appendix 2). In every stage systematic work is emphasized, since at the end of every stage there is a mechanism that verifies the accomplished stage. The process begins with recognizing the problem or task. Ambient information and possible solutions are described as facts. Ideas are produced with the aid of systematic methods; the best solution is selected mechanically and developed to an adaptable form. Authorization is meant for those who finally decide about the implementation. In the finishing and implementation stage the idea is simulated and tested to verify the functioning and good final result. A similar model, which Virkkala (1991) presented, has been used at the University of Buffalo. They understand problem solving as seeking information, facts and ideas. They also emphasize, that ideas do not come by themselves, and on the contrary they have to be looked for systematically from somewhere, somehow.

Quality Function Deployment (QFD) is originally generated for product development, but it is a great example of a systematic method to proceed in design. It is a planning tool where the customer's needs are transformed into features in the final product (Fig. 18).

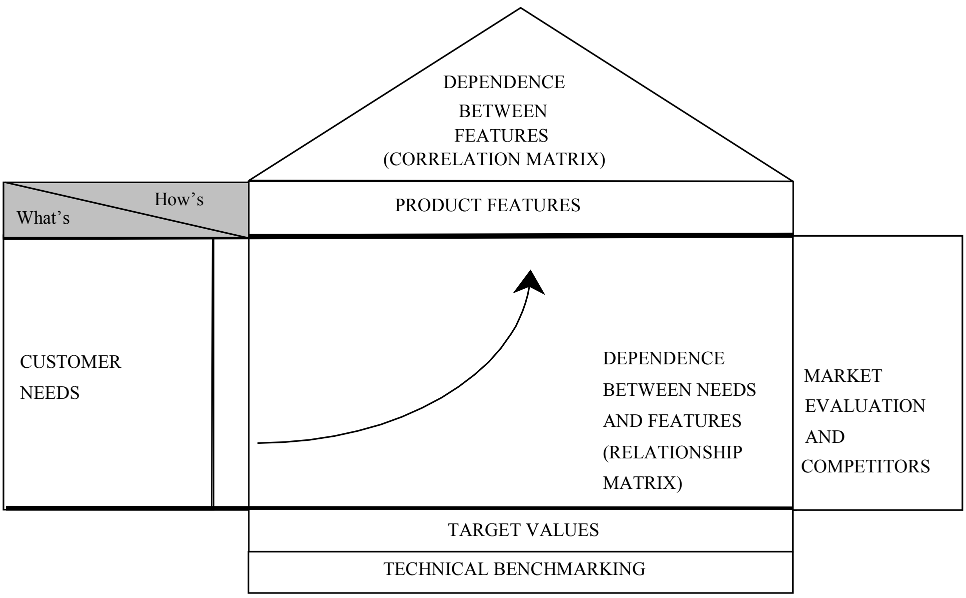


Fig. 18. Contents of rooms in the house of quality (Akao 1990, Ekdahl 1997).

QFD is typical multi-stage process where symbols and matrices are exploited (Fig. 19) (Akao 1990, Turunen 1992). It also aims to achieve high quality products by building every decision on actual facts. QFD contains many decisions, and many of these have to be based on subjective evaluations. Ideal and general experiences about QFD in product development are good (Fig. 20) (Ekdahl 1997). According to Lakka *et al.* (1995) QFD has been a good tool in assembling direct feedback systematically, but also very troublesome in the preliminary design of an apartment house. In designing a restaurant different QFD matrices were made for different parties and the feedback of needs was also good, but in addition to complexity there were difficulties to handle and differentiate needs and features (solutions). When designing industrial development it was noted that different type of buildings require different type of QFD -matrices and also it was noted that personal differences led to different weighting and a different final result.

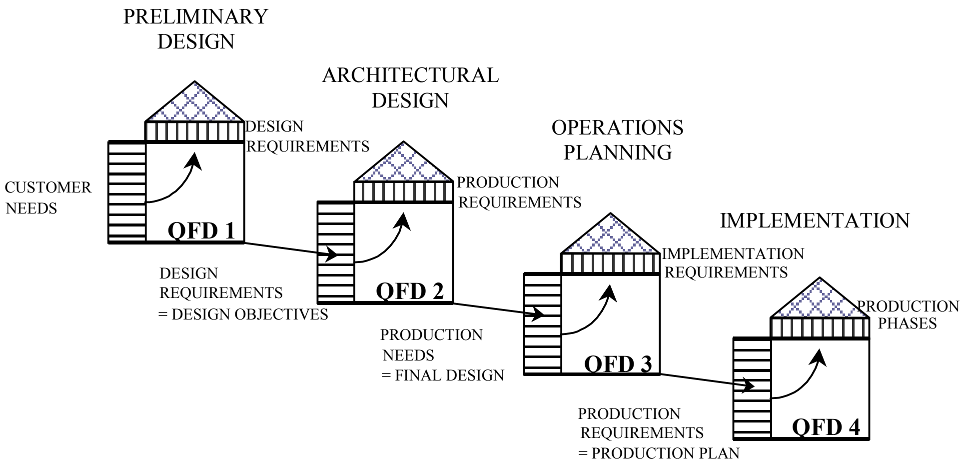


Fig. 19. Applying QFD to architectural design and construction project (Ekdahl 1997, Lakka *et al.* 1995, Turunen 1992).

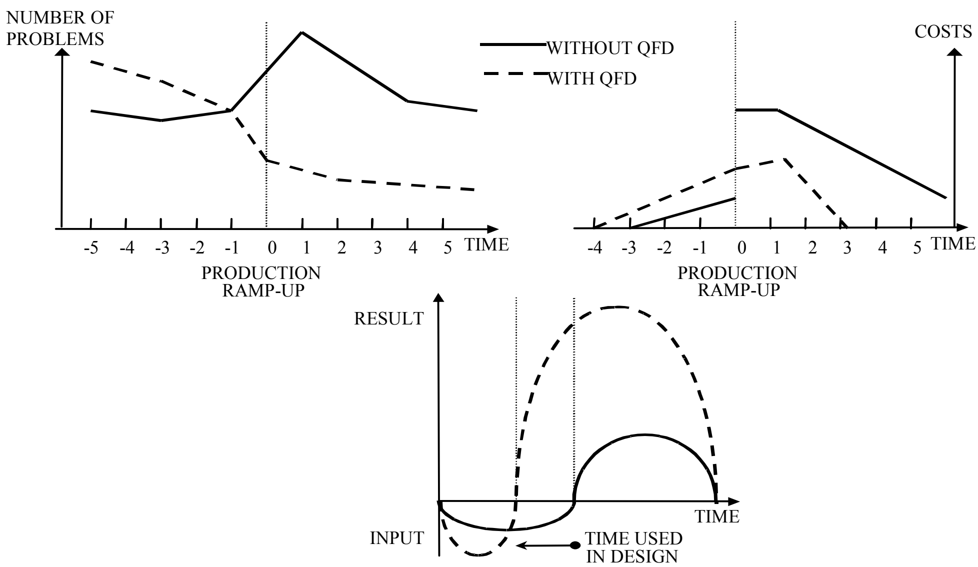


Fig. 20. Problems in production, poor quality costs and the time used in design decline when using QFD (Ekdahl 1997).

2.3. Information technology

Operations of the computer, hardware and software included, are based on a rational system defined in advance. Definitions have already been made when the system is designed, configured and manufactured. Some modifications can be made, but these options are, however, based on original settings. The computer accomplishes various programmed activities based on certain hierarchy and mathematical algorithms or command language. Algorithm is a mathematical term, which refers to the instructions used, decisions and steps to achieve the solution of a certain problem or accomplishment of a certain task. To enable rational and logical activity, hardware and software are based on these definitions, which are realized far earlier than applying or utilization. On the other hand it can be said that computers perform those, and only those tasks, which have been programmed into the system. Although computers and software create a complex system, Booch (1991) sees it as an important factor: ”The complexity of software is an essential property, not an accidental one”.

Booch (1991) has reviewed several typical factors for a complex computer system. Frequently, complexity takes the form of a hierarchy, whereby a complex system is composed of interrelated subsystems that have in turn their own subsystems, and so on, until some lowest level of elementary components is reached. The choice of what components in a system are primitive is relatively arbitrary and is largely up to the discretion of the observer of the system. Intracomponent linkages are, generally, stronger than intercomponent linkages. This fact has the effect of separating the high-frequency dynamics of the components – involving the internal structure of the components – from the low-frequency dynamics – involving interaction among components. Hierarchic systems are usually composed of only a few different kinds of subsystems in various combinations and arrangements. A complex system that works is invariably found to have evolved from a simple system that worked. A complex system designed from scratch never works and cannot be patched up to make it work. You have to start over, beginning with a working simple system. (Booch 1991).

Rather than planning new systems it would be more reasonable to study how these systems relate in interface with user. Then the usability of system is the essential issue to study with. If new elements into computer aided architectural design are needed existing solutions should be evaluated before inventing new ones.

2.3.1. User interface

The User Interface (UI) is used to communicate with the computer system. UI is a general idea used to describe the junction between user and system (Fig. 21). These features are usually divided into hardware and software. For instance CAD system hardware contains printers, plotters, display, keyboard, mouse, digitiser or other pointing device. In addition a system could be controlled with speech, look, movement and gestures. (Kuivakari *et al.* 1999).

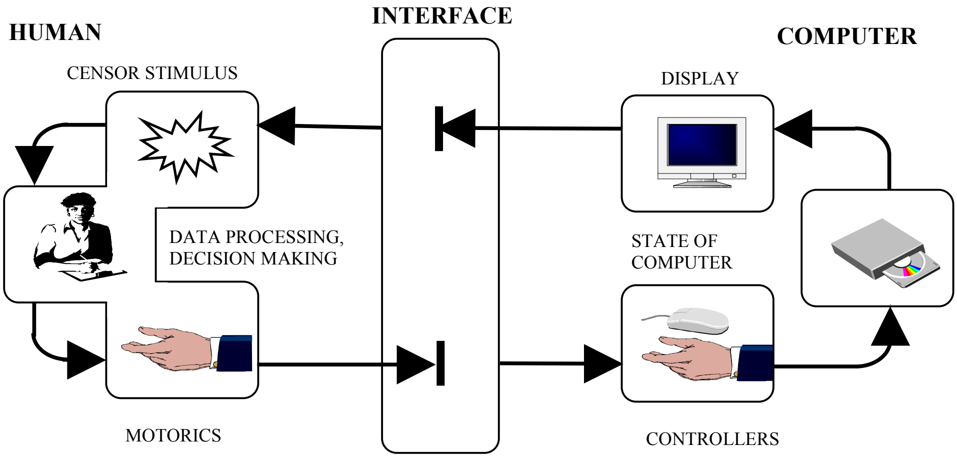


Fig. 21. Traditional outlook of the dense interface between the human and computer (Kuivakari *et al.* 1999).

Typical CAD UI hardware usually follows a certain standard, but the supply of software is miscellaneous. Some applications are general programs for drawing and need a special utility program in order to work properly (e.g. AutoCAD and MicroStation). Straight applications for architectural design work without additional applications (e.g. ArchiCAD). (Kiviniemi & Penttilä 1995).

Operations in different programs can be viewed and controlled through several windows, typically in CAD systems. Windows can be either a two-dimensional (2D) template or three dimensional (3D) information space. (Metsämäki 1995). These views are for instance plan cross-section, elevation or isometric view. Different toolbars, menus and icons are also windows, which are intended for drawing, manipulating and producing elements. (Kiviniemi & Penttilä 1995). In designing displays or user interface communication common sense is essential, because communication should be easy. Even a well-structured display is useless if the user cannot discover the meaning of the symbols. On the other hand different people can understand the same symbols in different ways. (Metsämäki 1995).

The Graphical User Interface (GUI) is configured with icons and shortcuts. The purpose of the GUI is to make communicating between humans and systems more effective. It has been studied, that information intermediation is faster by using e.g. graphical icons than a keyboard, pull-down menus or by using a Character User Interface (CUI). Microsoft and Zenith have found that GUI intensifies work over 35% compared to CUI. Also the failure rate in work is 58% smaller with GUI than CUI. (Metsämäki 1995). In practice modern user interfaces are based on GUI and the majority of modern operating systems provide a graphical user interface. Applications typically use the elements of the GUI that come with the operating system and add their own graphical user interface elements and ideas. The Body User Interface (BUI) (Fig. 22) uses the whole human body on a wide scale to operate with the system. It strives to be a less stressing, more informal and more natural way to operate with the system. This can be done with a thinner interface between the human and system. (Kuivakari *et al.* 1999).

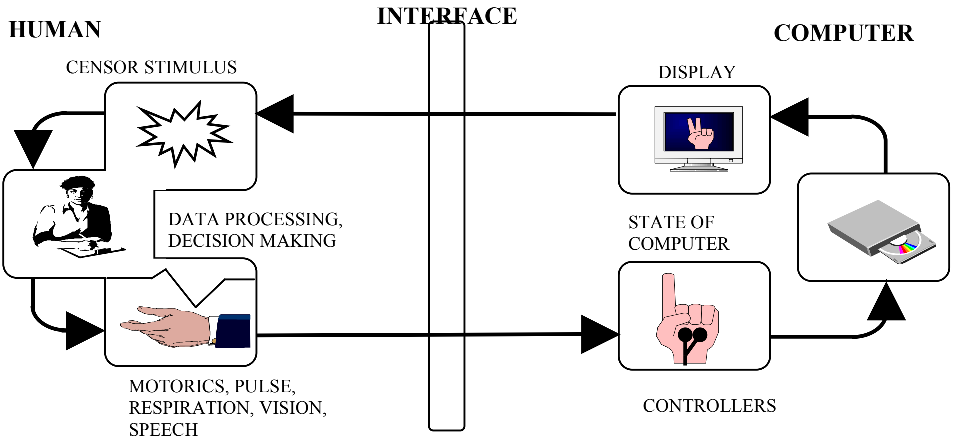


Fig. 22. Outline of the Body User Interface and thin interface between the human and computer (Kuivakari *et al.* 1999).

For example a virtual glove, scanner and different sensors are used in addition to traditional input devices in BUI. It involves instruments, which can be connected to a human sensory organ (touch, pressure, vision, breathing etc.). So eyes, feet, respiration, balance, pulse or head movement can control the computer as hands do. Traditionally hands control systems. BUI doesn't concern only input, output devices transfer the information from an electronic form to one suitable for a human. In addition to traditional displays and sound the system can respond by vibration or temperature. (Kuivakari *et al.* 1999).

The general trend in developing user interfaces is to understand more of the human basic functions. For example BUI is primarily a cognitive framework and only secondarily aiming at an actual device or application. (Kuivakari *et al.* 1999).

2.3.2. Usability

Interactive user interfaces have certain characteristics; symbiotic, continuous and constant interaction between the system and user, fast interdependency and psychophysical participation of the user and aspiration to improve intelligence of computers. An additional specific feature of interactivity is mutual and parallel action of the system and user. These features will not necessarily occur in the same application or system. Some computer games are good examples of goal oriented interactive applications, while media art consciously refuse to pursue a certain goal in design. (Kuivakari *et al.* 1999).

Interactivity is one character of usability. Usability is the quality measure of a user interface. Usability according to ISO 13407 (1999) is "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". *Usability means focusing on users*. The goal is to develop functions and features for a system, which can be used by actual users in real situations. *People use a system to be productive.* A certain system is enabled in order to gain a benefit or to be more productive. The system must be easy to learn and use in terms of time. *Users are busy people trying to accomplish a task.* Usability is often compared to productivity, because no one gets paid for time just sitting at a computer. *Users decide, when a system is easy to use.* People will have different experiences of using the same system. (Dumas & Redish 1993, Preece *et al.* 1994). The usability is not necessarily in the system, but it is in the experience of different individuals of the system. Usability engineering is an approach to system design in which levels of usability are specified qualitatively in advance and the system is engineered towards these measures.

The usefulness of a system is determined by its utility and usability (Fig. 23). Utility means that the system does something that people care about. If the system does something irrelevant or if it doesn't solve the main problem, then it doesn't matter whether it is easy or difficult to use, it will be a poor system in any case. Usability means as described above, that can the user use the system and can he or she do so effectively. Even if the system does exactly the right thing in theory, it will still be a poor system in practice if the user cannot figure out how to get it to work. (Nielsen 1995).

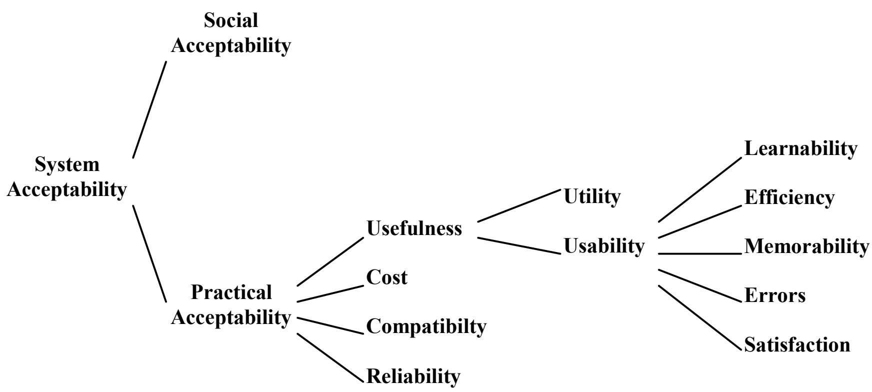


Fig. 23. Defining usability by typical ways of measuring it (Nielsen 1995).

Ease of learning means picking novice users for a system and measuring how fast can he or she learn it sufficiently well to accomplish basic tasks? (Fig. 23) Efficiency of use is difficult to measure. When an experienced user has learned to use the system, measure how fast can the task be accomplished. Memorability can be tested by getting samples from casual users (away from the system for a certain time), by measuring time to perform typical tasks (or does the user have to start over again learning everything every time). Error frequency and severity can be counted as minor and catastrophic errors made by users while performing some specified task. Asking subjective opinions from users (questionnaire, interview), after trying the system for a real task measures satisfaction. (Nielsen 1995). Nielsen (1995) has reviewed basic characteristics, usability heuristics, which should be included in the optimal system or user interface (Table 3). The principles are fairly broad and apply to practically any type of interface, including graphical and character-based interfaces.

Table 3. Usability heuristics should be followed by all user interface designers (Nielsen 1995).

Simple and natural dialogue	Dialogues should not contain information that is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility. All information should appear in a natural and logical order.
Speak the users language	The dialogue should be expressed clearly in words, phrases and concepts familiar to the user, rather than in system-oriented terms.
Minimize the users memory load	The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
Consistency	Users should not have to wonder whether different words, situations or actions mean the same thing.
Feedback	The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
Clearly marked exits	Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue.
Shortcuts	Accelerators, unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users.
Good error messages	They should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
Prevent errors	Even better than good error messages is a careful design that prevents a problem from occurring in the first place.
Help and documentation	Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, be focused on the user's task, list concrete steps to be carried out and not be too large.

2.3.3. Opportunities

Artificial intelligence is one of the new disciplines in information technology. It strives to be close of human thinking. So far most computer applications have been developed to intensify man's action in his weaknesses. It is an interdisciplinary tendency of information technology, where symbolic processes imitate human thinking. (Paulson 1995). Knowledge connected to artificial intelligence is also understood as utilizing the knowledge. (Kiviniemi & Penttilä 1995).

An expert system is a computer program which makes decisions on behalf of man by using the heuristic knowledge in the computer's memory. It can solve precisely defined problems and solutions are based on the information in the memory of the system. Expert systems differ from usual applications among other things structurally, because they use explanatory information instead of operational information. (Paulson 1995).

Cha and Yokoyama (1995) have presented a prototype of expert system. The hierarchy (Fig. 24) and data system is based on information, pictures, tables, instruction and regulation formulas for discipline and limitations. The designer's personal information and experiences can also be attached to the data system. Task and the process are described in the problem-solver, and the modeller generates a three-dimensional model from two-dimensional information. The idea of the user interface is to create a connection between designer and the information available. (Cha & Yokoyama 1995).

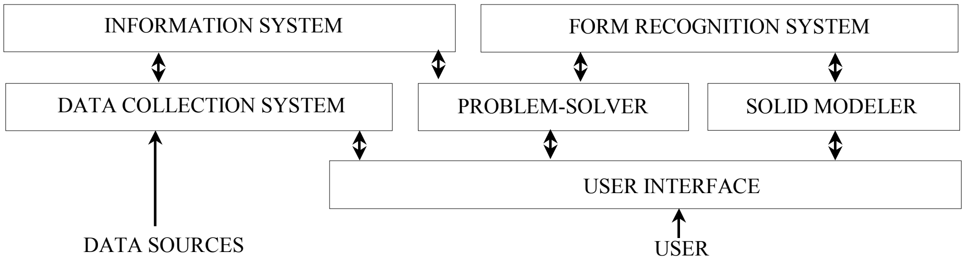


Fig. 24. A structure of example expert system (Cha & Yokoyama 1995).

Expert system distinguishes and assorts fundamental information into a usable, effective and optimised form, which is called conversed information. The system strive to assemble information from several specialists into one database and forms patterns and instructions from amassed information. Therefore expert systems are sometimes called rule systems. Different systems use different operations in data processing, but some of the most common are facts, logical impressions, rules, semantic networks and frameworks. Systems are using some of these elements to analyse and combine the hierarchic entity with the aid of links and residual information. (Cornelius 1998, Paulson 1995). To aid human thinking and solving-problems in demanding tasks is the intention of expert systems; therefore they should be called consulting systems. For architects it would be natural to develop consulting systems for constantly increasing rule collection. (Kiviniemi & Penttilä 1995).

A *neural net* is an artificial representation of the human brain that tries to simulate its learning process. The term artificial means that neural nets are implemented in computer programs that are able to handle the large number of necessary calculations during the learning process. Like the human brain, a neural net also consists of neurons and connections between them. The neurons transport incoming information on their outgoing connections to other neurons. In neural net terms these connections are called weights. The electrical information is simulated with specific values stored in those weights. (Chen 1996, Haykin 1999).

Artificial neural networks (ANN) are collections of mathematical models that emulate some of the observed properties of biological nervous systems and draw on the analogies of adaptive biological learning. The key element of the artificial neural network paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements that are analogous to neurons and are tied together with weighted connections that are analogous to synapses. (Haykin 1999).

The main idea behind *fuzzy logic* is that there are many cases where true and false or on and off fail to describe a given situation. These cases require a sliding scale where variables can be measured as partly on or mostly true and partly false. Traditional set theory is based on bivalent logic where a number or object is either a member of a set or it is not. With fuzzy logic, an object can be a member of multiple sets with a different degree of membership in each set. A degree of membership in a set is based on a scale from 0 to 1 with 1 being complete membership and 0 being no membership. In a control system, an output is calculated based on the amount of membership a given input signal has in the configured fuzzy sets. Each combination of sets is configured to have a specified output, and the fuzzy control system calculates an output based on the weighted sum of the amount of membership in each set. Information flow through a fuzzy control system requires that the system inputs go through three major transformations before becoming system outputs. (Chen 1996, Cornelius 1998).

Present knowledge, software and hardware resources allow even the most peculiar aids for design. Visually effective simulations and virtual reality user interfaces can and already have created a totally new media for architectural design. The designer can, for instance, walk in the designable building and change materials, colours and lightning to test and improve the final output (Novitski 1992).

2.4. Computer aided architectural design

2.4.1. Design principles

According to Kiviniemi and Penttilä (1995) the degree of utilization in CAD varies a lot (Fig. 25). CAD is utilized most in documenting the completed idea, when younger designers do the realization. In practice this means computer aided drawing. Computer aided design can be considered when it is utilized during the whole design process and also experienced designers exploit the possibilities. Then the CAD is used in sketching and generating alternatives, too. Utilizing CAD is advanced when in addition to the above also dimensioning, bill of quantities and other project documents are produced in integration.

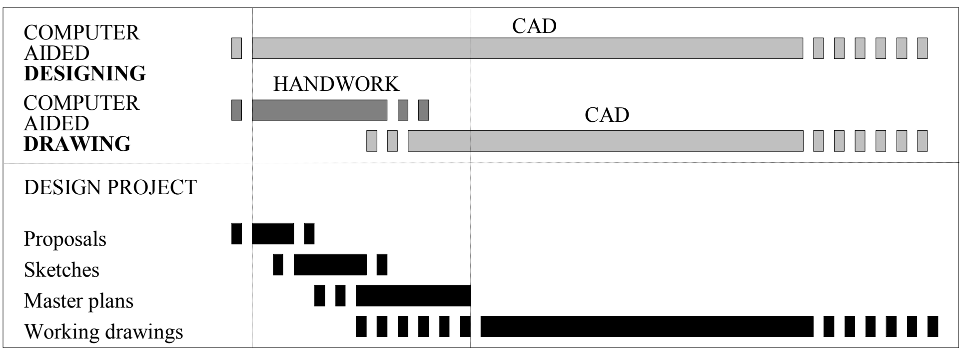


Fig. 25. Computer aided designing and drawing and ”handwork” in design project (see Kiviniemi & Penttilä 1995).

On the general level all processing of graphical information is included in CAD. In architecture CAD can means producing all documents with the computer. In addition to drawings, different bills of quantities like doors, windows and fitments are directly attached into the architect's work. In reasonable CAD these bills of quantities can be produced straight from the database. Building specifications and other text documents are, however, produced with separate computer applications, at least so far. (Kiviniemi & Penttilä 1995).

The ideal situation from the design point of view would be the possibility to process the building in three-dimensional models, which almost exactly matches the forthcoming building. Managing the model especially geometrical information is difficult and the size of the file will easily become too big to handle. In present applications there are two main solutions to treat the three dimensional information – vector graphics and object oriented. Applications with vector graphics (e.g. AutoCAD) are based on graphical elements, vectors and lines and they are generally used drawing programs. In contrast object feature specifications are the basis of object-oriented applications (e.g. ArchiCAD), which have a logical connection to real functional elements (Kiviniemi & Penttilä 1995). E.g. in ArchiCAD objects consist of three independent parts; information linked to bill of quantities, symbol definitions and two and three-dimensional Geometric Definition Language (GDL) –descriptions (Virolainen 1994). In addition some of the present applications behave like object oriented, but e.g. in editing or in modifying they loose their intelligence and turn into usual vector graphics applications.

Working with vector graphics application in based on drawing lines, curves or circles and therefore it is very laborious to generate three-dimensional models. However lines and curves can be amassed into blocks or symbols and saved into a directory. Later these blocks can be inserted with varied dimensions or features. Vector graphics doesn't contain attribute information directly about functional elements and they cannot be called intelligent applications. (Ekelund *et al.* 1992). Working can therefore be called computer aided drawing and it differs a lot from object oriented applications. The majority of applications in numbers are based on vector graphics. (Kiviniemi & Penttilä 1995). Anyhow, most of the general programs, like AutoCAD, have sub-applications which utilize the environment in the main application. E.g. PomARK and ARKsystems are special applications developed in architectural design and use the framework of AutoCAD.

Almost all present applications are based on working on two-dimensional levels, but in some programs the three-dimensional model evolve at the background and can be seen from another window. Three-dimensional models can be divided into wire frame, surface, space and rendered model (Fig. 26). The majority of 3D applications can produce wire frame or surface models, but all applications cannot make the space model. The wire frame consists of lines in the edges of the object, and the surface model is the surfaces of the object represented with visible lines. The space model describes the real object. (Davies *et al.* 1991, Holvio 1993, Medland 1988). Rendering means producing coloured and shaded pictures. Colour, brightness, material and transparent features, lights and shadows are added into space models (Kiviniemi & Penttilä 1995).

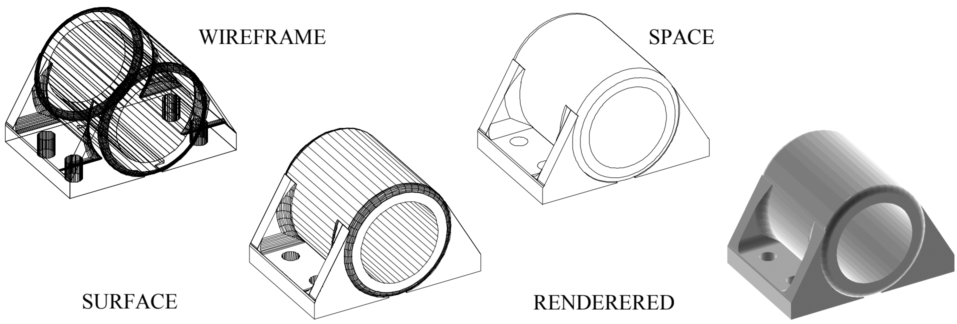


Fig. 26. Three-dimensional wireframe, hollowbox or surface, solid or space and shaded or rendered model from a bearing housing (Mitchell 1994, Tuomaala 1995).

Computer aided design and drawing is always done in real measures and the final scale of the plan doesn't play any role. Even the biggest drawings can be processed in one entity, and there is no need to split them. (Penz 1992). The picture in the screen doesn't have any certain scale, which may cause some problems to those designers, who have used a certain scale for a certain type of drawings. But for those who haven't got used to operating with scale, designing with real measures may be easier. (Kiviniemi & Penttilä 1995).

According to Kiviniemi and Penttilä (1995) computers have changed the time used in certain phases in design (Fig. 27). The most significant changes are in the sketches and working drawings. Generally the differences between phases have become even. Due to computers the workload has moved to the early phases of design.

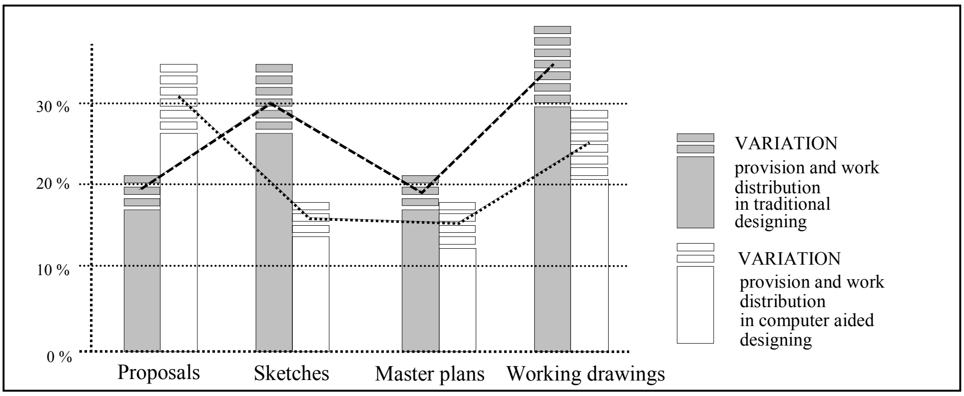


Fig. 27. Variation of designing activity in traditional and computer aided design (Kiviniemi & Penttilä 1995). The comparison is done with relative weighting of the amount of work.

2.4.2. Product model based design

Due to the development of information technology, computer aided building product models are possible to construct. The aim is to combine architectural and structural design in order to gain substantial information e.g. for the needs of quantity surveying or building. (Naaranoja 1997). The building product model (BPM) consists of concrete product data model and a structural entity of the organized information. It analyses and assembles the data describing the building, but not the data for the printouts (drawings). The main purpose of the model is that the same data is presented only once and the model contains links to the database. (Heikkonen *et al.* 1995, Leinonen 1996).

The Ratas –product model (Fig. 28) was developed in Finland. It analyses and frames the information in design, construction and facility management in fact all information in a building. (Heikkonen *et al.* 1995, Leinonen 1996). The building product data model is a general product model system, which determines the data needed in representing the design and the building (Björk *et al.* 1991). It represents the system to organize data and the data structure in a building (Penttilä *et al.* 1991).

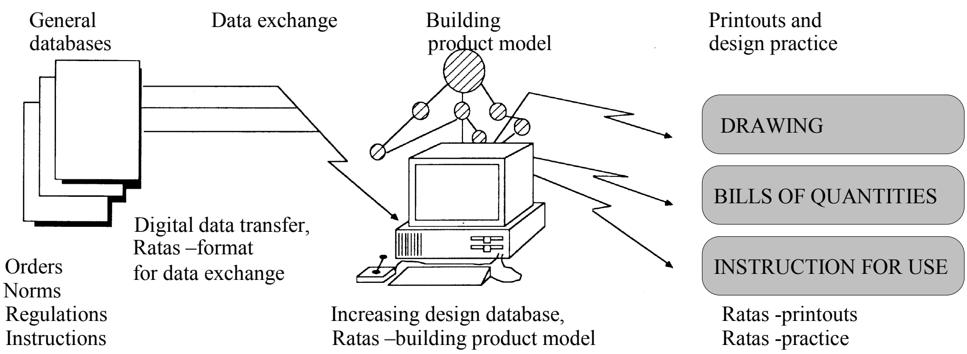


Fig. 28. The structure of Ratas model (Enkovaara *et al.* 1988).

A general database can contain e.g. regulations and norms. Between product models a general standard for data transformation (e.g. STEP – Standard for the Exchange of Product Model Data, EXPRESS – Information Modeling Language and IGES – Initial Graphics Exchange Specification) and is needed in order to utilize information effectively in databases and inside the design file. From the design point of view the product model or database of building and possible outputs is essential. The product model forms a database system, which represents the design information in the object oriented relational database. All information is in one database, and it is completed during the design and construction project. Then the information can be utilized during the whole life cycle of the building (Fig. 29). A fundamental requirement is to eliminate the overlapping work and multiple data. In design this is best achieved when additional information can be later attached to the database and thus information is created only once. (Kiviniemi 1994).

The structure of concepts is created for the product model in order to advance the development of compatible designing applications based on consistent data definition. This is based on the hierarchical definition of items according their features. Items (e.g. area, building, wall, board and nail) in the system are processed as objects, and these items have attribute features (e.g. length, weight and strength). Moreover objects in different levels can create new objects e.g. reinforced concrete, where steel and concrete are also itself independent objects. Relations present the connections between objects, which eventually form the building product model entity. (Hannus *et al.* 1988, Heikkonen *et al.* 1995).

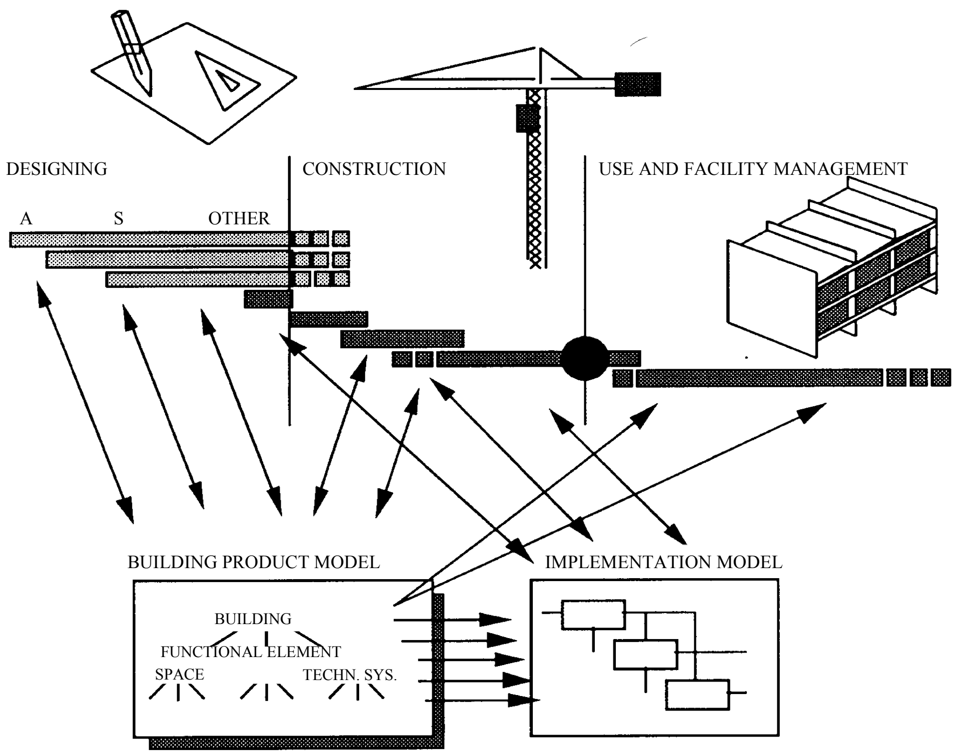


Fig. 29. Connecting the product model into the life cycle of the building (Penttilä *et al.* 1991).

The Ratas –product model contains five abstraction levels (Fig. 30) (Enkovaara *et al.* 1988). The purpose is to divide the building into appropriate entities from the designer point of view (Björk 1989). In upper levels objects represent the functional requirements of the building and the main selections in design. In lover levels objects determine specific information of the building and its functional elements. Design proceeds from up to downwards, when lower level objects are linked to at least one upper object. (Mattila & Leinonen 1995). The essential in the level system is not the number of levels, but some kind of sorting method in the structure of the product data model in order to divide the information content into separate levels (Penttilä *et al.* 1991).

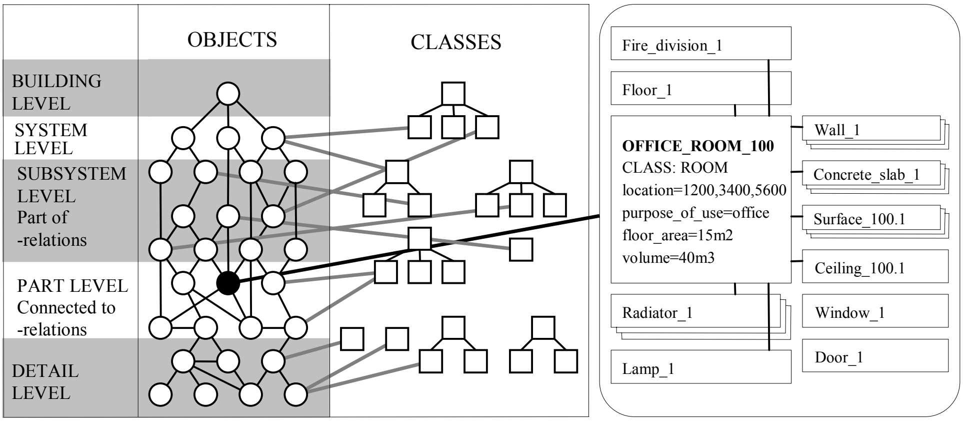


Fig. 30. Objects, relations and class hierarchy in the Ratas -model (Enkovaara *et al.* 1988), and example of class from the part level (Björk 1995).

Attributes or object features are not directly linked to objects. Classification (Fig. 30) is formed, where object features are determined (Hannus *et al.* 1988). Every object is linked at least into one class, where it inherits the attribute. Every attribute is determined only once for one abstraction level, when upper level attributes inherit to a lower level they set more specific features in addition to the former. (Mattila & Leinonen 1995).

Luiten (1994) has developed the building product model (BPM) (Fig. 31) by extending the STEP –project modelling approach. His BPM uses separate models to present abstraction mechanisms and relationships between objects.

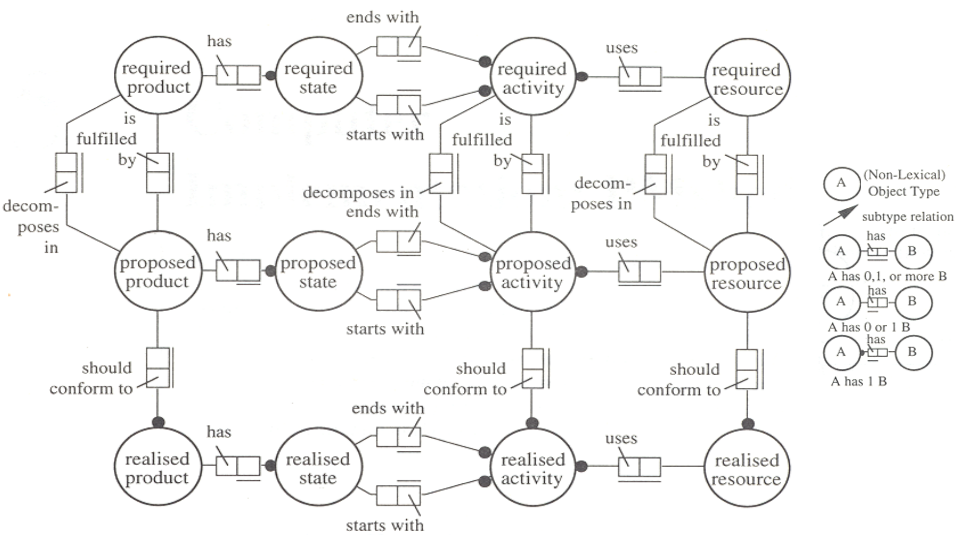


Fig. 31. The kernel of a BPM as a combination of the product activity model and the consideration model (Luiten 1994).

2.4.3. An example of an intelligent design system

At the university of Kaiserslautern a prototype of an intelligent design system has been developed (Mattos *et al*. 1991). It is realized using the knowledge base management system KRISYS. The system integrates all relevant information in the designing of one-story houses into a product model. The design process is divided in functional, topological and geometrical design aspects. The system is also based on a data management system, which integrates the artificial intelligence and database system.

The application consists of subsystems, when the model is examined from separate viewpoints. In the functional aspect the use of rooms, connections and relations between them are considered (Fig. 32). Features of these relations are in the system memory, and the application forms different proposed decisions based on these functional requirements. (Mattos *et al*. 1991).

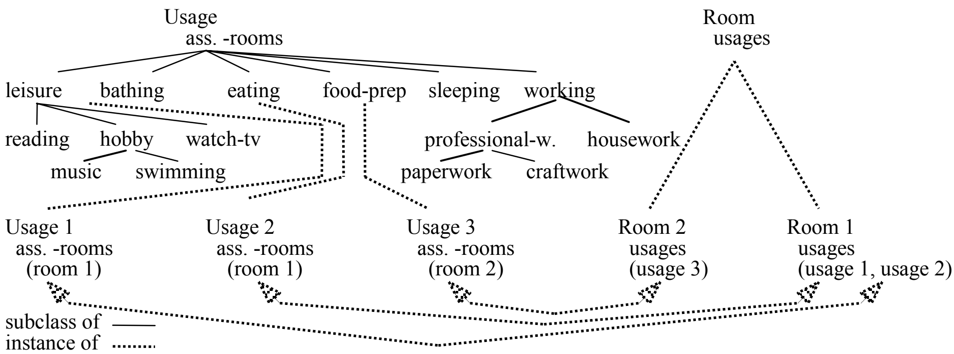


Fig. 32. Representation of functional aspects in KRISYS (Mattos *et al.* 1991).

In the topological aspect the building is examined according to the location and adjacency of rooms (Fig. 33). Alternatives are sought for room disposition. The application primarily compares orientation and adjacency primarily specified according to usages and not to rooms. The application forms different proposed decisions based on the given input. (Mattos *et al*. 1991).

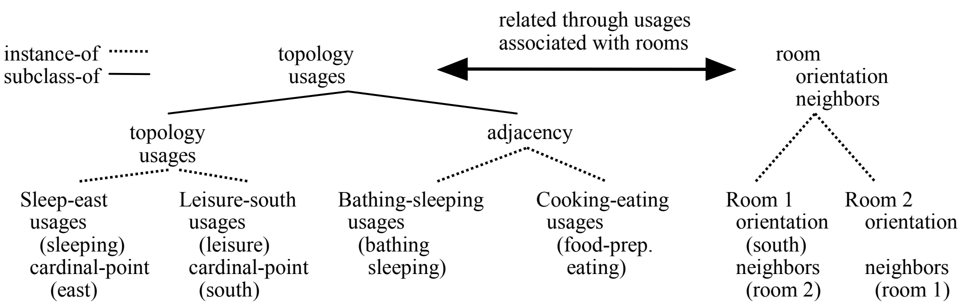


Fig. 33. Representation of topological information (Mattos *et al.* 1991).

Geometric aspect is fundamental for actually representing and producing an architectural design where the variable is area (Fig. 34). From this point of view a house consists of several areas, which may be split into sub-areas, which are finally identical to specific rooms. All areas are instances of the class area and thereby inherit geometrical attributes like position, dimension and size. (Mattos *et al*. 1991).

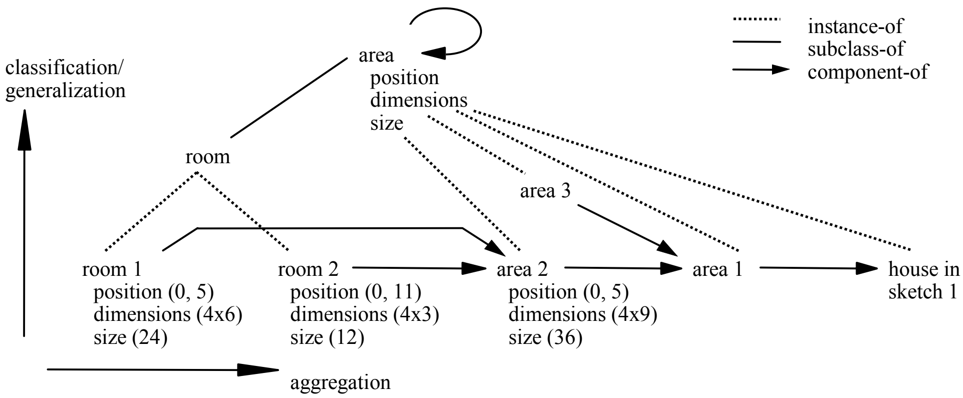


Fig. 34. Representing the geometry of an architectural sketch in KRISYS (Mattos *et al.* 1991).

The fundamental idea behind KRISYS is locating rooms, their functions and relations. In an entity these can be detected as different viewpoints hierarchies. E.g. the size and usage of room are closely related to each other. Anyhow, in practice the system doesn't work properly in all circumstances. (Mattos *et al*. 1991).

3. Creative computer aided architectural design

3.1. Creative and intuitive architectural design - a deduction from theory

Creativity is the ability to produce new ideas and solutions (Drabkin 1996, Heikkilä 1987, Ruth 1984, Virkkala 1991). It is a normal activity of the brain and the whole human body; it is also a primary quality of every human being. (Bergström 1984). Using intuitive methods man can solve problems, which cannot even be determined logically (Christopher 1974, Richards 1974). To research and develop the ability to be creative we should first recognize the existence and the mode of action of our four basic human functions: conscious mind, subconsciousness, motorics and senses. These human parts are in co-operation with each other, making our activities and the different tasks of life possible. Science knows the least about our mysterious subconsciousness. We cannot consciously leaf through our subconscious mind nor is the detailed investigation of its operation easy. (Tuomaala 1995). Anyhow modern medicine and especially psychiatry accepts the existence of subconsciousness, although the location is not determined.

Different practical observations can be made, which are at some point fictional because detailed authentication is very difficult. If the creative theory explains several observations as contradictory, they can be considered as complementary, at least until some discrepancy is indicated. (Harth 1993). The theory of creative architectural design presented in this chapter is based on Tuomaala's (1992, 1995, 1996, 1999) work. His concepts of creative mechanical engineering design are construed to be applicable to architectural design. The construction is based on literary findings, experiences from practice and interviews with specialists in architectural design. These findings have been made multidisciplinary, because features and confirmation of several phases has been sought for instance from medicine, psychiatry, pedagogics, history, creativity research and the research of Nobel prize winners, in addition to architectural and mechanical engineering design. Anyhow the presentation is made for architectural design and may differ from concepts and terms used in the general creativity research literature, because of the engineering point of view. As a reminder of the principles of qualitative research and hermeneutic approach, the theory constructed and presented is one possible way to illustrate creative design, which relates to the background and the preliminary knowledge. Creativity is a large and complex activity. In the following the features of creative, intuitive and subconscious design is approached and illustrated in several ways.

3.1.1. Human information processing

Descartes' aphorism "I think therefore I am," describes logic and rationality. According to Damansio (1994) rationality is based on neurological feelings in social situations: "I feel therefore I think". Feelings are interpretations for changing, experiencing and identifying emotions. Mario Botta's architecture comes thinking and feeling. The difference between these is only theoretical and in creative work both are needed (Broner 1982). Thinking is composed of logical and rational substances, which architects learn during their career. Feeling the architecture is influenced by irrational, poetic and subjective autobiography elements.

A system of human functions can be divided into conscious and unconscious thinking, motorics and senses (Fig. 35). Man consciously controls his actions only to some extent. We use our five main senses to perceive events around us and in ourselves. Clearly we also have other inner senses, for example, a sense of balance. Perception processing takes place both in the conscious mind and in the subconsciousness. The motoric consisting of our hands is controlled either consciously or subconsciously. Simultaneous controlling is also possible. Because of this control we are able to utilize our motoric parts, for example, speaking, reading, writing and walking. At the conscious level almost all operations can be controlled. The heart, as an exception, can be affected only indirectly. Respiration can be controlled either fully consciously to some extent or partly consciously or for instance in sleep totally unconsciously. (Tuomaala 1995).

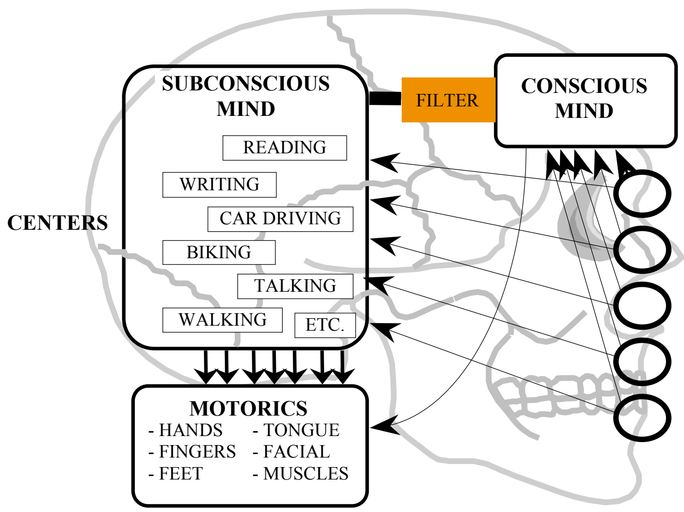


Fig. 35. A system of human functions (Tuomaala 1999).

Human information communication can be illustrated as the interaction between conscious and unconscious thinking and also the connection of human brains to motorics and senses (Fig. 36). One possible presentation contains intercommunication circles, one connection is “pneumatic” (conscious and unconscious) and the other is “electric” (connections to motorics and senses). Both consciousnesses dispatch information to motorics (output from human mind) and senses (input to human mind) receives observations from motoric action and from the environment. Observing (input collection) increases the pressure in the subconsciousness and shakes the funnel when the connection to the consciousness opens up. Subconscious learning is emphasized by motoric action and sense perception (e.g. learning to ride a bicycle, you cannot learn to ride even the manual is 5000 pages long or the world champion teaches you – you need to have personal experience of riding a bike) (see Kolb 1984, Schön 1987). These actions allow the information to be absorbed down to the subconsciousness. It requires sensitivity, humbleness and reducing the pressure temporarily to utilize ideas produced in the subconsciousness. Continuous and powerful conscious thinking increases the pressure in the conscious mind, which restrains the ideas from the subconsciousness. This usually happens when a problem is actively processed, but after relieving the mind works and creative ideas are able to come as insights.

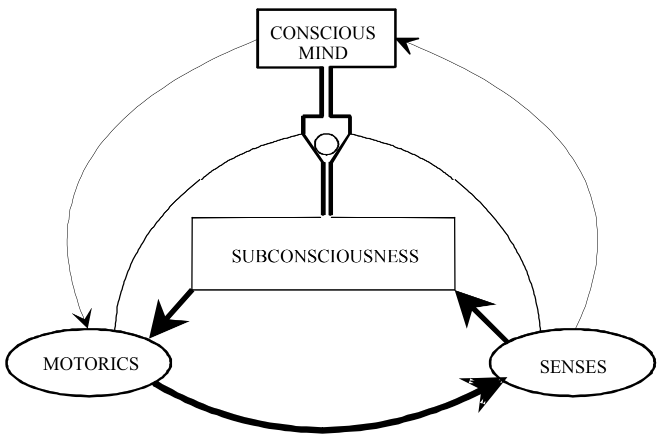


Fig. 36. An engineering model of human information processing and communications. The subconsciousness has a larger memory storage and the information circle is much faster than the conscious mind. (see Heikkilä *et al.* 1996, Tuomaala 1996).

Levels of thinking can be seen as a human central processing unit, where information is in some way processed and organized. As figures 35 and 36 present, human observing is done by senses as input receiver and manipulator. In contrast when both levels of thinking produces human action, motorics can be seen as a transmitter of output signals to outside the human information system.

Subconsciousness is the other dimension of human thinking. The structure and activities of our subconscious mind is unknown, but it is anyhow a large store of information. A huge amount of skills, abilities and knowledge is recorded during a human's life. According to Freud it contains everything that the individual has experienced after his birth. In contrast Jung thought that it can also even contain memories from ancestors. (Pallasmaa 1993). Regardless of the recording mechanism the subconsciousness manipulates this information in some way so far unidentified. When observing our own actions more accurately, it can be noticed that they are more or less automatic. For instance walking, we don't need to consciously control our walking, but it is controlled, however, in some way. And if we try to consciously control our walking it becomes a lot slower and unstable. Tuomaala's (1995, 1999) practical observations are:

a) Subconscious action is faster and more accurate than conscious action.
b) In subconscious actions senses can be read directly and motorics are controlled directly without the help of the conscious mind.
c) When it comes to the use of energy subconscious action is economic.
d) All subconscious action has once been learned consciously. Learning may be difficult and changing something once learned to the automatic level is very hard to do later.

Another example of the effectiveness of unconscious mind is a dream lasting a few seconds, thousands of words and a lot of time are needed to interpret it. In contrast e.g. riding a bike doesn't succeed without subconscious control. Ability in the subconsciousness has to be learned with senses and motorics thorough the conscious mind. Simultaneous interpreters need also subconscious abilities, when listening to speech in one language and translating it simultaneously to other.

It is interesting to note that in thinking e.g. designing all of the best ideas are attained apparently by chance almost without exception. Then ideas arrive to consciousness most probably from subconsciousness through subconscious information. Thus the subconsciousness has processed, manipulated and organized information with undefined processes. (Relster 1997, Tuomaala 1995). Then conclusions from Tuomaala (1995) are:

a) The exact defining and description of a task to learn does not help learning. On the contrary, it may even make it more difficult (some definitions are a necessity).
b) In some cases learning without physical contact to the task is impossible. It takes practical training to learn more complicated combinations of skills. An essential part of practical training is the insight when it is recording the movements into the subconscious mind.
c) Learning occurs when we get the insight. This is purely a subconscious process.
d) The action controlled by the subconscious mind is, when needed, much faster and more accurate than under the control of the conscious mind.
e) A subconscious insight does not come when consciously forcing it forward. It chooses, without exception, a moment when the pressure and conscious thinking is withdrawn from the problem.
f) In difficult tasks a subconscious insight also takes time. In any case it takes a lot of previous conscious work. Without work in problem solving there will be no real insight.
g) It can possibly be assumed that all learning requires a subconscious insight. It may even be that we can't learn anything based purely on our conscious mind.
h) When the learning of the action is ready the process is started by a command from conscious level. Otherwise it is fully automatic and the designer can be free to think about other things.

i) A fully automatic subconscious action uses senses outwith the conscious mind. In this way the action is faster and more accurate than the conscious one. It seems that controlling the use of time is more efficient subconsciously than consciously.

3.1.2. Subconscious working

The ingenuity of creative thinking is that irrational universality can solve more and larger problems than consciousness can (Lehti & Ristola 1990). In addition some large problems cannot be even logically determined (Richards 1974).

The key issue in developing and intensifying the ability to work is learning and transferring knowledge and skills to the subconsciousness and utilizing them. Subconsciousness can process the information and produces new thoughts and ideas and also directly control the motoric action effectively. The connection to the conscious mind has to be maintained, otherwise a sense of reality and the ability to consciously control action and thinking perish.

Tuomaala (1995, 1999) describes the information in the subconsciousness in the form of short elements (Fig. 37). These elements are connected to some other elements and form an information net. With these short elements and information nets, he presents the location of information and connections in the subconsciousness. The net represents a more complicated active connection, which can be seen as earlier fulfilled insight. So the entire net, as the subconscious information is described, contains holes, gaps and disconnected smaller nets. The size of the net describes the extent of the insighted entity and the incoherence in contrast to the complexity of the entity.

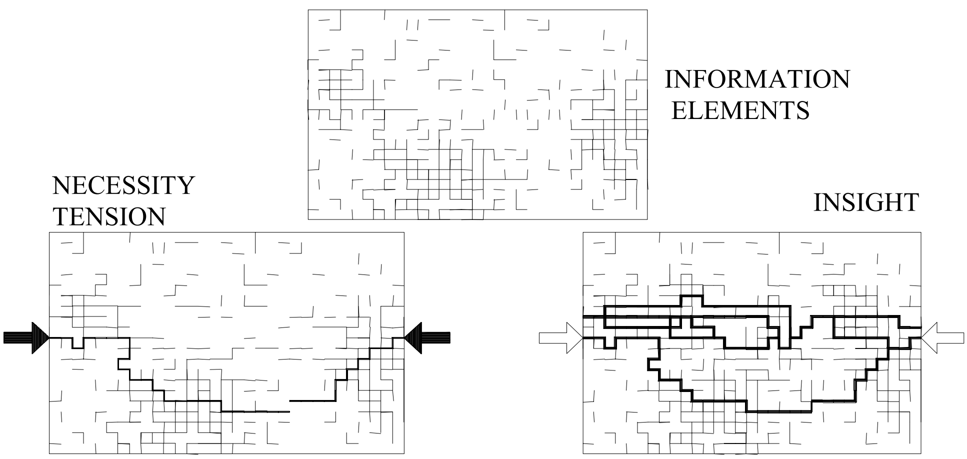


Fig. 37. Partly chained elements of information in the subconscious mind, directed necessity tension and completed insight (Tuomaala 1995).

To attain the solution the tension is also needed (Fig. 37). The tension is consciously sensed will to achieve a target. In other words tension is formed by defining an objective and developing the will to achieve it. The more carefully a target is defined and its necessity is accepted the stronger the tension will be. Arrows at the sides of the set of squares describe the necessity tension (Fig. 37). The tension attempts to turn the elements towards the arrows. It also tries to fill empty spaces (missing information), find analogical connections from existing chains and copy them into appropriate places. In this way a connection between the endpoints of the tension starts to build up and the problem begins to be solved. When this connection is achieved there is a pleasant relaxation of the tension - an insight.

Another way to complete the information matrix is bringing new knowledge into it. Of course the new knowledge must be learned deep in our subconscious mind. Otherwise it is not useful. In practice this mans that the information amassed has to be understood before it can be properly exploited. Time and effort are needed to form a connection or to get an insight. Powerful logical work, however, prevents the connection of information elements so a momentary relaxation of pressure and logic is needed. Lower continuous tension prevents the connection, and the net has to be completed by gathering and forming information. The results of this logical work are transferred via insights to the subconscious mind to build a connection. In demanding and complex tasks several information thickets (so called heuristic points) have to be built on the route of possible connection (see Bohm & Peat 1992 and Harth 1993). A heuristic point is a thicket of information formed e.g. by studying and drawing a detail that possibly belongs to the entity. The heuristic point can be widened and tightened gathering information into context. (Tuomaala 1995, 1999). Van Dijk (1995) emphasizes the sketching and especially physical activity in developing design ideas or working in heuristic points (see also Kolb 1984, Schön 1987).

Exploiting the subconscious mind in solving problems is called an intuitive solution of a problem. Of course a design does not proceed only by waiting for an insight, a lot of routine work like drawing and making documents is also needed. It is also useless to wait for an insight if its premises are not there - one has to acquire enough information about the field concerned and analyse it (to fill the empty spots). In the intuitive method it is essential that heuristic points, working details and sub-entities possibly connected to the solution are selected from the right direction (under the possible route of connected insight in Fig. 38). Systematic problem solving has been considered an opposite to the intuitive method. Systematic problem solving requires that sub-problems (information tickets or heuristic points in the intuitive method) are always constructed in a logical connection to one another. (Heikkilä 1982, Tuomaala 1995, 1999). It is also typical for systematic methods that these sub-problems or solutions may already exist and the actual design is connecting these together with a specified definition and framework.

Freud (1989) has determined logical activity as a secondary process and subconscious activity as a primary process in the human brain, without determining it more accurately. In comprehensive creative work both activities are needed, which is called a tertiary process (see also Bramham 1992). Perfect action is difficult to achieve, but varying the focus from one side to other is important. This means altering between divergent and convergent thinking or altering between generating ideas and developing these. (Arieti 1976, Bergström 1984, Heikkilä 1982, Tuomaala 1995).

The unconscious mind can be seen as a big store of information; however, we are not able to leaf through it. The capacity and amount of information in the subconsciousness is much larger than consciousness and its action is more accurate and faster than consciousness. Therefore it is very important to utilize it in design. On the other hand extreme freedom isn't good either. In design, thinking has to be structured in the conscious level at least in some point in order to utilize information chains developed or solutions. There is more information in the subconsciousness, so the information tickets are more compact and larger than in the consciousness (Fig. 38). An intermediate between the two levels has to be found in order to achieve the optimal result. In the level of the conscious mind a connection between tickets are formed with logical reasoning or cause and effect relationships, which should lead to subconscious knowledge. In practice this means forming the connections between solutions, sub-solutions and details with logical reasoning so that they can be combined. (Tuomaala 1995, 1999).

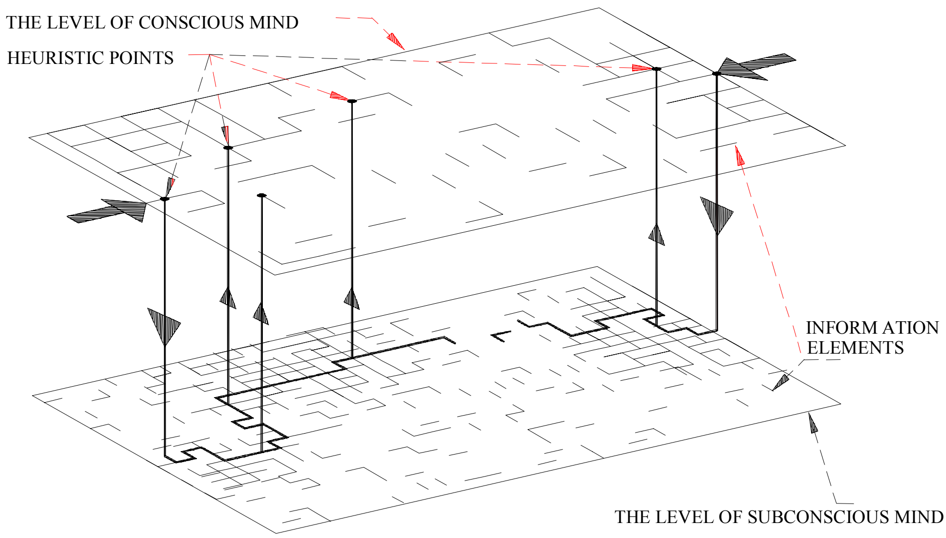


Fig. 38. The levels of conscious and unconscious mind and the formation of a presentiment (Tuomaala 1995).

Consciously sensed will and the tension are reflecting on the subconsciousness (see de Bono 1990, Heikkilä 1982), where connections between information elements and nets are gradually formed. Connections are not solving the whole problem, but they lead the way to search for solutions (for instance the experienced designer foresees, where and what information should be sought or studied). This is not a contingent action, according to Tuomaala (1995, 1999), but the ability to learn to utilize subconscious information and skills. (see also Eriksson 1994). Hakala (1996) has noted, that the mystery behind Nobel Prize winners is a scientific scent or hunch. It is a kind of sense of scientific beauty. Scientists have the ability to foresee the existence of a solution and search it from the right direction.

Another of Tuomaala's (1995, 1999) presentation of the levels in the mind is in figure 39. People have attained the skills and knowledge needed in creative work in their genes, in studying and also in social events during life. Studying, in this context, can be seen as obtaining experiences or increasing the amount of existing knowledge. The information penetrates laboriously through the surface boundary to the subconscious mind where it becomes attached to the existing information. When the information increases the connections also increase and gradually a new centre of knowledge, skills or actions, is formed whether it is programming a language or riding a bicycle etc. A completed and finished action centre can be used with very simple control commands and only one channel is needed for the connection. At that time the action centre also starts to slowly descend deeper down to the subconscious mind. For example, the action centre for speaking has sunk to a level where the connection to the conscious control channels is very weak. Driving a car is a different kind of action. It can be controlled in many ways even though it also operates perfectly as a subconscious action. (Tuomaala 1995).

Information can be uploaded by working in heuristic points, when also information nets can be extend with the connection of conscious thinking and unconscious processing (Fig. 39). The conscious mind has been noted to be above the subconscious mind. Tuomaala (1995, 1999) describes the filter (see also filter in Fig. 35 and funnel in Fig. 36) as a sand layer. Man's experiences and knowledge are information chains formed in the human mind, which are the model for future action (Eriksson 1994).

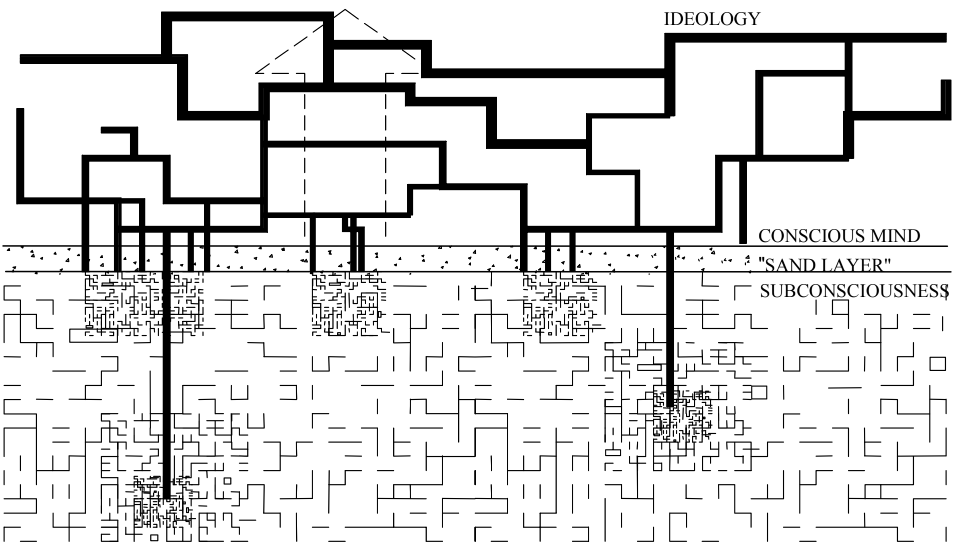


Fig. 39. A presentation of knowledge or action centres and of loading the subconscious mind (Tuomaala 1995).

Figure 39 presents the model of loading the subconscious mind and information and the co-operation between the conscious and the subconscious mind. In the upper edge of the conscious mind there is a simple main channel, the ideology. It strives to direct all the conscious actions in the same direction. The meaning of information has to be insighted in order be able to exploit it. During the insight, information infiltrates to the subconsciousness (see Fig. 36). If the designer has earlier experiences of the subject, information flows easily to subconsciousness and enlarges the existing or creates a new information centre. Specifying the subconscious centres is slightly problematic. If they are connected with movements or motorics they should be called action centres. When they are connected to knowledge they should be called skill centres. But a centre to be formed when solving a problem is at least in the beginning an information centre. Anyhow, when information increases also the number of connections grows and thereby itself creates new larger action, skill or information centres. (Tuomaala 1995).

3.1.3. Intuitive method of creative work

The learning of information filters down to the subconscious mind, subconscious processes, the sensitive listening to the ideas produced by the subconsciousness and the penetrative logical analysis are the fundamental factors of creative design (Tuomaala 1992, 1995, 1999). Usually creativity and the ability to be creative are considered a special talent, but it can also be expanded consciously (Bramham 1992, de Bono 1990). According to Dick (1985) creativity requires release from the traditional and restricted way of thinking.

The learning filtered down to the subconscious mind obviously presupposes motoric action and observing by the senses. Although we don't exactly know the subconscious processes, we can guide and control them by the tension created by our conscious mind. The tension is a consciously and subconsciously sensed will to achieve an objective or to go in a certain direction. Action is the most effective, when the conscious will produces several new tensions in the subconsciousness. When the conscious action is directed to elsewhere or the conscious mind is focused on anything else than the problem to be solved, intuitive tension maintains the subconscious thinking.

Studying several design projects afterwards it has been noted that the best solutions are achieved through intuitive tension and not squeezed by conscious pressure (Rantanen 1985). On the other hand Heikkilä (1982) sees conscious will as a basic necessity of successful creative solution. It is important to distinguish necessity tension, subconscious tension and intuitive tension. Necessity tension was determined as a consciously sensed will to achieve the goal (e.g. schedule and deadlines of a project). Tension in subconsciousness does not arise without a conscious tension. The conscious tension acts after a long interval. Subconscious tensions are of shorter duration. They reach from one insight to another. Both tensions are working continuously approximately in the same direction. Together they could be called an intuitive tension. (Tuomaala 1999).

It is very important to allow enough time for the subconscious processes. In practical design this can be done with painful copying and drawing of details. Although this in itself is an absurd and valueless task, it gives the subconsciousness permission to work. (Lehti & Ristola 1990, Pallasmaa 1993, Tuomaala 1995). That is why the connection to the conscious mind has to be maintained, otherwise the sense of reality and the ability to control thinking and action consciously diminishes.

Sudden insight formed in subconsciousness is called the eureka –phenomenon (Eriksson 1994). In contrast heuristics is a basic principle of creative working, where results are pursued with the aid of eureka –phenomena. It has got a lot of objections, because the subconsciousness cannot be directly controlled or studied and it is considered utopic, mystic and unreliable. Anyhow the existence is undeniable, according to the phenomena presented above, so there are some kinds of solid features in the actions of the subconsciousness.

The basis for the creative work of Tuomaala (1992, 1995, 1999) is tension, incubation heuristic points and also release from the traditional and restricted way of thinking. The method of intuitive creative working is that we consciously create favourable conditions for the eureka phenomenon. This is done by building a set of heuristic points and transferring information through them more efficiently than with words or more efficiently than could be consciously thought or even understood. In practice this means that senses obtain input information for subconsciousness faster than it could be consciously understood (Rantanen 1985). For instance two lines drawn to a right angle means to the designer more than two lines. The subconsciousness processes the information obtained and forms a connection between heuristic points. According to Bergström (1984), time for incubation or relieving brain activity from excessive pressure or control is needed in order to create something. This means in practice, that after amassing the information, needed there has to be some time for the subconsciousness to organize and process the information through an operation which is not known for the time being.

An additional tool in Tuomaala's (1999) work is short logic. It is used in the control of work. It is reasonable and consistent, but does not aim towards long term objectives. Tuomaala (1999) describes the concept of short logic with the example of compiling a puzzle. At first the image to be formed with puzzles has to be impressed on the mind. All parts have to be turned so that the picture side is up. By random scanning the pieces, some of them are recognized and placed in approximate locations as in original image. Then the particular spot is taken under detailed examination when seeking suitable parts connected to detail. The first heuristic point of the task has been noticed and the work goes on. Short logic was used to directly aid perception and interpretation. Mental images can change freely in the shambles of logical results, perceptions and the new associated mental images. In the example it can be seen that the work itself can be monotonous but the objects of interest alternate quickly. The main focus is not in the final solution, but in the logic of the knot at hand. In contrast logical moves utilize short logic. Transferring information between the heuristic points has been called logical moves. The information transfer, where the density is greater than that possible in oral or conscious transfer and the form of transfer is mental images. Short logic transfers the information through the logical moves to a new heuristic point, still as images but chosen by the subconscious mind. Logical moves transfer only information needed in the solution.

The "toolbox" used in Tuomaala's (1995, 1999) intuitive method of creative work (Fig. 40) has been presented above. In practice designing tasks are defined and outlined at some level. The first task is analysing and committing to a schedule, while intuitive tension forms (the tighter the schedule the greater the tension is). Similarly first heuristic points are formed and the internalising of these critical points is the basis for a successful solution. (Bramham 1992). At this stage these heuristic points may be dispersed and do not contain exploitable information for the task. Intuitive tension strives to translate the essential information and ideas suitable for solution. (Tuomaala 1995).

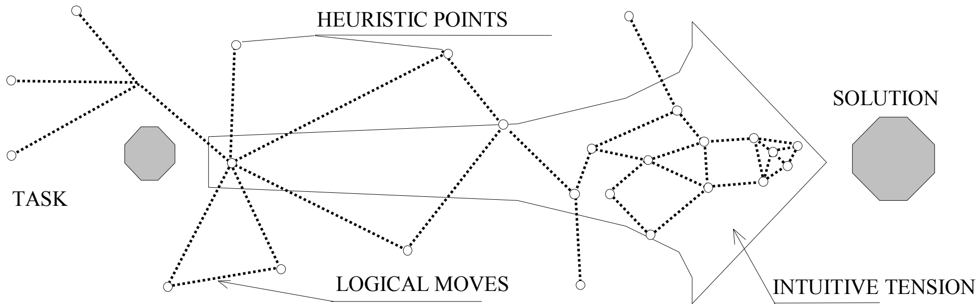


Fig. 40. The fundamental idea of Tuomaala's (1995) intuitive problem solving (see also Kirk *et al.* 1988, Pallasmaa 1976).

Heuristic points are working details e.g. designing the entry of a building. They are usually significant from the total solution point of view either larger entities or smaller details (Rantanen 1985). Information transfers as mental images and the flow is duplex. Designing has been determined as working with mental images, while designing spaces, in some context. Active points are already processed and passive are waiting to be processed. When designing proceeds the amount of active points increases and the net becomes denser and the sub-entities solved can be connected to each other. Work proceeds with longer jumps or with smaller re-engineering steps (Ruth 1984). Then all points are connected with each other and the tension relaxes and the total solution is formed. Also Pallasmaa (1976) emphasises that the work is done in smaller details, but the tension relaxes when total solution is formed.

In logical design the systematic method is based on the fact that all solutions exist. Designing is selecting the parts and connecting them to a functional entity. (see Rantanen 1985). As in the puzzle analogy earlier, the systematic method is an algorithm which tries every part of the puzzle in a certain order. When two parts are jointed together the algorithm tries to find a third fitting until it found. But the intuitive method dives much deeper and utilizes the knowledge and viewpoints from the existing structure (Fig. 41). (Tuomaala 1995).

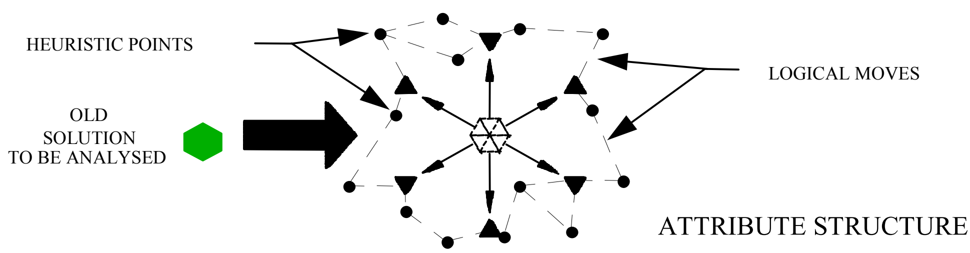


Fig. 41. Penetrative analysis or decomposing a structure of finished design or a sketch (Tuomaala 1996).

Penetrative analysis is a critical process, where structure, meaning and rationality is evaluated and analysed. Finished solutions from other designers can be assessed, but partition and analysing the designer's own work is very difficult, especially immediately after achieving it. Penetrative analysis or decomposition of a structure usually leads to a better final solution. (Rantanen 1985, Tuomaala 1995). This work is systematic, but a creative designer can leave the results floating and is able to catch them in varying ways.

Figure 42 gathers the theory and its features into the method of intuitive creative work as an entity, presented by Tuomaala (1992, 1995, 1999). The first phase ends in a solution. The tension arrow is extinguished and the connections with the net of heuristic points is not drawn any more but it nevertheless exists it still has a meaning with it. The original task is as before, as also the solution at the head of the tension arrow. The surrounding decomposed ideas or the competing ideas are new. They can also be other constructions whose applications are somewhat connecting with the field of the design task. As a consequence of analysis the results form heuristic points connects them. In this way the net of heuristic points becomes deeper and making it denser and more mature is more efficient. A better result can be achieved with a penetrative analysis. Once again it necessary to return to the basic elements and examine different possibilities dispassionately, although the penetrative analysis of the designer's own work is difficult. If the solution fails penetrative analysis is much easier.

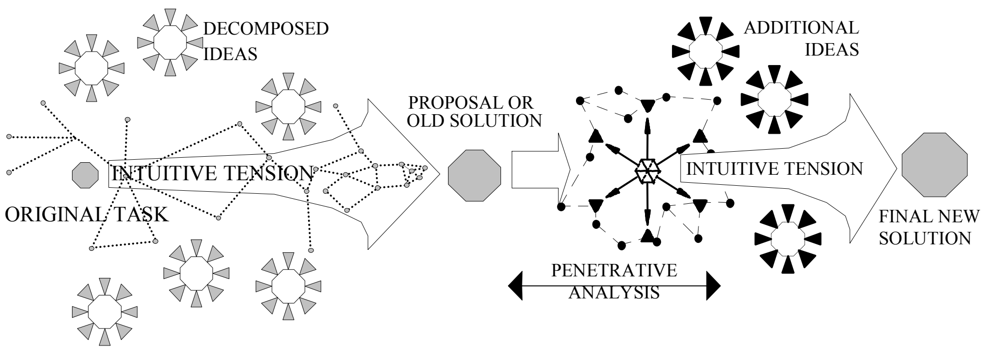


Fig. 42. Presentation of the method of intuitive creative work as an entity (Tuomaala 1995, see also Kirk *et al.* 1988).

3.2. Intuition in architectural work – a review of the theory

3.2.1. Creative architectural design

According to Aalto (1948) an architect have to face several incompatible and even inconsistent elements in his work. These elements form a complex problem, which cannot be solved rationally or by logical reasoning. Architectural design has to be always seen as entity. It is artistic action and processing engineering problems. The designer has to solve technical and practical problems and also express himself artistically. (Lehti & Ristola 1990).

Architectural designing has not been presented earlier as it is done in the previous chapter. Practical experiences have pointed out that the previous presentation is truthful. Also several literary findings refer to some kind of phenomena. For instance in the example of Aalto's (1948) creative design process outlining, incubation and sketching are the fundamental issues.

In practical work every designer has individual unique experiences and way of thinking (Pallasmaa 1975A, 1975B, Petäjä 1983). Therefore solutions to design tasks differ with different designers. This is easily seen from the results of design competitions. All participants are using the same basis, but the results may differ considerably. The design process begins with the job description where customer needs, instructions and regulations are studied. Usually in that phase most of the architects will already have a bit different opinion or feeling for the solution. Concurrently taking the task into its possession the subconscious mind begins to work. The subconsciousness processes the task or the problem during active work, free time or sleep. It is important to note the diphasic progress in creative architectural design (Fig. 43). These are the idea generation and modifying the idea into a generally acceptable design.

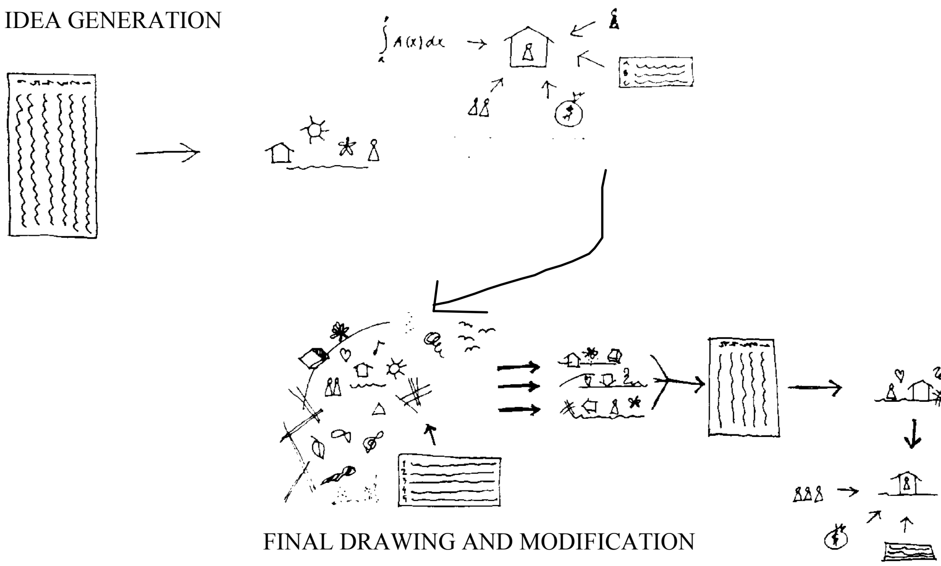


Fig. 43. The unstructured creative architectural design process (Lehti & Ristola 1990). The figure presents the freedom of creative design. (see also Christopher 1974).

Sketching is the first phase where a concrete solution emerges (Fig. 44). Before that, the idea has been processed in the subconsciousness and also as mental images from these ideas. When talking about intuitive creative architectural design, the solution may almost totally emerge with the aid of mental images. Sketching is the most useful tool for almost all architects. The meaning of sketching should be emphasized, because the first drawing is the basis for later processing. It somehow controls the later work, although several different sketches are made. The sketch is some kind of visual model for the forthcoming solution. (Cross 1994, Lehti & Ristola 1990). From the cost accounting point of view the meaning of first decisive sketch or primary solutions is important, because in practice costs are already fixed in the early phases of design (see Fig. 3). The meaning of images and pictures is essential in designing and Ferguson (1977, 1993) sees the ability to draw as the alphabet of a designer. First sketches are only for designers' needs and they are usually even intimate. They are also considered as a discussion mirror for the designer. (Van Dijk 1995).

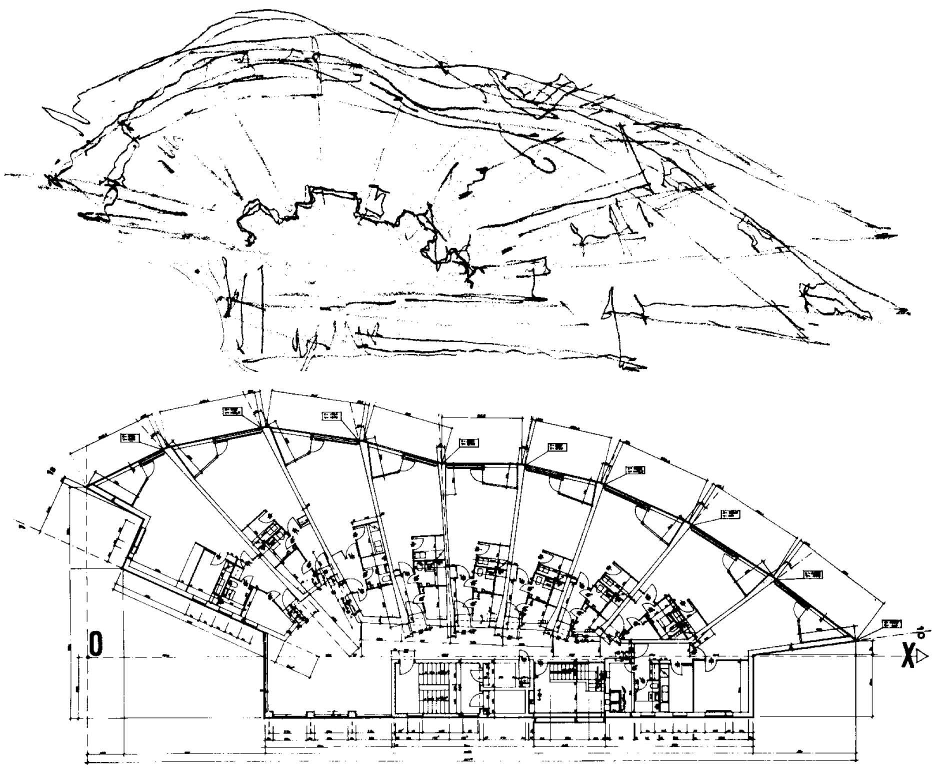


Fig. 44. A sketch and final plan made by Alvar Aalto (Lehti & Ristola 1990).

The forms existing in the picture represent the current idea and are directing at becoming solutions and dimensions. The development of the design is, according to Dick (1985), a conversation or communication of subconsciousness and design. The interpreting forms of design are important both conceptually and in the abstract. Gero (1985) sees the early phases of design as a continuous chain of drawing and observing. The designer sees the current form of a picture, makes some adjustments, sees the effects of modifications and gets new visual information. The picture is not a simple drawing, the designer forms a structure and sees the purpose and function in it. This model of visual observing is called emergence. (Soufi & Edmonds 1996). It has a significant role in creative work, when searching for new alternatives. It also allows the design to drift or lead in a new direction. (Christopher 1974, see also Bohm & Peat 1992).

Rauhala (1991) has described the average architectural sketching activity from the external observer's viewpoint. "In a certain design task the architect picks up a sketch paper, spreads it on the drawing board, picks up a lead pencil (usually 6B, a thick and soft) and drafts fast different kind of graphical images and maybe writes something down as an interpretation. Sketches, modifications and fixings are usually done rapidly. Some parts of the design are rubbed more intensively. Modifications are done with thicker lines more like finding limits between several elements. Images are partially getting stronger and darker. Suddenly the architect may tear a part of the drawn image away, take a blank piece of sketch paper, place it upon the older one and continue drawing new images partly following the existing ones and partly modifying and redrawing. In a moment the architect may abandon all existing images and start from the beginning. Later the designer may get back to the original ones and continue modifying those. At some point sketching ends up and the architect transfers those images to a certain scale. Usually some elements are not in balance and it has to be re-sketched. This may even destroy the whole idea and the designer has to go back to the starting point." Typically sketching is in the early phases of the design process, but may even continue to the implementation phase. (Rauhala 1991).

3.2.2. Comparison of creative and systematic design

Almost all, even the simplest, descriptions of design somehow deal with the relationship between information and activity, or the process how information is used in design. Optimal use of information naturally gives the best result, but the definition, how it should be treated is different from separate viewpoints. Systematic tries to find solutions with the aid of logical conclusions or causal connections, and it processes the whole store of knowledge all the time. A creative method uses intuition in searching for solutions, which cannot be reached mechanically. When considering design as an entity, it is very difficult to separate intuitive or systematic work into independent parts. Systematic amassing of information, creative and intuitive problem solving and logical and critical verifying of the solution are required in an optimal process. The former is also one of the reasons, why Tuomaala (1995) considers logic a tool for creativity. Korhonen (1979) does not consider observance of either design methods or systems as a guarantee for succeeding in the design. They usually only lead to a faultless, but average final result. On the other hand systematic design science sees intuitive work dependent on flashes of inspiration. Insights do not appear at the desired moment, and they cannot be attained again. Intuitive working is, according to systematic designers, processing the complicated causal connections in the subconscious mind. It has contributed to a lot of good solutions, however, systematic designers have perceived a few disadvantages like; the right idea rarely comes at the right moment since it cannot be elicited at will, the result depends strongly on individual talent and experience and there is a danger that solutions will be circumscribed by one's special training and experience. (Pahl & Beitz 1990).

Systematic design science underlines the discursive procedure. All steps are processed consciously so that they can be influenced and feedback can be achieved. It is typical for a systematic procedure to divide work into sub-problems, which are eventually united as one total solution. It has to be noted that intuitive and systematic work are not in opposition. Pahl and Beitz (1990) have also experienced that systematic work gives impulses to intuitive thinking. Some scientists have tried to find out the possibilities of systematic creativity, where work is done almost systematically, but the ideas and solutions are produced intuitively (Erdman 1993). In Tuomaala's (1995) creative work this is partially done by heuristic work.

In logical work, systematic design is based on the fact that all technical solutions already exist. Designing is only selecting the structures and elements and combining them to produce a functional entity. (Rantanen 1985). The intuitive method dives deeper and it utilizes only the know-how and views of the former structures and elements. (Tuomaala 1995). However, McLoughlin's (1969) systematic design process also develops future design with the aid of existing results. One of his basis for logical work is the tendency to learn about existing solutions and apply only successful solutions in the future.

The most significant difference between creative and systematic design may be the level of thinking, where solutions are generated. According to Tuomaala (1995) creative and intuitive problem solving takes place in the subconsciousness. Systematic design is logical reasoning and solutions are produced at a conscious level of thinking. Freud (1989) arranged subconscious and conscious thinking when he specified subconscious thinking as a primary process and conscious thinking a secondary process. Co-operation is required in creative work and Freud attributed that to a tertiary process. It is very difficult to attain perfect operation, but it is important to alternate the activity. This means alternation between divergent and convergent thinking. Niiniluoto (1990) has also noticed the operation problems between different brain segments. He has presented some segregation; reason - sense - intuition, analysis - synthesis, part - entity and knowledge - imagination - science. Mental abilities operate as one, however, and reasoning always contains sense, sense contains knowledge, knowledge contains imagination and so on. For that reason Niiniluoto (1990) also believes, that there is no real inconsistency between creativity and logic. Anyhow Ferguson (1977, 1993) has noted from history, that systematically or mechanically developed products or systems are not as good as creatively invented intuition based products. He proposes that evolution and practice has found those products which have been developed with more intuition than systematic design, more usable.

The best possibilities for creative work are to produce novel ideas or solutions. In contrast, processing and evaluating ideas or solutions are the best features of systematic methods. Creative problem solving can be seen as simplifying or outlining larger entities. On the contrary systematic design can be seen as dealing with entities or splitting entities into small pieces, solving them and again combining them.

When observing the phases of Finnish architectural design strong periods can be noticed both in creative and systematic design culture. This may also be a sign, that neither a creative nor a systematic method has alone optimally fulfilled the needs of design. Also observations from present, practical design demonstrate that the best results are achieved by partially creative and partially systematic design. Design methods or a designer's behaviour in work can become quite rational and systematic, even if he pursues creativity in his work. On the other hand, organization and management of design processes actually require the use of systematic design or logic. This is emphasized in present design controlling or in the quality requirements of design. Logic is also inevitable in analysing solutions and checking functionality. It has to be noted, however, that intuitive and creative methods seem to produce novel or better ideas than systematic design, thus a designer should also have enough creative freedom.

3.3. Applicability of computers in creative work – a review of the theory

Creative work is unique as described earlier and the meaning of the subconsciousness is very decisive. On the other hand designing is rational reasoning, applying logic and several mathematical methods, which are, however, only tools for design, because work in practice is wordless discussion between paper and the designer. Several specialists are convinced that designing could only be done by drawing and not by calculating, speaking or criticizing. Architect Scarpa draws, because he wants to see. He has also noted the magical connection between hands, eyes, brains, pencil and paper. According to Ferrare (1996) it may even be harmful to design totally by computer, because man has the instinctive ability to interpret his own thoughts in cooperation between hands, eyes and brain.

Creativity is an important sub-area in design where only a little formality is discovered. Therefore it is very difficult to find mathematical algorithms, which can imitate or increase creativity. On the other hand computers can be, according to Schmitt (1988), utilized in creative process or applications, if we understand that creativity is not a mysterious process, but it concerns understanding, learning and also reasoning.

3.3.1. Differences between traditional and computer aided design

The fundamental difference between traditional and computer aided design is, according to Kiviniemi and Penttilä (1995), the possibility to edit drawings and the lack of unambiguous scale. The essential difference is also the number of drawings. Traditionally architects have even made a huge amount of illustrations and with computer aided design only one model is modified and images needed are plotted from one or two databases. Additionally several applications includes symbol libraries which facilitate the design process. In contrast the mouse, keyboard and screen also creates different working states to pencil and paper. This can be one of the greatest difficulties in the beginning, because there is no direct physical connection in between hands, eyes and brains (Ekelund *et al.* 1992). In computer aided design the lines don't emerge where they are drawn, and the important items cannot be emphasized by for example pressing the pencil stronger than normally. These are, however, according to Penz (1992) only questions of learning and getting used to new design media. Using computers requires a lot of learning, but also the ability to apply skills to the theory of architecture so that the results will be as good as possible.

Computer aided design differs from traditional methods regardless of the design phase. In traditional methods old and incorrect lines must be drawn again even to a new sheet. Therefore a drawing has to be made again and again several times, but in computer aided design lines are just edited or modified. Models in computer aided design can contain a lot of additional information to that appearing in drawing on paper or on the screen. (Kiviniemi & Penttilä 1995). A line can describe the whole wall structure in CAD, and when drawing a determined line in design the designer actually draws the whole structure of the wall. If the application exploits a three-dimensional system of coordinates, the wall can even have height element with one drawn line. Traditionally with pencil and paper all layers and lines have to be drawn separately.

In traditional drawings all information is visible in illustrations (e.g. type code for door; wooden door, opens left, 900 mm wide and fire class 60). In computer models other geometric information can be included in the database as invisible attribute information (Fig. 45) as dimensions, texts and graphic symbols (Holvio 1993). Attribute information describes the features and definitions of graphic symbols, which are in the database and drawing contains only references. A database can be utilized to produce e.g. different lists of doors, windows or fixtures from alphabetic or numeric information. Computerized operations decrease the work of the architect and also the possibilities of mistakes (Holvio 1993, Kiviniemi & Penttilä 1995). Some applications also allow producing for instance lists of square areas and surfacing. These features are not used on a wide scale, because these are not traditionally included in architects' work and the designer themselves is not gaining anything by producing this information. (Virolainen 1994).

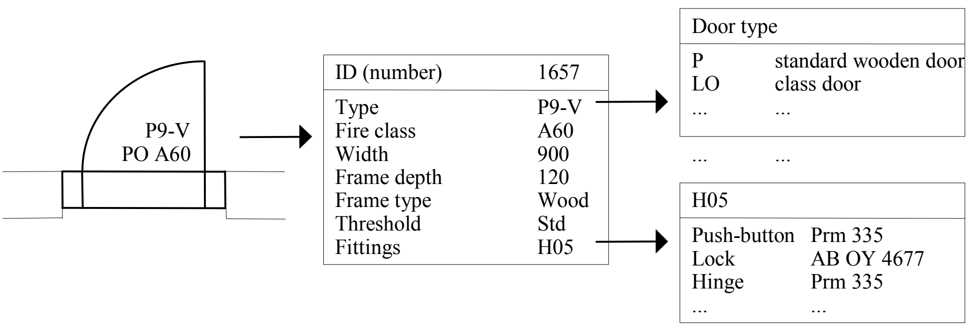


Fig. 45. A sample of alphabetical or numerical information in one computer application (Kiviniemi & Penttilä 1995).

According to Ekelund *et al.* (1992) the experienced designer in computing can produce drawings much more faster with the computer than traditionally with pencil and paper. This is emphasized especially in projects where is a lot of repetition. Producing alternatives and variations is also much more faster with computers in different phases of design. Experimenting with different space or mass layouts, shading, facades or furniture are easy to produce. Changes are easily on view without constant redrawing.

In CAD the constructed model can be modified in different platforms or layers when traditional design occurs in one sheet. Platforms are the reasonable basis for creating computer models (Fig. 46). They can be compared to several transparent sheets, which can be selected to create different drawings from a design file. Platforms can be on or off and defreeze or freeze while designing or printing. Both ways layers can be hid, but the depth of hiding varies. (Ekelund *et al.* 1992, Kiviniemi & Penttilä 1995).

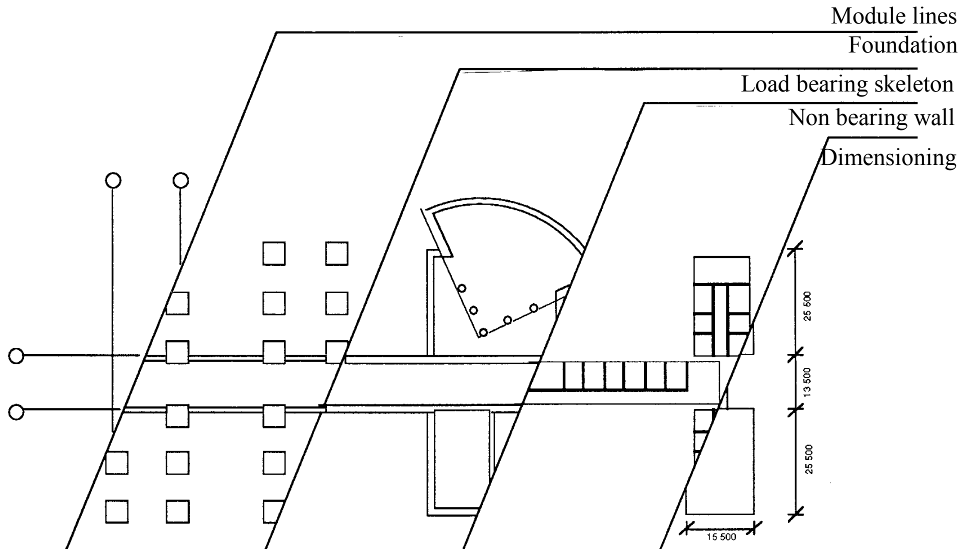


Fig. 46. Information layers or platforms in CAD (Kiviniemi & Penttilä 1995).

The model in computer aided design can be divided into several or created from several different files. These reference files allow automatic information updating to different files of the same model or links to other models and integrate the design database. The reference file contains only a link to the original file and several files or drawings can be integrated in one drawing. This decreases the size of design files and thereby speeds up the work. For instance a plan can be embed in a general layout. (Ekelund *et al.* 1992, Kiviniemi & Penttilä 1995).

The accuracy of handmade drawings is always approximate, but they aren't supposed to be exact. In dimensioning real measures are counted and, if necessary, emphasized with underlining. In computer aided design measures are always precise and absolute. This may lead the work to accurate millimetres or even smaller units in design, although real tolerances in construction are much bigger. Dimensioning with computers is easy, because all objects contain the exact information and the dimension line can be formed, strictly based on the object. (Kiviniemi & Penttilä 1995).

3.3.2. Weaknesses and benefits in computer aided design

Computer aided design shakes traditional routines. Therefore Penz (1992) states that the inconveniences experienced are mainly because the way of working has changed. Using computers in real work in the beginning is difficult, like all new equipments or tools. This draws the main attention to technology, while the work itself suffers. On the other hand the actual work has more time when routine tasks are done with computers. Therefore it would be essential that computerized working is learned and adopted exhaustively right from the start. (Clark 1988, Stevens 1991, Kiviniemi & Penttilä 1995). In practice the time saved has not been used in more demanding tasks, but it has been used to shorten the total duration of the design project. Clark (1988) would like to see information technology as a tool or assistance in design, which allows new dimensions or possibilities, especially in three-dimensional modeling. It should be used also in managing the design information and not only drawing or producing documents. Practical sense and the professional opinion of architects is needed in utilizing information technology, because the nature of design methodology changes very slowly when compared to the built environment (Mitchell 1994, Penttilä 1989).

According to Stevens and Kish (1991) computer aided design reduces the time used in routine work. Copying and modifying functional elements is fast especially when a project contains a lot of repetition. Additionally several printouts can be made to different scales. (Clark 1988). Overlapping work diminishes, because the designer doesn't have to draw it nor similar lines several times in computer aided design. In addition some parts of the design file can be linked to another file. (Kiviniemi & Penttilä 1995). Working can also be partly automated, because complete blocks of e.g. furniture, fixtures, doors and windows which have certain features can be inserted (Holvio 1993). Drawing e.g. walls can also be automated. The designer can define the type, structure and layer of the wall and in design draws only the line linked to the structure. Also different lists can be generated from the design file to help the designer (Kiviniemi 1991). In traditional design these have been done manually.

The applicability of computers to creative design is strongly doubted, but also benefits are available. According to Ekelund *et al.* (1992) the possibility to rapidly test several alternatives is a clear advantage. Also different space or mass layouts, shading, space utilizations, facades or furniture are fast and easy to test, because the effects are immediately visible and the returning to the original state is easy.

It is also obvious that architects use paper to think with, so the features of a building can be seen from the paper. The essential difference in computer aided design, compared to traditional design, is the scale of design when the work is done in real dimensions. Therefore design is experienced as displeasing, because the working scale is changing constantly when zooming in or out. With the computer, dimensions have to be exact, they are needed in traditional design too, but they are, however, considered indefinite. (Kiviniemi 1990). A certain fuzzy state can also be created for computer aided design. It can be implemented by setting the module lines to be suitable e.g. in computer sketching the accuracy of 100 - 200 mm is equivalent to a traditional scale of 1:200. Afterwards dimensions can be stretched, abbreviated or moved to the correct positions. (Kiviniemi & Penttilä 1995).

Computer graphics also gives the impression of final design already in sketch phase (Mitchell 1994). Anyhow working and printing methods can be changed so that the results are the traditional design. The size and accuracy of the screen have been disadvantages, because only small details can be seen with acceptable accuracy. (Holvio 1993). Therefore a lot of paper printouts are needed when using computers. In contrast information is packed in compact electronic form and doesn't require much space and the management of design information get better. According to Penttilä and Kiviniemi (1995) complex graphical information requires a lot of resources from hardware. In small projects resources are not the problem, but when the amount of information increases, design become clumsy and slow. Development of software and hardware will facilitate the resource problem in future. A computer aided design system is expensive and therefore the benefits of the investment have to be concrete in order to justify the use.

Analysing creative processes is very difficult, according to Schmitt (1988), because the features in creativity are unique and it is difficult to study individual design activities. Identifying rational activities and setting those in a certain order is required in constructing computer applications. Kiviniemi (1991) emphasizes that programs are based on certain formulae or procedures and the same input produces the same output. Random numbers are exceptions, but a solution generated by lottery is not creativity. Therefore Schmitt (1988) believes that it is impossible to construct software, which is fully creative.

Computer hardware and especially software are developing and therefore dimensions are difficult to set and development work is also done all over the world so standardization is even more difficult. The main points in preparing standards are user orientation, usability, control criteria and comparison criteria (Senyapili & Özgüç 1994). The system usability means that can a user use the system and is the use effective. Several architects have rejected CAD as being complex and confusing. Mouse and screen are different means to design compared to pencil and sketch paper. On the other hand modern information technology allows forming a user interface close to traditional methods of working. The graphical user interface creates the smoothest efficiency, because the visual symbols speed up the working. Present hardware is fast enough maybe, on some occasions even too fast, because a competent system should use the capacity steadily. The precision is different in separate phases of design, and therefore sensitivity suffers, if absolute precision is constantly required and the precision is directed to secondary matters. (Senyapili & Özgüç 1994).

Van Dijk (1995) considers that it is important to maintain several features from handwork in computer aided design. Graphical icons are much easier and faster to detect than numerical or written information. In contrast connection from hand movement to lines and forms appearing on screen should maintained, because physical movement finalizes the thinking process in design. The user interface should allow working in entities and occasionally in details, because some detailed ideas may come e.g. in the facade design and it should be possible to save the information in a design file for later use (Negroponte 1995).

Computer aided design divides the field of architects. Some are using computers in design and hope that the work is more effective. Others are just willing to design traditionally. Tasks in a design project are usually related to the experience of the designer. Experienced architects are head designers and do the outlining and sketching, and are responsible for the progress in the design project, while younger people take care of the routine work. Computer aided design deepens this gap, because sketching is usually done with pencil and paper and the final drawing with computers. (Stevens & Kish 1991).

4. Empirical research

4.1. Research method

The research method follow the principles of hermeneutics as more accurately presented in the introduction. This is important in the analysis, because the principle of hermeneutic circle (Fig. 47) is adapted in empirical research. The hermeneutic circle adjusts the phenomena to be perceived between details and entities, however so, that the understanding gets deeper in every phase (Räsänen 1993). In principle the hermeneutic circle fits in this analysis very well, because the analysis of qualitative data doesn't have any fixed format (Miles & Huberman 1994). Then several iteration laps and even different analysis in examination make the understanding more deeper and more accurate and therefore increases the reliability of analysis. However, according to Koski (1995), the hermeneutic circle is not a method.

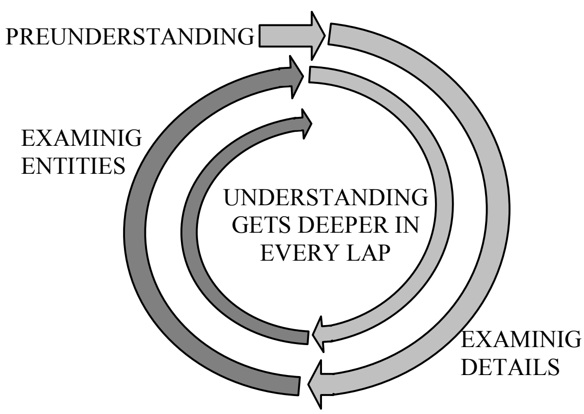


Fig. 47. Hermeneutic circle (see e.g. Koski 1995, Räsänen 1993).

Applying the principles of the hermeneutic model in this research begins from the first interviews proceeding to the analysis of results, but since the hermeneutic circle is not a method, some methodology is needed in order to process the material. According to

Strauss and Corbin (1990) phases in qualitative empiric data analysis are open coding, axial coding and selective coding. This classification has been used in context of the grounded theory (Glaser & Strauss 1967, Strauss & Corbin 1990), but it is easily applicable in other qualitative studies too, as in this research. According to Strauss and Corbin (1990) one can sample or code from existing data as well as data yet to be gathered. In multi-stage data assembly the early stages are then the preliminary classification for further data collection.

In open coding concepts are sought to describe the material and classes examined are named after those concepts (Strauss & Corbin 1990). Surveys in this research are operationalised to serve the purpose, goals and research questions of this study. The time horizon of these surveys can be seen in the introduction (Fig. 5, chapter 1.3.3.).

The definition of the architectural design process (settings in chapter 4.2.1. and results in chapter 5.1.) is used to make a description of the progression of the design process and practical creative work. The survey has been made in order to improve the pre-understanding and the correspondence to the practice and to form a classification (open coding) of empiric material. The purpose of the very informal interviews was to get all possible nuances of the architect's work connected to the creative computer aided design process in order to get reliable and valid results later on. The perceptions based on results and documents are compiled into one process description. These results, documents and process description have been used to bring up the significant factors in order to form the essential questions from the state of the art in computer aided design (chapters 4.2.4. and 5.4.1.) and creative architectural design process (chapters 4.2.2. and 5.2.). These surveys have been made in order to obtain information from creative computer aided architectural design. Both surveys contain open questions, because it is important that the spectrum of forthcoming results is not defined beforehand in any way. The survey of the state of the art in CAD has some similar questions from the same topics, because there may be some possible misunderstanding among those designers who haven't used CAD and that has been excluded with several similar types of questions. All questions have been unstructured, open and the answers are based on the opinion of the informants in order to attain reliable analysis and results.

The information obtained, in the first survey of the state of the art in CAD (chapter 5.4.1.) was not watertight in all respects, because questions of the applicability between different programs did not produce homogeneous information and reliable conclusions could not be drawn. Therefore the influence of one market leader application had to be excluded and a more detailed survey of feature differences between different applications had to be made. To do this, a survey was carried out (chapters 4.2.4. and 5.4.2.). This survey indicated only a minor difference between applications, but not in the favour of the market leader. The results of the applicability between programs are in chapter 5.4.2., but the features itself are not reported in this thesis, because they did not introduce any new information in addition to the perceptions presented in chapter 5.4.1.

In axial coding classifications are examined first one by one and then the relations and contents of classifications are compared to each other. Open and axial coding are not only sequential, but also concurrent and recurrent phases. Open coding can be seen as idea phase and axial coding is systematic seeking the internal consistency and correspondence of the structure of concepts with empiric material in research. (Strauss & Corbin 1990). Perceptions in the survey of creative architectural design pointed out the need for more detailed examination of the need and applicability of systematic and logic in design. Therefore a survey of the applicability of one sample systematic design method or tool in creative work was needed (chapters 4.2.3. and 5.3.1.). The difference between design fields is examined (chapters 4.2.3. and 5.3.2.), because systematic tools have had positive acceptance in some other disciplines. These surveys have been done in order to explain the applicability of one sample systematic tool in design. The example tool – QFD has had good acceptance in some fields, but the applicability in architecture has not been studied earlier. The purpose of these surveys was to indicate the complexity and possible resistance to new tools for architects in creative design.

In selective coding the analysis framework (Fig. 48) is formed in order to present the perceptions as an entity. It uses the classifications formed in research earlier. In selective coding the most fundamental and essential core class, concept or category is selected in relation to the research question, then the theoretical description is presented. Other classes, which have emerged in open coding and connected to each other in axial coding, are subordinated to this core class and parsed to a one narration. The intention is to reach synthesis and integrate the theory around the most important concepts (Strauss & Corbin 1990). That is done in the analysis (chapter 5.6.), where the entire framework of empirical research is accurately explained. In other words the applicability of CAD creative architectural design (see double framed box in Fig. 48) is evaluated in order to find answers to the research questions.

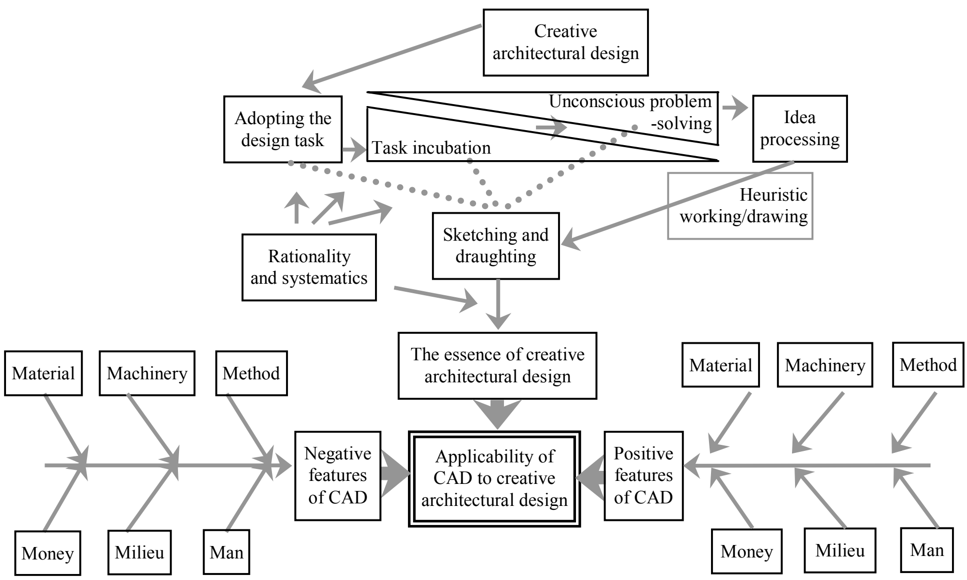


Fig. 48. The triangulation framework is used to evaluate applicability of CAD to creative architectural design.

The empiric material in this research is mainly classified in the form of individual surveys and then analysed as an entity towards research objectives and questions. Alasuutari (1999) emphasizes, that in qualitative research the material has to be analysed as an entity even when it consist of several surveys. In the analysis of this research also the perceptions and factors related to other classifications are noted in the final analysis. Therefore possible factors influencing through classification are also noted. As mentioned earlier there is plenty of research material collected during the research project, which is not integrated in this thesis. It has not directly influenced the conclusions, even when they are parallel and similar perceptions as in this thesis. It is then, however, giving support to the results.

The final framework (Fig. 48) of analysing the results of this research (selective coding) consists of one relation and two fishbone diagrams (analysis presented in chapter 5.6.1.). A relation diagram has been formed from features and factors behind the creative design, noting only the most critical factors. The relation diagram (relationship diagram or linkage diagram) itself is a method used to identify, understand and clarify complex cause and solutions and effect relationships to find the causes and solutions to a problem and to determine key factors of the phenomena. Relation diagrams are used when the causes are non-hierarchical and when there are multiple interrelated problems. This diagram requires a lot from the analyst. (Dale 1994, Oakland 1995). On the one hand it is a systematic approach to classify the empiric material, and on the other it requires creativity in order to accumulate and compress the process to correspond the reality.

A fishbone diagram has been used to evaluate positive and negative features of CAD (analysis presented in chapter 5.6.2.). This type of diagram has usually been used to evaluate relations between effects and causes. It is one of the visual methods for qualitative and complex analysis, developed by Ishikawa (1985). It is used to analyse actual factors behind the consequences or features. In this research a 6M framework is included in it. These six M's are Material, Milieu, Machinery, Man, Method and Money. Furthermore every M can contain the additional question "why" five times. (Dale 1994, Oakland 1995).

The framework of analysis rises from the approach and results of this research. This emphasizes the hermeneutic approach to interpret and analyse empiric material. Finally two practical cases have been presented in order to evaluate final framework (chapters 4.6. and 5.5) and "arrows and boxes" in it. These cases have not actually had an influence on the framework. They have only been example cases of the practical design process and they have tested the validity of the description in figure 48. The designers in these case examples were first utilized after the analysis in order to verify the analysis and secondly reflect features and elements toward practical cases.

4.2. Individual survey settings

4.2.1. Defining design process

This survey has been done in conventional design projects in the practical design process, where Finnish architects have been interviewed. In first phase design methods were examined and informants were asked to explain their own experiences in practical design processes. In the second phase informants were asked to explain their creative process and possible separate events during the process. Finally the creative and intuitive design process, according to Tuomaala (1992, 1995), was presented and discussed with architects. The applicability of Tuomaala's theory in architectural design was examined. This survey is dated in early phases of research and the information attained is partially used in constructing the creative design theory (chapter 3). The results of this survey have been presented in chapter 5.1.

4.2.2. Specifying creative architectural design theory

This survey has been made in order to explain the creative architectural design process. The main parts of this questionnaire (appendix 4) were defining the creative work and features of the process. Also the need for systematic design and logic and the need for information technology in the architectural design process were queried. The classification was attained from the theory and mainly from the definition of the design process (chapter 4.2.1.), in order to ask the right and valid questions. Informants were picked by simple random sampling (Pahkinen & Lehtonen 1989) from the list of members of the Finnish Association of Architects SAFA (1996). The results of this survey have been presented in chapter 5.2.

4.2.3. Testing the QFD –method in creative work

The survey was implemented in two separate parts, where the applicability of a certain systematic design method (Quality Function Deployment - QFD) was examined. The main principles of QFD are accurately explained in theoretical part (chapter 2.2.4.). It was first studied in creative architectural design and secondly also in creative mechanical engineering design. In the first survey (appendix 5) the applicability was examined as a systematic tool in creative architectural design. Informants were picked by simple random sampling from the list of members of Finnish Association of Architects SAFA (1996). The results of this survey have been presented in chapter 5.3.1. In contrast the same questionnaire (appendix 5) was used to examine the applicability in another area of design - in creative mechanical engineering design. This was done in order to define possible differences between two design disciplines. Informants were picked by simple random sampling from the list of members of SKOL (1997). The results of this survey have been presented in chapter 5.3.2.

4.2.4. Defining the state of the art in computer aided design

The survey was made in order to explain the state of the art in computer aided design, applied CAD –systems and also the disadvantages and benefits in CAD (appendix 6).

Also this survey was made in two separate but similar parts, first at the end of year 1995 and second at the end of year 1999. Informants in the first part were from the list of members of the Finnish Association of Architects SAFA (1994) and were picked by simple random sampling. The second part of the survey was made with those who returned the first questionnaire. The results of both surveys have been presented as combined in chapter 5.4.1. After the first part of the survey several interviews were made in order to ascertain possible differences in the applicability of different CAD programs. Informants in this survey were randomly selected from the group of CAD users. All designers examined were using traditional drawing and designing applications and the interview was aimed at these features, while 3D features were mainly given lesser attention. These results are presented in chapter 5.3.2.

4.2.5. Modeling architectural design process

Two practical design processes have been modelled in general outline as a case studies. Cases designers were selected randomly from the group of relatively experienced designers, who also have used CAD. The purpose was to present the personal design process as it happens in randomly selected projects. The cases are from genuine projects in real buildings. The modeling has been carried out so that designers have kept a diary of their work and marked up occasions e.g.:

- important dates,
- important events in design (e.g. project meetings, changes in requirements),
- development of ideas,
- any other significant factors that may have influenced the final solution and
- how ideas are processed and how ideas have emerged.

Both designers had similar instructions for documenting the process. The purpose was to describe two practical design process and these descriptions are presented in chapter 5.5.

5. Results and analysis

5.1. Architectural design process

In the research into methods, the first objective was to study the progress of creative architectural design in the designing of a single family house. After that the architects were presented with the theory of creative and intuitive designing presented by Professor Tuomaala. In the architects' view, the theory is suitable to architectural design. They had applied corresponding methods in their own work without being aware of the existence of the theory in question. With Professor Tuomaala's theory, architects also observed such events and similarities they had not been earlier aware of in their work.

In architectural design, one is never given a totally free hand with regard to creativity. In real design, there are always some rules, regulations and restrictions which restrict the design. Too much freedom might even cause faults in the design. In case "the forced reality" (regulations and instructions) is not taken into consideration early enough, bad solutions which cannot be realised will be created. Architectural design is a highly technical field, although it should create construction art. Therefore the limitation of design tasks both facilitates design and renders it more difficult, since restrictions give finished values for some parameters.

The results of the interviews are gathered into one description which covers a total of thirteen architects' experience in designing. The description presented below was constructed by combining the notes from the interviews and other documents. Interviewees selected were experienced designers, some of whom used computers for designing, and some traditional pen and paper, in order to get as thorough a picture as possible of the reality of designing. The designers' jobs were mainly located in Oulu and Helsinki, but buildings designed by them can be found all over Finland, and also abroad. The reliability of the description presented has also been verified by some architects. Reliability is also emphasised by the fact that the last interviews performed gave no significant additional information for the description. The description is uniform, although the methods used by architects differ from each other. The most essential fact is that the description gives a reliable starting-point for follow-up research.

Architectural design process is assembled from the answers gathered on the basis of the interviews. The starting-point of design is usually both the need and the building plot. The need means, for example, the space required by the customer's family for its activities. These could be the size of the family now and in the future, hobbies and other plans for the future. The needs are clarified on the basis of the customer's details, when the customer has to present not only his/her needs, but also wishes, hobbies and dreams. In other words, everything that is expected of the house. Requirements may sometimes be even totally contradictory, and thus, impossible to be realised. In this case, the architect him/herself must form a well-proportioned solution from the elements available. In the design of a single-family house the plot is also very important, since neighbours, cardinal points, the path of the sun and other factors relating to the plot together form the "spirit of the site". Designers do consider getting acquainted with the plot a condition for the commencement of the design work.

The actual design work is started with the design of the main functions of the plot, when the elements are the cardinal points, difference of levels, characteristics of the landscape, vegetation, neighbouring plots and the rest of the environment. This phase is carried out on the basis of zoning regulations and official regulations, and especially of the space required. When the main functions of the plot are arranged, the designing of the main forms of the building is started. Here preference is given to the external factors influencing the building. Also the functions relating to internal spaces of the building must be considered in the form of "designing automation" or "somewhere in the back of your head". Usually, more than one alternative is drawn for the framework of the lay-out.

Based on the main forms, spaces are designed and mass distribution sought for in accordance with the space programme. For this purpose, connection diagrams between various spaces are used without an accurate lay-out of the rooms, including entries, bedroom, wet spaces, kitchen and household management rooms, as well as possibilities to move between the various spaces. The objective is to outline "the main functions within the forms of the building". Rooms are not yet actually located in the plan, although they exist in the form of the designing automation in the architect's mind. On the basis of this stage mass distribution of the design work is specified in a larger, and for the first time, dimensionally accurate drawing. The final lay-out solution and its functionality are verified in accordance with the customer's needs. Throughout the whole design work, it is important that the designer is able to outline the forms of the building three-dimensionally, although the work takes place only on the two-dimensional level.

The functionality of the completed lay-out solution can be tested and analysed in various ways, for example, by drawing a circle the size of a wheel-chair that is then moved around the lay-out and checked that it is able to move freely everywhere. The functionality can also be tested in the form of a "mind game" where the designer puts him/herself into the building user's position and then "uses the building".

On the basis of the final and accurate lay-out solution a first section drawing is made, which facilitates the drawing of façade drawings. Façade design is preliminarily carried out in the drafting phase of the lay-out drawing, when the most important issue is how the building opens. The façade is designed and considered simultaneously with the lay-out drawing as "designing automation" e.g. it is not worked on actively although it has a constant influence on the designing work. In the interviewees opinion, façade-oriented design has a negative influence on the design and especially on the functionality of the lay-out solution. Therefore, the lay-out solution should be as completely designed as possible before moving on to the façade designing.

Practical creative design consists of many factors. Drafting designing is a combination of many matters and outlining of entities on the conceptual level. “There might be even 50 different matters to be managed, and they will be brought on paper as an over-all solution.” On the other hand, “when one thing changes, it usually changes everything else, as well”. “Here working means working on a three-dimensional image, although scrapping and drafting takes place on a two-dimensional level.” Drafts are often drawn in considerable amounts which is exactly what we mean by “interpretation of images”. “Design is not completed” if it has no idea or perception. Images should be made rather complete in the mind before one starts putting them on paper. Each completed solution should “just be good” in the designer’s own opinion. The functionality of the solution will be checked later. The subconscious should have enough “provisions” in order to be able to work adequately well. As a result of the work carried out, the creative solution will “pop out” which often occurs by itself. After that it is drafted onto paper.

Time must be reserved for the design by the architect. The design projects of today, with their tight timetables, are not the best possible solutions with regard to design. The architect must be able to stand back creatively, in other words, to develop ideas by doing something else and let the information be “incubated” in the subconscious. The over-all solution can be worked on with numerous degrees of incubation. As the work proceeds, there will be several solution phases, after which new information is gathered. Each solution phase should be give time to be “up-graded” in the subconscious. Through incubation and drafting, an “aha” experience will come for each building to be designed.

Architects usually process their thoughts with the help of drawings – drafting works as a way of clarifying thoughts. In this case, the motorics are also combined with the subconscious. On the other hand, the subconscious communicates with the drawing with the help of the sense of sight, without having all information using, or passing through, the conscious mind. Thus the actual good ideas are created on the level of the subconscious. Ideas are developed consciously when the matter is handled further, but the final solution will come to mind as the work is eased off, for example: “the subconscious works especially during the night”. Some architects keep a note book called “the Architect’s dreams” on their bedside table. This is the book where the dreams from the night are described in writing or drawings. The subconscious should have enough material in the “great storage” of the subconsciousness, in order to produce mature and good solutions. Creative architectural design is connected with an external tension, which is generally the timetable. A dead-line when the plans should be completed usually intensifies the design.

The use of the computer as a tool for drafting was not directly opposed to by the architects interviewed, but they stated that it was a question of learning. “How to learn to communicate with the subconsciousness?” “How to dismantle thoughts into completed solutions?” (cf. the use of pocket calculators by today’s pupils and computer aided word-processing programmes). Thinking with a computer is, however, a little difficult, because the direct “computer-like lines” give the draft a “final touch”.

5.2. Creative and intuitive architectural design

The questionnaire was returned by 26 offices. Three offices returned it, but had not answered it due to a busy working situation, so the answers of 23 designers have been taken into consideration in the results of the inquiry. Only about a fifth of the inquiries were returned, which can be considered a low result, but there is no reason to assume that the background population would have had viewpoints with considerable added value. On the basis of the low returning quota of inquiries carried out earlier in the same industry, the questionnaire was sent to one hundred offices, in order to get an adequate number of answers for the analysis. The results of the inquiry can be deemed reliable, because they are rather surprisingly uniform, even about information technology. Reliability and validity can be considered well accounted for, especially since interest in the results of the inquiry was emphasised in many answers, because designers had already pondered the matters in question in relation to their work. In this case also the reliability of observations is increased, because the respondents' expertise on the subject is greater. Partly also due to the above-mentioned reason, the answers related to CAD may not be held very reliable, although they are quite similar to the results of the actual sections relating to CAD. However, an essential fact is that the inquiry was answered by those who work with the computer, as well as by those who do not, which for its part speaks for the reliability of these results, because alternatives in accordance with the preliminary understanding are represented from the creative design point of view.

All answers are presented in their entity in appendix 7, because the results cannot be presented mathematically or simplified without generalizing them. The answers in appendix are classified in the order of questions and respondents (appendix 8). The same code has been used in the answers of each designer, in order to be able to separate the consistency and references of the answers. In the following there is a compressed interpretation of the results in general question by question. Results are more accurately analysed in the analysis (chapter 5.6.) through the framework presented in chapter 4.

Summary of the results. It has to be noted that designers were asked to answer only to the open questions presented (appendix 4) and therefore statistical appearances may seem bit peculiar. It is also essential to note that, if several designers have expressed their opinion about a certain issue or feature, it has to be noted in analysis. Therefore it is not essential that the number of certain factor is 6/27 or 8/27, but the fact that the factor has been adduced. Statistical appearances are presented in order to indicate only the rough appearance.

Defining creative architectural design is very difficult as noted also from the literature. Besides definitions usually lead to some kind of simplification of the whole domain of creativity. Some of the answers describe the extent of creative architectural design "the whole working field of an architect" and "creativity is the basis of everything". Creative work is an abstract concept, which can be seen from the figurative answers. On the other hand architects, as a profession, are very familiar with it. When interpreting the formulations, the creative work always contains freedom in several respects at work, which is actually the designers' possibility to work. On the other hand the control and ability to be creative sets considerable requirements on expert knowledge in design and is emphasised in complex problems. Since the design objects of design vary with regard to their conditions and contents, creative design often brings individual and unique results, although emphasising dissimilarity has not been a conscious goal. Creativity can appear on many levels, it can be an over-all idea or a sudden perception on the level of details. The concept of creative design is often used to mean aesthetic creativity, but it can as easily be of a functional or technical nature. Architectural design is comprised of different artistic, functional, material, ecological, etc. demands which may be even inconsistent, combined through architectural design in a novel way. Therefore creative architectural design can also be seen as a creative problem solving.

All informants had *experiences of subconscious problem-solving* (27 of 27 architects). The most common situation for the emergence of ideas was taking place somehow surprisingly during a peaceful period (12/27), wherever else, but not at the drawing board. Examples of these situations are events where a certain factor of the environment brings about an association of ideas, but this is not necessary. Another typical example of subconscious problem-solving for many architects is presented by sleeping over the night (9/27). In practice, this means that the design has been worked on the previous day and in the next morning a solution for the task is created as if by itself. Three of the architects noted that subconscious ideas overflow constantly in all situations. Some of the architects (4/27) mentioned that one can only do routine work at one sitting, but this work is a starting point for subconscious processes. These results don't mean that active working with a drawing board cannot develop ideas, but the question was only about emergence of subconscious ideas, which evidently need relief from conscious pressure.

Incubation is a necessary phase in creative design according to (27/27) architects. Incubation means in practice that designer has to free himself from work from time to time (17/27) so that the pressure in his brain is relieved. However, during incubation the brain processes the problem and solutions apparently do stew somewhere, evidently in the subconscious. Incubation takes place through logical thinking in a shorter or longer time (6/27), when logical thinking starts the process in task adoption. Design in haste brings a successful end result only in easy construction targets and usually leads to a poor solution (5/27). Pressure is needed in order to keep the subconscious processes running, but the pressure cannot be too great (4/27).

Ideas of images are often born of action and of the environment. A challenging building site usually offers something to grab. Images are always there in the back of the head and images can be generated in everyday events. Building *images of the solution ideas,* is like playing with images in the mind (9/27). The situation can also be the opposite in this play - images create solution ideas. Images, visions build solution *ideas, which are complemented and deepened through sketching* (13/27). It is almost like disentangling a subconscious work to give it a visual form. Ideas develop during the work, which usually requires sitting by the drawing board and drawing, in which case the work also develops as if by itself. Also computers are sometimes used to visualize ideas.

Defining *creative drafting* is as wide concept as creative design, but it can be divided into two main categories – inspiration and perspiration. Inspiration means interpreting thoughts, testing ideas and images and leafing through brains at great speed (15/27). Drafting is testing of the world of ideas – continual feedback and the development of ideas into a form that can be implemented – perspiration. In the drafting phase, the design plan achieves a real form and the tool of expression, pencil, follows the commands from the brain. In other words perspiration means physical working (11/27).

Systematic logic is required in architectural design (22/27). It is needed for organizing the rational design process in with creativity has the ability to operate. Creativity cannot function with success before systematic logic has given it the input with which the entity is able to function. Logical thinking and work are required, in order to gather the different partial factors into consistent and intelligent entities. Systematic logic is not needed in the linear and perpendicular repeating of things (4/27).

The *applicability of the computer in creative architectural design* is difficult to answer briefly. It partially applies and partially does not (8/27). This category couldn't give a straight answer. The applicability was seen best in routine and in final phases of design (14/27). In contrast, the inapplicability (5/27) was noted and explained in early phases of design.

5.3. QFD in creative work

5.3.1. Applicability in architectural design

The inquiry was sent to 80 Finnish architectural offices. A total of 15 was returned which is about 20%. The percentage of replies is poor and only represents a part of the basic multitude of architectural offices. Although the sample is a random sample of the whole list of architectural offices, it can not be considered a very reliable one. The majority of the answers is, however, clearly against the applicability of QFD. Another factor which decreases the reliability of the results is the fact that not all architects have previous knowledge of the QFD method or its use, but the inquiry tests the possible application of the QFD method in architectural design. On the other hand, the inquiry verified the preliminary understanding prior to the inquiry – that a fully systematic method which would dominate the whole of design work and produce the final design solution cannot be brought to the architect's work.

In the following there is a compressed interpretation of the results question by the question. Answers received are presented in appendix 9, following the order of the question in the list of questions (appendix 5). The same code (appendix 10) has been used for the answers of each designer, in order to be able to separate the consistency and references of the answers. Results are more accurately analysed in the analysis (chapter 5.6.) through the framework presented in chapter 4.

Summary of the results. Statistical appearances are presented in order to indicate only rough appearance. *The QFD method was seen* as indistinct, complex and mathematical, too much meticulous data and therefore shackles design (11/15). On the other hand it was also seen as systematic, but still questionable one, anyhow design proceeds roughly as presented in QFD (5/15). *QFD could be applied in architectural design* in small details, but the object should be rather simple and repeated as, for instance, in the construction product and material industry (12/15). It can be applied only as a background process, because "you can not draw with a book-shelf" (7/15). When comparing *QFD and creative design process* it clearly noted that a mathematical and systematic method can not at any rate work in place of a creative design process (12/15). QFD is a linear process, it does not really follow the illogical logic of a creative process, but still the phases of QFD can be found from design process, although they are not followed directly in practical work. The traditional way of thinking, that the older generation of designers have a negative or sceptical attitude toward everything new or change didn't hold true. There wasn't *any great difference between experienced and inexperienced designers*. As a new tool *QFD raised several questions and problems*. In architectural design it is very difficult or even impossible to define the average customer. On the other hand customers may not even know all possibilities or restrictions in construction. Even if these factors could be determined, the size of the matrix and amount of information will grow pass sensible limits.

5.3.2. Applicability in mechanical engineering design

The inquiry was sent to 60 Finnish mechanical engineering design offices. Only a total of 13 answers were returned which is about 22%. The answering percentage can be considered poor, but we do, however, have the insight of 13 machine engineering designers on the QFD method available. Although we can approach the results from the factual point of view, and they can be considered reliable, due to their relative uniformity, they can only be given an indicative significance with regard to the over-all study.

In the following there is a compressed interpretation of the results question by question. All answers are presented in appendix 11 in their entity, in the order of the question and respondents. The same code has been used for the answers of each designer (appendix 12), in order to be able to separate the consistency and references of the answers. Results are more accurately analysed in the analysis (chapter 5.6.) through the framework presented in chapter 4.

Summary of the results. Statistical numbers are presented in order to indicate only a rough appearance. *QFD was seen* as indistinct, difficult to understand and complex method. It is not necessarily inapplicable, but since the complex and heavy method requires too much time in busy schedules. *QFD can be applied in mechanical engineering design* (10/13). Some restrictions exist and adaptation must be done, but the acceptance was rather good. *QFD and creative design process* can be combined (10/13) in mechanical engineering design. Anyhow an important note is that QFD cannot replace creative design (4/13). QFD can form an operation diagram for an otherwise rambling activity. The QFD method *is suitable for younger (10/13) as well as for experienced (5/13) designers*. Anyhow, experienced designers may be slow to adopt new methods. The complexity and difficulty in learning to utilize QFD effectively was expressed as the greatest problem.

5.4. Computer aided architectural design

5.4.1. State of the art

When adding together all offices who returned the first questionnaire, the answering percentage is about one third. The result can be seen as satisfactory when compared to other corresponding inquiries carried out in the industry. After classification, bar diagrams were selected as the presentation method of results, also for qualitative material, because the number of responses grew to such an extent that it would not be sensible in any other way. The diagrams do not, however, describe the entire situation relating to the corpus of designers, but only to the results of this inquiry. It must be noted here that some interpretation of the answers was unavoidable, but even in slightly unclear places it has been left undone, and a class of its own was founded for the property in question. Two main classes can be observed in the material: the first class has voluntarily adopted, or accepts, the use of computer aided design due to practical necessity, and the other class does not approve of it. With regard to reliability, it is essential that the views of both groups are brought forward, because even though the most essential results would be the same, the other group brings them up in a more emphasised manner. Also with regard to fields of designing, the sample seems to represent the situation well.

Since the results of the first inquiry describe the situation at the end of the year 1995 (Fig. 49), it was appropriate, with regard to reliability, to renew the inquiry for the situation at the end of the year 1999. The renewed inquiry was returned by 42%. The second inquiry was directed to those offices which had returned the first inquiry. The results were highly coinciding in other respects, except for the relative share relating to the utilisation of information technology. Neither inquiry shows significant differences between quick or slow respondents. The offices, to the first inquiry, were selected on the basis of random selection. There is no reason to assume that the background population would include viewpoints which would significantly change the results achieved. Moreover, it can be stated that the results gained in conjunction with other tests (chapter 5.1., 5.2. and 5.4.2.) largely support the views given in this chapter. Thus these results give a reliable description of the state of Finnish architectural design in relation to CAD.

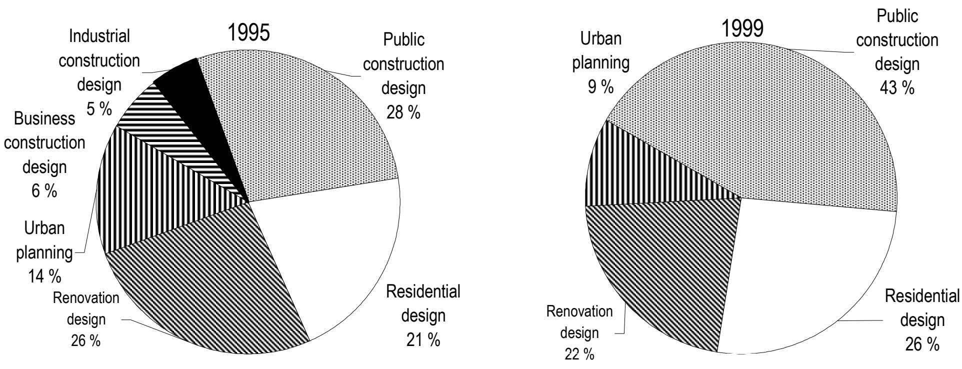


Fig. 49. The fields of design of the offices that participated in inquiries.

Offices which participated in the inquiries operate in more than one field of design (Fig. 49). Those who responded to the first inquiry, 44 design public construction and 42 primary renovations. More than half of the offices operate in these two fields of design. 33 offices designed residential buildings and 22 specialised in urban planning. Business construction was the field of design for only 10 and industrial construction for only 8 offices. The results show the situation in the construction industry in 1995, the share of public construction is the biggest, and the shares of business and industrial construction only cover a few per cent. The share of primary renovations is relatively large (26%). In the renewed inquiry, the distribution of the fields of design is almost the same.

Degree of utilisation of computer aided design. The total number of designers working for the offices that participated in the first inquiry is 550 (Fig. 50). The information of a total of 224 designers relating to the use of CAD has been gathered in the second inquiry (Fig. 51).

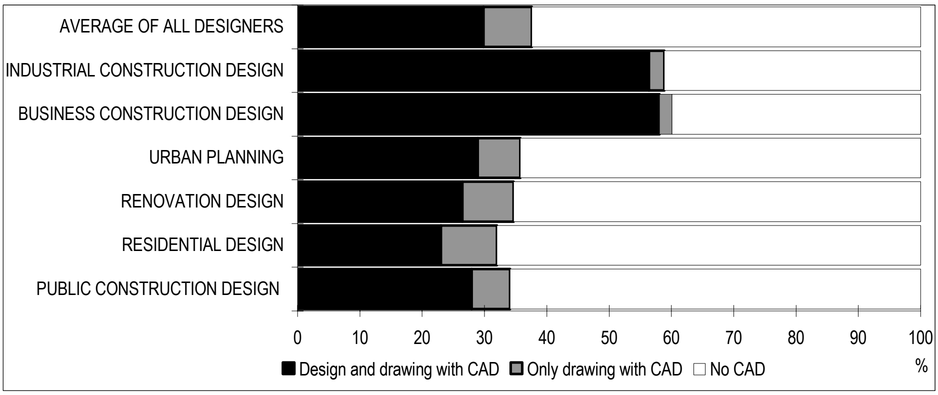


Fig. 50. The relative shares of all the designers of the first inquiry who utilise CAD programs for designing and drawing, or only for drawing, or who do not utilise CAD programs at all.

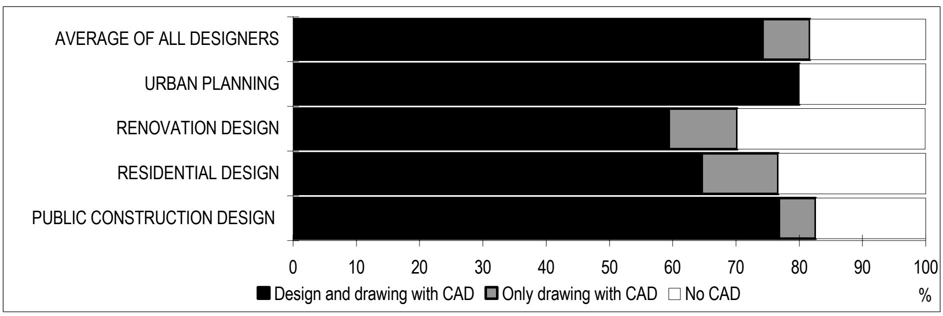


Fig. 51. The relative shares of all the designers of the second inquiry who utilise CAD programs for designing and drawing, or only for drawing, or who do not utilise CAD programs at all.

At the first (Fig. 50) inquiry 29,8% of all designers work with computers, 7,8% only use the software for drawing, and 62,4% do not use the computer at all. The designers of the relatively smaller fields e.g. designers of business and industrial designing seem to work significantly more with the computer aided manner than other designers. In the designing for business and industrial construction, computer programs also are designing tools, and not only drawing equipment. The results gained in the second inquiry (Fig. 51) show that the use of CAD has increased significantly. Of all designers, 74,2% work with computer aided designing, 7,5% uses computers only for drawing, and 18,3% do not use the computer at all. No changes have occurred between various fields of design.

The share of computer aided designing and drawing of all architectural designing is almost the same as the share of designers in both inquiries (Fig. 52 and 53), although the relative share has increased significantly.

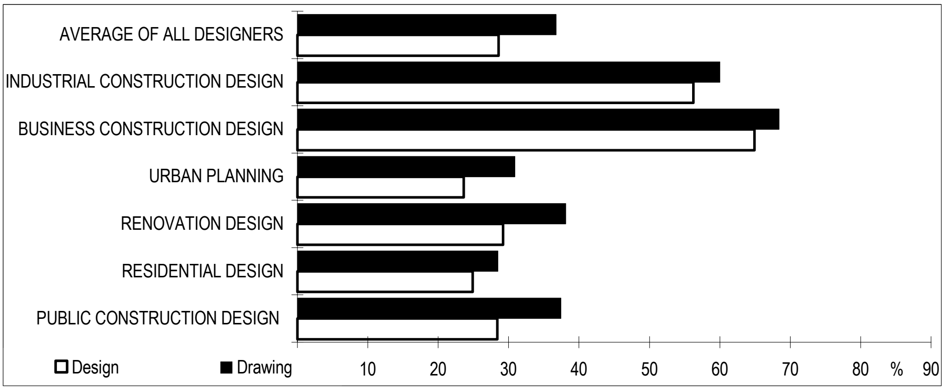


Fig. 52. The share of computer aided designing and drawing of all architectural design in the first inquiry.

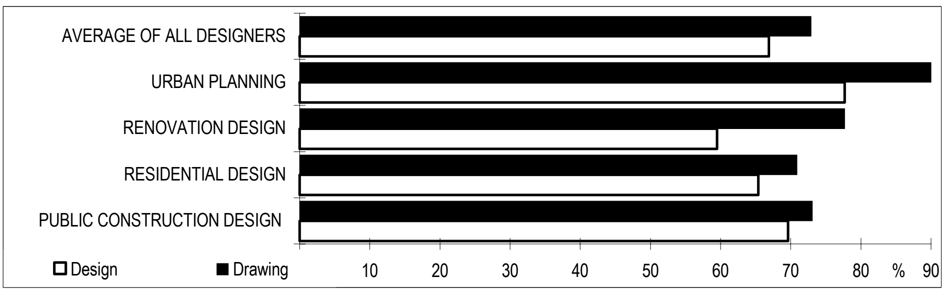


Fig. 53. The share of computer aided designing and drawing of all architectural design in the second inquiry.

Values in figures 52 and 53 have been calculated as averages of all architectural offices, and also of fields of design. At the end of the year 1995, an average of 28,6% of all architectural design, and 36,8% of drawing is carried out computer aided. Correspondingly, at the end of 1999, an average of 28,8% of all architectural designing and 71,4% of drawing is carried out as computer aided. The relative shares and distributions are approximately the same as in the comparison of the manners of working of architect designers. Also these figures show that those who use a lot of computer aided design also apply it proportionately more to designing in addition to drawing.

Computer applications used in designing. Results gained from design programs do not give a very precise image of the CAD programs used by offices. 55 offices (66%) which had returned the first inquiry, reported the programs they utilised in design. The corresponding number in the second inquiry was: 39 offices (93%). AutoCAD have a clear market-leading position (Fig. 54 and 55), since about two thirds of those designing with the CAD utilise some AutoCAD program and about half of those also utilise an addition application of the AutoCAD, such as ARKSystems, PomARK, KIVImenu, KCAD or YT-CAD.

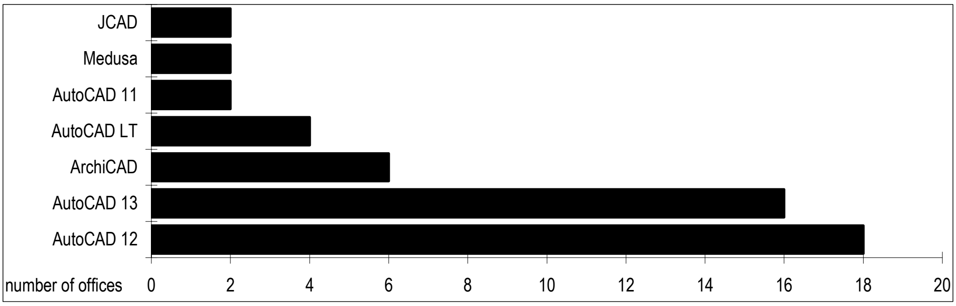


Fig. 54. CAD applications utilised by offices in the first inquiry (only one licence per office of the program in question has been taken into account in the calculation).

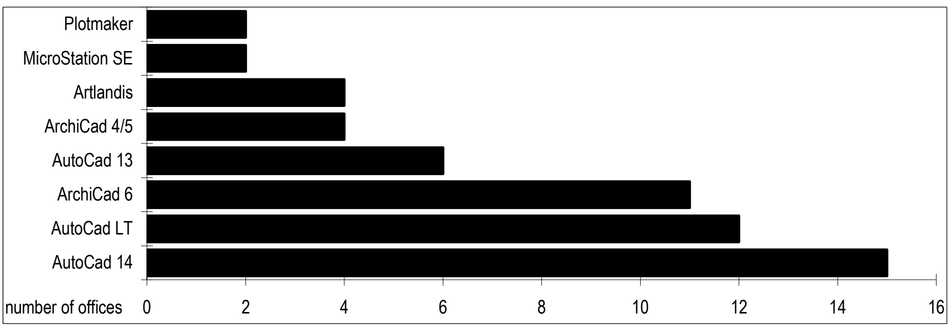


Fig. 55. CAD applications utilised by offices in the second inquiry (only one licence per office of the program in question has been taken into account in the calculation).

Moreover, one offices utilized following programs in 1995; DOGS, GDS, MicroStation, Form-Z, AutocAD 10 and FASTCAD and correspondingly in 1999; AutoCad2000, ArcView, Vector Works, ArchiSite, IntelliCad and Accurender. Offices considered the programs they used as being good in comparison to other applications available on the market. The users of AutoCAD and its applications consider them good, but the users of ArchiCAD are more satisfied compared to the users of AutoCAD. Most users did not have very much experience in other applications than those being used in their own office.

At the end of 1995, 27 architectural offices (33% of offices) applied computer programs for three-dimensional modelling. Correspondingly, at the end of 1999, they were utilised in 24 offices (57,1%). The objective of modelling varies somewhat. Some architects use it for sales purposes or for preparing presentation pictures with it, but there are also those who prepare a model in order to get all the details of a building solved. In addition to the most general applications (Fig. 56), also the following programs are applied for 3D modelling: Renderstar, Microstation, Infini-D, Form-Z, Medusa, Real 3D, CDS, Autosurf, Zoom, Accurender a K-CAD (programs are only used in one office).

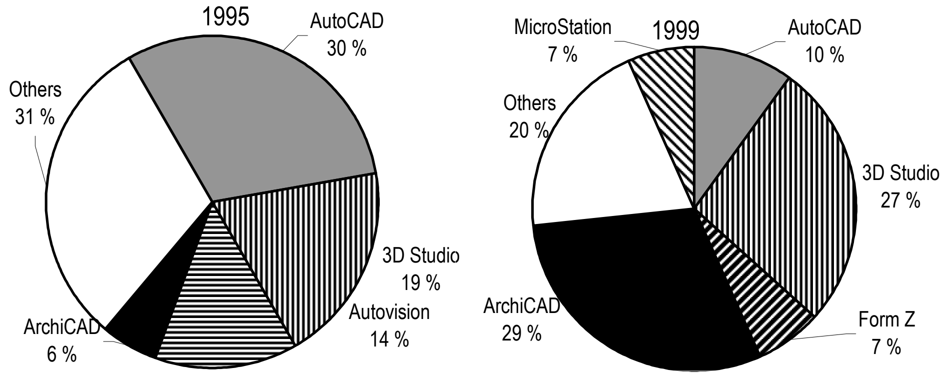


Fig. 56. Applications used in three-dimensional modelling, and their relative shares at the end of the years 1995 and 1999.

The use of text processing programs is mainly restricted to the preparation of text documents required for the planning documentation. Spreadsheet calculation is primarily used for the preparation of calculation documents and, to some extent, for spatial management. The use of databases as help for the designing process is minor. No actual programs were applied to the co-ordination and management of planning documents, but some data bank applications of certain projects were, however, utilised. Until today, project management programs have only been used a little in designing. Other programs relating to design are mainly image processing programs which are used for the preparation of material for presentations, sales, and comparison between different alternatives. In addition to that, some programs relating to the animation and their presentation are utilised.

Use of computer programs in different phases of the design process. The use of the computer in the different phases of design and three-dimensional modelling varies significantly (Fig. 57 and 58). In the requirement study and project planning phase, application are used for making diagrams for spatial utilisation and for mass-layout, but still their use is relatively minor. Most of the architects who use the computer in design, also utilise programs for sketching, but some designers still make the roughest sketching by hand. Applications are used for the documentation and modelling of sketches made by hand, and for gathering data relating to scope and surface. Almost all computers users carry out implementation designing with the computer including the preparation of main and workshop drawings, and of mass lists. Architects' tasks during the construction period mainly consist of preparing modification and explanatory drawings. Computer-based plans are highly useful for making these, since the data files of the previous stages are available. In the Finnish building culture, the role of the architect traditionally ends at the completion of plans, but in the future architects probably will produce more and more information and material for real estate maintenance. This is in part demonstrated in the small amount of commissioning tasks at the moment. Architects working in special tasks produce special and additional material for the constructor, the customer or for another presentation purpose.

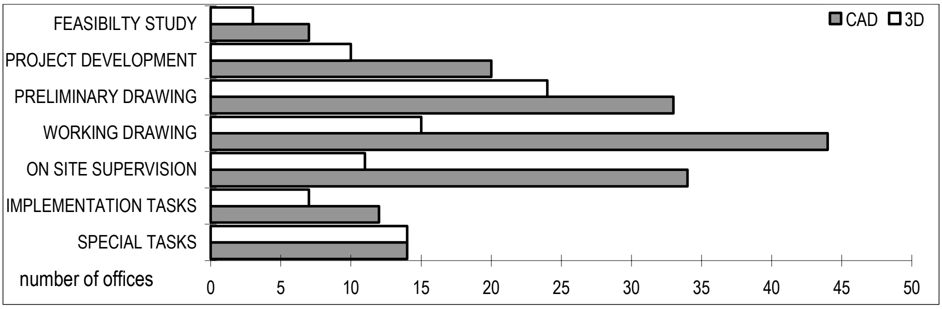


Fig. 57. Use of three-dimensional modelling and computer programs for working phases in accordance with the task list of ARK 95, in offices which used computer aided designing programs at the end of the year 1995.

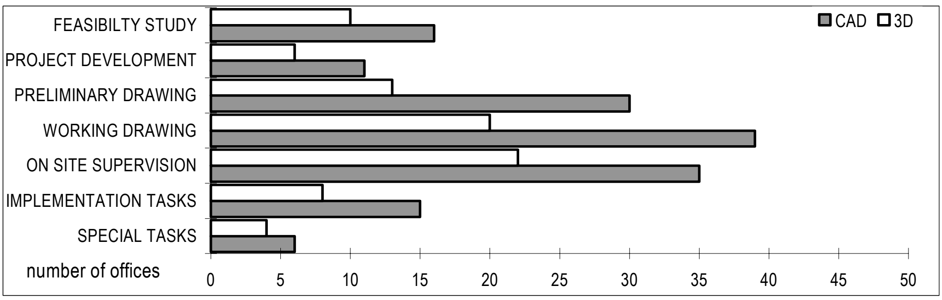


Fig. 58. Use of three-dimensional modelling and computer programs for working phases in accordance with the task list of ARK 95, in offices which used computer aided designing programs at the end of the year 1999.

The preparation of three-dimensional models is most common in drafting design. Architects use three-dimensional models either for studying entities or solving small details. Models are also used for the sales of drafts or presentations. Their use is significantly more restricted to the presentation of plans than to the actual designing of the construction process. This can be observed when comparing the relationship between computer aided design and three-dimensional modelling, especially in drafting and implementation designing, as well as in special tasks.

Justification for designing by hand. 52% of the architectural offices which returned the inquiry justified the grounds why they had not user computer programs earlier (Fig. 59). In the second inquiry, no reasons were given for designing by hand. The most common justification (19 offices; 44,2% of those who responded) is the great costs caused by programs, hardware and need for training. The majority (14; 32,6%) has not made any investments in hardware, because the present work situation is poor. This is emphasised especially in small offices, since their turnover is low in comparison to the magnitude of investments.

Unwillingness to learn and use information technology and the lack of correct knowledge and skills (11; 25,6%) are also a common reason. For the time being, drawing by hand is easier and more practical, e.g. computer aided designing has not been needed yet (6; 13,9%). Designers of small primary repair projects do not use computer programs in designing, because for the time being these are not suited for primary repair projects (5; 11,6%). In architects' opinion, more and more construction projects in the future will be carried out with computer-based Then also the designing of primary repair projects will be facilitated, because the present-day state of the building will be directly available for the designers. In small offices, the work so far has been of a smaller scale so that the architects have no needed programs for designing (4; 9,3%). In a couple of offices, designing work is carried out by the architects themselves, but drawing services for the preparing of computer aided drawings and documents are purchased in the form of sub-contracting (2; 4,7%).

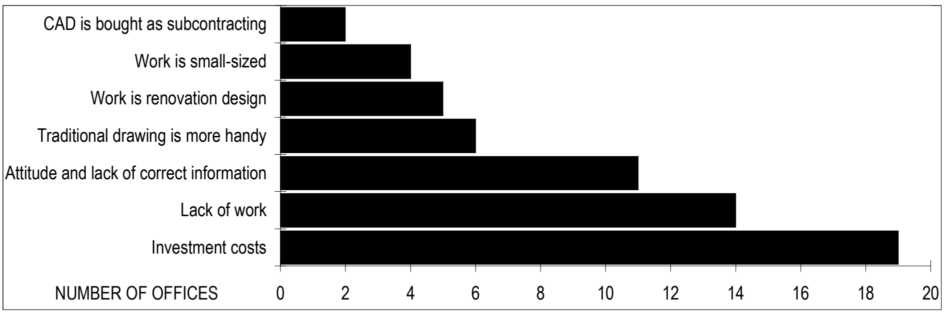


Fig. 59. Justification for the reason why computer programs have not been purchased for the architectural offices in accordance with their order of frequency of occurrence (first inquiry).

In addition to the justification presented in figure 59, there were some individual reasons for not purchasing a user interface:

- the scales of drawings are lost on the screen,
- computer programs are not suited for drafting and
- computer programs are only suited for final drawings.

The following handles strengths, weaknesses and development needs of computer aided designing as brought up in the first inquiry. Because the results of the renewed inquiry are so coinciding with those of the first inquire that no new information would be gained by their detailed commenting, only the diagrams derived of the data from the second inquiry are presented.

Experience gained from the use of computer aided design programs. 60% of respondents of the first inquiry commented on their experiences (Fig. 60) and 86% in the second one (Fig. 61). The most typical, good experience gained for the use of computer applications can be generalised in computer aided design. Decrease in the routine work (in 14 offices; 29,2% of respondents) and making the work more efficient and quicker are a consequence of carrying out routine work on the computer, especially when repeating similar solutions and structures. Working up on drawings, making modifications and preparing various alternatives for plans is a lot easier than in drawing by hand (12; 25%). The management and storage of data related to designing and designs has become a lot easier (8; 16,7%). With the help of the computer, dimensioning is quick and easy, and the drawing are dimensionally true (4; 8,3%). There are fewer dimensioning faults than in traditional design, because the dimensioning programs of computer applications give accurate surface and dimensional data (7; 14,6%). Moreover, drawings made by computer are tidier (5; 10,4%) than when drawing by hand. One can make several different print-outs with several different scales of the same model, in which case there is no additional load for making final drawings (2; 4,2%). Also the fact that the programs function properly and in accordance with the instructions, as long as you remember to follow the instructions, was considered good (2; 4,2%).

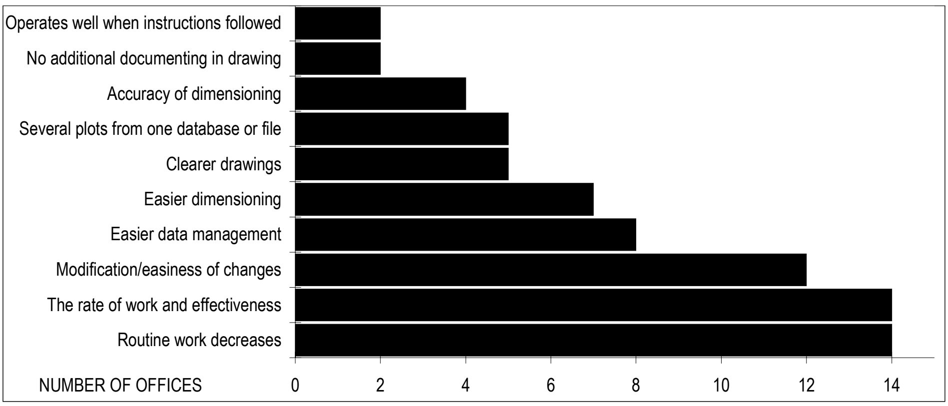


Fig. 60. Good experiences related to the use of CAD program in the order of occurring frequency (first inquiry).

In addition, individual offices had the following positive experiences in computer aided design: three-dimensional modelling and studying of the model become easier, once the model was made. With the computer it is possible to merge a drawing and a photograph, and to carry out rendering e.g. describe the surface materials corresponding to actual materials.

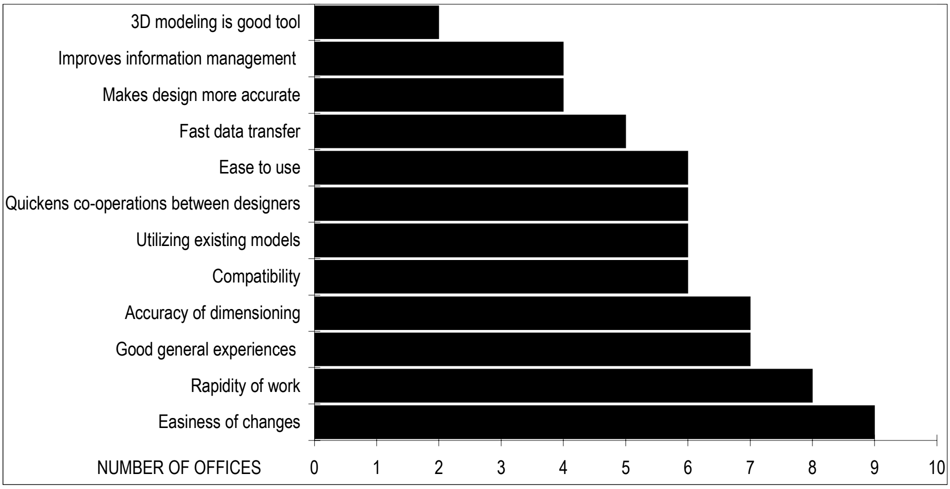


Fig. 61. Good experiences related to the use of CAD program in the order of occurring frequency (second inquiry).

The spectrum of bad utilisation experiences is a lot more extensive than that of the good ones (Fig. 62 and 63). Adopting a new mode of operation and the difficulty and complexity of information technology are the most common bad experience (11; 22,9%). This often also contains a negative attitude towards information technology and a threshold formed against the learning of a new matter. Non-compatibility of various programs and the lack of standards (9; 18,8%) hamper the transfer of information between different parties, causes a lot of additional work and additional costs. With certain programs, the additional applications required in addition to the basic programs, and the up-dating of older versions lead to the fact that the software in its entirety becomes very expensive (9; 18,8%). This again brings up the fact that in the future, additional funding must be found for new software investments and time must be available for their learning.

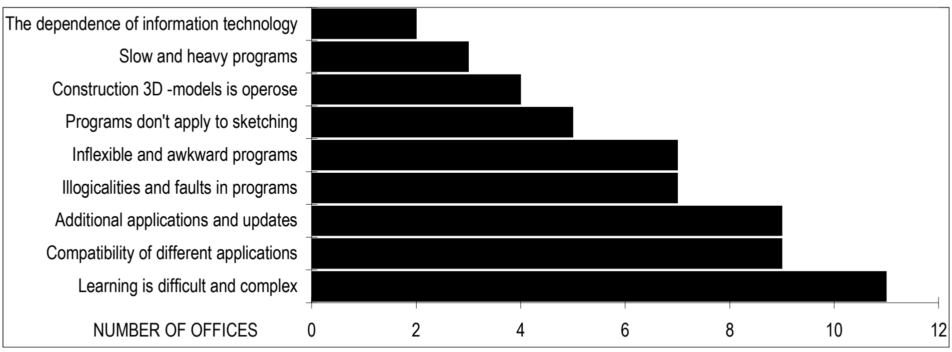


Fig. 62. Bad experiences relating to the use of computer programs in the order of occurring frequency (first inquiry).

There was an astonishing amount of bad experiences due to illogicalities and program faults (7; 14,6%). The rigidity and clumsiness of the programs (7; 14,6%) refer significantly to the above experiences, but also the over-all efficiency of the hardware has an influence. It has been assumed that computer programs cover the entire field of designing, but people have been forces to be disappointed, because not all programs are suited for the designing methods of individual users. It has been noticed that applications are not very well suited for the sketching phase (5; 10,4%). Using the present design and modelling programs for making 3D models has been perceived as troublesome (4; 8,3%). Also the slowness and heaviness of the user interface has caused difficulties in designing (3; 6,3%). A few offices had bad experiences in being dependent on technology in design, because offices hadn't actual experts on information technology, and when the technology falls down, the designers are unable to solve the problems (2; 4,2%).

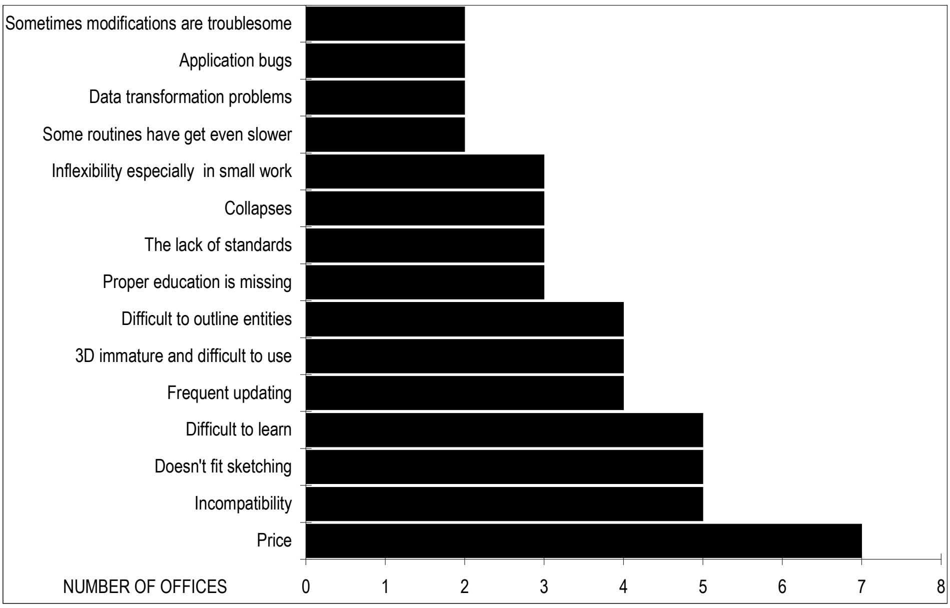


Fig. 63. Bad experiences relating to the use of computer programs in the order of occurring frequency (second inquiry).

In addition, offices have had the following individual bad experiences:

- unnoticed faults occur in designing and scale is lost in too small screens,
- a small alteration in the completed design requires the whole drawing to be reprinted,
- multiplied need for printouts,
- customers do not need computer aided designing,
- applications have not been complemented for architectural designing and many of them are merely general drawing programs because they are drawing tools
- working on a computer is more tiring than working in the traditional way and
- computer aided design does not as such improve the quality of designing.

In general, there is a bipartite nature to the responses between those who apply computer aided designing a lot and those who are just beginning to use it. The answers by those who are just beginning also demonstrate a lack of proper information and skills.

Advantages of computer aided designing. The rate of design and drawing are seen as the most important advantage of computer aided designing in comparison to working by hand (Fig. 64 and 65). Quickness here means the quickness in both producing the pictures (21; 48,8%) and making modifications, as well as the quickness of producing various alternatives (16; 37,2%). Modifications can be carried out easily and quickly on the completed design data. A completed base of the previous designing phases is available, and from there one can proceed, for example, by changing the wall material. However, it has often been stated in this connection, that the time spared in the use of information technology has not been given to the architect to be used in another work. For the time being, it is almost solely been used for speeding up the time used for the design project. With the help of a set of co-ordinates one is able to get the exact, correct measures and distances (13; 30,2%). It can also be used for getting exact values of measurement and surface data. In addition to that, dimensioning has been facilitated (2; 4,7%) and the amount of dimensioning faults has been decreased in conjunction with CAD.

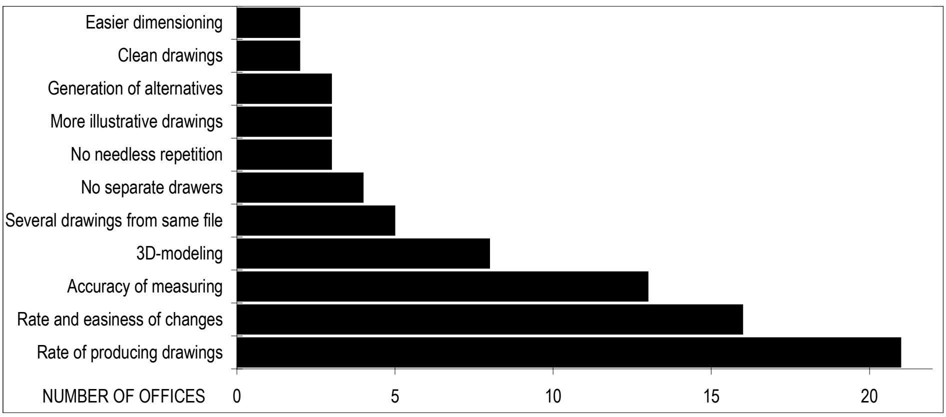


Fig. 64. Advantages gained by computer aided designing in the order of occurring frequency (first inquiry).

Three-dimensional modelling brings new possibilities for the designing of buildings (8; 18,6%). With the help of models, it is possible to study the entities of buildings or small details three-dimensionally. Moreover, three-dimensional models give possibilities for examining building with the help of animation. Several pictures of the modelled buildings can be got from the same data file (5; 11,6%). Offices do not need people to make finished drawings (4; 9,3%), because the architect carries out the designing, but also all drawings by him/herself. The same picture only needs to be produced one time (3; 7,0%), when the unnecessary repetition is removed. Thanks to the working and repetitive functions and the speed of producing pictures, several designing alternatives of the buildings can easily be generated (3; 7,0%). The clearness (3; 7,0%) and tidiness of the completed drawings can be directly observed for the print-outs. (2; 4,7%).

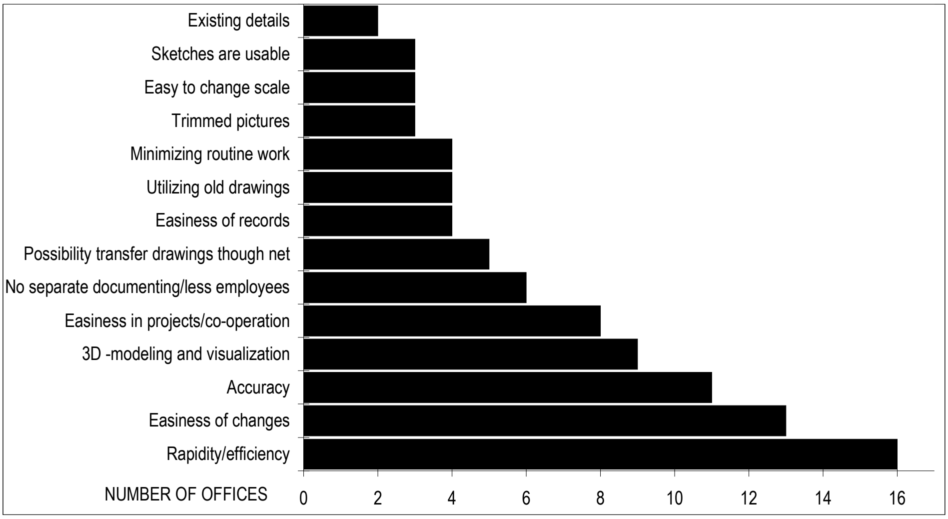


Fig. 65. Advantages gained by computer aided designing in the order of occurring frequency (second inquiry).

Moreover, the following advantages have been gained with computer aided designing in comparison with the traditional methods:

- data transfer between designers is facilitated and data management relating to designs is made easier and designing is more economic,
- thanks to accelerated routine work, there is more time for designing,
- quantitative data gained from the design data are more accurate,
- the quality of designs is improved,
- different designs can be combined together and
- the architect is able to carry out even large project by him/herself.

Practical problems and needs for development. The most common practical problem (Fig. 66 and 67) with computer aided designing is the mutual incompatibility of applications and the lack of standards (19; 38,8%). The designers of the project often have different applications (5; 10,2%), and the data formats of them are not quite coinciding. For this reason, a drawing that has been made on one application always looses at least a part of the drawings intelligence when transferred to another program. Another essential fact relating to this is that some designers still draw by hand which makes the utilisation of the possibilities of information technology more difficult. Another requisite for an effective use of application is the long time required for studying and training (11; 22,4%). Studying is also made difficult by the slowness and clumsiness of the applications (9; 18,4%). In addition to that, the use of information technology in designing requires a continual use of the equipment and software, because their fluent application requires a lot of information to be managed. Also new versions and up-dates enter the market at short intervals which leads to studying of new usage (5; 10,2%). Also prejudices and negative attitudes towards computer aided designing in many cases slow down the generalisation of information technology (5; 10,2%). The price of programs and hardware is a threshold question for small offices to purchase the equipment (7; 14,3%).

The entrance of new versions and up-dates on the market also reduce the eagerness to buy. Earlier, negative user experiences included the mentioning of offices dependence on experts in information technology, which prevents the expansion of information technology to all small offices (3; 6,1%). The constant changing of scales on the screen when working with the computer (3; 6,1%) makes the architects learns a new way of working without scales. CAD requires a change in the manner of thought and the designing method, since the designs have to be in correct scale from the beginning. The drafts e.g. sketches no longer are just sketches, but they already look like final designs.

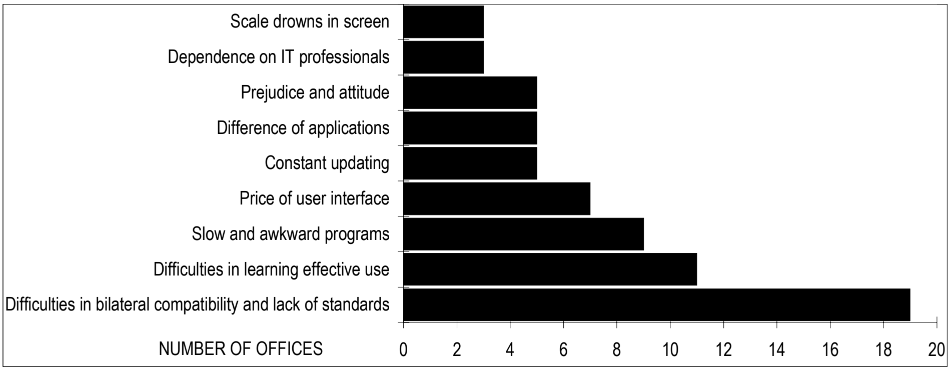


Fig. 66. The biggest practical problems of computer aided designing in the order of occurring frequency (first inquiry).

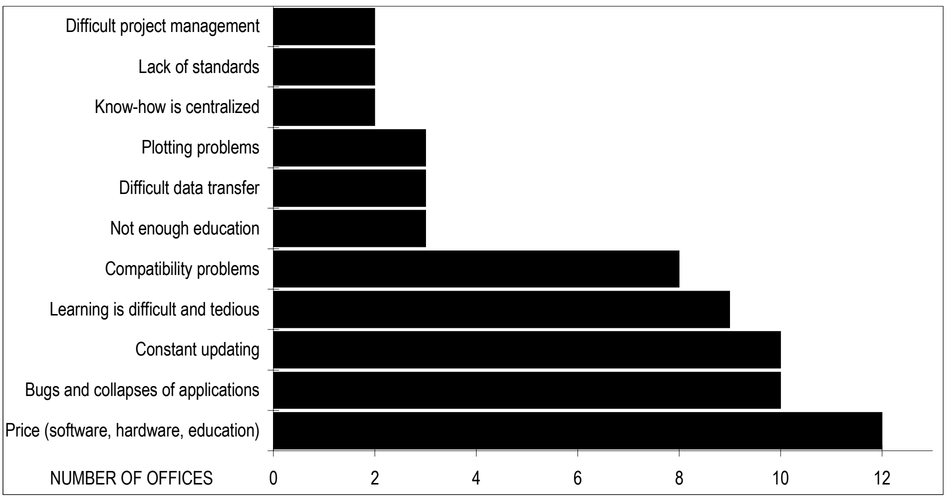


Fig. 67. The biggest practical problems of computer aided designing in the order of occurring frequency (second inquiry).

Other practical problems relating to computer aided design are:

- attention is paid too much to the use of the computer and the applications e.g. on unessentials,

- inflexibility of the programs is special situations and illogicalities in programs,
- difficulty and technical nature of programs,
- development of three-dimensional modelling,
- dependence on the functioning of the equipment,
- poor graphics of the screens, and the strain they cause and
- costs caused by the great number of print-outs.

The most common need for development (Fig. 68 and 69) is the development of applications in a more user-friendly direction (20; 44,4%). This means making the applications easier to use and more flexible than they are today. The second most important need for development was the compatibility of different programs and various versions (12; 26,7%), which has been pointed out at several points earlier. Compatibility here means mainly the creation of standards for the data forms of applications and data transfer. Especially design offices operating on the basis of a small turnover think that the decreasing the prices of hardware and software would be preferable (7; 15,6%). This would enable the use of information technology in design. According to the traditional distribution of work in architectural design, the tasks of the architect only include the production of construction drawings and explanations. In computer aided design, it would be possible to produce quantitative data from the design in the form of completed tables (4; 8,9%), in which case they could easily be used for the needs of cost calculation. The development of object-oriented design was also considered important (3; 6,7%).

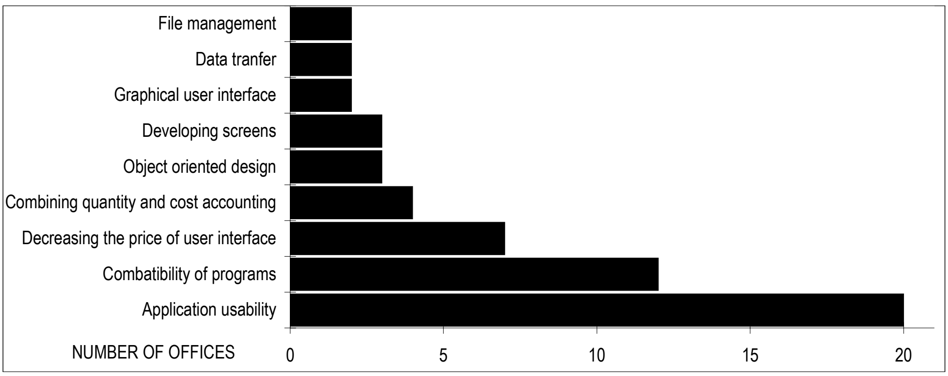


Fig. 68. The greatest needs for development of computer aided design in the order of occurring frequency (first inquiry).

Drawings and their appearance will always remain the most essential matters in architectural design. When working with the computer, the development of screens is naturally an important sector (3; 6,7%), in order to be able to make designing graphic and effective. In some designers' opinion, the development of the graphic user interface would be important (2; 4,4%), because when working with the keyboard and the mouse, the sensitivity of designing is lost with the computer. Systematic maintaining of computer aided designing is based on data transfer (2; 4,4%) and on data file management (2; 4,4%). This way, data is transferred between designer in accordance with standards agreed upon, and joint design files are given classification and user rights.

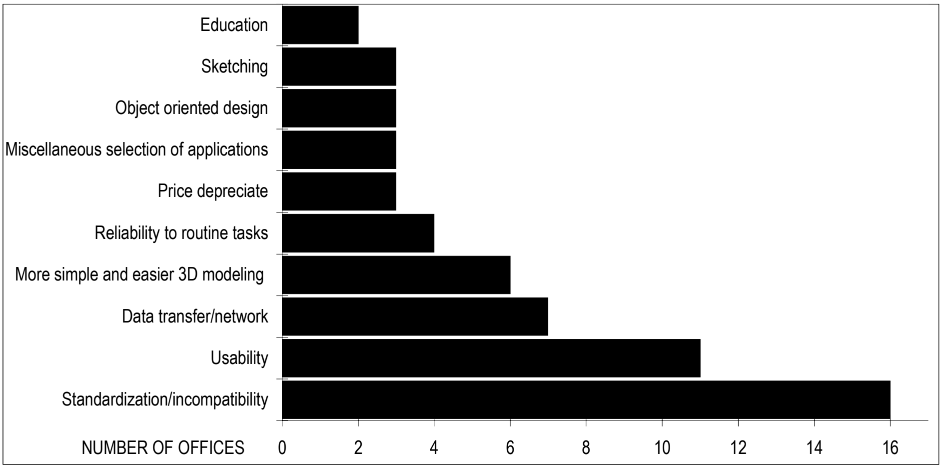


Fig. 69. The greatest needs for development computer aided design in the order of occurring frequency (second inquiry).

In addition, the following individual needs for development were observed:

- development of three-dimensional modelling and making heavy programs lighter,
- finishing the programs for architectural design and removing program faults,
- generally applicable product models,
- scanning of handmade drawings to the computer,
- organisation of training and
- development of computer aided design towards traditional design.

Computer-integrated design projects. At the end of 1995, about one third of the offices had never participated in a design project where all parties would have carried out designing with computer aid. About 66% had participated in such projects, and the experiences gained had been mainly positive. At the end of 1999, the situation had been improved, since about 72% had gained good experience from CAD projects. The best results had come from the projects where all designers had used the same application. Most problem cases had been generated by the lack of compatibility between the data and its form, caused by different applications and by different versions of the same application. Data transfer taking place via a network was considered a good principle, and also in practice, as a well-working solution. In some projects, co-ordination had been left to the sole responsibility of the architect and thus it had caused additional work. Requirements for the success of a project are:

- the rules of the project must be agreed on right at the beginning with regard to timetable, data transfer, designing methods and other matters,
- all parties must carry responsibility and participate actively in the project, so that others will not get additional work load, and
- one of the designers will act as the co-ordinator.

Development trends and their influence on design and architecture. Architects consider the present state of the utilisation of information technology rather good, although there is need for development. Some offices seek to use computers in all projects, and a part only in those where it clearly is advantageous. On a general level, offices have already moved for automated drawing to data processing and guidance of construction processes. In many offices, the situation at the moment is that "the bicycle is procured, but the chain keeps dropping off". The usage is not fully effective, because the office has purchased a design program, the advantages and possibilities of which are not utilised.

According to architects' evaluation, the amount of computer aided design will increase. This is influenced by the demands set by builders, because in the future designers will be expected more and more to deliver drawings made by computer. According to architects, also the "megalomania" which is plaguing the applications will increase, because as the programs are developed further, they will become heavier than those of today. Designing will become the building of a three-dimensional models, and the information traffic will be increased.

The applications of the future should be easier to use, e.g. they should be developed to be simpler and more flexible. Construction part specific that is object-oriented designing should be taken into consideration when aiming at developing more extensive designing programs. In some offices' opinion, computer aided design should be developed to be closer to the traditional design method of an architect, in order for description of work of the architects to remain as similar as possible, despite the computers. According to the majority, computer aided design has changed architectural designing for the better. Working has become more oriented, clearer and more precise.

More than half of the respondents were of the opinion that information technology has not changed architecture, and less than the half thought it has. Some architects think that architecture has not been changed so far, but it will in the future. Some are of the opinion that computers will not change architecture, if you are able to use them correctly, e.g. use them as tools. Others think that computer aided design will bring both good and bad things, e.g. it will partly make architecture worse, and partly better. Simplification of designs and a decrease in their quality are seen as negative changes, the use of neat drawings only as a sales argument. moreover, they think that architecture will become formal and free forms will disappear with the oncoming information technology. Numerically, more changes were considered positive than negative. Positive changes included the management of geometry becoming easier, the progress of visionary architecture, and rendering new forms and dimensions possible in the architecture.

There were only a few constructive additional comments and ideas relating to computer aided architecture. The most common of them was the worry about the quality of architecture because each industry has their share of abusers, and designs made poorly with the computer may look the same as the good ones.

5.4.2. Applicability of different programs

The inquiry was realised in thirteen architectural offices and a total of 18 architects participated in it. The results gained can be approached from a factual point of view, since there is no reason to doubt the reliability of the users' experience. Naturally those architects who utilise a computer in their design were interviewed only, because otherwise the information gained may not necessarily have been reliable. The number of architects interviewed per one application (4 to 5) is rather small, but the uniformity of the answers does, however, increase the reliability of the results. On the basis of the results gained, it can be stated that architects are not quite satisfied with the programmes they have used, regardless of the application in use. Although the present state surveys (chapter 4.1.1.) show that AutoCAD and its applications hold a significant position on the market, according to the results gained it is not necessarily the best application available on the market.

This interview contains CAD applications aimed to traditional design process and programs aimed especially to 3D modelling are intentionally left outside. Even the 3D features of these CAD applications were also left to lesser attention. This is because the different nature and purpose of the 3D modelling applications. Good or bad experience and applications were not observed to concentrate on a certain application, although the experience gained in the use of a certain application were relatively somewhat better than those of other applications. Even though certain properties of certain applications received thanks from all the users of the application in question. Correspondingly, the existence of certain individual bad properties, or the lack thereof, in a certain application was noticed. On the other hand, the design methods of architects differ from one another and therefore one property may be suited for one architect, but not to another.

Due to the character of this research, the number of observations is rather low. The results are also somewhat influenced by the fact that the interviewees apply different versions of the same program, and the designer him/herself may not have been aware of the version or up-date in question. Programme up-dates received generally a very reserved attitude. Improvements must be clear, in order for the investment to be profitable. This is also certainly influenced by the financial situation of the architectural design offices.

With regard to hardware, the results are rather coincident. Demands on the efficiency of the CAD system are high, but on the other hand, their constant updating to the level of the latest novelties is not sensible. The most frequent input devices used e.g. devices to convey commands were the mouse-keyboard combination. In other words, also in this field the interfaces were coincident. With regard to the interface, the evaluation is thus limited to graphics and software ergonomics.

The evaluation of results is realised with the help of a relative scale both application-specifically and by comparing them with one another. The result achieved after the over-all evaluation will be adopted to correspond to the over-all picture generated by the interviews and the results. It should be emphasised in conjunction with the evaluation that this interview is not aiming at testing the applicability or goodness of different programmes in detail, but to evaluate on a general level, whether there are any significant differences between the experience of architects using different systems. Factors applied in the evaluation are presented, for example, in Table 4. In order to illustrate the evaluation, simple symbols are used as follows:

- property is lacking or it does not function --
- property is weak or adequate -
- property is satisfactory +
- property is good ++
- property is excellent +++

Useful design segments for the application A (CAD A) are small and medium-sized dwelling and office construction targets. According to the experience gained, the system is not suited for the designing of industrial buildings (Table 4). On a general level, CAD A was seen as a “jack-of-all-trades” of computer aided work by the architect. It tries to offer help on a wide sector without being especially remarkable in any of those sectors. Of these, for example, the quantity calculation routine of CAD A was understood as being a totally useless addition.

Table 4. Compiled results of the analysis of the CAD A system.

Features of the CAD system	Evaluation
Applicability to sketching	-
Applicability to editing and modifying existing drawing	+
The quality of object oriented drawing	+
The functional quality of database operations	+
Functional troublefreeness of the system	+
Possibility to system support and the activity of manufacturer in developing the system in co-operation with users	-

The CAD A system can not be used for sketching, because the main programme alone offers a better sketching environment. Alteration measures, e.g. alterations to already drawn structures, are very troublesome. Small functional faults make working difficult. Drawing tools for the drawing of objects (e.g. wall, door, window, etc.) were not criticised in particular, so the interviewees were satisfied with their functions. The fact that drawing was possible also in 3D was considered a positive factor. CAD A creates an ordinary drawing tool for its user, and thus is satisfies the basic needs of architectural design. The utilisation of the database with regard to door and window cards split the opinions from good to not satisfactory. No use was found for the quantity listing routine.

The functional reliability during the utilisation of the system was not stable. However, the reason presumably in this case was not in the actual application but in the supporting system and in their compatibility. This view is supported by the more stable experiences gained by other interviewees using earlier versions of the system. In the field of product support, the application developer of CAD A has been passive and the flow of information is one-way only. With regard to the system developer, the situation is now much better, since both the developer and the importer have been in contact with the users. Claims made to improve the programme have, however, not been realised by the programme developer.

With regard to useful design segments, the CAD B system is suited for the designing of all targets, although there are several characteristics in the programme which irritate users. The CAD B system was conceived as “raw” and ”stiff” which, however, does not try to serve the architect over such a wide area as, for example, CAD A does. The drawing properties for both plot, diagram and details are poor. These operations are, however, facilitated by additional programmes sold separately. Also level management which is difficult to use, and the pull-down menus of the interface received negative remarks. In the comparison between the CAD A and the CAD B systems, no essential differences were found. The applications compete with the same tools and also fail in the same tasks. One more and the other one less (Table 5).

CAD B is not suited for sketching due to its stiffness, poor level management and also due to the non-satisfactory interface. These drawbacks also cause their own problems in later stages of drawing. In the same way as with CAD A, the main system is better suited for sketching than CAD B. Alteration work can be carried out well with CAD B, especially when you do not need to change the dimensions of the object to be moved. With reservations, alteration work was thus carried out satisfactorily. With regard to the drawing of objects, the wall-drawing routine is satisfactory, but it really needs properties which would give the user freer hands. There are more serious short-comings in the door and window tools. Also detail-drawing properties are weak, this short-coming is, however, compensated for by a separate application designed for the drawing of details.

Table 5. Compiled results of the analysis of the CAD B system.

Features of the CAD system	Evaluation
Applicability to sketching	-
Applicability to editing and modifying existing drawing	+
The quality of object oriented drawing	+
The functional quality of database operations	+
Functional troublefreeness of the system	+
Possibility to system support and the activity of manufacturer in developing the system in co-operation with users	-

In CAD B, the database contains good possibilities for the automatic generation of, for example, element diagrams. On the other hand, the creation of window and door cards is appallingly bad due to, among others, the lack of automation. There is no use for the quantity calculation routine. Generation of facades on the basis of the object databases of the lay-out drawings is carried out adequately. Two of the architects had had problems when using CAD B with Windows 3.11. ”Modernisation” of the user interface had helped both designers considerably. All interviewees had learned to use the system at work, with the support of instruction by older designers. The instruction manuals were satisfactory, but the communication from the developer had been non-existent.

With regard to useful design segments, CAD C is suited for the designing of all targets (Table 6). One of the interviewees saw it best fit for designing small houses, another had used to draw a large and demanding building for the public sector.

CAD C is suited for sketching with the same conditions as CAD A and CAD B. It can thus be used in a supportive role, but the designers had not been able to use CAD C for full-scale sketching. Alteration work can be carried out slightly easier with CAD C than with CAD A and CAD B. Freedom of drawing can be seen as one of the best factors of the quality of object drawing. Users of competitive CAD's praised the freedom given by CAD C. Especially the wall tool was considered good, but there also were contradictory comments, because it was perceived that full action in drawing could only be achieved very slowly.

Table 6. Compiled results of the analysis of the CAD C system.

Features of the CAD system	Evaluation
Applicability to sketching	-
Applicability to editing and modifying existing drawing	+ +
The quality of object oriented drawing	+
The functional quality of database operations	+
Functional troublefreeness of the system	+ +
Possibility to system support and the activity of manufacturer in developing the system in co-operation with users	-

With regard to database utilisation, CAD C differs slightly from other programmes compared. It offers, among others, relief in the formation of titles but, on the other hand, there was no quantity calculation routine. Although the said routine may not be needed right now, the job description of an architect will be widened in the future. After all, it is silly to bake first, and only afterward measure in detail how much flour was used. The functional reliability of CAD C can be considered rather good. It is an independent programme and does not require a main program, as do CAD A and CAD B. Product support of the CAD C system was almost non-existent.

The programme was conceived as being easy to use, which already had been typical for the CAD C system in earlier versions. It is rather a good auxiliary tool for an architect's drawing device. CAD C offers some specialities which can not be found in other programmes in this comparison, such as the control of the level of accuracy, and a certain freedom of drawing experienced by the users. In addition to that, the functional reliability of the programme is ok.

In the offices interviewed, the latest version of the CAD D was just in the running-in phase, or the investment had not been made yet. CAD D can be used for sketching with reservations, but first one has to adopt the new way of thinking in design work required by the programme. Sketching, in that case, is not the traditional outline sketching, but a sort of "play with blocks" (table 7). CAD D was considered to be a kind of CAD application for the future.

Useful design segments of CAD D are mainly in the construction of residential houses, some think it is best suited for the design of small houses. On a general level, it is considered to be suited for all targets. Sketching is rather practicable with CAD D, since the application offers the architect some tools that speed up the sketching process. Designing is facilitated by seeing the building in 3D, although it is not necessary right at the beginning. Making alterations to an existing model later on was considered easy. One of the best properties of CAD D was considered to be the fact that alterations in the façade mode were immediately transferred to lay-out drawings and vice versa.

Table 7. Compiled results of the analysis of the CAD D system.

Features of the CAD system	Evaluation
Applicability to sketching	+
Applicability to editing and modifying existing drawing	+ +
The quality of object oriented drawing	+
The functional quality of database operations	+
Functional troublefreeness of the system	+ +
Possibility to system support and the activity of manufacturer in developing the system in co-operation with users	+

CAD D manages object-based activities adequately, although there are some shortcomings. For example, in building plot planning there is an immediate need for three-dimensional symbols of various species of trees and shrubs. In addition to this, a specific tool for generating eaves should be developed. Database utilisation works well in CAD D. On the other hand, even the latest version does not automatically recognise two identical objects upon one another, and does not warn about this. The functional reliability of CAD D is good. The offices interviewed were pleased with the functionality. Problems had mainly been caused by printing.

With regard to product support, the users of the CAD D were in a lot better position than the users of other programmes in this comparison. This is because the users of this application in Finland get information through a magazine of their own. CAD D has an architect-like image. It was considered easy to use and attractive. It can be picked out as the best of the comparisons, because it offers architects something more than just a tool for making final drawings. From the architect's point of view, CAD D is the only real CAD programme in the comparison which is classified by user experience as being suited for computer aided design and not only for drawing.

5.5. Architectural design process

This chapter presents two design processes in an actual operational environment. The CASE descriptions presented can be approached from a factual point of view, since there is no reason to doubt the reliability of the informants in the description of their own individual design processes. On the other hand, it must be considered that the descriptions are individual events in the field of design and are, in no way, able to represent the entire field of design, so that their reliability is limited to the description in question only. The descriptions are documented by the designers themselves, and they have not been handled or shortened in any way.

5.5.1. Case A

The project was started in August 99, when a suitable plot was found for the building. The work was commenced by surveying the utilisation plan of the area, which outlined the relationship between the buildings to be built and the surrounding buildings, principle solutions for traffic and parking, as well as the influence caused by the construction on the city image. In the initial stage, in addition to the actual pilot project, preparations were made for the implementation of possible corresponding projects to be carried out later, as well as, combining these together in a flexible manner. In conjunction with sketching, several visits were made to the building site. The first draft of the utilisation plan was dated 30 August 99, and it aims mainly at giving a formal illustration of the building site, as well as, outlining the size of building masses, main traffic connections and parking arrangements. In a draft dated 8 September 99, the main traffic connections have become more detailed, which also has influenced the grouping of the building masses based on the new street. Simultaneously, a thought has been born about the order of construction on the plot so that construction will be started from the direction where one comes to the area, in which case the "façade" of the whole area would be completed after the first phase is built. The first drafts were made entirely by hand.

In September, a base map of the area was made available in numerical form (AutoCAD), after which the drafts of utilisation plans have been prepared in a computer aided manner. The actual design work and generating ideas did, however, mainly take place with the help of covering drawings made by free hand. Since the whole design work was carried out without the office's internal technical help (draughtsmen, etc.), it can be estimated that 90% of the whole working time was spent in the technical manufacture of computer aided drawing and 10% in drafting by free hand – e.g. the actual designing. This generally features the utilisation of time through the rest of the process.

In a series of drawings dated 21 September 99, three alternative utilisation plans were presented, each of which was designed to be built in two stages. All alternatives "grow" from the same starting-point: the pilot project located in the southern corner of the lot, which consists of two parts of building mass, sliding in regard to each other. The purpose of the set of drawings was to show how the future, at the moment still unpredictable building stages may have several different implementation possibilities by altering and varying the same starting-point. By using limited sizes and free location of building units and a manner of space formation which aims at the spirit of the location, we aimed at adopting the construction to the wooded environment. At this stage, the client, however, specified the design objectives in more detail so that the need for expansions was defined to only one project corresponding in size to the pilot project. Moreover, the city planning authorities view of the later construction of the area was based on a more familiar formation of blocks, typical of residential construction, where buildings rigidly form the boundaries to streets and the courtyard spaces of the houses are located in the middle of the block. With these borderline conditions, we could start designing with a clean slate. The only thing that had been found, was the location of the building and approximately right size for it. On the other hand, the designing task was actualised from here onwards specifically to the design of this individual building, and the further development of the utilisation plan for the area was left to the zoning official.

At the beginning of October 1999, the first drafts of the actual building and its shape were developed. As a design task, the construction project under description was exceptional in the sense that the internal lay-out of the building was made by an Englishman, a consultant specialising in the designing of special spaces in question, in which case the local architect was left with the responsibility to accommodate these plans to the local conditions, and to design the building's exterior shell, as well as to adapt the building into its environment. The basic idea of the internal lay-out was very simple: the building consists of three storeys with the actual clean rooms located on the middle floor. Directly from the beginning it was clear that, due to the character of the building, its final shape would be very compact, with scanty apertures and subdued details. As the work progressed, it became a clearer and clearer striving for as minimalistic, even mute architecture as possible.

During October, a total of three set of preliminary drafts were produced, dated 7, 19 and 22 October. All these studied the principal lay-out solutions and outlined the first façade drawings. Since the building to be designed was, after a long period of time, going to be the first new building in the environment, and have a different application from the other buildings, not much help could be found from the existing buildings in the neighbourhood, but the decisions relating to the form would rather originate from the characteristics of the site and the internal requirements of the building. The client had expressed a wish for the external extraction of water, in other words, the "prohibition of a flat roof" inspired us to look for a simple shape with a mono pitch roof, which is the form the building is presented in the drafts made in October. The mono pitch roof fits the building into its environment parallel to the slope, the scanty lines of windows are the only details in the façades covered with black profiled sheets. In order to accentuate the entrance, the stairs leading to the first floor have been taken as an external addition to the framework. The most important fact with regard to the utilisation of the plot became clear at the turn of September-October: a laboratory and office building (which would serve companies utilising the pilot factory) was supposed to be realised simultaneously to the south of the pilot project to be designed. This meant that the lot which originally had seemed very spacious started to feel quite cramped with regard to parking space and expansions. The expansion anticipated in the drafts made in October was supposed to take place in the direction of north-north-west, which in the later study turned out to be impossible with regard to the arrangement of parking. Since no actual plot had yet been formed for the building, it was possible to get allowance for expansion by altering the boundaries of the supposed plot to the north-east of the building. This, however, led to the fact that the highest spaces on the top floor of the building designed, which until now had been naturally located on the side of the top of the slope, had to be turned correspondingly to make the mono pitch roof face across the slope, which turned out to be very difficult to control in an aesthetic manner. So, after a design meeting held on 10 to 12 November, it was decided to re-study the form of the building from this starting-point.

Several negotiations took place in November between the city planning authorities and the consultancy group set up by her, relating to the wider development of the entire surrounding area, as well as, evaluating the fact how the preliminary plans of the pilot project and the adjacent laboratory building followed the spirit of the areal plan. The discussions revealed, among others, that it was considered important that the typical light colouring of the façades of the building also were continued in relation to the new buildings. Thus it became necessary to re-estimate not only the form of the building, but also the façade colouring of the pilot project which had been envisaged as being black.

The design meeting held at the beginning of December set the goal to get the L1 (Draft stage 1) drawings completed by the middle of the month. During the end of November, the form of the building had developed into a cubical mass with no eaves, where the mono pitch roof had been concealed by lifting the façade, like a scene, on three sides to a uniform height. In the development phase, also a solution was studied where the actual clean space floor would have a corridor made of glass suspended by external steel structures. Extraction of water from the roof would have been easy to realise with the help of vertical channels located behind the external structures. At the same time the underused top and ground floor of the building would have become smaller, the use of space more efficient, and the costs decreased. However, a preliminary study of the structures showed, that the structural solution generated in this way, being located half within and half outside the mantle of the building, would have been risky with regard to moisture. In the end, we decided to abandon the external structures and to realise the side corridor in a normal way drawn inside. Of the external structures, only steel pillars acting as vertical channels remained. In the final version, the steel pillars support a canopy visually levelling the line of eaves.

In the L1 designs presented in the middle of December 1999, the building has rather achieved its final form with regard to mass distribution. As an alternative, the drawings also depict a connecting corridor to be realised later to the adjacent laboratory building. From the middle of December, design work has progressed mainly in the form of making the approved L1 drawings more precise, and of principle solutions for details. Apertures for windows, as well as the handling of surfaces has undergone some minor alterations as it has become more specific, but we have tried to maintain the minimalistic spirit. The connecting corridor has been raised by one floor, to the same level as the actual clean space floor. At the same time, this allows light general traffic to pass between the buildings. In conjunction with the generation of the designs for the L2 stage, presented in the middle of January, 3D visualisation pictures of the building were made – on the one hand, for presentation purposes and on the other, to support design work. In the L2 designs dated on 14 January 2000, and in the visualisation pictures, the building is presented as having a light silver-coloured façade. Coloured visualisation pictures (although they do not correspond to reality) gave grounds for rethinking the colouring of the building one more time. At the turn of January and February, the decision was made to change the main colour of the building to white which, after the study of details, was enriched by natural coloured aluminium parts, as well as black areas realised in small fields. The construction work should be commenced at the end of April 2000, and the building should be completed at the beginning of the year 2001.

As shown by the description, the design process has been quite eventful, and the task in fact quite extraordinary. Due to the character of the building, the manner of design (interior design by another office) and the lack of an areal plan, the number of participants in the project has been considerable. Thus the final result has been formed as a compromise between various interests, even more than usual. The creativity of a single designer has in this case been mainly creative problem solving, which is exactly what the practical work of an architect quite often is. At least in this project, these problems have occupied one's mind both at work and in the spare time. Factors or methods influencing the generation of ideas are extremely hard to describe in any detail. Also during this project we have drawn logical conclusions, sought for analogous images from various images and objects (among others, from a deep-freezing box, rhombic forms of salted liquorice). Experimenting has probably been one of the most essential methods, which has been used with the help of a "trial and error generator" to exclude wrong solutions and finally find the correct ones. In practice, this has taken place in the form of making free-hand covering drawings on the basis of the present design, where aesthetic evaluation has been the most important indicator. In this case, the openness of the starting situation and the alterations caused by the interests of various decision-making partners have probably been the most essential factors influencing the creativity or the creative process. As a designer, it thus is impossible to find a single finished "creative" thought in the end result – a central idea that normally is the basis for a proposal in, for example, an architectural competition.

5.5.2. Case B

The design of the target was commenced at the end of 1999 by photographing the target and getting acquainted with the room-space programme. At this stage, no discussions were yet held with the client, but drafting was carried out looking for various solution ideas. The target was first outlined mainly by reflecting various alternatives. After about a week, I started to outline the building mass on sketching paper with a felt pen. A great number of sketches like this were produced during a couple of weeks. The sketches were mainly general drafts without an accurate scale, but also some details of more critical points. I did not much discuss the idea with others during the sketching phase, but tried to keep my basic idea as clear as possible. My objective was a clear and simple form of a building, despite the complexity of the room-space programme.

When I had outlined what in my mind was a well-functioning draft, I started to move the idea to the computer. The first drafts made with the computer were designed to be printed out on the scale 1:500. This design stage contained several coloured print-outs, which were used for a more precise development of the target by hand on drafting paper. Drafting with the help of a computer is not natural. At this stage, the work was controlled by haste, since the first meeting of the committee was to take place about a week from the time drawing with the computer started. I prepared the lay-out and the sections with the computer myself. At this stage we held the first design meeting, in which all sub-designers participated, but the representative of the client did not.

On the basis of the sketches, architectural student X prepared the location drawing and façades by hand. Preparing the draft façade drawing by computer is relatively laborious compared to the level of accuracy that is required for the façade drawing in the stage L1. In the same way, the location drawing would have been laborious to prepare with a computer, since there was not a digital map of the area available. The municipality of WW had, in fact, supplied a three-dimensional landscape model of the plot, because the building site contains an old gravel pit and a steep slope next to it. With the help of the landscape model we were able to prepare a preliminary computer model of the entire building and to utilise it in the making of a presentation picture. The model and the presentation picture were prepared by Y.

The project committee meeting was held on 25 October, and there I presented the L2 stage draft designs on a 1:500 scale, the presentation perspective picture and the room-space programme based on the drafts. The designs were discussed in a lively manner. The committee granted us permission to continue design based on the solution presented by me. The next committee meeting was agreed to be held in six weeks time. That was the time we had for designing the L2 stage drafts and making a budget estimate.

In the L2 design stage, the drafts were made more precise so that they were printed with an accuracy of 1:200. At this point, architect Z stepped in to work on the project. Also the façades and the location drawing were now prepared with the computer. For the preparation of the location drawing, the base map of the area was scanned into a file with which the drawing was made. A preliminary building method description of the project was prepared. At this stage we visited several corresponding targets in the neighbourhood. Similarly we were given a lot of comments and improvement proposals from various users. Drafts were also presented to the municipal building inspector, with whom we also went through fire technical and other official requirements. Drafts were also send by e-mail to other designers who gave us L2 level surveys and drafts for the preparation of the cost estimate. In this design stage, the plan was developed and made more precise, but no essential alterations were made to the basic solution.

The L2 drafts were handled in the committee meeting on 7 December. Representatives of the users and from the neighbouring schools had been invited to the committee to comment on the designs. The representatives of the users and of schools made several proposals for modifications. The needs for alterations were so big that the final L2 designs were not accepted. The meeting agreed that the drafts would be presented to the city of B District Council of Physical Exercise, because the project was supposed to receive governmental aid. Also the council wished certain modifications and alterations to be made to the designs. Moreover, the addition of rooms, agreed upon in the first meeting, increased the costs to exceed the budget reserved for the project.

Restricted drafts were made of the designs for the design meeting held on 12 January 2000, which also dealt with the plans for the expansion of the adjacent high school. We also are the designers of that project. The designing of the high school and the wishes received from there (among others, a connecting corridor between the high school and the ice-rink/multi-purpose hall) brought additional problems for the designing of the hall.

The drafts for the hall were further clarified after the meeting held on 12 January. The design committee was supposed to accept these drafts on 24 January. More comments on the designs were also given by potential users of the hall (players of floor-ball, Finnish baseball, volley ball and tennis). The height of the multi-purpose hall had become the main problem. The original demand for an internal height of 7 m had grown to 11 to 12 metres at the wish of volley ball players. This demand would lead to the abandonment of the whole basic idea (a homogenous clear building mass for both the ice-rink and the multi-purpose hall). We drafted an internal height of 9 m for the multi-purpose hall, which was accepted by the design committee on 24 January 2000.

Because the municipality of WW had already decided in the project planning phase to study the possibility of having the hall financed by private funding, they interrupted the designing at the beginning of February, so that the potential financier could get their own special wishes implemented in the design of the hall. The final acceptance of the L2 stage drafts was postponed. At the beginning of February, we mainly worked on the utilisation plan of the plot of the hall and of the schools, and acquainted ourselves with halls already built.

5.6. Analysis

This chapter presents the decomposition of the framework (see the entity in Fig. 48 p. 91) and interpretation of the contents. It is not the only possible manner of presentation, but changing the manner will not, however, change the contents of the analysis. The structure of the framework and its features has risen out of the empirical material. After interpreting these "arrows and boxes" designers who presented the case descriptions of the design processes were utilized in two ways. They were first interviewed and discussed in order to verify the framework and the contents of the analysis on the general level. Then, secondly the case processes were examined in order to find features presented in the framework or possible different and enriching elements. Dividing the analysis to examine creative design and computer aided design from various points of view is appropriate, because on the basis of practical experience, the applicability of the computer to creative work has until now been poor. In this analysis, it is possible to talk about a penetrative analysis or decomposition in accordance with the model presented in Chapter 3; in a penetrative analysis the completed entity is taken apart, its functionality and validity are checked. The analysis is based on the interpretation and perceptions of empirical results. Some main and critical references are presented in order to verify interpretations, but they have not influenced the interpretations of empirical material. The analysis is divided into two main sections. These sections are presented in the analysis in order to find out the essence of creative architectural design (Fig. 70 in chapter 5.6.1.), positive (Fig. 71 in chapter 5.6.2.) and negative (Fig. 72 in chapter 5.6.2.) features of CAD and also find the answers to fundamental questions presented at the beginning of this thesis.

5.6.1. Essence of creative architectural design

In the following the contents of the framework (Fig. 70) is explained and the essence of creative architectural design is presented from a creative design point of view. It is not essential in *the definition of creative design* to find a precise definition, but to look for one in different directions and the understanding of the importance of characteristics in creative work. Although technical and practical problems are solved in architectural design, characteristics of creativity are clearly visible. This is shown, among others, in the abstract nature of certain definitions (see Aalto 1948, Pallasmaa 1993). When describing their own work, architects like to use symbols, because giving an explicit definition of a complex entity is difficult. This is done in a symbolic way by e.g. Aalto (1948). Creative work consists, among other, of moulding images, sentiments, association of ideas, the present moment and the passing time into a part of the task given – of the concrete building. At best, creativity combines many ideas coming from the environment, or small partial factors, to an entire design. The ideas and solutions to be used may be very old and proven good, since creativity is combining things in a new way. Since design projects have different sets of conditions and contents, the result of creative design often is individual and unique, although emphasising of difference may not have been a conscious goal. Creativity presents itself on many levels, it can be an over-all holistic idea or a sudden perception on the detail level. It involves the ability to get into the role of the user of the building and the ability to have sudden perception. The concept of creative design often is used to mean aesthetic creativity, but could as easily be of functional or construction-technical nature, since a building in itself is a technical entity.

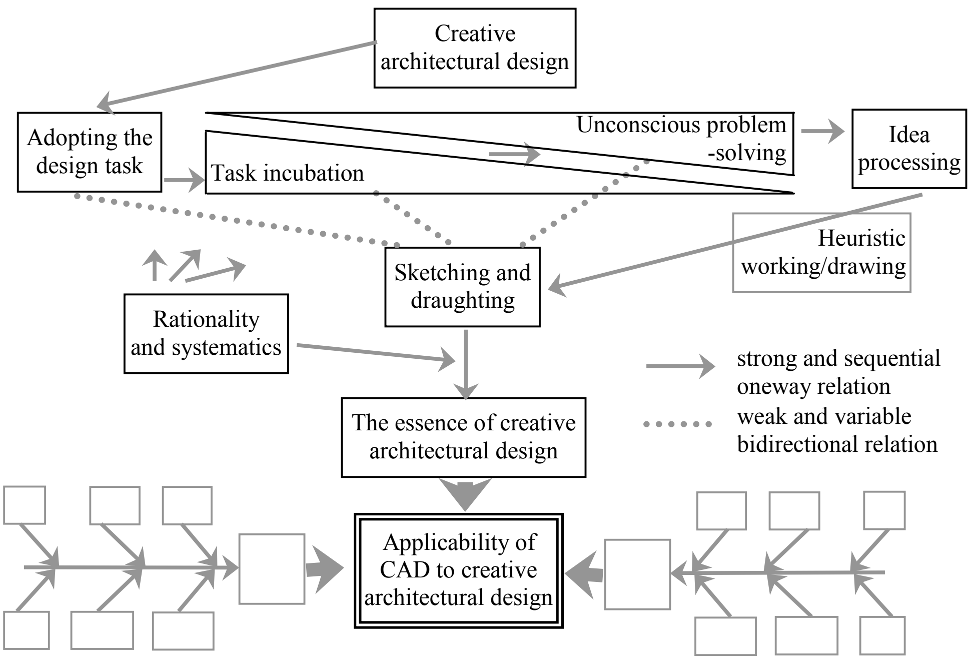


Fig. 70. Relation diagram of creative architectural design process. The diagram presents the main features in ideal design task. Arrows present the progress of design process as a strong relation and connection. Dotted line presents the weaker relation or connection between two elements and they can be bi-directional and can form a loop.

Creative designing begins with the internalisation and adoption of the task. This event is an essential part of any designing task for every designer, in order to be able to solve the task at all. In the issuance of a task in systematic designing, all basic values are required, and furthermore, these have to be correct, in order for the system to bring about a solution. (Hubka & Eder 1992, Pahl & Beitz 1990). Creative design does not require exact basic values, nor does it need all sets of conditions to begin (see Tuomaala 1995, 1999). In creative design, the architect gets the first visions directly on the basis of the first information or the building site. In some cases it is best, if the designer is given the freedom for interpretation. This is the emphasis in architectural design, because in most cases the one who orders the design is not aware of all practical possibilities or restrictions. The creative design process is started immediately when the architect is given impressions or stimulus of the target of the design. The subconscious mind starts to work on the design target and may even produce principle solutions without even having started the actual design work. This means perceptions produced by the subconscious intuition. From the designing point of view, internalisation of the task means *starting the subconscious processes*, which in turn means the beginning of the so-called *incubation phase*.

The incubation phase is started after the adoption and internalisation of the task. Incubation is essential with regard to designing, in order to analyse the indefinite and undetermined factors relating to the design. Almost without an exception, architects consider incubation very important. Internalisation of the material and basic data of the target is significant with regard to the end result, because the solution is made of the basic values available, the designer's own reserve of data, and also of external factors influencing during the design period (see Aalto 1948, Pallasmaa 1993, Tuomaala 1995, 1999). *The incubation phase describes the activity of the subconscious* in order to find a solution, when, in the issuing of the task, the subconscious is given an impulse to start designing. On the other hand, already in the incubation phase, the designing should include a certain pressure or tension which will make the subconscious work on the problem in question. A pressure, for example, a timetable, will force the great storage of the subconscious data to process the information relating to the task. Stress is another element, which may turn the subconsciousness to process for the task, but too high stress can also prevent the becoming solution to emerge.

Almost without exception architects present experiences with *subconscious problem-solving.* Amongst the architects who participated in the inquiry, the most common situation for the emergence of a subconscious ideas was to take place somehow surprisingly during a peaceful period, wherever else, but not at the drawing table. Clear examples of these situations are, for instance, such events where a certain factor of the environment brings about an association of ideas, but this, however, is not necessary. A typical example of subconscious problem-solving for many architects is presented by sleeping over night. In practice, this means that the design has been worked on the previous day and the next morning a solution for the task is created as if by itself. Many designers even have a dream diary on their bedside table to draft the possible solution ideas into. This is an essential difference to designing by calculation and deduction. The subconscious arranging, analysing and combining of data creates the possibilities for the generation of totally new ideas, when deduction is only based on sets of conditions given and on existing data (see Andreasen 1991, Eder 1998, Hubka &Eder 1992, Pahl & Beiz 1990). As described earlier, sub-conscious problem-solving, requires the internalisation and processing of some kind of basic data, in order – so to speak - to start the subconscious to go to the direction of problem-solving.

Working on ideas takes place either on the detail level or working on the entities. This occurs both during the passive and active activities. Passive working takes place in the subconscious. The subconscious collects information on observations and on the environment forming, for example, with the help of associations and analogies solutions ideas of images and based on these, new images. In active activity, which takes place on the level of active thinking, the role of drawing is significant in the development of ideas. Making the drawings and the drawing itself convey information to the subconscious in greater extent and quicker than we consciously understand. The subconscious compares the old solutions to the present task, which again generates new information to be conveyed into a drawing, or creates new solution ideas. On the other hand, presenting the solution idea, for example, through speech often also develops the new idea. Other possibilities of working on ideas or images is, for example, an imagined tour within the building.

Heuristic working means working on the detail ideas on some part. In this case, a connection is created between two details during drawing and working without conscious pondering, but which, however, is logically a correct one.

Drawing is a significant part of creative designing. The phenomena described above form the most important part of the design, e.g. that what the design contains. The importance of drawing is emphasised by the fact that the end result of the design must be presented in the form of drawings. Drawing may be conscious or interpretation of the unconscious thinking. The influence of the subconscious on the development of the design is important, because during sketching, ideas "flow" onto the paper, get polished, more detailed, over it get changed altogether. Sketching is testing of the world of ideas, where constant feedback is given from the developing picture. (see e.g. Ferguson 1977, 1993, Lehti & Ristola 1990, Petäjä 1977, Rauhala 1991). On the other hand drawing is also used already in adopting the task in order to outline the object to be designed.

Systematic and rational working also form an essential part of the architects work, although it is not explicitly noticed. Regular modes of operation and systematic designing methods are also aimed at in the designing. People tend to search regularities from every repetitive activity. Moreover, each design process includes logic and systematic working at various stages of the work. For example, at the beginning, the basic information and sets of conditions are studied and internalised systematically. It is essential, however, that the mode of action applied is not too extensive and thus confines the designing. The design methods of architects are so individual that there is no clear rationale that could be given a concrete form in a systematic mode or a process description in total. This is due to the fact that individual design methods look for systematic approach from various phases. Moreover, a systematic or organised mode of action can be understood in different ways.

Several different systematic and also computer aided tools have been developed for designing, and on a general level these have also gained popularity as tools that make designing more effective or tools that support designing. An example of this, is the QFD method, examined in this study, the applicability of which was evaluated with rather incoherent results. The applicability of such tools in architectural design is not good due to the individuality of the design target or of the designing methods, although they would be well suited for another field of designing as in mechanical engineering design. On the one hand, their applicability is better in architectural designing where there is a lot of repetition, such as in construction product industry. On the other hand, the results demonstrate a certain attitude of the architects towards new and systematic designing methods. Or more likely it may mean that complex systematic methods don't apply to creative architectural work. But this isn't due to the resistance of systematic or logic, because they are clearly needed in architectural design. However, architects recognize these phases presented in OFD in their own design process, but getting the design process through is not possible in specified mode required in QFD.

The *essence of creative architectural design is the ability to draw*. The ability to use, control and manage complex entities and large amount of information, which may be even inconsistent in some occasions, is also essential ability to architect. This excludes the possibility of fully systematic architectural design method, because simply the amount or quality of information increases to unmanageable amount. After the task adoption and incubation and so on, drawing is the tool to give form of thoughts, interpret unconscious mind, process the idea and see with the "minds eye" (see Ferguson 1977, 1993). These are the requirements of architects in creative working, which are developed during year hundreds. For CAD user interface, in order to operate effectively in creative phase, possibility to draw as a flow of consciousness should be included.

Until now *the role of the computer in creative work* has not been very good, because it requires conscious striving and concentration too much on the design tool itself. This may be due to the fact that individual designers have not adopted CAD on the level of automation. On the other hand, the possibilities offered by the computer in 3D modelling, visualisation and in the testing of different alternatives are obvious and thus it also stimulates and gives impulses to creative work. When processing ideas, there must be an idea or an image that is developed. At this stage, CAD does not differ methodologically or principally, but experience gained in practice does show that the utilisation of a computer in the interpretation of ideas is more difficult. The reason for this can be found in the fact that architects do not have adequate user experience in computer aided designing with the present-day applications. This again may be due to the rigidity of the user interface or to the architects' adopted design skills on the computer. Generally, the CAD user interface may be considered a complex system which again demands a lot from the user. For this reason, the development of the CAD user interface and the traditional hand and paper method can not be compared, for example, to writing by hand, typing and text processing. Writing is a significantly simpler process, and thus it can not be compared to designing. Typing and text processing are almost identical activities and the applicability has only been improved by the arrival of the computer. That is also one of the reasons why CAD systems at present form will not replace pencil and paper totally.

5.6.2. Positive and negative features of CAD

The positive and negative features of computer aided designing have been examined on fishbone diagrams (Fig. 71 and 72) through the framework and the schema of 6M as presented in chapter 4. This analysis is based on empirical results. When examining the results of the analysis, it must be taken into consideration that the pros and cons of different viewpoints may not be directly proportional to one another. Moreover this analysis is mainly aimed to the whole CAD process and assisting solutions like 3D modelling is considered as enriching element. In addition to that, the influence of various habits or individual designing methods of architects must be considered in the examination. *On the whole, it can be stated that the positive and negative features of computer aided design can not be reliably evaluated in a detailed manner. In its most sensitive stages, architectural design is a complex and individual occurrence, and the goodness or weakness of computer aided designing does not lie in the CAD system, but in the fact how the individual designer sees this tool under observation, and its possibilities in various situations in his own work. Therefore, many designers can no longer live without computers and correspondingly, other are not even able to design with the computer, even when similar user interface is in question.* Moreover, the analysis is influenced by the difference of the CAD applications used, although according to the results this does not actually have any significant importance to the applicability of CAD applications aimed to the whole process for designing.

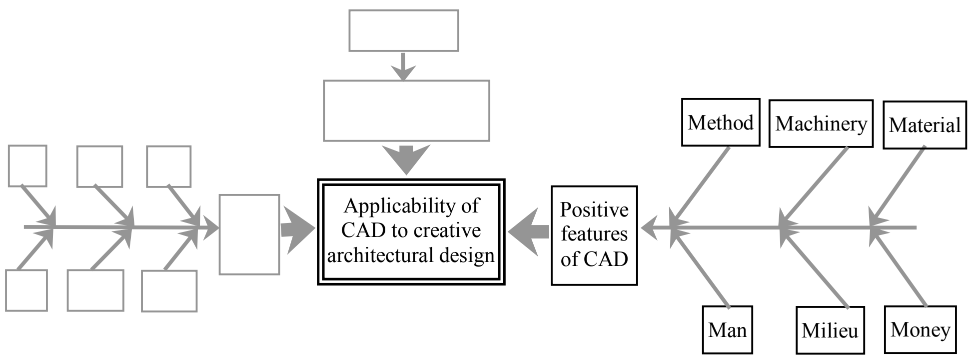


Fig. 71. Positive features of CAD presented in fishbone or cause and effect diagram.

Method. The amount of routine work has decreased, editing and working on alternatives becomes easier. With the help of the computer, it is possible to carry out demanding mathematical calculations very quickly. This is emphasised, for example, in conjunction with the generation of exact dimensioning, surface calculations and quantity lists. The designer can, for example, easily test various wall structures that are geometrically demanding. Also the use of completed construction parts and details speeds up the designer’s work. With regard to the design method, the structure of the work is changed, because no time needs to be spent on repeating, so-called routine functions. Furthermore information technology allows designer to do digital image processing, which changes the emphasis in the working time, but as mentioned it can extend and create possibilities in architecture. On the other hand, the time saved has not gone directly to the architect's disposal, but it has shortened the time available for the design work.

Machinery. Methodologically, many architects have great difficulties in making the computer interface work in drafting in a way that the "flow of consciousness" is not broken when using the computer, e.g. the chain of drawing, observing, sudden perception and drawing would work in an optimal manner. On the other hand, it is possible with CAD to provide the designer with such models and experiences that for their part can extend the "flow of consciousness" chain into a chain of producing, observing, sudden perception and producing. These are demanding geometrical three-dimensional models, animations, and other effects generated with the help of computer. On a general level the capacity to logically process information is huge already at present. On the other hand the computer is "dummy" and does what it is ordered to do. Therefore it is essential to utilize these "fast dummies" in an appropriate way.

Material. The possibility to utilize existing *input material* will significantly ease designer in early phases of design especially when considering e.g. site planning. Digital file of terrain model gives directly the base to start design from current situation. Another form of existing digital material are e.g. geometric information in objects, blocks or in any other functional elements which has been defined or produced beforehand. Because of digital information design can contain information, which isn't visible. This facilitates the design process, because it is not necessary to process all less critical or routine information. Furthermore CAD allows to remove unnecessary information during design by the platform management. CAD partially increases the amount of material during the design process, but partially decreases. More printouts and therefore paper is needed during the design, but the digital information is easier to store and manage, it also remains in order far more easier and better. *Output material*. The results of design can be presented in various different ways, which in practice can be carried out without extra work. Information generated during designing can easily be used to build print-outs and listings suitable for various needs. For example, the same file can be used to print out the main drawing of a building that is hundreds of metres long, and just by changing the settings for printing you can print out one room, its dimensions and properties. Precisely the generation of the above-mentioned 3D models and animations, and their utilisation in the presentation of designs becomes easier. In addition to that, the designs are tidier and all are uniform.

Man. Computer aided designing has in practice removed one craft – the draftsman of final drawings, so that the design offices no longer need to hire individuals for the documentation of designs. On the other hand, the developing computer aided designing has divided the architects in a way that young designers often work in transferring the design documents on the computer, whereas the experienced designers still prepare the preliminary designs as handicraft. Therefore some CAD digitisers are still needed, but they usually are younger designers.

Milieu. With computers, the designing environment of an architect will change from working independently of the time or place to a more time and place dependent office work. This will improve and facilitate the management and co-ordination of design. The designer is able to utilise ready-made data banks and information in digital form. This will decrease the amount of material required in the designing environment both during the designing period and after the design project. The CAD system facilitates the communications and creates possibilities between designers e.g. when files and folders can be transferred from designer to other in few seconds through network even when offices are located in other side of the world.

Money. As routine work is decreased, the total time for the design project is shortened, and, as a whole, is thus better for the constructor or the builder. This, however, has not been visible in the designers' work, but it is shown as a decrease in fees.

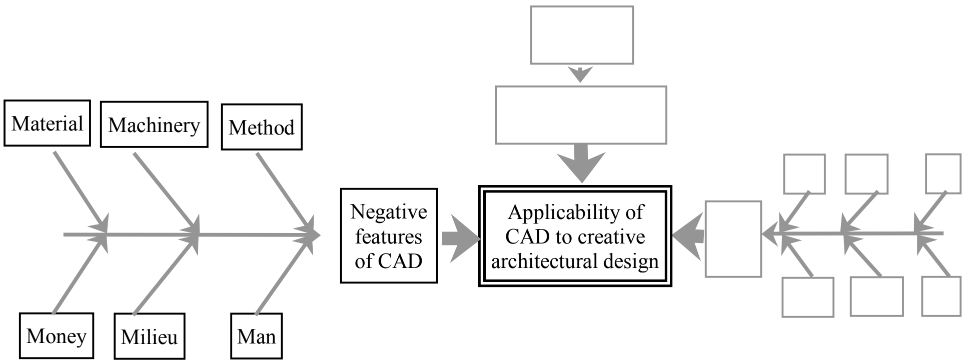


Fig. 72. Negative features of CAD presented in fishbone or cause and effect diagram.

Method. Designing with the help of a computer causes problems for many architects, because the use of a computer means a new way of working. Drawing by hand is perceived as an easier solution, and learning a new way of working is considered difficult and arduous. The non-applicability of computer aided design to sketching has cause great disappointments to designers and slowed down the introduction of CAD. On the other hand, the negative attitude of those who have tried computer aided design is emphasised by the difficulty of learning how to use computer aided design, since the designers have not been able to get to work directly. Present hardware is usually fast enough maybe in some occasions even too fast, because a competent system should use the capacity steadily. The precision is different in separate phases of design, and therefore sensitivity perishes, if absolute precision is required constantly and the precision is directed to secondary matters e.g. a architect may get stuck in modifying lines while he should be thinking the entity of building.

Machinery. The computer interface will change design also with regard to designing tools. The size of the screen sets limits to the visual nature of the design, whereas a paper may be almost as big as possible. The problem may be removed by changing the scales (zooming), but also working without a scale with absolute dimensions requires a new way to orient oneself to designing. For most designers, using the pencil as a direct extension of the hand forms an uninterrupted connection with thinking. When in a computer interface it is possible to enter a piece of information in many different ways, none of which is comparable to the learned drawing with the pencil on a paper, the connection of thinking to the design target is often broken. Although the transfer of information between various designers can be considered a positive matter with regard to the design co-operation, it often has also become a problem. Although general standards are being developed, their functionality in practice is not on a very high level, which in many cases has caused additional work, for example, due to the fact that a part of the "intelligent" information is lost when transferring from one application to another. The complexity of CAD programs makes them heavy and, through that, slow to use. On the other hand, the complexity, for example, forms a complex menu structure for issuing commands and increases the clumsiness of the user interface.

Material. Digital input material will be processed only with mouse and screen, while traditionally designer may have had even the feeling (touch, sight, smell…) from material to be processed. Using existing material may lead to unpurposeful interaction, because inserting blocks or functional elements may not be as controlled or totally considered as it is in traditional design, while designer have to draw it with pencil. A printed CAD drawing already gives a completed and finished impression in the drafting phase which might deteriorate the quality of designs. This in contrast may lead to unfinished thinking, because the drawing already looks like final. Making modification and print-outs is easy in computer aided design, but a small change may cause a multiple need for print-outs of final designs. On the other hand, the modification has to be made also when designing by hand, which on its part decreased the neatness of the drawing. However, with the use of CAD, the "need for printing" of various designs has increased significantly.

Man. A significant factor on a personal level is often the attitude towards information technology. There are designers who do not even want to learn how to use CAD properly which again makes the optimal utilisation of the CAD more difficult. On the other hand, it can still be said that the true learning of the use of CAD is difficult, it takes several years and the actual final learning only takes place by using it. And, on the basis of experience gathered, the CAD is not adequately well suited for design by sketching. Architects who haven't learnt to use CAD systems together with other things they have to make additional investment to learning.

Milieu. With computers, the design environment of an architect will change from working independently of the time or place to a more time and place dependent office work. From this point of view, the timelessness and freedom of designing is lost. From the design office's point of view, problems are caused by the difference in the programs, due to incompatible applications they may be forced to communicate with the help of paper print-outs, and thus the advantages gained through the use of CAD are partly lost. Another difficulty is the fact that architects are not experts in information technology, and therefore there should be at least one expert in information technology (a person who maintains the IT system) in the design office. In addition to this, especially designers with poor knowledge of information technology have to concentrate on the user interface and not on the target of design.

Money. The present-day equipment is already efficient enough to be able to also run complex and even structurally heavy design applications. However, offices which a few years ago joined the investment rat race both with hardware and software have been forced to notice that new and more efficient hardware and new versions of the programs are entering the market rather frequently. This often forms a challenge to the design offices, because the extent of business activities in contrast to investment needs with regard to the newest hardware and software may be too large with regard to the profitability of operations. On the other hand, especially up-dates of software cause even more problems with incompatibility between designers. Another negative matter relating to CAD with regard to the business activities of design offices is the project-specific decrease in design fees. This is partly caused by the shortened design projects, which again is due to computer aided design projects.

5.6.3. Summary of analysis

When the applicability of CAD to creative architectural design is evaluated as an entity, it is possible to find two ends of the same continuum on the basis of this research. At present, the applicability of CAD to routine work is rather good, but to the sketching phase it is poor, even when 3D increases possibilities. On one side of the development continuum, there is the modification of the design methods of architects to correspond to the present user interfaces, and on the other, the modification of CAD applications to correspond to the traditional creative design method of the architect. The reality lies between these extreme ends, but it is more closer to the user interface that makes creative designing more efficient – in other words in present user interface there has to be some changes. The creative designing process of an architect has developed as the practical result of a long period of time (evolution), in which case changing it in a short period of time (revolution) would be difficult and even harmful. For example, there is no clear understanding of CAD's influence on architecture, although experience has already been gathered for some decades. Thus CAD has had, and will have, evolutionary influences on the design process of architects as an entity, but it should have those in a way that the user interface will be adopted to follow the architect's design process, and not vice versa.

Several analogies of the development can be found from digital world. The essential shouldn't be and isn't the medium or user interface itself, but the process or activity to be done. As Negroponte (1995) points out, the purpose of telephone call is to deliver a message not to use the phone. Information technology allows something new to design and design will naturally also change, but it should not change the evolutionarised design process too much in terms of user interface. Moreover it has to be noticed that CAD systems don't contain all possible information technology in construction industry. One example is software for 3D modelling, which is often seen as another abbreviation for CAD. CAD is much more wider concept that 3D modelling and they don't mean the same activity in design process, even they are closely related to each other. There are also several other devices or applications that can facilitate design process, but are not directly related to design activity.

As perceived from the cases, compared to Aalto's (1948) general narration of his work, architectural design is far from regular model. These random and practical projects demonstrates the nature of architectural design and features in it. According to designers in cases "elements of the presented framework are inside the design process both in general and in case level, but they may occur quite disorderly or concurrently". With both designers the diversification and complexity of design projects was clearly observed, even with these two cases. And also the comment "the emphasis of different factors in different design projects varies" was noted with both designers. Therefore it is not reasonable or possible to define general design process very accurately, but find out the most critical features and explain those. As noted in final discussions with case designers, the elements can be seen as arrows and boxes in the figure 70, 71 and 72.

Furthermore the perceptions noted from cases show that the scope of architects' work (ARK95 see Fig. 2 and Fig. 10) and also the interest groups of construction project are generally setting the guidelines to the process of practical design. The former can also be clearly noted from the cases. In addition to the preceding, a considerable amount of logical thinking and reasoning is needed in design work in several phases. As noted, especially from case A, the problem-solving between technical requirements, practical possibilities and creativity of architect consist of several smaller and one larger entity to be solved. This even increases the need of theory presented in chapter 3 and the understanding contents of it. Designer in case B underlines the meaning of the tension in design, "even with imperfect basis it is possible to produce good solutions, when the dead line is set tight and there is, at least, some room for subconscious to process the problem".

The findings indicate that neither creativity nor systematic can fully alone produce optimal results. Logic is one of the tools of creativity, since the analysis and implementation of creative solutions requires logical thinking. It is, however, important to notice, that design system prepared beforehand, can produce solutions only based on this system and input, which usually aren't the best possible.

Creative and systematic methods differ mainly on means, how information is processed to achieve optimal results. Practice has indicated that the best results can be achieved in various ways. At the beginning of the design process certain systematic methods or manners create the best basis for real work. In the early stages of design the amount of processed and required information is huge, and it is not possible to distinguish the necessary from the unnecessary. When design has proceeded to the ideas stage it is essential that the designer does not have to use the whole capacity to treat information, but he or she can concentrate on producing ideas or solutions. This is very critical element with inexperienced CAD users. Almost all attention is focused on producing e.g. a wall structure while it should be directed into the object to be designed. Particularly at this stage a creative and intuitive method seems to be much more effective. Correspondingly, with complete ideas or analysing mature solutions, systematic and logic are needed. For the best possible final result it is not significant whether design is done creatively or systematically, but that the work should be done by exploiting the best qualities of both design methods.

6. Conclusion

6.1. Evaluation

The most central feature in hermeneutic philosophy is the emphasis of understanding activities. In this research this can be seen specially in the analysis and evaluation, where the chosen approach makes the final results more reliable and valid. One of the origins was triangulation, which also increases the reliability and validity of results. Reliability increases, when different surveys from different viewpoints indicate the same features to be significant, as occurred in this research. Also the total validity increases through triangulation, because one simple survey may give misleading results from the phenomena, but several surveys make the material more accurate or they exclude misinterpretations. The hermeneutic approach with focused knowledge increases the accuracy of perceptions of the chosen problem. The multiphased classification of empiric material also increases the validity, while focus can be aimed in the right direction. Another significant factor for total reliability and validity is that initially existing design theory is deductively concluded from another design discipline and secondly concluded inductively from the empiric material. When identical factors or features emerged in theoretical deduction and in empirical induction the reliability and validity can be considered good in total. Furthermore it is essential in qualitative research that documenting is done so that the reader can see where the validity forms. In this research the original background discourse concerning the whole research is done in the introduction. The scope of theory is described at the beginning of chapter 2, the empirical research framework is presented in chapter 4 and results and analysis are in chapter 5.

Although all Finnish architects are not in the sphere of this research and the percentage of answers in some of the surveys was not very high, there isn't any reasons to suspect that the background population would give any other information, which would change the perceptions made. When comparing fast and slow responses in separate surveys no difference was found and this also decreases the possibility of divergent opinions in the background population. Already in the preunderstanding it was noted that architects are divided into two separate groups, when concerning opinions of CAD. The first were in favor of CAD and others against it. The practice has indicated that both groups will bring their opinions into awareness, even with slight emphasis. Therefore it could be assumed that no divergent opinions could appear.

In all surveys unconditional confidentiality was emphasized so that it isn't possible to connect answers or opinions afterwards to a certain designer. This is a very significant factor in the study of sensitive issues, because some architects see their own work as an intimate thing and as an anonymous informant they could share their know-how more sincerely. This was especially important in interviews, because it took a while to gain confidence and therefore confident and objective answers in sensitive subjects. Results obtained in surveys can be approached from the factist perspective in total because, based on the former, there is no reason to assume that informants would not have given sincere answers.

The empiric material consist of different surveys, which have partially been iterated from different viewpoints e.g. in specifying creative architectural design and in defining the applicability of different programs, both surveys have also contained questions from the features (weaknesses and strengths) in CAD. Therefore, at least in some classes, the empiric material achieves saturation point (Alasuutari 1999, Strauss & Corbin 1990), which means that no new information is attained.

In survey analysis the researcher only knows what predetermined options each individual, described by predefined variables, has chosen as answers to predetermined questions (Alasuutari 1999). Therefore it has been essential to use open ended questions in order to bring all possible, even divergent, information up to the surface. Also the use of the hermeneutics as an approach and three-phased coding procedure in order to attain reliable and especially valid empiric results on a larger scale than a few interviews or cases was chosen for the empirical method. Usually in qualitative research statistical probabilities are not accepted in qualitative analysis (Alasuutari 1999), because the number of observations is too small to make any conclusions. In this research the number of observations in some surveys is close to one hundred and therefore a statistical presentation is used in documenting some of the results as bar diagrams. Anyhow, correlations between different questions has not been calculated, because it isn't reliable to do so with current data and it isn't the purpose of this study. A more important factor in presenting statistical appearances is the existence and the rough appearance of a feature or factor.

6.1.1. Applicability of computers to architectural design

The applicability of CAD is evaluated through the state of the art in Finland. Based on the synthesis of this research some significant findings about the applicability of computers to architectural design can be presented:

- present CAD systems suit architectural design quite well in routine tasks and the final phases of design,
- for the time being approximately two thirds of designers utilize CAD and also approximately two thirds of the work is done with CAD,

- the degree of utilization rose during the research (1995 - 1999) by one third, but there was no significant improvements in the applicability,
- present CAD systems apply poorly to architectural design in the early phases of design - in sketching and
- applicability or inapplicability is not in the user interface or in the features itself, but it is in how the individual designer experiences the computer user interface or these features when he applies the system.

The applicability of CAD has not been systematically evaluated so far in the scientific context, at least on a larger scale. There are, however, some practical opinions on applicability. These practical reviews and narrations, however, support the applicability evaluation done in this research (e.g. Kiviniemi & Penttilä 1995, Penz 1992, Senyapili & Özgüç 1994, Stevens 1991, Van Dijk 1995). Therefore the concluding remarks in this chapter are based on the empirical findings during this research and there isn't the possibility to present research references for comparison.

These findings mainly agree and validate the practical pre-understanding, even when they are not scientifically studied earlier. However, the low utilization rate was a bit surprising and even when it rose during the research the applicability did not surprisingly get better. The conception that all architects can and should use similar compact CAD systems was neutralized. The final point of the findings indicate CAD systems should be more open and flexible to correspond to the user's individual way of working.

Applicability in general and in the final phases of design. *Present computer programs apply quite well to architectural design,* even when only a part of Finnish architects are using these. Benefits and positive experiences from CAD are explicit and rational. Negative experiences are more loosely-defined and obscure. This may be a reason of defective expertise and a negative attitude towards information technology. Therefore the reliability of these features is not particularly high, because the identification of action is reasonable only when the actor knows what he is doing. On the other hand there wasn't any particularly significant changes between surveys and therefore they indicate at least some important factors. Present user interfaces are based on systematic methods and logic. They systematically perform only those functions and commands that they are programmed to do. CAD doesn't produce creative output or solutions if the designer themselves isn't creative. Random numbers can be exploited in computer procedures, but a lottery is not creativity. On the other hand it doesn't either necessarily prevent the user from fulfilling creative mental images, if the user masters the CAD well enough. This, however, requires changing the traditional design methodology with current user interfaces. Difficulties and conscious effort with CAD transfers the attention and concentration away from the object to be designed. The more conscious effort the user interface requires, the more harmful it is for creativity. From this perspective creative computer aided design can be seen only as a question of learning.

CAD yields substantial benefits especially in routine tasks. Examples of these are rate of changes and repairs and also the rate of producing different alternatives. The capacity of the computer allows methods and solutions which have not been possible earlier because of the huge amount of work. Examples of these are generation, exploration from different directions and in some applications even from the inside of three-dimensional models. Furthermore exact dimensions and surfaces are automatically attained and therefore errors in dimensioning decreases. CAD facilitates information management in design and also in the design process, among other things this diminishes the amount of overlapping work and allows different printouts and outputs from the same file or database.

As mentioned, *negative experiences of CAD are more obscure than positive features*. Learning a new design medium causes additional work for architects and transfers the concentration away from the actual work. The difficulty and complexity of information technology is usually seen as the main obstacle to achieve the ability to use CAD. This is even emphasized with the lack of general standards and the adequacy of different programs. Moreover some programs require additional applications in order to apply in architectural design and the updating of both these programs in a short period requires investments. Then these updates require the learning of new features and despite these updates programs still contain some illogicalities and faults, which make the work awkward and laborious. Furthermore the whole architectural office and design is dependent on information technology, when the system collapses design with CAD ends also.

The state of the art in computer aided design. Only one tenth of architects saw information technology unnecessary in architectural design and in contrast nine tenth saw it necessary. However, the amount of usage varies between designers, some strive to utilize CAD during the whole design project and some only in the latter phases of design. At the end of year 1995 *almost thirty percent of architects did design with CAD* and in addition a bit *under ten percent used CAD only in documenting solutions.* Then almost two third of designers relied on traditional pencil and paper. In contrast the estimated *amount of design was also about thirty percent and a bit under forty percent of drawing was done with CAD*.

When comparing former figures at the end of the year 1999 *it can be perceived that the number of designers utilizing CAD and the amount of design done with CAD has increased to about two thirds.* The most significant perception is, however, that *even when the amount of work with CAD and share of designers has increased and also there has been a four-year development in user interfaces, there has not been any significant change in benefits and inconveniences with user interfaces.* However it is not accurately known do architects use the same system with newer version or different system as four years earlier. Despite the fact of four-year learning experience no significant improvements ware noted. In both surveys there was also an important note; there is anyway excess capacity in CAD in architectural offices, but designers are not able, or willing, to utilize it. In general all these utilization factors are very interesting and even surprising, because in general estimations in the construction industry the utilization rate was evaluated significantly higher. This may be a consequence of the fact that larger surveys on this topic are totally missing and so is the information on it.

Dividing applications into design and drawing programs is an obscure concept and mainly based on user experiences. *About two thirds of CAD users utilize the computer also in sketching, at least in some parts of sketching, and one third of these relies on pencil and paper in rougher sketching.* Documenting and implementation is, however, done with CAD. It is quite obvious that present CAD user interfaces will not replace traditional drawing totally. 3D modeling is mainly used in the sketching phase, when they are used as real design tools in examining smaller details or the entities of buildings.

However they don't produce final documents for building process, so a different application is needed for that purpose.

In contrast almost all architects utilizing computers in design have had CAD integrated design projects. Experiences are mainly positive, especially in those projects where all designers have similar applications. Compatibility and therefore transferring the intelligent information has been the greatest problem. However, this has been the sector where development has proceed very well during this research.

Applicability in the early phases of design - sketching. *It is difficult to give an unambiguous and reliable answer to the applicability of computers in sketching.* The features in different programs vary a bit, even when the general applicability doesn't differ in practice, at all. The classification between traditional CAD and 3D modeling also complicates the evaluation, because the systems are used bit differently. CAD is utilized throughout the whole design process and the purpose is to produce documents for the implementation. Comparably 3D modeling, from the design point of view, is aimed usually at the early phases of design in order to examine and visualize details or larger entities, where the 3D model is the critical output, not the process itself or its complexity. Therefore the usability of the modeling process is not so critical, e.g. Tovey (1997) sees this as computer aided sketching. Some CAD systems are planned to be a tool only in traditional drawing, others are only modeling tools and between these extremes is a group where modeling and drawing are combined. The former and also non-compact user experiences complicate the evaluation. Therefore the applicability can be drawn from an analogy of Jurans (1989) definition: "quality is fitness for use". The purpose of use seems to be very difficult to determine when developing applications.

It could be concluded that the applicability hasn't been good in sketching, partly because there isn't so much experience of CAD. According to the results three main groups can be found. Two of the first groups see that CAD doesn't apply to sketching, because the efficiency and rate of manual drawing is greater in traditional design. They see the user interface as an additional and slowing factor in design. The first of these two groups contains architects that utilize CAD in routine work, but do the sketching manually. The second of these two groups has designers who doesn't have experience in CAD, either because of they haven't had the possibility or willingness to get it. In the third group architects already apply CAD and 3D modeling in sketching and they usually master the user interface and they utilize most of its features. The level of working with CAD approaches automation but, however, these architects too take up the pencil and paper sometimes. They usually utilize several tools in their work concurrently e.g. 3D applications in visualization and traditional to documenting the output. This can be seen as a higher utilization rate of 3D modeling in the sketching phase. *When comparing different groups and experiences it can be said that the applicability or inapplicability is not in the user interface or in features itself, but it is how individual designer experiences these features when he applies the system.*

Some architectural offices have not acquired the user interface at all and they design manually. The most common reason is the too high investment costs of hardware, software and education. This is emphasized in offices with a small turnover, especially when there is a shortage of work. However, a negative attitude towards CAD has also been sincerely confessed in some cases.

Based on results and perceptions it is obvious that CAD intensifies working, at least with some users in some phases, but not all users or phases. This is a consequence of individual methods of working especially in the creative phase. On the other hand the intensification is difficult to measure, it could be measured from the quality of the end product – the building, but that isn't in the field of this research. Nor did the architects themselves have a consensus on the influences of CAD in the design process or to the end product. Therefore it is difficult to evaluate the influence on creativity, because it partially stimulates thinking e.g. 3D possibilities and partially restricts thinking when conscious efforts are directed to the system. This ends up with the note that creativity and design methods are individual, which in contrast complicates the development of methods, systems and user interfaces. Then the conclusion is that *problems in CAD may not necessarily rise from a certain application or user interface. They rise from the relation between the designer and the user interface or how designers individually experience the usability of the CAD user interface. On a larger scale it can be noted as some fundamental differences in designing methods between CAD users and those who don't use, e.g. the possibility to draw.* The "evolutional" sketching usually requires drawing and the operation of the human information system, but the present "revolutional" CAD system doesn't allow it optimally.

When observing the development of CAD between 1995 and 1999 it can be said that the utilization has increased, even when the applicability or usability has not significantly improved. One reason for this is the hardware development and another may be the requirements of the parties in a construction project. It should be easy with a simple survey to specify the benefits and inconveniences of the development of specific CAD system. Some problems may disappear as hardware develops or with technical development of applications. These may facilitate the final phases of design, but the greatest challenges for development in the user interface are in the early phases of design, especially in sketching. This in contrast requires a more profound understanding of the features identified in this research and their relation to CAD. The research discipline is challenging and it also requires a lot of interdisciplinary thinking. As separate research paradigms for human computer interaction (HCI) and usability issues will have a significant role in future research.

6.1.2. Developing creative computer aided architectural design

In the following the problem of non-applicability, according to empirical findings, is likened to the empirical induction and theoretical deduction of the essence in creative architectural design. This leads to the synthesis and emphasis of some critical factors in developing design with but also without, CAD:

- present CAD systems apply well in the final and routine phases of design, but the applicability in the early phases is poor, when on the other hand the most significant features and almost all costs are fixed,
- therefore understanding these early phases, the core of architectural design (motorics, senses, conscious and subconscious thinking and the information flows

between those and so on), is essential in developing creative computer aided architectural design,

- systematic tools don't apply to creative architectural design as a dominant method, because the entity of architectural design contains so much information and even unspecified variables, therefore systematic methods as the predominant method may transfer attention from the task to the tool, anyhow some rationality is needed as support in design,
- even CAD has had, and will have, evolutionary influences on the design process of architects as an entity, but in a way that the user interface will be adopted to follow the architect's design process, and not vice versa,
- maintain the possibility to draw – sketching and drawing are essential manners in the early phases of design, they are tools to interpret thoughts and process the forthcoming idea further, then if the medium used in design doesn't support drawing it may easily needlessly hinder the optimal work of the designer and
- applicability or usability of computers in creative work is not in the user interface or its features, but in the relation between the designer and computer user interface.

Creativity has been studied in various contexts, but scientific research in the entity of creative architectural design is missing, however, at least in the context of the theory of methods. These findings agree and carry on the present understanding of the creative design process. However, existing creativity research has mainly splintered into the separate and dispersed parts, while this research strives to integrate both theoretical and empirical findings as an entity and therefore the approach is multidisciplinary. Therefore only partial references for comparison can be found. Understanding the core of the design process offers a solid basis for further research and development. This has been clearly noted also among the most critical authorities of the design discipline (e.g. Cross 1994, Gero & Maher 1997). A tendency toward this paradigm has been noted in the school of systematic design too (see e.g. Andreasen 1991), but practical action and evidence is yet missing. Theoretical possibilities or research paradigms studied in other disciplines (e.g. HCI, GUI, BUI, fuzzy applications, usability) should be adopted, applied and utilized also in computer aided architectural design in order to attain more flexible and open systems in the future.

Understanding the core of architectural design. In this research the core of architectural design has been processed in two ways. It has been first deductively concluded from several references from several disciplines. The human information system is essential in theory deduction is (see fig. 36, Heikkilä *et al.* 1996, Tuomaala 1996) and the method of intuitive creative work as an entity (see fig. 42, Tuomaala 1995, Kirk *et al.* 1988). In contrast the empirical induction presents these factors significant in practical creative computer aided architectural design (see fig. 70, 71 and 72). The results of different surveys are on a high level of abstraction, but in this research they are so congruent and interpretations point out that they can be considered reliable. Furthermore the theory deduction and empirical induction also agree between each other. It can be said that the theory deduced (chapter 3) agrees mainly with empiric surveys (chapter 4 and 5) made for architects and also with the cases presented.

Understanding the difference between conscious and subconscious thinking and the information flows between those, motorics and senses forms a solid base to develop *creative design.* After reviewing the “checkered” field of creativity research Akin and Akin (1996) noticed that using information processing models is the way to study the creative process. Eastman and Shirley (1994) enhance the meaning of information flows in managing the design process. The greater rate and capacity of the subconscious mind compared to the conscious mind (see Cross 1994, Feud 1949, Richards 1974, Tuomaala 1995, 1999) means that it should be exploited in order to achieve the optimal output. So the perception has to be noted that senses connected to motorics transfers the information to the subconscious faster and to a greater extent than can be consciously perceived (see Tuomaala 1992, 1995). These factors are essential, especially when comparing CAD and traditional design and with perceptions of present user interfaces these aren’t optimally exploited. Therefore the design medium makes a great difference if the designer has to aim his attention at the system and not at actual work. In addition to the former features (motorics, senses, unconscious and conscious thinking), creative design has other significant concepts as presented in chapter 3: tension, short logic, action centres, incubation, penetrative analysis or decomposing and also rationality. The difference of these factors to the former ones is that they aren’t so dependent on the medium in design. The challenge of developing a CAD user interface containing all these features will be great, but however there isn’t any, at least fundamental obstacle to doing it.

Systematic methods or tools have usually had positive acceptance as an aid in the design process in some fields and the development in numbers has been successful. There are certain reasons for those, but they don’t apply to all working phases or methods. However, they generally facilitate the design process, but usually externalise the design thinking. Rasmscar *et al*. (1996) emphasize that assisting tools and the designer should take the form of a dialogue. A typical example of the systematic method is QFD. Is has good experiences in several sectors (see Ekdahl 1997, Lakka *et al.* 1995, Turunen 1992), but it doesn’t apply to creative architectural design, even when the applicability to creative mechanical engineering design is moderate. *The survey of QFD indicated that a systematic tool doesn’t apply to architectural design as a dominant method, because the entity of architectural design contains so much information and even unspecified variables especially in the early phases of design. Therefore the control and processing turns into a difficult and complex system. Then there is a danger that reality becomes obscure.* However, the main steps of the architectural design can be recognized from the QFD process. The creative design process can solve problems, which cannot be even determined logically or accurately. Therefore too systematic methods, at least in early phases of design, makes the design process into a complex procedure and hinders creative design or the design system cannot start without all input data. Systematic design methods cannot be directly compared to CAD systems, but both methods as a predominant method may transfer the attention from the task to the tool.

The most significant difference between creative and systematic design may be the level of thinking, where solutions are generated. Creative and intuitive problem solving takes place in the subconsciousness. Systematic design is logical reasoning and solutions are produced at a conscious level of thinking. (see Hubka & Eder 1992, Pahl & Beitz 1990, Tuomaala 1995).

As a consolidation of the core in architectural design it could be noted that *when developing CAD systems supporting creative design it is important to maintain the natural architectural design process and develop user interfaces towards it and not the* *opposite. On the other hand architects should learn the use of CAD systems so that it doesn't hinder the design process, but, however, so that the design methods is maintained close to the natural and optimal.* It has to be anyhow noted that these former factors don't necessarily secure the good output of design, but they allow the designer to use his resources optimally. Nor does CAD produce creative output or solutions if the designer himself isn't creative. Requirements of the natural architectural design process are linked to the ability and possibility to draw.

Maintain the possibility to draw. The main and essential function in architectural design is drawing. In sketching pencil and paper are aids to clarify and develop ideas or images. These were clearly found from empirical perceptions and also from the literature. Drawing and drafting are almost exceptionally the channel to give form to the idea. One simple line in sketching will tie the emerging picture, but it also carries on the whole design.

In Tuomaala's (1995, 1999) theory of creative design, heuristic working was one of the significant means. It means working on the detail ideas of some part and the connection is created between two details during drawing and working without conscious pondering. Making the drawings and the drawing itself convey information to the subconscious to a greater extent and quicker than we consciously understand. The subconscious compares the old solutions to the present task, which again generates new information to be conveyed into a drawing, or creates new solution ideas. On the other hand, presenting the solution idea, for example, through speech often also develops the new idea. This is one of the reasons why sketching may sometimes even be on the unconscious level and then the action is controlled by subconsciousness. This is evidently such a sensitive and vulnerable a phase that it will not succeed if the designer has to concentrate on the design system.

During the centuries drawing has become the optimal activator in creative design and thinking. Conscious and unconscious thinking, senses and motorics have formed a fast and effective information circle. Anyhow this is not working properly in present CAD systems and the main problem is the lack on connection between hand movement and the forthcoming line, because the hand movement differ from the forthcoming line on the screen. Nor can the line be emphasized by pressing the pencil harder than normally. In present CAD systems input devices are mainly the keyboard and mouse. This may have worked in routine design with less concentration, but it hasn't work in sketching. *One opportunity to intensify creative architectural design in early phases compared to present CAD systems would be a user interface corresponding to traditional sketching "B6 – pencil and paper".* This can be the solution to the most critical phases, when extreme concentration in required in processing the idea, but it is not so necessary in 3D modeling.

Mitchell (1992) sees that it is enough for human information processing when the hand movement corresponds to the line created. But according to the results it is quite probable that in present state CAD cannot totally replace traditional drawing, even when 3D features help in developing the ideas. So the connection between hand, eyes and forthcoming line is needed. In traditional sketching the pencil is straight extension of the hand in making different impressions and effects in drawing. *For current information technology it should be easy to develop an interface corresponding to traditional sketching*. A "Drawing board" would be possible to implement as a modification of the digitizing board, but the pointer instrument should be an "electronic pencil". The trace of the drawing should be seen also on the surface of the plane, when the information circle (conscious and unconscious thinking, senses and motorics) can operate optimally. The basic principle of this kind of idea was first published in the 1960's in MIT as a "Sketchpad". It was a line drawing system where a light pen was used directly on the screen. As practice has pointed out the development has at least partially broken the system of human information processing. In developing user interfaces the issue has been the communication and physical outfit, but not the usability of the interface. (see Negroponte 1995). Therefore also present CAD hardware needs rethinking. An analogy from the telephone call points out the purpose should be to design buildings or objects effectively not the use of computers or information technology.

However, as noted from experience and several experiments the graphical user interface GUI (see Metsämäki 1995, Negroponte 1995) makes design more effective and utilizes the natural information circle. The whole user interface also needs developing, because a lot of evident difficulties lie in software too. Another theoretical approach to improve this may be adopted from e.g. the body user interface BUI (see Kuivakari *et al.* 1999).

As mentioned, in architectural work drawing is essential, however, the level and purpose varies during the process. In traditional design the roughest sketching is done with a thick and soft pencil. Structures and walls are presented with one thick and indefinite draft. When design proceeds thin pencils are used to draw surfaces for hollow structures and the final version contains all layers and structures depending on the use. From this perspective theoretical *applications of fuzzy logic may apply to sketching* (see Chen 1996, Cornelius 1998). The CAD system in sketching has to be able to process unscaled and indefinable information and lines, and when design proceeds existing lines and structures should be able to be modified and, later on, they should be able to be changed into a certain structure. Then in the optimal user interface preliminary drawings could be implemented as in traditional design, which would be easy also for designers with less experience in CAD.

Optimal CAD systems should work in the beginning with simple vectors, completed sketches should be able to modify vectors into hollow structures and finally these should be possible to be modified into the final structure. Some of the present applications allow the use of e.g. final wall structures in sketching. This presents a final impression even in the roughest sketches, which in contrast may cause poor quality and even faults in final design. This among other things means that *user interfaces should be developed towards the traditional design process so that sketching would be only drafting lines. Then the sketching would be as close as possible to traditional work developed in the evolutionary process.*

As presented earlier the unconscious mind has a larger memory and its action is faster than the conscious one (see Tuomaala 1995, 1999). When conscious efforts are aimed at the design medium, subconscious action gets slower. *One obvious solution may be a wide education in CAD and information technology for architects. The profound understanding of information technology and CAD will improve designer's possibilities to utilize CAD and form a solution effectively with CAD.* However architects are designers who exploit the possibilities of CAD and not specialists in information technology. Therefore the usability of CAD systems needs further research.

6.2. Summary

In this research creative architectural design, the design process and opportunities of information technology in intensifying architectural design are studied. The target group has been Finnish architects in practical design projects. Empiric material consists of several surveys containing the opinions of almost three hundred architect in total. The theory deduction of the creative design process has been confirmed with the aid of specialists also from disciplines other than architectural design. This research forms an multidisciplinary and compact approach to the human creative and intuitive design process, where applicability in practice has been evaluated from the perspective of architects. Final answers to details in intensifying and developing design have not been produced, but the profound understanding of the design process shows clearly where these opportunities are and where they can be found. These opportunities have been examined triangularly from a hermeneutic approach.

When combining architectural design and information technology multidisciplinary research is automatic, which can easily be seen also from the analysing theory. Then there can be seen a third combined discipline – computer aided architectural design. Architectural design has strong research traditions in the theory of contents, while the theory of methods has not been as popular. The theoretical background and generations in architectural design are somehow connected to the phenomena in the background of information technology – systematics. Information technology itself is a young but wide and dispersed discipline. The theory in this thesis contains only those elements of information technology which are closely linked to this research – the user interface, usability and future opportunities. The development of computer aided design has so far been strongly driven by the development of information technology, but the research interest towards the methods has risen significantly.

Human thinking can be divided into conscious and unconscious thinking and additionally the human information system contains motorics and senses. The capacity and memory of conscious thinking is limited or in the other words only one entity can be processed at a time. The subconsciousness is a large store of memory where all information and skills during the human life is recorded. It cannot be consciously examined and therefore it isn't very well known in science. However subconscious thinking and action is faster and more effective than the conscious. Through motorics and senses more information is transferred to subconsciousness than consciously can be noticed or understood. On the other hand thinking has to be build up on the conscious level in order to utilize the ideas produced. In creative work novel ideas are produced, which requires both conscious and subconscious resources.

Basic concepts in creative work are tension, incubation and heuristic working. Intuitive tension is consciously or unconsciously sensed will to achieve an objective. When conscious effort is aimed to somewhere else intuitive tension keeps the subconscious processes in action. Practice has indicated that the best solutions are achieved through intuitive tension and not stressed by conscious thinking, e.g. in work the best solutions may pop up into consciousness apparent occasionally. Therefore brains need periodic relief from pressure and control, which is called incubation. Heuristic points are some kind of working points in the field of the task. Automatic information

transfer between these points is called logical moves. Heuristic points are essential, either details or entities, in the object of design. The preliminary solution confronts penetrative analysis where the solution and its structure is broken down in critical analysis.

Unconscious problem-solving is called also intuitive problem-solving. The opposite is systematic problem-solving. Systematic design science underlines rational and logical procedures. All steps are processed consciously so that they can be influenced and feedback can be achieved. It is typical for a systematic procedure to divide work into sub-problems, which are eventually united as one total solution. The most significant difference between creative and systematic design may be the level of thinking, where solutions are generated. Creative and intuitive problem solving takes place in the subconsciousness, while systematic design is logical reasoning and solutions are produced at the conscious level of thinking. The best possibilities for creative work are to produce novel ideas or solutions. In contrast, processing and evaluating ideas or solutions are the best features of systematic methods. When observing the phases of Finnish architectural design strong periods can be noticed both in the creative and systematic design culture. This may also be a sign, that neither a creative nor a systematic method has alone optimally fulfilled the needs of design.

Architectural design is creative work containing several even inconsistent, elements like customer needs, regulations and orders, which cannot be solved with logical reasoning. Architectural design has to produce construction engineering and cost effective solutions, which are a part of art in the infrastructure. Systematic design methods have not been popular among architects, because they lead almost always to a complex information mass. On the other hand these systems will always produce, at least some kind of, solution.

In present architectural design two thirds in done with computers and also two thirds in numbers of architects are using CAD. Also the majority of architects support CAD. Present applications apply well to the implementation of designs, when the most significant factors are effectiveness and the rate of design. The utilization has also large list of problems and the capacity is not in effective use. It is difficult to use on inflexible and awkward system effectively, when also the incompatibility causes problems. However, the lack of competence in information technology causes some of the problems. The main problems, however, are in the early phases of design, because CAD systems don’t seem to apply in sketching.

One possibility in developing user interfaces is move in a more flexible direction and more close to the natural and traditional architectural design process. Also the effectiveness of drafting has to be considered. Applications directed at the early phases of design should be as close as possible to traditional drawing, because it is the most effective way to operate. The information circle – conscious and unconscious thinking, motorics and senses should have the possibility to operate in order to optimise the designer’s capacity. An important finding is also the sensitive fact that applicability or usability of computers in creative work is not in the user interface or its features, but in the relation between the designer and the computer user interface. On the other hand architecture and also architectural design will be an evolutionary process and CAD may be utilized more effectively in the future also due to the learning process of CAD.

There are several possibilities in developing CAD systems aimed at architectural design, but the practical creative design process has developed during a long period of time, in which case changing it in a short period of time would be very difficult. Although CAD has had, and will have, some evolutionary influences on the design process of architects as an entity, the future CAD user interface should adopt its features from the architect's practical and creative design process, and not vice versa.

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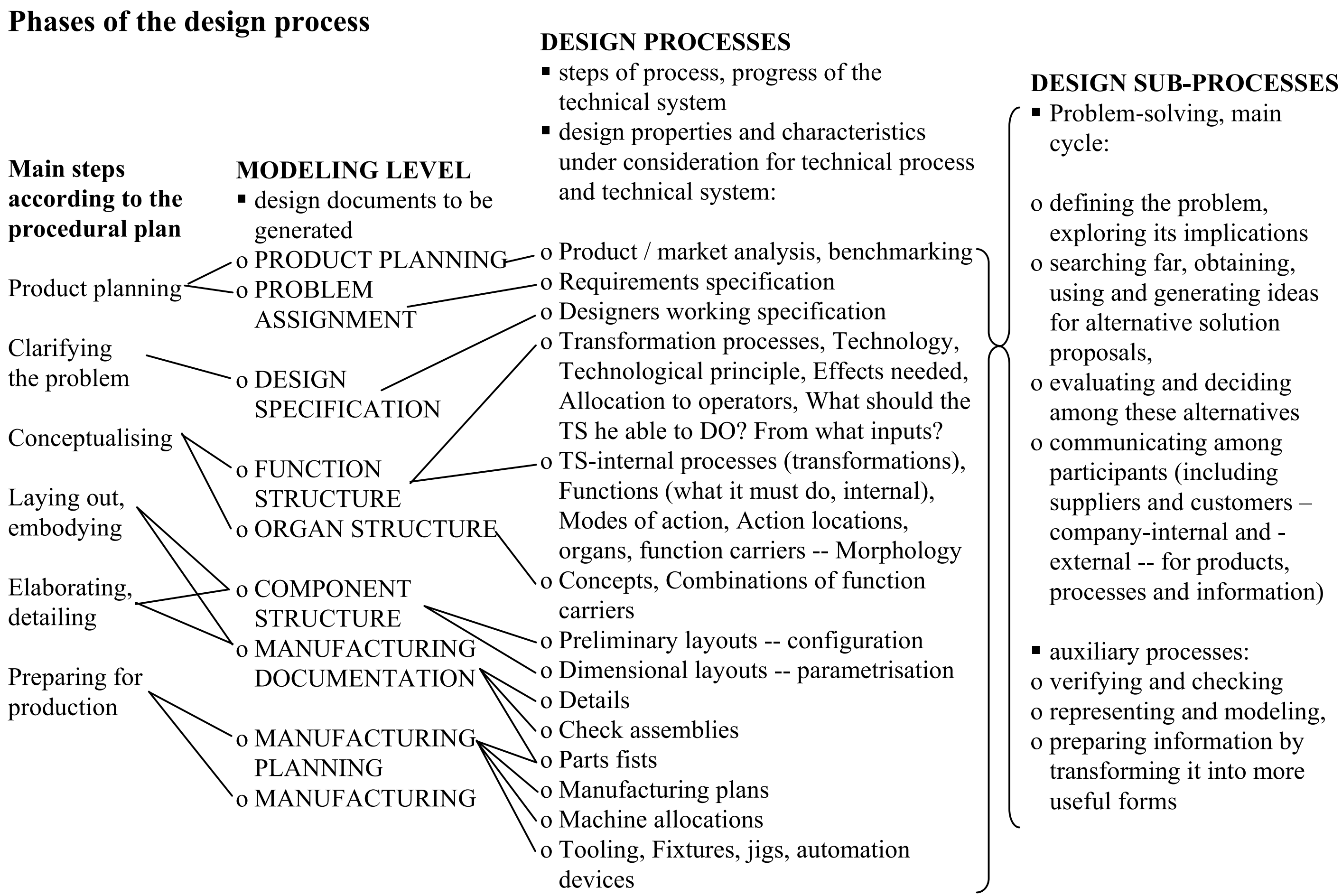
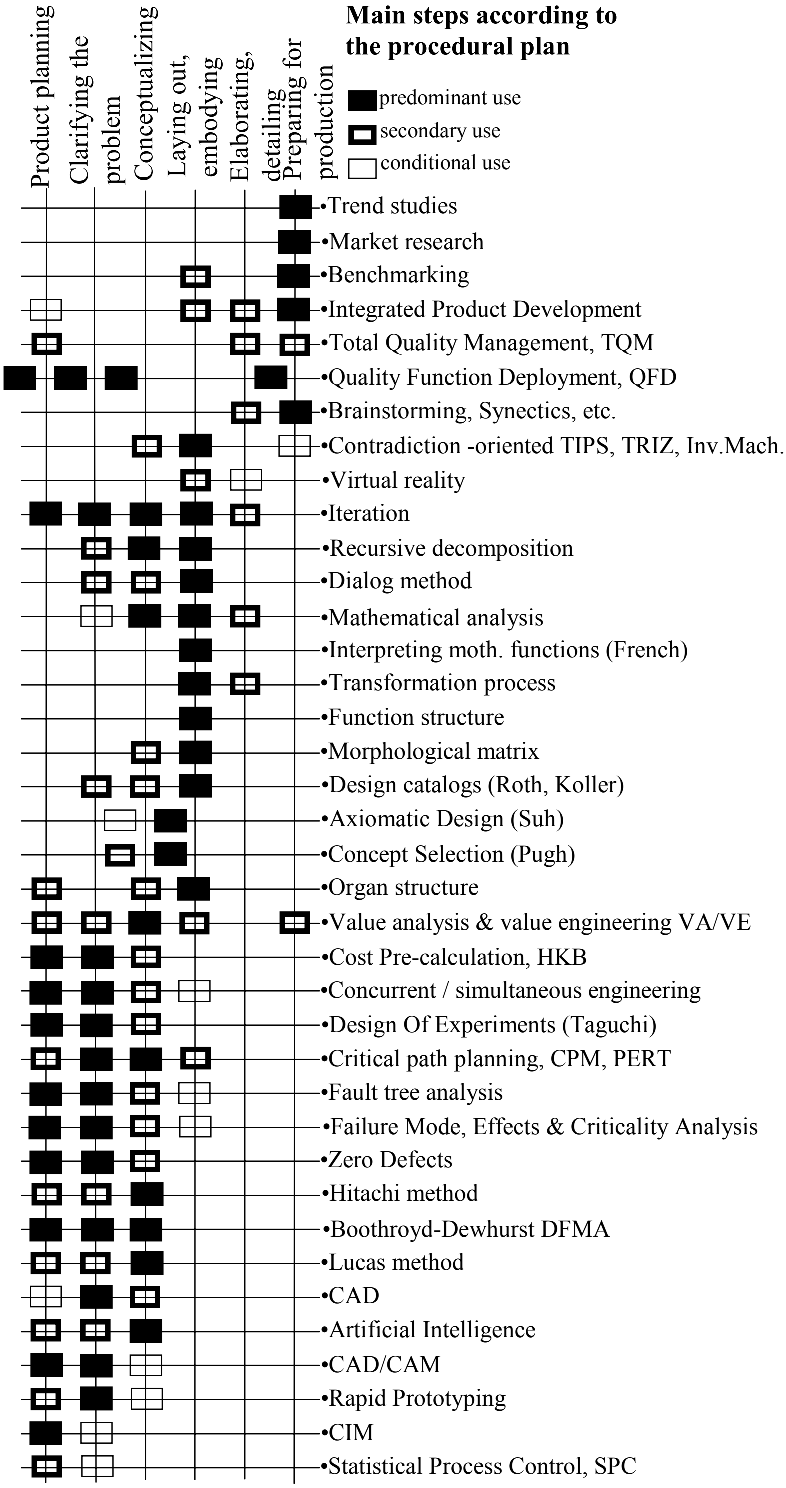
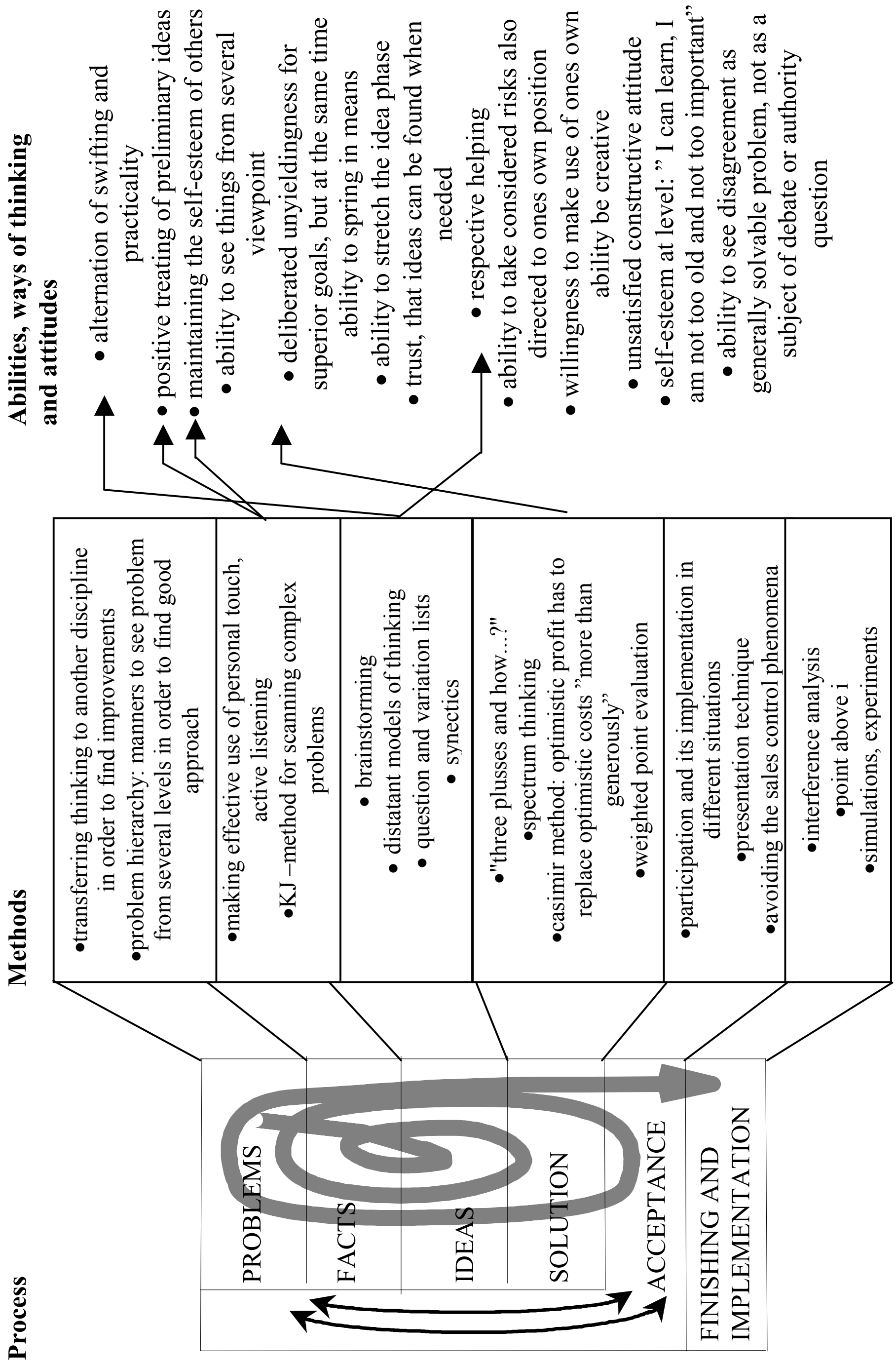
Usability of methods in phases of the design process (Eder 1998).



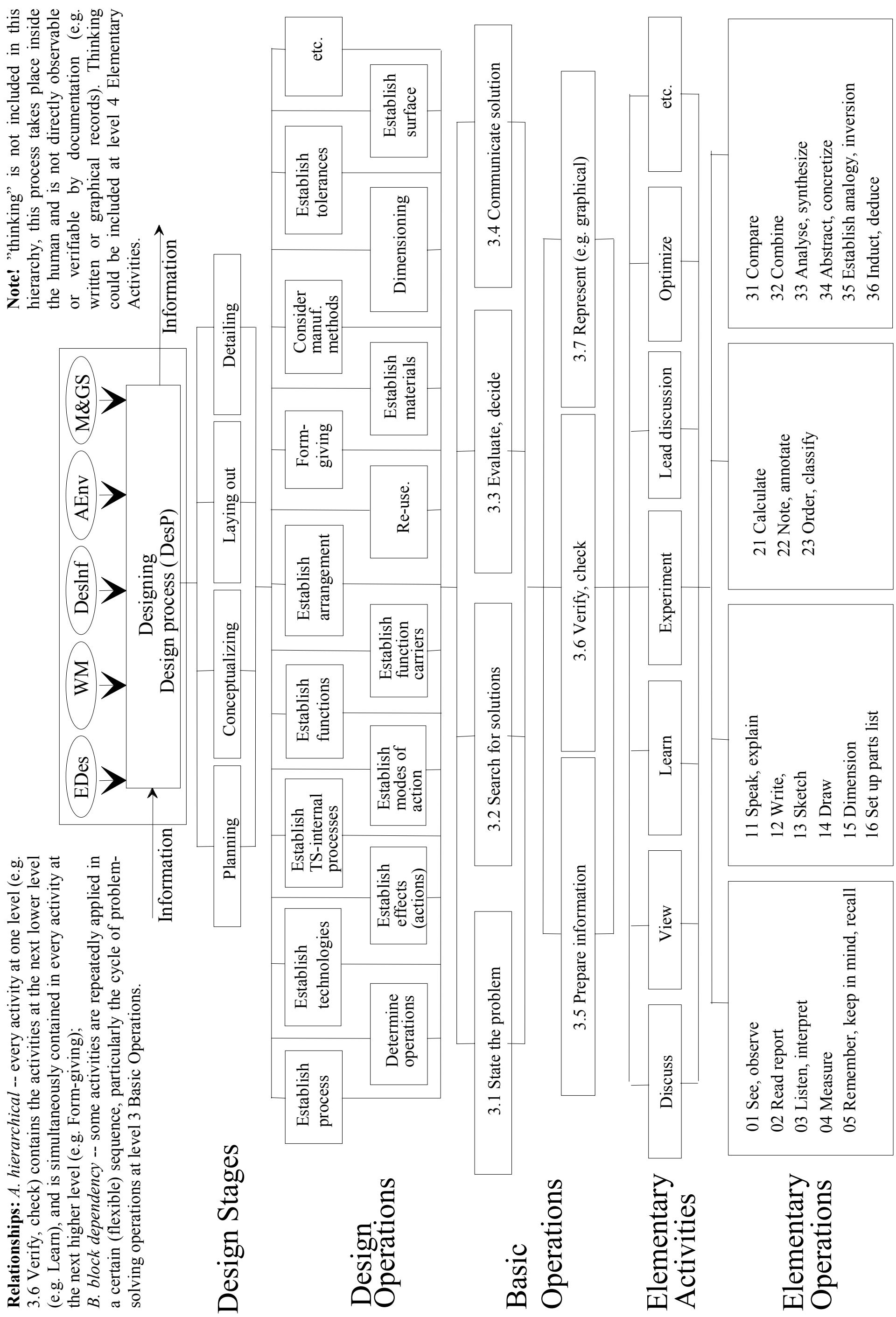


NOTE: Usage marks placed between the main stages indicate that the method is useful as bridging item. QFD is a tool for coordination between designing and management, esp. for performing design audit. Suh and Pugh are (problem solving) evaluation tools for comparisons among alternatives, and decision□making.

Systematic creative problem-solving framework (Virkkala 1991).



Design hierarchy in systematic design (Hubka & Eder 1992).



APPENDIX 4

Survey questions of the creative architectural design.

1. Mitä on mielestänne luova rakennussuunnittelu?
   What in your opinion is creative architectural design?

2. Onko teillä kokemuksia alitajuisesta ongelmanratkaisusta? Millaisia? Miten ja missä ideat tulevat esiin?
   Do you have experiences about creative problem solving? What kind of? How and where did ideas emerge?

3. Onko "hautuminen" välttämätön vaihe luovassa suunnittelussa? Miten se tapahtuu käytännössä?
   Is "incubation" a necessary phase in creative design? How does is take place in practice?

4. Miten rakennatte mahdollisista ratkaisuideoista mielikuvia ja miten ne kehittyvät valmiiksi?
   How do you build images of the possible solution ideas, and how do they develop into finished ideas?

5. Mitä luovassa luonnostelussa oikein tapahtuu?
   What actually happens in creative drafting?

6. Tarvitaanko rakennussuunnittelussa systemaattista logiikkaa? Mihin?
   Is systematic logic required in architectural design? For what?

7. Soveltuvatko tietokoneavusteiset suunnitteluohjelmat luovaan rakennussuunnitteluun? Miten?
   Are computer-aided designing programmes suited for creative architectural design? How?

Survey questions of the QFD –method in creative work.

1. Millaisen mielikuvan edellä kerrottu QFD -menetelmä antoi?
   What kind of an image did the QFD method presented above give you?

2. Voidaanko QFD:tä mielestänne soveltaa rakennussuunnitteluun/ koneensuunnitteluun?
   In your opinion, can the QFD be applied in architectural design/mechanical engineering design?

3. Luova suunnitteluprosessi ja QFD?
   Creative design process and QFD?

4. Entä soveltuisiko menetelmä nuorelle kokemattomalle arkkitehdille esim. oppimisvälineeksi? Entä kokeneemmalle suunnittelijalle?
   Would the method be suited for a young inexperienced architect, for example, as a tool for learning? Or for a more experienced designer?

5. Millaisia kysymyksiä mielessänne heräsi, kertokaa ainakin havaitsemistanne ongelmakohdista?
   What kind of question came to your mind, please, tell at least about problem stages you observed?

Survey questions of the state of the art in computer aided design.

1 Vakituisia työntekijöitä toimistossanne on tällä hetkellä __ henkilöä, joista varsinaiseen suunnittelutyöhön osallistuu __, ja lisäksi tilapäisiä suunnittelijoita on ___ Suunnittelijoista noin ___% käyttää CAD-ohjelmia suunnitteluun, ja noin ___% vain piirtämiseen. Suunnittelijoista ___% ei käytä lainkaan CAD-ohjelmia.
The number of regular employees in your office __, the number of actual designers__, the number of temporary designers___. ___% of designers applies computers in designing, and % applies only to drawing. Designers who don't use CAD at all ___%.

2 Toimistonne pääasiallinen suunnitteluala on ☐ julkinen rakentaminen, ☐ asunto-rakentaminen, ☐ peruskorjausten suunnittelu tai ☐ yhdyskuntasuunnittelu, ☐ muu mikä________________.
The main design discipline is ☐ design for public construction design, ☐ resindential design ☐ renovation design or ☐ urban planning, ☐ other what_________________.

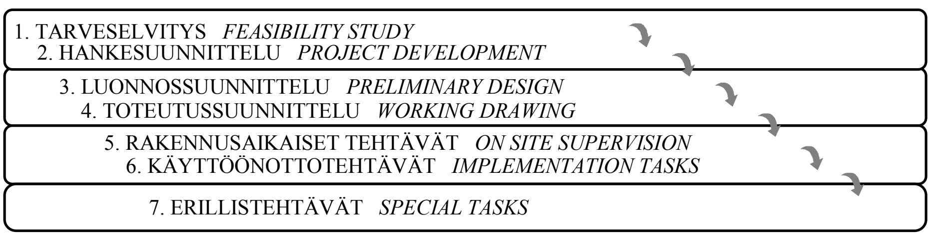
3 Suunnittelusta tehdään tietokoneavusteisesti noin __% ja piirtämisestä noin __%.
___% of all design is done with CAD and ___% of all drawing is done with CAD.

4 Mitä suunnittelu- tai piirustusohjelmia toimistossanne käytetään (jos useampia ohjelmia, mainitkaa myös ohjelmien käyttösuhteet); mainitse ohjelman nimi, versio, ohjelman lisäsovellus sekä laiteympäristö?
What design or drawing programs are used in your office (in case of several, mention also the utilization factor); mention the name, version, additional application and also the hardware of the system.

5 Mitä muita tietokonesovelluksia käytätte suunnittelussa kuin piirustusohjelmia? Ohjelman nimi, versio, ohjelmaan liittyvä lisäsovellus, laiteympäristö sekä ohjelman käyttötarkoitus.
What other than drawing or design programs are used in your office; mention the name, version, additional application, hardware and the purpose of use.

3D mallintaminen:	*3D modelling*
Tekstinkäsittely:	*Text processing*
Taulukkolaskenta:	*Spreadsheet*
Tietokanta:	*Database*
Tiedonhallinta:	*Data management*
Projektinhallinta:	*Project management*
Muut suunnitteluun liittyvät ohjelmat:	*Other applications connected in design*

6 Arkkitehtisuunnitteluun on esitetty RT -kortistossa alla olevan kaavion mukainen tehtäväluettelo ARK 95. Missä vaiheissa, mihin ja miten käytätte aiemmin mainitsemianne tietokoneohjelmia?
The scope of work in architectural design ARK95 is in figure below (national regulations and instructions in Finland RT 10-10577 1995). In what phases, in where and how do you apply applications mentioned earlier?



7 Mikäli toimistossanne ei käytetä CAD-ohjelmia, mikä tähän on syynä?
If CAD is not used in your office, what is the reason for that?

8 Millaisia kokemuksia teillä on käyttämistänne CAD-sovelluksista?
What kind of experiences do you have from CAD systems what you have been using?
Hyviä: *Good:*
Huonoja: Bad:

9 Miten arvioisitte käyttämiänne CAD-sovelluksia muihin markkinoilla oleviin sovelluksiin verrattuna?
How would you evaluate your own CAD system compared to other systems in market?

10 Mitä etuja CAD:illä on saavutettu toimistossanne perinteisiin suunnittelumenetelmiin verrattuna?
What advantages CAD has offered to your office compared to traditional design with pencil and paper?

11 Mitkä ovat mielestänne suurimmat käytännön ongelmat, joita CAD-sovelluksiin liittyy yleisesti?
What are the biggest practical problems, when using CAD applications?

12 Mitkä ovat CAD-sovellusten suurimmat kehittämistarpeet?
What are the greatest needs for development of CAD applications?

13 Onko teillä kokemuksia suunnitteluprojektista, jossa kaikki osapuolet ovat käyttäneet CAD-sovelluksia? Millaisia kokemuksia?
Do you have experiences about design projects where all participants have used CAD? What kind of?

14 Mielipiteenne rakennussuunnittelun tietotekniikan nykytilasta ja kehityssuunnasta. Mihin suuntaan CAD-järjestelmät ovat kehittymässä ja toisaalta mihin suuntaan niitä tulisi kehittää?
Your opinion of the state of the art and the development trends in CAD. To what direction CAD systems are going and on the other hand what should be the direction in development?

15 Onko CAD muuttanut rakennussuunnittelua tai tuleeko se muuttamaan, jos CAD yleistyy entisestään? Entä arkkitehtuuria?
Has CAD changed architectural design or will it do that later on, if it keeps becoming more general? What about architecture?

16 Mitä muuta tärkeää tietokoneavusteinen suunnitteluun liittyvä kysely herätti? "Luovat ideat"?
What other significant factors or features did the questionnaire evoked? “Creative ideas”?

Data of the survey of the creative architectural design.

What in your opinion is creative architectural design?

a) *In creative architectural design, one must find individual viewpoints, comfort in the required spaces (personality), in addition to the logical basic solution.*
b) *The combination of as many environmental and functional requirements as possible, without using ready-made models as the primary starting-point. The shaping of images, atmospheres, associations and the time here and now, to form a part of the concrete building.*
c) *The whole working field of an architect.*
d) *Creative architectural design is the ability to solve the given design task in a manner that the solution contains either aesthetic or functional value added.*
e) *Creative architectural design is, in my opinion, just the same as any other creative thinking or design. That what a human does, but a robot is not able to do. Creative design is, among others, the ability even to find solution models for architectural design from everyday life. The ability to make a proposal, forget it, start again from the beginning and thus make several proposals and maybe go back to the start, or combine these into a final solution. The ability to study a problem from many angles. The ability not to lock yourself onto the first idea. The ability to solve an unexpected problem with the means available, which one often has to discover and compose by oneself. The ability to use your imagination. The ability to be like a child. The ability to put your soul into it. Good creative architectural design also means the ability to survive and solve the problems of the building combined in one entity, to the functions relating to the building and, above all, to the people utilising it. The ability to see matters from many points of view, and to make different solution models based on them.*
f) *The understanding (reading) of the customer's unconscious needs and bringing them to a physical, visible form. Finding new solutions models for the dimensions of our physical environment, for large shapes and small details. In my opinion, creative architectural design at its best combines the ideas from the environment (the creativity of the environment) into a plan upgraded by the designer. The creative process is accelerated, if the designer is able to listen to others and to gather the essential from it. Several brains combined are like an extension of the computer – the process is speeded up enormously through the additional memory. This is not commonly understood, but designers tend to aim at individual performance. Creativity is the basis of everything. Creativity must be used in all work and activity. By creating this society and by doing our utmost, we are building the paradise of the ideal society. At least this should be its goal – its vision, otherwise we do not know what we should build.*
g) *Creative architectural design always starts from the task at hand: time, place, needs. The ideas to be used, solutions, models may be very old and proven good; it is essential which ones are chosen and what kind of an entity they will form right now and tomorrow. Creativity is combining matters together in a new way.*
h) *Creating ideas about the building entity and its parts, rethinking and testing ideas. With regard to architecture, creative architectural design is the most important part of an architect's work.*
i) *Architectural design is not creative when one is content with copying the existing ordinary type of solutions. In creative architectural design, the core of the task at hand is entered and the task is solved expressly from the starting-points of that particular task. Since the design targets vary with regard to their conditions and contents, creative design often brings individual and unique results, although emphasising dissimilarity has not been a conscious goal. Creativity can appear on many levels, it can be an over-all idea or a sudden perception on the level of details. The concept of creative design is often used to mean aesthetic creativity, but it can as easily be of a functional or building-technical nature. In my opinion, I embed creativity on all levels in the principle of creative design - from the basic solution in the zoning plan to the smallest connection joints or colour definitions. A typical, creative phase in the architectural design is the solution of the installation network formed by the structures and technical solutions for buildings, and their organic application in the basic solution selected. This is an example of creative design taking place as teamwork between various experts, where one must be able to picture the target's functional development far into the future in the period of the building's life*

cycle. Thus creativity in architectural design also entails the ability to receive new information, and flexibility to change the solutions on its basis.

j) *The ability to see each design situation as a different one, not forcing one's ideas to the reality, but raising the reality towards the ideal.*
k) *Architectural design is comprised of different artistic, functional, material, ecological, etc. demands which are combined through architectural design in a new, unique manner in such a way that the end result is beautiful – durable – applicable to the application in question.*
l) *Creative architectural design is solving the various sections relating to the design task in a way that results in a new and unprecedented solution.*
m) *Creative design seeks the best possible solution for each problem, based on the goals, conditions set by the site and other material environment (resources), knowledge, experience, even tradition. It can also apply old and familiar partial solutions to the situation in a suitable manner creating a new entity. It does not seek the easy way out by copying. It can be high-flying letting loose, but it cannot be frolicking without responsibility. It is questioning, doubting, studying and, in good moments, having sudden perceptions.*
n) *In my opinion, the question of creativity is difficult to define unambiguously in brief, but I will, however, try. Creative architectural design is design which often takes place elsewhere but not on the drawing board, although it does take place there, too. In the following I will try and make the event somehow more concrete. The design process is started by a survey of the basis data of the task given. The space programme often exists, and also the users and utilisation programmes of the design target are already known (in this case the given mathematical values, as well as the connection diagrams of the functions are already creating the solution). If this is not the case, creative design starts with a tabula rasa without any preconceptions (in this case we can talk about especially creative design). At all events, the building as target starts to form itself either based solely on (e.g. I imagine the form of the building first without a more detailed distribution of space – what the building could be, is wanted to be; the process is an attempt to sketch images by hand, by pencil – perspective dabbling), or the mass distribution of the building starts with some level of outlining the space diagrams, squares into lay-out drawings (with pencil) and little by little into a three-dimensional model, raising façade-diagrams and making drafts in perspective. The result should be useful spaces, building with nice mass distribution, and in addition to that, solutions that are technically and financially applicable. True creativity in the situation varies, but at all events, design when unprecedented solutions can be created from previously unknown starting-points can be considered as being actually creative design. In this connection I will not go into the requirements set for beauty which are an essential part of an architect's work, but which can be speculated on endlessly, without finding more detailed clarity. Solving any kind of a spatial programme in a building might be considered creative design, but the definition is too broad, and does not tell enough of the actual situation.*
o) *I guess good design is that the prevailing situation, existing needs and resources available are combined in a manner that creates something new. Creating something new, on the other hand, isn't actually creating something new, but it is the ability to see the existing possibilities. After all, all solutions always exist for everyone. The question is more about how widely each of us is able to see them. Creating something new is more the ability to look at the prevailing situation in an open and unprejudiced manner in order to see all solution possibilities hidden there. A great part of designing is not at all creative in reality, but it is working on the problem to make it be in accordance with the pre-set solution. In creative designing, the solution should be worked on to make it be in accordance with the conditions. It is typical for a person capable of creative work to have the child-like ability to see and become enthusiastic about things without thinking in a utilitarian manner. He/she must not have the ready-made world-view of an adult or fixed attitudes.*
p) *Creative architectural design seeks and finds new ways of solving problems and tasks.*
q) *Creative architectural design is design that achieves the basic principles of individuality, uniqueness and aesthetics.*
r) *To think back, I can state it as being quite a normal situation, architectural design must always be creative in the initial phase.*

s) *Reacting to the environment, inspire the joy of living.*
t) *The human being consists of three elements, the universe, the world and the earth. From the point of view of creativity, all elements of the human being, and the manner of its being are essential. Creativity is simply living it to the full. Then the human must, without prejudice, take risks, be in child-like association with the chaotic basic state of experiencing, fearlessly draw material from there for the creation of his/her own scheme of the universe. Finally he/she must have the means and the skills to attach the world to the earth. Architectural design is all of the above. It is only life. Architectural design is only one means of attaching to the ground. Architectural design is special expertise. If it is disconnected as a field of its own, where you only realise thoughts presented by others, it will lose its connection to the entire process and its creative life. Creative architectural design requires an educated human being to live a full life as an individual.*
u) *Creative architectural design is work that is based on architectural civilisation and understanding with an uncountable number of different and contradictory objectives, instructions, parts are woven and arranged together.*
v) *Creative architectural design is a striving for design by sensing the creative force which is harmonious and which, obediently dictating, follows the rules.*
w) *A solution is finally found even to a contradictory task which seems impossible.*

Do you have experience in subconscious problem-solving? What kind of? How and where do the ideas emerge?

a) *Constantly, especially when the timetable has not been pressuring tightly – solutions for problems generated in the subconscious mind can only surface during a peaceful period - suddenly."*
b) *My technique is the politician's old one: to sleep on it. The problem is thought of with the brain sizzling after the working day and just before going to bed. In the morning, the problem is usually solved, if it is to be solved at all."*
c) *Ideas come all the time subconsciously."*
d) *Knots often become untied in the night, in the first hours of the day after 2 to 3 hours of sleep. The solutions is completely clear, and surprisingly enough, also applicable in the daytime."*
e) *The subconscious works all the time. Ideas pop up sometimes when baking, when raking, at the concert or even in the woods picking mushrooms. The majority of ideas surface in this way, if they have first had the opportunity to simmer and stew for a time. Waking up in the morning you often find that even a difficult problem has been solved, a problem that the day before was not going forward or backward."*
f) *I have sometimes had to face a task, of which I immediately could have said that it won't work. Having sat around for a couple of hours pondering the problem I have, to my surprise, noticed that a solution has come up. In other words, working systematically towards the impossible, it is possible to find a solution (with the brain). A classical example, of course, is to sleep on it. Sometimes the solution (idea) comes in the night. The final solution is largely dependant on the individual, whether he/she is able to believe in his/her idea, or abandon it at the first obstacle? One must hold on to the main idea and systematically solve the problems encountered within it."*
g) *The subconscious works all the time. Problems may be solved in the night whilst you are dreaming or some minor matter comes to mind again and again waking you up, and only after some weeks I notice that the matter in question is very significant with regard to other matters. Solutions which surface very strongly from the subconscious, come to mind just before falling asleep in the trance state when ideas flow without tight limits. I might read an art magazine and after a long time notice that some issue sticking in my mind is the solution for a totally different problem."*
h) *Everybody has, but maybe not everyone is aware of it. In practice, almost all problems are solved subconsciously by themselves when they are left in peace. For me, the best and wildest ideas flow at the most in situations where ideas are fed to me. Such situations are concerts, movies, the theatre, and good lectures."*

i) *The subconscious is constantly with me in design and it produces solutions. The process is as follows:*
   - *get acquainted with the contents of the task, the programme seems clear, but there also are problems,*
   - *select a solution model which seems to fulfil most conditions,*
   - *design proceeds based on the basic solution selected, but some parts are constantly a source of pain, they are belittled,*
   - *the subconscious does not forget the problems, and then one day at the supermarket, skiing slope, waking up in the morning, or something else, it is bang! this is the way it should be, the whole thing is totally wrong!"*

j) *Subconscious problem-solving takes place when the brain is resting. You must be able to pull yourself free from work, from time to time."*

k) *When all the different factors of the problem have been recognised and some kind of peripheral rules set for them, the brain starts to analyse and organise the material. Often there is so much material and different demands are possibly contradictory, and there are so many alternative routes to follow that the solution can not be found so quickly. The problem is kind of left to grind in the background in the brain in relation to other activities, so that it is first cut to pieces and the pieces into smaller pieces, etc. in the way moves are calculated in the game of chess and the alternatives produced by the moves to the extent the capacity allows. The brain starts producing solution models for problems which come to the conscious mind when a possible solution for the problem has been generated.*

l) *The importance of the subconscious process is essential. After conscious work has stopped, the subconscious mind produces solution alternatives which are the basis for progress.*

m) *Difficult tasks always demand time for the subconscious. One can only do routine work at one sitting.*

n) *Yes, I have such experience. Quite often when I am doing something else, a thought comes up for the solution for a problem, detail, etc., rather often when I am going to sleep.*

o) *Designing is always subconscious to a great extent. If everything is known in advance, it is no longer creative problem-solving at all. Sometimes I feel that designing is expressly subconscious.*

p) *They come up when jogging, watching the TV or in my dreams.*

q) *Subconscious problem-solving is unconscious processing of the programmed assignment of tasks in the subconscious mind, when the brain registers material from the environment and solution models for the assigning of tasks. This can be called incubation. Solution models may thus be generated wherever, given the right stimulus or when the right piece of the puzzle is found.*

r) *Subconscious problem solutions are exhibited in all areas of the human life, not only in design. When you really think about something, you can be sure that either in the morning, or after a suitable seminar you will find a new and good solution for your matter.*

s) *If you see the task as being important and challenging for yourself, and believe that people are waiting for your solution, the subconscious mind is started automatically.*

t) *The idea of the problem starts from being a universal object e.g. unspecified knowing. A thinking human being is aware of the problem and creates questions. Problem-solving is thinking. Thinking is a conscious activity. It is making questions, producing answers and comparing the two. Answering takes place both on the conscious and the subconscious level. The subconscious level is imagined as being a mystical element, but in my opinion it is only another characteristic of conscious thinking. The subconscious works best through ostensible abandonment of the problem. The subconscious works best when you clearly define the problem, seek for a solution and then desist from the seeking for the solution (often in despair). Thus the subconscious mind is free to think in peace. And, if all goes well, then – sometimes at a surprising moment, some external factor creates an association of ideas to the original problem and a sudden perception is generated.*

u) *Problem-solving is at best subconscious. All design tasks include the subconscious creating of ideas. The question is simply that, after active working and pondering, the subconscious is* *given enough time. One must get a little distance from the task at times, so as not to tread the same path over and over again.*

v) *I attempt to describe the problem, however, in a not too linear or systematic way. It is important that the written demands of the project are clearly formed in the mind, with the requirements relating to traffic, connections and space. I draw the spaces into squares in some kind of dimension; from these squares it is also possible to see the connection diagrams for mass distribution. Environmental requirements, neighbouring buildings connected to the requirements of the project, and the regulations set by the authorities are combined somehow. Then I start making drafts by hand, starting from a thought which has no meaning, but something emerges anyhow. I try to give a form to these thoughts coming from the subconscious. This process could be compared to starting a programme in a Windows environment, the programme is running, even though you are not using the application at the moment. At some point, the aha experience will come. I often wake up in the night at 4:30 or 5 a.m. and notice that I am thinking of a problem. However, I do not think of the task as logical phases, nor do I approach the problem as a structural logical matter.*

w) *The matter is clarified during the night and in the morning it is clear.*

Is "incubation" a necessary phase in creative design? How does is take place in practice?

a) *The above had to do with incubation – design in haste brings a successful end result only in easy construction targets.*

b) *Yes. It can be accelerated in the manner stated above. The necessity of time become clear, if you have had to prepare the plan in a hurry. In that case, great ideas about how the job would have had to been done keep popping into your mind afterwards.*

c) *Through logical thinking in a shorter or long time.*

d) *Incubation is necessary. A subconsciously creative human processes all projects, also the ones in a resting phase. A longer design period in usually required in small projects, unless it is not about a clearly technical solution. Feedback/criticism during the project makes you check on your own black holes.*

e) *Designing work is accelerated significantly in practice, when you get acquainted with the project in advance (quickly or long and thoroughly, depending on the extent of the work), move to other jobs and let it incubate, and start the actual design work days or often even months later. This should be done several times during the design work, if you want to get off easily. Even with smaller-scale design work, incubation facilitates and accelerates the solution. Ideas surface also when getting acquainted with, for example, the publications, exhibitions, studies, etc. of our industry. In my opinion, knowledge rather frees than chains down creative thinking.*

f) *Incubation means understanding and internalising the programme of the problem. It is makes no sense trying to create ideas too far, if the basic data is not yet known and internalised. A certain type of escape route or haste helps to solve a problem quickly. The work will take as long as there is time for it – this saying really holds true.*

g) *Incubation is a necessary phase, but it can also take place quickly. An adequate, sometimes excessive pressure will accelerate the event. You must have time to go through all the matters relating to the plan, test various alternatives, be able to make a huge amount of decisions. Digesting.*

h) *Not necessary, but often desirable, and almost always quality correlates with the incubation time. Thoughts have had time to incubate and ripen, and thus they can be applied either directly or adopted. My own incubation times are rather long, often as long as years. In practice, it is a question of a problem that has to be solved. One day you just see that all the pieces lock into place and it is time to realise the solution.*

i) *Incubation is a necessary part of creative design and there must be time for it. I refer to the process diagram of the previous item..*

j) *Subconscious problem solving takes place when the brain is resting, you must be able to pull yourself loose from work from time to time.*

k) *Incubation is necessary in creative work, see previous answer.*

l) *Incubation is a phase of work connected to the previous one. During the incubation phase the subconscious is working. It is absolutely necessary.*

m) *Incubation is necessary. Some matter will ripen during the coffee break, another will take sleeping on it, a third one will need weeks of rest. The solutions are usually found on the second day or later, when you have first worked enough and driven yourself to several dead ends. Sleeping seems important. Generally ideas come up when you start again on the same task, at the beginning of one sitting, sometimes also when working with other things. It seem to be advantageous for all tasks to have several different tasks going on at the same time and pulling each one simultaneously. The time schedules of practical work are generally such that there is not enough time for incubation. The clients do not understand that the same money will give them better quality, if the work is given enough time. You do not invoice working in your sleep.*

n) *In my opinion, the incubation of solutions is important, it can take place in many stages during the design process. Even though you would not want it consciously, solutions apparently do stew somewhere, because suddenly, for example, a detail or even another basic solution may feel a lot better than the solution already made. In that case, one must test the viability or superior quality, at least on the level of one's mind (the safest way is to make sketches). In the time of the present, mostly very tight design timetables it seems that it would be best if no stewing took place.*

o) *The most important auxiliary tool of design is the imagination, the ability to imagine you already are there at what is just being designed. Someone could, of course, call it incubation. However, the actual designing always takes place in the imagination (I think I would rather use the word imagination than the subconscious). Every thing else, the maps, space programmes, sketches, calculations with EDP or on a cigarette packet are necessary only in that the imagination has a way to function. The problem can be programmed into the imagination.*

p) *Solution ideas must be matured by incubation. The solution will circulate in your mind for a couple of weeks, or sometimes as long as it takes to make the solution.*

q) *Incubation is a necessary phase in architectural design. It should not be too short, in which case the process of item 2 is not possible to think through, but is shouldn't be too long, since the right kind of forcing yourself into the task will not take place and the process will not start, but be postponed and maybe grow stale.*

r) *It depends on the situation. Of course it is necessary.*

s) *The longer you have worked in a positive design environment, the stronger is the incubation. This phase is necessary, otherwise you will tread old tracks. In practice, the subconscious compares the new information with the memory experience and the matter will seek its correct size or characteristics.*

t) *In addition to thinking activities, the incubation of a problem is returning to the level of experience prior to thinking. Creative activity is thus a continual process between experiencing, thinking and activity.*

u) *Incubation is as important a part of designing as the actual drawing is.*

v) *I am never at my best when put under pressure, and I have the habit of working in a way that I organise things so that I will have time for incubation. Things must given the time to rest and rise like a good bread dough.*

w) *It is, if the job does not proceed, it will be left there to stay, later on the job will be solved by itself.*

How do you build images of the possible solution ideas, and how do they develop into finished ideas?

a) *The brain is able to compare the nature of various solution ideas - one of them seems fit for development and could develop into a finished idea through designing. Here a novice designer lacks the background of experience.*

b) *First, with your eyes closed, you must develop in your head, a vision of what you want. Then you must take a thick pencil and draft forms and operation diagrams. The phases are alternated as many times as it is necessary. In between, you must leaf through architectural magazines or books absent-mindedly. Also the ideas of other people are provisions to be used freely by the subconscious. When the red line is found, designing is one happy celebration after that.*

c) *By drawing.*

d) Ideas are often born of action and of the environment. A challenging building site usually offers enough to grab hold of. There is a force to react to, which is transferred to paper and the display in scrappy sketches. They will develop into completed works through redrawing several times and through the feedback received along the way. Sometimes the feedback may drown the whole idea of the project, in which case it has not had enough vital power.

e) It depends on the project. Images are always there in the back of your head. They are changed and organised in different ways whilst they develop. Circumstances and facts influence the decision. They often develop during the work being done. It requires a familiar atmosphere, and for me, usually sitting by the drawing board and drawing, in which case the work also develops as if by itself. If the design work deviates from what I have just been doing (for example, from architectural design into design–formulation), it will require getting down to it and preferably a continuous, long-time working session (depending on the extent or quality of the work), a kind of breaking in and warming up, before the work will start to proceed as if by itself. Drawing is for me a kind of therapy and a learned way to think, design and solve problems simultaneously. Colours and materials, and working with them, are very important elements. I seldom make models, but more often sketch perspectives and details. I really could use good user-friendly three-dimensional software. Different ideas evolve, joint, diverge and develop into completed works, usually around the ideology of a certain world of ideas.

f) In problem solving, you should be able to stay in the one big solution, and not to water it down as the work progresses.

g) I use both words and picture to create images. Single words, a couple of sentences might be able to keep an idea together. In my mind I spin up stories about a plan; for example, how people wander about in the spaces, what kind of light would come to a certain space… In my mind these stories (they do include words, too) are illustrated, so that I myself wander in the building, the environment, and look whether I am pleased with what I see.

h) Only in the head, with pencil and paper, or with the computer. Generally, complex problems contain so many factors that the use of a computer is a must in order to manage all the matters. Here you must pay attention, so that the importance of the matters is not distorted when using the computer. In the last years, I have used the computer more and more for the visualisation of ideas. Alleviated thinking might not be good for you, maybe you should use your brain to the utmost limits.

i) A generated idea must be illustrated, in order to test your own images and also to present it to other members of the team – an architect's work is mostly group work. In my drafting, I apply the following methods:

- *Drawn, rapid sketches of ideas and visions on the corners of every possible variation of paper goods,*
- *program-based extension test of the idea with Excel - e.g. the distribution of the programme into floors – a table is easy to update after it has been made once,*
- *dimensionally accurate diagrams, dimensioning and module surveys with AutoCAD,*
- *(earlier) rough mass models made of blocks of wood, (nowadays) roughly rendered mass models as solids with AutoCAD and viewing them from various angles,*
- *rapid drafting with pencil between all phases: plane and façade sketches, and express perspectives for communication with others.*

j) By drawing.

k) The brain produces entertaining and possible problem solution models, which can be clarified and illustrated further, as well as tested, with the help of thinking and drawing. Each person will make selections from these based on their own world of ideas and experience, and these selections will promote the problem solving.

l) In the creative phase I draw rather haphazardly and seemingly without a target, just something on paper, where, through the layers of many superimposed pictures, a solution or an idea starts to form. It is almost like disentangling a subconscious work to give it a visual form.

m) I imagine spaces, structures, exterior, detail and the work at hand in my mind when I work, but often also at my leisure when I'm driving my car, going to sleep, etc. Imagination at the desk is rather organised and it is carried out with a pencil, but at other times, matters come to your *mind at random, often due to an external stimulus which necessarily does not seem to belong to the matter at all.*

n) *I am not able to clarify the exact generation process of the images created from the original idea, but earlier I have describe the design process itself, which can give you something. I think, that there is always some image, a preconception, a form which starts to live when the work is commenced; when you form it with the imagined developments produced by the hand and by the brain, little by little the building – problem – detail is given a basic form which then can be worked into a more finished form with details. This situation is somehow described, for example, by the form solution given for spaceships; designers have had an image of what they would look like and that image corresponds largely with the space adventure comic strips the designers used to read as kids, here it is also about a kind of self-fulfilling prophecy. Professor Reima Pietilä told once in conjunction with the history of the origin of his buildings about a kind of memory of the hand, just let the hand draw a form. It might somehow be connected with the trinity of thought, subconscious and hand in creative design.*

o) *In all design work, the main issue is to define the problem as clearly as possible. The problem must be analysed, grouped and presented as clearly as possible, and in all entirety without knowing what we are aiming at. The basic data must be fed in as clear a form as possible. If a solution can not be found, one must work with the problem from all directions where there seems to be a possibility to proceed. It is a known fact that genius consists of 90% of pure work.*

p) *The situation is the opposite, images create solution ideas. Images can be generated in everyday events, or, for example, from the phenomena of found in flora or fauna.*

q) *Images, visions build solution ideas which are complemented and deepened through sketching.*

r) *The whole event is a strong comparison with memory data and the finding of positive material. Only the desire to gladden or be delighted, or such feelings, are what solve the issue in the end.*

s) *Image is a good word. The connecting factor between experiencing and thinking is the state of pre-thinking. It is full of images generated by experiences. Working on images takes place through thinking and concrete design activities. Design activity is attaching the image, which has gone through thinking, to the earth e.g. onto the drawing paper, which often is quite a desperate task. Attaching the image to the earth through a thought is a continual process. The final solution model e.g. the manner of attachment is only one possibility in an array of endless possibilities.*

t) *The environment, for which the plan is being made, always influences images.. This happens both intuitively and through analysis. Images are about, for example, seeking the architectural form of a building. In designing, various things take place superimposed. The designing task immediately begins to create images, the solution of the problems contained in the programme requires a rational and mathematical compilation of a puzzle, finding a architectural idea that both carries and gathers is essential.*

What actually happens in creative drafting?

a) *Creative drafting is based on a developing ability to do so.*

b) *Creative drafting by an architect contains 90% of knowledge, techniques, weighing values and making comparison, as well as experience. In order to form it to a finished entity, you need 10% of sudden perception, the yeast or lubrication oil of design which locks the pieces in their correct places.*

c) *The thought moves from one problem to another.*

d) *The brain is capable of looking for solutions even from new and surprising directions. The result of creative drafting may not necessarily be something new, but a solution which is in harmony with the environment in a deeper meaning.*

f) *Without prejudice you set yourself loose from a prevailing solution model. In accordance with the realities of time, place and resources you mirror the developing new solution. I personally feel that during the design process I am leafing through my brain at great speed. I find something, check it out and discard it. This I do over and over again with immense speed. I feel my brain is like a book with a million pages, from which I am looking for the parts I need for this work.*

g) *At best, ideas flow onto the paper in the same way thoughts do in the moment just before falling to sleep. But ideas have to be tested by drawing. The pencil is a tool, like a lie-detecting machine. Pictures are generated on top of and between each other.*
h) *Ideas are polished, made more detailed and replaced. The field of problems in processed constantly in your head, and drawing may just be a surrogate activity. In that case, a computer would just be a disadvantage, since it does require more concentration on the tool itself than the pencil does. A computer is, however, a splendid tool in the comparison of various alternatives in the visual and calculatory way, and in conveying ideas to other parties. In teamwork it is almost irreplaceable.*
i) *The three-dimensional model of a design idea is developed in the brain as the designer becomes aware of the various partial factors. In my experience, the ability of most people to manage and complement a model solely on the level of thought is so unreliable that you need drawings, explanatory pictures and three-dimensional computer-based models, through which the plan is made more solid and can be presented to others, as well. Drafting is at the same time also testing of the world of ideas –continual feedback and the development of ideas into a form that can be implemented take place there. Personally I think it is very important that part of drafting takes place spontaneously through the hand and pencil, because the co-operation between the brains and the hand is, however, one of the oldest skills we all have learned in life*
j) *Ambiguous images are given forms.*
k) *In creative drafting, new, different and unique possible solution models are created. After selecting from these, you proceed to new solution models and selections, until the whole problem has been solved. Creativity contains a new and unique component, as far as I understand, a creative solution can not be reached by splitting a problem down to partial factors and by giving unambiguous selection arguments for each partial problem*
l) *The seemingly pointless drawing with no goal is guided by the subconscious. There you are approaching the solution without even being very conscious about it.*
m) *Organised thinking, seeking for alternatives, changing points of view, turning matters upside-down, testing ideas by drawing, discussion, looking for stimuli. In my opinion, rigorous pondering and working on solution possibilities will create some kind of partial structures in the memory and these will then, either there during the work or often only during rest, subconsciously be connected and reorganised. The next time you will continue on a new level. In athletics, too, your condition will improve during rest, but first you have to practise*
o) *In drafting design, working on paper or with EDP is more like testing images in more detail. In the Tiede 2000 magazine, there once was an article which handled chess players' way of solving problems. Especially the part which stated that an experienced player very quickly sees the directions where the solution for the situation can be found and, on the other hand, the directions where the solution can be sought in vain. Here, of course, lies the danger that you will cut of a solution which might, however, be possible.*
p) *The tool of expression (pencil) follows the commands from the brain.*
q) *In the drafting phase, the design plan achieves a real form, functional and physical demands are driven into it, the plan is outlined and smaller themes complementing and supporting the main idea are added to it.*
s) *The will of the designer is essential, the motivation or social drive, etc. The internal necessity drives to solutions, the event has the same form as Pavlov's tests with monkeys.*
u) *Creative drafting is stirring the soup. Drawing at times in the form of stream of consciousness and at times with careful measuring, definition and evaluation of the task and of the environment, getting acquainted with the source material, taking architectural baths in a real environment, and leafing through magazines, pondering the design task in a bus, and after a desperate phase, ideas start to pop up (the same from the beginning again). Creative design is at times strenuous, going into overdrive might cost you your sleep at night (too long working days at any job may cause the same). In creative drafting the designer little by little submerges themself into his/her task and lives in it.*
w) *Coincidence comes into the game.*

Is systematic logic required in architectural design? For what?

a) *Systematic logic belongs to the beginning of design with certain kinds of buildings, and often a public building may succeed on that kind of basis.*
b) *A whole lot is required. Creativity cannot function with success before the systematic logic has given it the blocks with which the entity is able to function.*
c) *Yes, for the implementation.*
d) *Yes and no. Man seeks for systematically in matters and in places. Things should be a part of some kind of system. It does not, however, mean a linear and a perpendicular, or repeating things.*
e) *Yes. The human always goes subconsciously through some alternatives in a systematic way. Many times it is good to go systematically through different alternatives, in order to achieve the best solution. The quicker this goes, the more time you can spend in creative designing. For example, in the designing of a boat. How can different spatial arrangements be taken care of, the travellers, the crew, the cabins, public rooms, safety, profitability, difference, etc. Having new ideas would be easier to do, if you could get past the above-mentioned quickly, and thus, it could even be possible to find a totally new solution model. Logic is needed in everything, and often also systematic logic, if I have understood it right, whether it is the question of assembling a rack of shelves without instruction, or raking the yard. Everything should be handled and thought about in advance, in case you want find the easiest and least troublesome way out. The saying: well prepared is half done, really holds true.*
f) *The creative process is also systematic logic. It only is finding new, unused routes, unprejudiced creating of new combinations from the basic parts.*
g) *Systematic logic is definitely required in architectural design, after all a completed building consists of a huge amount of various parts which must be fitted together. An architect should be able to put the matters, the parts into an order of precedence and then manage the way they are connected to one another.*
h) *It is not required, but it is typical and characteristic of architectural design. Let's take the brick as an example, it can be used in very creative ways in accordance with systematic logic. You must know the logic, in case you are striving for an end result that is similar to the accustomed. Without the logic, we are able to achieve a more liberated, should I say fully unprejudiced architecture.*
i) *Architectural design aims at the implementation of a plan through building. Our society sets various legislative restrictions on building, it requires the building to have strength and safety, and requires that the validity of the building can already be proved in advance, prior to building. Also construction as a technical and financial activity requires accurate documents for agreements and implementation. The design economy is simultaneously given very tight limits, according to which the design documents must be generated. Thus it is difficult, even in theory, to think of a building plan which would be brought to the state of implementation totally without systematic logic. In that case we are no longer in the area of construction, but of sculpture and spatial art.*
j) *For the outlining of spaces, co-ordination of technique and spaces.*
k) *There are very many issues in architectural design with which the use of systematic logic helps a lot. In drafting design, the use of a systematic approach in problem management helps a lot and a building project is the documentation of a certain image; systematic logic is an important factor in the management of the documentation and in the production of documentation.*
l) *Logical thinking and work are required in systematic design, in order to gather the different partial factors into consistent and intelligent entities.*
m) *Combining the needs, objectives and resources of the client, the requirements of the building lot, and the regulations and instructions set from the outside, is mainly logical thinking. Spaces have their own relationships of cause and consequence, their inter-dependency, as well as the structure of various parts have with one another, spaces and structure with one another, form-giving with spaces and structures. Maybe the logic's share is at its biggest in the dimensioning and lay-out, and at its smallest in the form-giving, where the share of intuition is at its greatest. All phases contain something of them both.*

n) *In my opinion, it is required. Of course, it is a question of the designer's personality, how much importance this is given. Is it needed in the initial phase of sketching? Not necessarily in my mind – it might even be an inconvenience; it depends on the designer's personality, the manner of designing and also on his/her objectives – whether the designer aims at making a rational, systematic building or is his/her style more of a non-rational, amoeba-like building utilising natural forms. At all events, in the workshop drawing phase of architectural design, systematic logic must be there in one way or another, in order to be able to make images into a plan which can be implemented by a rational constructor.*
o) *Processing extensive and complex problems at once is not possible. The outlining and arranging of the task into different entities, into main and partial problems, and into demands they set for each other, etc is essential in the solving of complex problems. All this is in a way connected with the previous item about outlining the problem. For example, in the handling of large spatial programmes, the problem can be outlined to a great extent, utilising purely mathematical (or geometrical) methods. Similarly in functional design (e.g. production facilities), matters can be viewed purely theoretically. What kinds of solutions are possible in theory, and what are not, can be surveyed. There is use for all the systematic logic that can be found. Often it is precisely in the examination of what the limits of possibility are. Where you must look for a solution.*
p) *Yes, it is required. One must take care of the task in time, in quantity and in quality. It is not possible without logic.*
q) *Systematic logic can be used to ensure the functionality of functionally demanding targets, test the properties of a plan, and look for possible weaknesses by channelling spaces and needs, for example, of extensive user populations (e.g. problem-seeking method).*
s) *Absolutely! One must dare to be logical, but also understand that logic always leads to a partial truth about the entity.*
t) *Systematic logic is a part of thinking. It is a natural means of arrangement, and a tool for thinking. Designing is, however, a process that takes place the way I have described it above, a process where all the elements of the creature and of being are needed. Detaching systematic logic from it as a separate and predominating part may cause an interruption in the whole creative life process. A creative human being is inseparably simultaneously a mystic, a logician, and a worker.*
u) *Systematic logic may be a good help in architectural design, in a large target maybe even a necessary one. In practice, however, it is often so that the architecture is based on repeating parts and the building looks very systematic, but from the technical construction point of view there may be rather little repetition.*
v) *I am not a systematic, although I should be, but on the other hand, this is really something that I have emphasised as being the only correct way of working in a human manner when you assume you have the gift of logic.*
w) *Yes, it is needed.*

Are computer aided designing programmes suited for creative architectural design? How?

a) *I am not acquainted with the aid of a computer in design, in large building targets it might be able to produce basic solutions – some personal expression would need to be located in the building in places in a creative manner.*
b) *They are the better suited for it, drawings can be more easily altered with their help. Their accuracy of measurements and the exclusion of the mechanical drawing phase free the designer to study the influence of alterations to the plan. For the very beginning of initial outlining, a pencil is the better design tool, but even there I use a basic situation (location drawing, old buildings and structures) printed from the computer as a drawing foundation.*
c) *To record and to copy the results of design work.*
d) *Yes, they are. A computer is an extension of the pencil. If it does not bend as a tool, you can always take out your pencil and continue with it. On the other hand, the computer does not enhance creative design.*
e) *Various software is available for designers, architects and engineers, etc. For repair construction they are too difficult to use. All programmes seem to run only in their own spheres. I do not know personally that there is any software with which I could study spaces,*

masses, details in a simple manner, easily altering them, drafting, drawing, painting three-dimensionally and reality-based. Not everything needs to be accurate to the millimetre, nor based solely on figures and measurements but on the entity. What if there was a programme you could ask to give a golden section to a certain space, or something else or, for example, window solutions for a certain space, in order to achieve a certain lighting at different times of the day or of the year, or something similar, or if the machine would present various plane mass solution alternatives on the basis of the programme of a building. It would go systematically through these alternatives, and the designer could develop them further. In other words, you could be able to interact with the machine and not hold a monologue, and that the machine would be more than a pencil which is moved by your own brain. It is not enough that you just learn to use to machine, but you must also learn to create with them, which requires a totally new manner of thinking compared to that already learned. The complexity of the software does not make this easier.

f) *Designing software can be helpful in the recording of matters and managing the data. Computer programmes can be used for modelling and also to understand the creative process taking place in the human brain. Also the human brain must be emptied from time to time (cf. reorganising the hard disk) and reorganised so that the essential and necessary is first at hand when required.*
g) *I haven't used computer aided designing programmes in the actual designing work but only as an aid. Programmes should be more flexible and easier to use.*
h) *Design software is suitable, but drawing software not. As far as I understand, the only software that fulfils the requirements of design is the application we represent. There are also other programmes that function in the design phase, but they are not very widely used, because they are not suited for the generation of drawings. A computer is nice to generate ideas with, because it is quick and you can also try impossible ideas. You cannot have access to internal spaces, correct colours, lighting conditions and views at the real eye level with the traditional scale model. A computer is also scaleless. Simultaneously you can test ideas for the same design in very different scales. The most important advantages brought by a design programme are the speed of visualisation and calculation. Good and flexible 3D characteristics and quantity calculation provide excellent possibilities for the comparison of various ideas also in the present cost-critical environment. Through this, the programme works as an irreplaceable tool for communication, not only between the various partners, but also interacting with the designer him/herself.*
i) *Auxiliary tools have always been used in architectural design and they have a clear influence on what solutions and forms are applied more readily. The lineal and the right angle have left their permanent marks in construction, and only a decade ago it was really hard to make workshop drawings of, for example, a curved building when the centre point of a pair of compasses did not fit on your desk or in the whole room. As a tools, even with its short-comings, computer aided designing software is a clear improvement to the designer's tool box. It helps in technically difficult information management tasks, and at the same time, gives more possibilities for three-dimensional study and presentation of the target. With regard to creativity, it is possible to safely test out solutions, the testing of which would have been financially impossible with earlier methods. The ease of the use of various shapes and sets of co-ordinates has freed the architect from the strait-jacket of triangular and dashed lineals, and the designer is easily able the present the form he/she has created in dimensional data when required. CAD software has been rather rigid tools-oriented in technical drawing, and the older generation hardware has set its own limits on its application. But now the situation has changed. With the joint application of various software (3D modelling, rendering, scanning, halftone background, hybrid printing) one can quickly build three-dimensional observation pictures, move inside them, and also print out graphic pictures which can be copied, which are always needed in the presentation of the idea to be developed. Skills are the bottleneck here. Only some architects have a continuous opportunity in practice to learn, maintain and develop their skills in computer aided design. In that sense, CAD quickly divides architects into various castes by their skills which is tangible when applying for a job.*

j) *Not in any way. Why should you force a pen worth tens of thousands between the designer and the paper? Good drawing skills are a direct extension of the imagination – a immediate contact to the paper as swift as lightning. No 3D software is able to construct the first idea of space when a good draughtsman already has completed it without selecting parameters and technology. An architect must be a good draughtsman.*

k) *The computer will very rapidly replace the architect's pencil to a great extent, although the brain and the pencil are irreplaceable at the beginning of design, for the time being. With the computer, one cane rather quickly and reliably visualise different alternatives and attach other information to them, in which case, one is able to gather reliable information for the basis of selections, with rather a small amount of work. Due to the database properties, the same information can be utilised again and again better, more efficiently and with less cost than before.*

l) *Computer aided work in not needed in the creative phase. Instead of that, it is of use when testing whether the ideas and pieces of work can be realisable and sensible.*

m) *I have not personal experience with house applications. I have used the basic AutoCAD for making the final drawings. Instead of that I have been using the zoning application for 5 years. It has not cut down the use of the pencil, but replaced the felt-tipped pen. Three-dimensional modelling has facilitated spatial studies and illustration. In architectural design, creativity might be endangered by the fact that the copying of standard solutions and your own old solutions is easier than before. Here as well, I hold it an advantage that 3-dimensional designing is now easier. Even drafting by hand is made easier and becomes more true to the dimensions when you first build rough models with the machine. Masters are probably able to imagine and illustrate spatial experiences even without a computer model, but for a poor draughtsman as an architect, the machine is helpful. Photo-like pictures are, in my opinion, not important, except in marketing.*

n) *I have not used any CAD programmes myself, so the value of my answer is what it is. For one who has followed the situation from the sidelines, I have come to the conclusion that I personally would not do any drafting with existing software, it is too clumsy for that (see above). The wandering pencil which makes the first images visible can, in my opinion, not be replaced by a tool which requires the scale 1:1, in order to be able to make any kind of a draft. In later stages of design, especially with larger buildings, short timetables and skilled programme users, the advantage of CAD programmes is probably clear, as long as you have the presence of mind to put things on their proper levels. Altering the building on your drawing board is an advantage, as well as altering and repeating details, and also the ease of printing out. In short: CAD programmes may be suitable for creative architectural design, provided that the user is professional and knows how to use the programmes and devices as easily as a pencil. I, however, am shy of the CAD design process due to the fact that it is difficult to outline the entity in larger buildings; you are, for example forced to make plans for workshop drawings by seeing only a part of the building at a time, in order to see the entity you have to change the scale, in which case you are not able to see the previous, more detail workshop-level drawing at the same time. This, in my opinion, is a grave short-coming, because in the design process with the traditional pencil method you manage both the entity and the details simultaneously. I feel it is important to be able to jump in a plane from item to item, pondering either the entity or the details, at the same time thinking about the influence of the detail as a part of the entity, at the same time by seeing you are able to observe both levels. It can be that, not being experienced in CAD, I am not able to think in the right way, but thinking theoretically I cannot believe I am totally wrong*

o) *As far as I know, there is no design software. Not the kind that would design a building when it is given the lot, zoning regulations, the size of the family, hobbies, financial resources available, the client's wishes relating to the looks, the environment, quality, etc. Instead of that, EDP is well suited as a tool for creative design. The essential addition brought by EDP is the fact that it enables such ways of working as have not been possible before due to their heavy workload. Just as in mathematics, EDP enables calculation which would take a lifetime to complete with the old methods. EDP provides us with ways to analyse and outline a problem, which earlier have been either too laborious or impossible. Similarly in some cases they* *provide a possibility to test the influence of various alterations in a quick manner. We could think that EDP could even be used to test the influence of various alterations with somewhat random methods.*

p) *Not as such. A creative presentation is best transferred from the brain to paper with the help of a pencil. CAD programmes may however support creative design.*
q) *Computer aided design may support creative design to some extent, but the design itself is a visionary goal, which the architect wants to work into practice, and it is outlined completely between the ears. A computer does, however, provide more justification for the plan rather than help to create them.*
r) *They are suited, but clumsily. Creative architectural design itself, however, is independent of them. If you have had the money to buy a good programme and machines, it does not cause any harm. You can not make creative design work more effective with a machine, if it otherwise does not exist. A machine is a machine, and creativity is something else.*
s) *The are suited in the assembly stage. One must avoid CAD programmes when looking for the essential matters of a solution.*
t) *Computer aided design programmes are an auxiliary tool for thinking. They handle data based on experience. However, one must remember that there is not such thing as universal thinking which is able to solve all problems. Creative thinking can only take place on an individual level. This enables the continual experiencing of the process of life e.g. interacting movement between thinking and doing. Computer programmes are the optimised experiencing, thinking and doing of many individuals. Thus they are the products of culture. Computer programmes are suitable as tools to help the individual in their own creative activity.*
u) *In my opinion, drafting should still be done by hand. It would be ideal to utilise the efficiency of a computer daily, but you also need the living line in the search for solutions. It is important that architects also maintain their traditional professional skills, it is a kind of handicraft profession. Beauty and aesthetics are central values in architecture, but also the beauty of drawings has a meaning of its own. Here the computer is not able to compete with handicraft. When drawing with a pencil on drafting paper, it is possible to quickly create different impressions of distance, depth, surface structure and materials by turning, pressing, rotating the pencil. This is not about drawing a beautiful drawing fit for printing, but just drafting. The photo-like computer images made for the presentation of the new additional buildings of the Vantaa Airport are gorgeous, but they are for marketing, not for design. The possibility provided by the computer to generate quick perspective drawings is very interesting.*
v) *On the basis of the previous answers, on might think that I hate computers and their use in the creative process. I used to think so for a long time and it took me long before I stepped over the threshold, but after that, there was no return. I am a freak - dedicated to computers. I started by using AutoCAD and thought that it was the answer to making continual alterations. Then I started to use 3D modelling in AutoCAD. It was time-consuming, but enabled me to study models from various points of view, when the model had been completed. Next, I started to use ArchiCAD, and now I do not see any other possibility to work. The AutoCAD is lines and a silly gigantic programme for everyone, but ArchiCAD is a tool for architects. I always work in the 3D state and I work a lot with 3D models, and do it all the way from the beginning. I haven't used AutoCAD for two years, and it felt like a nightmare when I had to process an old design again. I am a devoted computer user, but I do not utilise those properties where my own logical thinking is more efficient. For me it is a tool of irreplaceable value. At time, however, I have to be able to draw by hand. You must not use the computer at too early a stage, because it is too easy to use it to finalise the design too early.*
w) *They are not suited, they are tools for final drawing.*

APPENDIX 8

Data of the respondents in the survey of creative architectural design

a) architect and licentiate in technology, over 50 years experience with traditional designing methods.
b) architect, 13 years experience as a designer.
c) architect and licentiate in technology, almost 40 years experience.
d) architect, 20 years experience as a designer mainly in renovation projects.
e) architect and interior designer, graduated 15 years ago.
f) architect, graduated bit over 10 years ago.
g) architect, 13 years experience as a designer, doesn't use CAD.
h) architect, computer expert and has a lot of CAD experience.
i) architect, over 50 years experience with traditional designing methods, later applied also CAD.
j) architect, graduated 10 years ago.
k) architect, almost 30 years experience as a designer.
l) architect, almost 40 years experience as a designer.
m) architect, graduated about 20 years ago, has applied CAD in final drawing.
n) architect, graduated bit over 10 years ago, doesn't have experience about CAD.
o) architect, graduated 20 years ago
p) master in science (engineering), a bit over 13 years experience as a designer.
q) architect, graduated 10 years ago.
r) architect, graduated 10 years ago.
s) architect, over 30 years experience as a designer.
t) architect, graduated over 30 years ago.
u) architect, 10 years experience as a designer.
v) architect, graduated 10 years ago, applied also CAD.
w) unidentified respondent.

Data of the survey of the QFD –method in architectural design.

What kind of an image did the QFD method presented above give you?

a) *A mumbo-jumbo image. Of course, you must always emphasise and proportion matters, but there is, and there is not, right.*
b) *A confused and rigid one.*
c) *It is certainly good in the designing of a product of a narrower range, but not in architectural design, or even in the design of a flat, where the lifetime of the product should be half a century or more. The ideal family will have time to be born and to die, to be dissolved and merged.*
d) *The system is heavy, but suitable for big industrial development projects. But innovations can not be created by force, it is true.*
e) *It sounds systematic and very theoretical for actual building and when projected to the situation of a buyer and seller of a flat.*
f) *The method itself is, based on the description, one of many similar method which I have encountered in the course of years. In general, one can say of the method that, on a rough level, designing proceeds exactly as in the described method.*
g) *A complex and mathematical image, too much meticulous data.*
h) *The great influence of the client is emphasised, that will result in problems. Generally, in the targets I have designed there has been no possibility for copying, because each building is different, therefore you must assume that the needs vary, too.*
i) *A lot of detailed information. The method will certainly require a lot of time, in order to be able to start with the application phase.*
j) *A complex one that shackles design.*
k) *A systematic, but questionable one.*
l) *A tool suited for the construction product industry.*
m) *A systematic method. A good end result requires a sample that is big enough, but also regionality has an influence, e.g. a city area, interior of the country, coastal areas, Lapland. In addition to that, it is also important to consider the most important needs given by different consultants.*
n) *It is difficult to realise the preferences and emphasis of various decision-makers.*
o) *It sounds quite logical, but it really does not give a lot of freedom.*

In your opinion, can the QFD by applied in architectural design?

a) *Why not – of course.*
b) *Yes it can, if additional financing for the programming of design work is directed to architects.*
c) *I do think that construction and architecture are that stream-lined. In the beginning of the 3D stage of a structural part, QFD is OK.*
d) *Usually no.*
e) *I think it will be suitable for a situation where the client is known, e.g. for the client of a single-family house.*
f) *Only as a background process "you can not draw with a book-shelf". Each architectural design project is a learning project for the client and most often leads to the fact that after the building is completed, the so-called client's needs have developed into something other than that what they were at the beginning of the process.*
g) *Not really, when it comes to individual projects, but maybe to a part of the project. Especially in political processes they are not, because there are a lot of decision-makers and it is difficult to define the needs. Application should be looked for mainly in the construction materials industry, ready-made houses, block-house construction, where the average customer is sought.*
h) *It is suited, for example, for projects relating to terraced houses and blocks of flats, where the client is a big team, such as Polar, but not the projects based on political decisions. The method is OK also for the construction materials industry, e.g. doors, windows.*
i) *It is difficult to imagine a systematic method in architectural design.*
j) *Yes, it can, when it is about the designing of a small detail.*
k) *It is quite possible that it is suited. The targets, however, should be rather simple and repeated.*

l) *Yes, provided that the targets are concise and unimaginative, and why wouldn't the method also be suited for small parts of big projects.*
m) *The method might work well as a teaching tool for architects who as yet do not have a lot of mileage. And why not for the construction materials industry for the manufacture of "shelf goods".*
n) *For the designing of simple and small parts, such as kitchen cupboards, the washing room, stairs, entrances and porches. In general, for such targets, where the client buyer can influence with their opinions.*
o) *I constantly design with computer aid, so why could I not bring a programme that would influence the importance of needs and requirements? In the future, a similar method might even be a special demand of a client.*

Creative designing process and QFD?

a) *There isn't always client, but there always is someone who ordered it. The process and correlation can not be built in many layers (constructor, financier, user, ...).*
b) *The creative designing process can always be started again also from the beginning.*
c) *In my opinion, a mathematical and systematic method can not at any rate work in place of a creative design process.*
d) *The QFD is a pigeon-holing and partially lineal process, it does not really follow the illogical logic of a creative process.*
e) *In my opinion, the method is built in the head of every designer, Although there might not be a calculation of comparison points, but the QFD sounds mainly like a description of the normal design process.*
f) *Understanding the target requires the architect to have the ability to study the target from different points of view. The QFD might be one of them. Points of view = brain-storming, inspector, researcher.*
g) *It does not make any sense to bring tools to creative designing. They do not fit together.*
h) *It won't work, because the needs vary so much.*
i) *It is not applicable. It is rather difficult to imagine a creative and systematic design method in conjunction.*
j) *It is in no way possible, nor sensible.*
k) *Maybe as tool, if the designs do not sell.*
l) *Creativity and systematicism should not be used to mix the other one up.*
m) *No.*
n) *I do not think it can be applied.*
o) *Doesn't this kind of a system just remove the creative from designing.*

Would the method be suited for a young inexperienced architect, for example, as a tool for learning? Or for a more experienced designer?

a) *The method should tested especially for a young designer, before it is possible to say something about its suitability, but I doubt whether it will be suited for a young designer at least.*
b) *The matter must be tested especially for a young designer, before that one can not take a stand based on assumptions.*
c) *Not for a young one in any case. There are enough element suburbs already.*
d) *No. One must be able to outline both the entity and its part as a dynamic multi-dimensional field of interaction.*
e) *Maybe it would have some kind of pedagogical value. I myself try to interview the users when the building is completed ... and become wiser from what I've heard when I design the next target.*
f) *Yes, if the user seeks to understand the QFD as a certain point of view for studying. In that case the completed building is an entity formed of many parts.*
g) *Maybe it would be easier to apply for an experienced one, because you also need to manage information technology in its use.*
h) *Yes, it can be applied, as long as you are able to separate it from actual designing.*

- *i)* *In the future, the young designer will certainly meet similar systems, which are offered by the constructor and clients. You must just be able to separate it, in other words, use your layman's wits in situations where it is needed.*
- *j)* *In case a young designer is interested in the method, he is in the wrong industry, because when they come to school, students are already urged to put creativity into their designs. QFD restricts creative thinking.*
- *k)* *It can be so that it will guide the architect on the wrong path.*
- *l)* *It is quite possible, that it could be suited.*
- *m)* *As I already mentioned, it would be excellently suited for a young one, for example, as library material to help in teaching situations, to support Archicad or Acad, especially for road machine designers.*
- *n)* *Maybe easier for a younger than an older one. Computer technology progresses very rapidly and the demands increase.*
- *o)* *A good point. The future young designer certainly could use a logical method like this.*

What kind of question came to your mind, please, tell at least about problem stages you observed?

- *b)* *There is a danger present: what kind of mumbo-jumbo is again being brought up to make design even more difficult.*
- *d)* *Design theory should rather be built on information technology (brain processes), cybernetics, and on the understanding of aesthetic experiencing.*
- *e)* *A flat can be only designed to meet the client's needs when we know the client and his needs. Most often this is not the case in the design phase. The client may enter the picture only after the house has been built (terraced houses and blocks of flats).*
- *f)* *What is the average satisfaction relating to the houses?*
- *g)* *The needs of future clients will certainly become more demanding, so why not aim at having the clients bring their own model of values and needs in addition to the space programme. Give demanding customers the possibility to influence matters.*
- *h)* *Constant up-dating of new information is necessary, because needs do change.*
- *j)* *How to make time for a method like this when the timetables are tight already?*
- *k)* *How is it possible to compare the products of competitors in architectural design. It might be difficult.*
- *l)* *The method does not consider the fact that often there are quite many different parties influencing a construction project (constructor, client, financier, tenants, and the authorities). Needs will become complex, difficult to manage. Who will respond to market research?*
- *m)* *The sample must be large and regional*
- *n)* *There surely are problems in architectural design where there are many decision-making, influencing parties.*

APPENDIX 10

Data of the respondents in the survey of the QFD –method in architectural design

a) architect, detached houses and churches, 25 years experience as a designer.
b) architect, all subject matters, 18 years experience as a designer.
c) architect, all subject matters, 25 years experience as a designer.
d) architect, detached houses and public construction, 22 years experience as a designer.
e) architect, all subject matters, 20 years experience as a designer.
f) architect, product development, 25 years experience as a designer.
g) architect, all subject matters, 12 years experience as a designer.
h) architect, all subject matters, 14 years experience as a designer.
i) architect, detached houses and terraced houses, 15 years experience as a designer.
j) architect, all subject matters, 21 years experience as a designer.
k) master in science (engineering), all subject matters, 14 years experience as a designer.
l) architect, public construction, 20 years experience as a designer.
m) architect/construction engineer, churches, renovation and public construction, 33 years experience as a designer.
n) architect, detached houses, terraced houses flats, 12 years experience as a designer.
o) construction engineer, detached houses, terraced houses and public construction, 5 years experience as a designer.

Data of the survey of the QFD –method in mechanical engineering design.

What kind of an image did the QFD method presented above give you?

a) *I feel that the above description means designing concentrated on product development where rendering the idea into a product, etc. are concentrated on. For us, designing is mainly implementation/cost calculation of investments, in which case making ideas into products is more difficult.*
b) *It did not quite unfold to me within the time allotted, but is does seem applicable.*
c) *In principle one should always operate this way, so that the needs of the client are taken into consideration. Practical realities:*
- *"thorough-going" QFD designing is in the client's opinion expensive,*
- *hard competition of prices,*
- *the design budget is hard due to the above-mentioned reasons, and the timetable is tight, and*
- *especially the acquisition of adequate preliminary studies is seen as being expensive, even painful.*

d) *Surely a good way to clarify the characteristics required of the products. Or that the method could be at least be used as an indicator. The factors, however, are drawn from thin air -> accuracy is as can be expected (as it surely is with other auxiliary methods, as well).*
e) *Slightly confusing. The method description should be more precise.*
f) *The method seems heavy. Is the definition of factors an art form on its own?*
g) *Too much mathematics and too complicated, at least for the designing of steel structures. QFD seems rigid and time-consuming.*
h) *Confused and time-consuming.*
i) *Faint recollections from school. Reminds me of other methods which are being used. Seems applicable.*
j) *Systematic and restrictive for designing.*
k) *Help to design systematically.*
l) *The description is very shallow, properties are described on a general level, could be applied to almost any designing method. I missed more concrete and more exact information. In addition to that, it seems too slow and heavy a method.*
m) *Too theoretical.*

In your opinion, can the QFD be applied in mechanical engineering design?

a) *In the case when the design target can be made into a product (if, for example, the sub-contracting relationship is such).*
b) *Yes.*
c) *Yes, the best application will probably be in sustained R&D.*
d) *It will certainly create a good checklist where the direction of design can be checked.*
e) *Yes.*
f) *Certainly, at least in a limited way for some certain properties of the product.*
g) *For traditional machine engineering design, yes. Why not to other purposes, too.*
h) *Maybe not in its entirety.*
i) *Yes, in case, among others, the client can be assured of the advantages brought by the system, in other words, that the advantages gained are worth the time lost.*
j) *Yes, it can, depending on the product.*
k) *Yes, it can.*
l) *The image I got is one that is on a much too general level. I cannot take a position.*

Creative design process and QFD?

a) *Creates an operation diagram for an otherwise rambling activity.*
b) *It seems to be suited as a tool for a creative process. At least it is suitable for development.*
c) *It is applicable.*
d) *OK, when you have to choose between different alternatives keeping an eye on various demands.*

e) *It depends on the company atmosphere, the designer, the management, etc.*
f) *QFD will probably entirely remove creativity from the design process.*
g) *They do not fit together. All kinds of methods kill creativity.*
h) *Adapting both you can achieve a good end result. However, one must be aware of too much formalism.*
i) *It depends on the designer's spiritual life. In principle, they fit together.*
j) *At least, the QFD can not totally replace the creative process. Adapted in a suitable manner it will work.*
k) *The QFD will not kill creativity.*
l) *Creativity is used and ideas generated exactly as far as the client is willing to pay for them. The end result must be a well-functioning product, and the responsibility for that lies with the designer. Everything has its price. A successful end result is the most important.*

Would the method be suited for a young inexperienced architect, for example, as a tool for learning? Or for a more experienced designer?

a) *It would certainly help both.*
b) *For a young one, yes. For an old hand it is usually difficult to get new ideas adopted.*
c) *It is suited for everyone, the problem is that earlier, "easy" solutions are too easily accepted.*
d) *Of course, it is suited. On the other hand, in normal, everyday tasks I think the best instruction is: the simpler, the better. The security of operation must also be taken into consideration.*
e) *A young one could try it, the old ones change their working habits unwillingly.*
f) *For both, to a certain extent. Experienced designers often oppose new methods.*
g) *Possibly better for a young one. Why not also for an experienced one depending on the person and his attitude.*
h) *Maybe more for an experienced one. The experienced ones know how to take only the most applicable parts of the method into use.*
i) *Yes, it is suited for both.*
j) *For a young one, yes, and probably experience will not cause any problems.*
k) *It is suited for initial work. It will open your eyes to new points of view.*
l) *I cannot take a position.*

What kind of question came to your mind, please, tell at least about problem stages you observed?

a) *Further, making products of our designing activities is still difficult, adaptation would also be difficult for this reason.*
b) *Reliability of the end results? A person or a team that is doing this work, gives his/her/their own opinion. The final conmensurability of the doings of various persons. When you make several matrices from the same theme, you get an average, but how do you judge one?*
c) *QFD is best suited for sustained R&D? Expensive in small projects?*
d) *You are seldom free to start with a tabula rasa. Usually, the existing constructs bind you. The QFD is certainly applicable, when you want to know which property of the product must be developed.*
e) *Maybe too time-consuming and laborious, for some jobs totally applicable.*
g) *Where to get the time to apply the method?*
h) *Weighting factors, time of the matrix?*
k) *How does the training of designers for the method take place?*
l) *You must be able to demonstrate the advantages of your method better. Are there any references for projects carried out?*

Data of the respondents in the survey of the QFD –method in mechanical engineering design

a) engineer, head of department, steel structures, 17 years experience as a designer.
b) chief designer, 28 years experience as a designer.
c) master in science (engineering), mechanical engineering design, 21 years experience as a designer.
d) master in science (engineering), mechanical engineering design, 9 years experience as a designer.
e) engineer, conveyer systems, 15 years experience as a designer.
f) engineer, mechanical engineering design, 14 years experience as a designer.
g) engineer, steel structures, 19 years experience as a designer.
h) engineer, 22 years experience as a designer.
i) master in science (engineering), mechanical engineering design, 6 years experience as a designer.
j) master in science (engineering), mechanical engineering design, 10 years experience as a designer.
k) engineer, head of development, industrial design, 19 years experience as a designer.
l) engineer, entrepreneur, mechanical engineering design, 20 years experience as a designer.
m) master in science (engineering), managing director, chemistry processes.