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Knowledge Visualization

The Use of Complementary Visual Representations for the Transfer of Knowledge.
A Model, a Framework, and Four New Approaches.

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ABSTRACT

This thesis introduces the new research focus **Knowledge Visualization.** To do so, it provides two theoretical and four practical contributions on how **complementary visual representations** can be used to improve the transfer of knowledge in organizations.

The transfer of knowledge is a core process in knowledge management with several challenges: The time in which to communicate knowledge is more scarce, the contents becomes more complex, and the audience is more diverse. Today mainly text and numbers rather than visual formats are used in the transfer of knowledge in organizations. Architects, in contrast, practice the opposite: They transfer knowledge mainly by using complementary visualizations, which means they use different visualization types that complement one another. Further, architects are experts in interfunctional communication, which is the transfer of knowledge among individuals from different backgrounds, such as engineers, workers, authorities, or customers.

This thesis adapts the method of architects to use complementary visualizations in the domain of business knowledge management. Secondly, it discusses the strength and weaknesses of complementary visualizations for the transfer of knowledge in organizations with the aim to improve the quality and effectiveness of the knowledge transfer.

The contributions of this thesis are, first, a **framework** that structures the most important aspects in regard to the visual transfer of knowledge. Second, four practical contributions for key problems in organizations were invented, implemented, and evaluated. Each case study on its own is a specific contribution to the four scientific domains to which I refer. The case studies introduce (1) a new **paradigm** for the exploration of digital libraries, (2) an **evaluation** of a Knowledge Visualization application in a real business context, (3) a **new approach** to improve the knowledge transfer effectiveness between architects and decision makers, and (4) an **application** of the theoretical framework in one scenario. The case studies together allowed empirical data to be collected and specific knowledge transfer situations from the framework to be tested. Third, I collected and structured both arguments that support and reject the theoretical hypothesis. Together with my own empirical data, this dialectic argumentation allowed a synthesis to be deriven: a first **Knowledge Visualization Model** for the use of complementary visualizations in knowledge transfer tasks.

In concluding, the new research focus Knowledge Visualization, the new framework, and the model have major implications for researchers in the realm of knowledge management, information visualization, communication sciences, and architecture.

ZUSAMMENFASSUNG

Diese Arbeit führt einen neuen Forschungsschwerpunkt ein: **Knowledge Visualization.** Dazu führt es zwei theoretische und vier praktische Beiträge ein. Diese zeigen, wie **sich ergänzende Visualisierungen** genutzt werden können, um den Wissenstransfer in Organisationen zu verbessern.

Wissenstransfer ist ein Schlüsselprozess im Wissensmanagement mit verschiedenen Herausforderungen: Die Zeit wird knapper, die Inhalte komplexer und die Empfänger unterschiedlicher. Ein Blick in Organisationen zeigt: Heute werden vor allem Text und Zahlen für den Wissenstransfer verwendet - selten Visualisierungen. Bei Architekten ist es genau umgekehrt: Hier dominieren Visualisierungen im Austausch von Wissen zwischen Personen mit unterschiedlichen Hintergründen, wie Ingenieuren, Beamten, Bauarbeitern und Kunden. Kurz: Sie sind Experten für Interfunktionale Kommunikation.

In dieser Arbeit adaptierte ich die Methode von Architekten sich ergänzende Visualisierungen zu verwenden im Wissensmanagement. Weiter reflektiere ich Stärken und Schwächen von sich ergänzenden Visualisierungen für den Wissensaustausch in Organisationen mit dem übergeordneten Ziel dadurch die Qualität und Effektivität des Wissenstransfers zu steigern.

Die Beiträge dieser Arbeit sind ein theoretisches **Framework**, das die Schlüsselperspektiven und entscheidenden Komponenten im visuellen Transfer von Wissen strukturiert. Zweitens vier praktische Anwendungen für aktuelle Probleme in Organisationen, die ich je entwickelt, implementiert, angewandt und ausgewertet habe. Jede Fallstudie führte je zu einem veröffentlichten wissenschaftlichen Beitrag in den vier Hauptgebieten auf die ich mich wissenschaftlich beziehe. Die Fallstudien behandeln: (1) Ein **neues Paradigma** für das visuelle Suchen in Digitalen Bibliotheken, (2) eine Evaluation einer Knowledge Visualiaztion Anwendung in einem realen Kontext, (3) einen **neuen Ansatz** wie der Wissenstransfer zwischen Architekten und Entscheidungsträgern verbessert werden kann, (4) und eine **Anwendung** des theoretischen Frameworks in einem realen Projekt. Zusammen bilden die Fallstudien die Grundlage für eigene empirische Daten und als proof of concept der entwickelten theoretischen Überlegungen. Drittens stelle ich Argumente und Gegenargumente gegenüber, um so die Hypothese erst zu bestätigen und dann zu widerlegen. Dies mit dem Ziel aus einer sachlichen Distanz eine Synthese abzuleiten. Diese ist die Grundlage für ein erstes **Knowledge Visualization Model.**

Der neue Forschungsschwerpunkt Knowledge Visualization, das Framework, die vier Anwendungen und das Model sind relevant für Forscher in den Gebieten Wissensmanagement, Information Visualization, Kommunikationswissenschaften und Architektur.

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In three years I would like to thank the person who enabled that Knowledge Visualization became an integral course in the curriculum of architects, engineers, and business administrations.

In 2010 I would like to thank everybody who enabled to realize Science City ETH. With one of its attractors: The Knowledge Visualization Lab.

Remo Aslak Burkhard Science City ETH, May 2005

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"If fish were to become scientists, the last thing they might discover would be water"[1] (Samuels, 1970)

[1] Samuel addressed in his first serious review of instructional visual research the failure of researchers to study one of the most widely adopted instructional aids: pictures. A similar situation was the starting point for my thesis where I figured out that in knowledge management the potential of visual representations was not explored in the literature.

1. INTRODUCTION

Why should we be interested in *visualization*? Because our innate visual system is a high bandwidth channel into the human cognitive center. Or in simple words "A picture is worth thousand words". Why should we be interested in *Knowledge Visualization*? Because Knowledge Visualization stresses one key process which is important in a knowledge oriented culture: The transfer of knowledge. In contrast to information, which is explicit, knowledge has to be re-constructed by each individual. This process happens through communication and interaction with explicit information - verbal or visual. To improve the effectiveness of the knowledge transfer process, Knowledge Visualization concentrates on (1) the *recipients* (i.e., customizing the visual formats to the needs and backgrounds of the different stakeholders), (2) on different *knowledge types* (i.e., distinguishing different types of knowledge, such as "know-why" or "know-how"), (3) and on the *process* of communicating this knowledge by (4) use of *complementary visualizations* (i.e., combing different visualization methods that complement each other).

This thesis presents the foundation for the research field *Knowledge Visualization.* To do so, it introduces a first theoretical framework and a first theoretical model. These contributions bridge the gap between isolated research fields in knowledge management and visualization research. These theoretical concepts are important, because they are currently a missing common base for researchers that are interested to improve the transfer of knowledge by using visual formats. These theoretical contributions are important (1) to structure and mediate visualization research, (2) to establish the role of visualizations in the context of knowledge management, and (3) to prevent reinventing the wheel and to take advantage of synergies.

The transfer of knowledge is a core process in knowledge management (Alavi and Leidner, 2001) and is difficult to manage (Probst, et al., 1997). It faces different challenges: The time to communicate knowledge decreases, content becomes more complex, and the recipients more diverse. If we look into organizations today, mainly verbal representations and quantitative business diagrams are used for the transfer of knowledge. This is in contrast to architects who, for the transfer of knowledge, use mainly visual representations.

This thesis analyzes how architects use visual representations to transfer knowledge and then adapts their method to the domain of business knowledge management, not replacing but complementing today's best practices. Architects in general are experts in the transfer of knowledge between individuals from different fields such as engineers, workers, lawyers, or clients. In my analysis of how architects use visual representations for the transfer of knowledge, I found a simple but important insight: Architects use *complementary visualizations,* which means that they combine different visualization types that complement one another. This allows them to illustrate different levels of detail (e.g., an urban scale, the scale of a window detail), different atmospheres, or to illustrate relationships among concepts.

This thesis proves that the use of complementary visualizations is a promising approach in organization to improve the transfer of knowledge and to increase the quality and effectiveness of knowledge communication: Namely to get the *attention* of recipients, to illustrate *relations,* to improve the *motivation,* to activate workers which leads to an *elaboration,* and to create *new insights.* The use of complementary visualizations (1) speeds up the knowledge transfer process, (2) reduces the information overload, and (3) improves decision making.

To prove and counter the theoretical hypothesis that the use of complementary visualizations helps to transfer knowledge, I analyzed the state of the art in the relevant literature. This is described in Chapter Two. This allowed me to refine the hypothesis which is described in Chapter Three. The analysis of the literature in the related fields allowed me to isolate the features that are most important for the transfer of knowledge. This framework was refined in several steps to finally present the *Knowledge Visualization Framework* that is described in the Chapter Four. The integrative approach of the framework structures and mediates between different research areas, i.e., information visualization (Bertin, 1967, Card, et al., 1999, Chen, 1999a, Spence, 2000, Ware, 2000), cognitive art (Horn, 1998), communication science (Fiske, 1982), information architecture (Wurman, 1996), and knowledge management (Alavi and Leidner, 2001). The framework further helps practitioners (e.g., teachers, managers) to think about the relevant questions and to identify the most promising visualization method for the specific needs. To prove the theoretical hypothesis and test the framework four specific situations of the framework were tested. To do so, four key problems in knowledge management were addressed and four new solutions were invented, implemented, evaluated, and discussed through scientific publications. Chapter Five presents these four case studies. Each one is an independent research contribution, therefore they can also be studied seperately. Taken together, the four case studies test four extreme positions in the framework. I evaluated these case studies because I did not find studies or evaluations of applications in the literature for the questions I tried to answer. The four contributions, which are discussed in chapter five are: (1) A new visual document search paradigm, (2) a new metaphor for interfunctional communication, (3) a new approach to improve the transfer of knowledge between architects and decision makers, and (4) an application of the whole Knowledge Visualization Framework in one scenario. The evaluations of the case studies allowed me to derive relevant empirical data to test the proposed Knowledge Visualization Framework. Chapter Six and Seven provide a dialectic argumentation. Chapter Six structures and discusses arguments that support the hypothesis; Chapter Seven's arguments reject the hypotheses. In both cases the arguments are supported with sub-arguments that are grounded in findings from the literature and my own empirical data from the evaluation of the four case studies. The synthesis of this dialectic argumentation are described in Chapter Eight. This chapter presents a first *Knowledge Visualization Model* for the use of complementary visualizations in knowledge transfer tasks. Finally, Chapter Nine concludes with a discussion of the main research contributions, the implications of this research, and the future trends in Knowledge Visualization.

In conclusion, the contributions of this thesis are original and have implications for the research areas knowledge management, information visualization, and visual communication sciences. The findings indicate that Knowledge Visualization solves predominant and omnipresent problems in today's organizations concerning the transfer of knowledge, and set up an agenda for future research.

1.1 Problems and Needs

This thesis is *solution-oriented* and *visionary*; both in theory and practice. Solution-oriented, because it presents solutions to existing problems rather than proposing novel approaches that are not grounded in real world situations and do not provide evaluations on its strengths and limitations in comparison to previous approaches. Visionary, because it proposes the clear name and the new research field *Knowledge Visualization*, which is integrated into the context of business knowledge management. This clear name and research direction accelerates the discussion on the potential of visualizations in organizations, because it is directly attached to the predominant problems. In that way it helps future managers to understand how to use and how to create visual representations in the different business processes, which will be a core competency in the next decade.

This section discusses the problems and needs in theory and practice to which I refer and propose solutions in this thesis.

1.1.1 Problems and Needs in Theory

Problems and Needs in the Research Area Knowledge Management
The transfer of knowledge is a core process in knowledge management. It can be improved by using visual representations. However, the use of visual representations for the transfer of knowledge is currently not investigated

systematically in the domain of business knowledge management which results in different problems and needs:

The need for a distinct research focus in knowledge management. To get the attention and to accelerate the discussion on our innate abilities to process visualizations for knowledge related process, a clear name, and a new research focus is necessary. When I started this dissertation in 2002, I introduced this missing name and called it Knowledge Visualization.

The need to apply novel visualization methods to real world problems. Today, only a small subset of the existing visual formats are used for the visual transfer of knowledge in organizations. Examples include business diagrams and clip art. Other formats are discussed by researchers, but they are not yet used. One reason for this is that these applications have not been attached to real world problems in organizations and often they have not been evaluated and compared to traditional methods that are used in organizations. The challenge is not only to develop new visualization methods, but to first apply the existing methods to real problems and evaluate the strengths and weaknesses. This thesis discusses and evaluates four applications to solve real world problems.

The need for a mediating framework as a basis for future research. Several studies and isolated contributions have already proven the potential of visualizations in knowledge management tasks. Currently, however, there is no established classification, framework, or model on the use of visualizations in knowledge management, to which one can refer. A mediating framework is necessary in order to integrate findings from other domains such as visual communication sciences, information design, and information visualization research. This should prevent us from reinventing the wheel. This thesis introduces the missing framework.

The need for a Knowledge Visualization Model. The framework structures the field and illustrates the features that are most important in Knowledge Visualization, but does not provide the interrelationships between these features. However, a model that isolates and relates the salient features that contribute most to its behavior is needed. This Knowledge Visualization Model complements the Knowledge Visualization Framework. This thesis introduces the yet missing model.

In conclusion, the main need in the research area knowledge management is to create a theoretical basis for the new research field Knowledge Visualization.

Problems and Needs in the Research Area Information Visualization

In the research area information visualization new information exploration methods are used to explore data with the aim to derive new insights. Different problems and needs can be identified:

The need for the transfer of insights. While information visualization researchers succeeded to create novel methods in creating new insights, they did not focus enough on how to transfer these insights to different recipients. Information visualization can leverage its potential if it also provides solutions on how the transfer of knowledge can be achieved. This thesis introduces a framework with four important perspectives that can directly be used by information visualization researchers.

The need for further visualization type. Information visualization concentrates on computer supported visualization methods, but it limits itself by only considering computer-supported tools. Although the field is now established, it should become more interdisciplinary and learn from the experience of other fields that have the same aim. One field that has not yet been investigated by information visualization researchers is the visualization methods of architects. This research introduces the visualization methods of architects and introduces the concept of complementary visualizations.

The need for a mediating framework in visualization sciences. Information visualization research needs a framework to mediate between other visualization researchers. Today, graphic designers, architects, and other visualization experts hardly know about the results and existence of information visualization. This thesis introduces such a generic framework.

The need to evaluate information visualization applications in real world situations. In the last twenty years various information visualization methods were invented. Linking these methods to the needs in organizations, however, has been neglected. As a result, the benefits of the new approachs are often not evaluated and clear and non-specialists in organizations have difficulties understanding the potential of these tools and adapting these new methods. What is missing are case studies and evaluations of the information visualization tools in predominant problems in organizations. This thesis presents the adaptation of the tree map technology to solve the exploration of digital libraries.

In conclusion, the main needs in the research area information visualization are (1) to provide insight on the transfer of knowledge, (2) to integrate findings from other visualization domains, and (3) to perform evaluations.

Problems and Needs in the Research Area Visual Communication Sciences
In the research area visual communication sciences, different problems and needs can be identified:

The need for a framework and a model. From a communication science perspective the theoretical models are too general with regard to the use of visualizations, therefore they are seldom used by visualization experts. From a visualization research perspective, the findings and advice are too specific. The big picture is missing. Therefore what is important is something in between: A framework that mediates between the domains, a model that is grounded in the findings from the literature, and a model that structures and relates the features that are most important for the visual transfer of knowledge.

The need to care for the recipient. Visualization research did not concentrate enough on the role of the recipient. The creation of visualizations that are tailor-made to the needs and backgrounds of the different recipients or stakeholders in an organization is an important need. This thesis stresses the importance of the recipients in all contributions.

In conclusion, the main need in visual communication sciences is a mediating model that integrates the perspective of the recipient.

1.1.2 Problems and Needs in Practice

In the previous chapter I discussed problems and needs in the realm of theory and research. This section discusses omnipresent and predominant problems in organizations. I discuss these problems because I aim to create both theoretical and practical contributions. Both aim to overcome these problems. The challenges in organizations I refer to are: knowledge transfer, interfunctional communication, and information overload.

Knowledge Transfer

Today, contents are more complex, abstract, and interrelated. In organizations there is a need to complement verbal representations with visual representations. This is also true for digital information systems where the existing technologies need to be exploited more efficiently. Organizations need theoretical models to be put into practice to face their challenges: The war for attention, the limited time and mental capacity of the audience, and the need to provide the relevant information in different levels of detail.

Today, in organizations only a limited set of tools are used (e.g., PowerPoint, Excel, business diagrams, clipart), and a lack of visual competency results often in poor use or misuse of such visual formats, which can lead to misinformation or misinterpretation. In organizations a lack of knowledge about the various different functions of visual representations and the different novel methods leads to the fact that visualizations are only used rarely. Examples for such novel methods are the interactive visual exploration of data, the mapping of information to present both an overview and details, the use of visual metaphors to transfer and remember complex concepts, or visual storytelling to disseminate knowledge.

This thesis applies the framework and model in four applications that are discussed in the four case studies.

Interfunctional Communication
Today, the transfer of knowledge needs to solve another difficult problem. The needs and background of each recipient is different. We can only understand something if it can be connected to something we already know. Therefore the context of the recipient is decisive. This results in a challenge for the visual knowledge transfer: On the one hand, the visual formats need to be target group specific; on the other hand, the contents that are presented to the different stakeholders should not be contradictory.

This thesis introduces the strategy of architects to use complementary visualizations for interfunctional communication.

Information Overload
Today, we are surrounded by information and have a limited capacity and time for absorbing new information. This so-called information overload is a predominant problem in organizations. It can lead to information paralysis. On the one hand, we can perceive an increasing quantity of information; on the other hand, we can indicate a decreasing quality of the information provided. As a consequence, it is hard for recipients to identify the relevant information. The needs with regard to information overload are to get attention, to offer strategies to better filter and explore potentially relevant information and to improve the information quality. To do so, it is important to prevent misunderstanding, misinterpretation and misuse of information. This thesis presents several examples and strategies against information overload, e.g., it introduces a new approach for the visual exploration of digital libraries.

In concluding, the problems and needs, both in theory and practice, defined the overall research goals for this thesis.

1.2 Research Goals

The overall research goal is to adapt the methods of architects to use *complementary visualizations* to transfer knowledge to the domain of business knowledge management.

To do so, I collected and structured findings, methods, and theories to a first Knowledge Visualization Framework. I tested this framework with my own empirical data from four case studies and findings from literature and derived a general theoretical model for the use of complementary visualizations for the transfer of knowledge.

The main steps to reach this goal were:

- To analyze how architects use complementary visualizations for the transfer of knowledge and to devise a new and simple visualization taxonomy.
- To test whether the methods of architects to use complementary visualizations for the transfer of knowledge can be adapted to organizations.
- To prove and measure that the use of complementary visualizations allows predominant problems in organizations (knowledge transfer, interfunctional communication, information overload) to be solved.
- To introduce the new field Knowledge Visualization by defining it and distinguishing it from information visualization.
- To integrate Knowledge Visualization in the research areas knowledge management, information visualization, and visual communication sciences.
- To create a Knowledge Visualization Framework that helps to systemize Knowledge Visualization research and that mediates between isolated visualization research directions.
- To envision, implement, test, and evaluate four *new approaches* for the described key problems and needs in organizations.
- To generalize the different examples and derive a *model* for the use of complementary visualizations to improve the transfer of knowledge.

All these steps were investigated in iterative steps and refined various times. This process was only possible through my motivation for visualizations and most importantly, through collaboration and discussion with various friends and experts.

1.3 Motivation

My aim was to adapt the methods of architects to use complementary visualizations in the domain of business knowledge management. The motivation for this is to offer architects that do not want to work in architecture a new field for practice. I call this field Knowledge Visualization. I believe that the skills of architects are important in today's organizations because:

Architects are visionar. Architects are trained to create unique and customized solutions in each project. That is why they develop a competition and passion to be exclusive and visionary. In doing so they developed methods for innovation. These methods to innovate can be adapted to organizations.

Architects think in different levels of abstraction. Architects have an ability to think in different levels of abstraction, i.e., they can simultaneously design a building and control a detail of the window. This competence to simultaneously think in different conceptual levels is crucial in today's organizations. In organizations, only few people are trained to simultaneously think in different levels of abstraction and even fewer are trained to visualize these different levels of details. However, this is the daily practice of architects.

Architects are experts in interfunctional communication. Architects are generalists and can mediate between experts from different fields. This ability is important for today's organization where interfunctional communication is a challenge.

These skills are already well-known by human resource managers and business managers. Nevertheless, today's job profiles for professionals in organizations look for graduates from almost every domain, except for architects. Interestingly, not a single job advertisement in managerial positions asked for visual communication competencies. My motivation is that in the next ten years, business professionals need to prove their visual intelligence. Architects will then start to shape organizations.

1.4 Contributions

This thesis provides four main contributions:

- A *dialectic argumentation:* It structures and relates arguments that support and reject the hypothesis that the use of complementary visualizations improves the transfer of knowledge.
- *The Knowledge Visualization Framework* structures and systemizes research, mediates between isolated research areas, and is suitable as a tool for practitioners to find the most appropriate visualization method to transfer knowledge.
- *Four practical contributions* for key problems were invented, implemented, evaluated, and discussed with publications. Each case study presents a research contribution for each field I refer to: (1) a new visual document search paradigm, (2) a new metaphor for interfunctional communication, (3) a new approach to improve the transfer of knowledge between planners and decision makers, and (4) an application of the framework in one scenario. The evaluations of the case studies allowed me to derive relevant empirical data to test and refine the model.
- *The Knowledge Visualization Model* is the synthesis of the arguments and my own empirical data from the case studies. The model identifies, structures, and relates the key aspects for successful Knowledge Visualization applications, serves as research outline for future research, and as a guideline for practitioners.

To achieve these knowledge bricks, I used various scientific methods that are described in the next section.

1.5 Methodology

The thesis is based on a combination of different research methods. It combines quantitative and qualitative methods. Quantitative methods were used in the evaluations. The qualitative research approach was chosen, since research in the areas of knowledge management, information visualization, and visual communication sciences requires a close relationship between researchers and subjects. The research process in this thesis iterates own experiences, experiments, evaluations, analysis of the findings, reflection of the observations, analysis and structuring of findings from other researchers, and a constant refinements of the framework and the model. The main methods are:

Grounded theory is the name of a method that has been used in different social science disciplines. It was developed by Glaser and Strauss (1967). The two major proponents state, *"the grounded theory approach is a qualitative research method that uses a systematic set of procedures to develop an inductively derived grounded theory on a phenomenon"* (Strauss and Corbin, 1990, 24). The basic approach is that a theory must emerge from the data, it must be grounded in the data. The method can be used if there is not enough theory about the research question or if the existing knowledge is not sufficient to formulate a theory (Punch, 1998), which clearly is the case for Knowledge Visualization. In this thesis the grounded theory method was used to focus the research questions and to determine the literature to be reviewed in the interdisciplinary fields.

Case studies are used to demonstrate behavioral phenomena and to study phenomena that cannot be reproduced in a controlled laboratory setting. *Triangulation* (Yin, 1994) is used for double checking results. In that way the findings are more reliable when different methods lead to the same result. In this thesis case studies are used to examine the effectiveness of complementary visualizations in real-world situations.

Surveys help collect quantitative information. If the questions are administered by a researcher, the survey is called an interview. If the questions are administered by the respondent, the survey is called a questionnaire. Surveys are efficient and flexible for collecting information from a large number of respondents. Surveys can be used to study attitudes, values, beliefs, and past behaviors. In this thesis surveys are used to get quantitative results on the effectiveness and limitations of the new approaches, e.g. the *Tube Map Visualization* or the *Metaview* approach.

Apart from these well-known methods **various experimental methods** were invented for a variety of specific experiments, such as visual perception experiments. All together, the variety of methods allowed to collect the data that was necessary to prove and reject the hypotheses in the chosen dialectic approach.

2. FRAME OF REFERENCE

This chapter presents the related literature and the state-of-the-art in these fields. First the main definitions for this thesis are introduced.

2.1 Definitions

The definition of the concepts *data, information* and *knowledge* is important because in the literature there is no consensus yet. A common view is the so called knowledge pyramid, which distinguishes between data, information, and knowledge. While different authors criticize the knowledge pyramid (Schreyögg, 2003), this thesis is based on this distinction and uses the following definitions:

Data
Data consists of different signs which are related to each other ordered by a special syntax rule. Data are numbers, characters, images, or other outputs from devices. Data are in a format that can be further processed by a human or put into a computer, stored and processed, and/or transmitted to another human or to an other information processor. Data on its own has no meaning. Only if interpreted by some kind of data processing system does it takes on meaning and become information.

Example: The thermometer measures a temperature of 5 degrees Celsius.

Information
Information is data in a context. Information can be persistent (contained in an information system) or virtual (deducted from persistent information).[2]

Example: The 5 degrees were measured in downtown Zurich on February 12th at 4pm.

Knowledge
Knowledge emerges when someone combines different information to accomplish a specific task. According to Wittgenstein (1958), knowledge is in the eye of the beholder, which brings meaning to it through the way he uses it. *"Knowledge is empirically collected or internalized information. Knowledge is hosted in brains. Knowledge can be implemented from one*

[2] based on the definition "information" by Beat Schmid, provided by the netacademy (www.netacademy.com), retrieved 5th of July, 2004

agent (brain) into another agent (brain) by externalizing it, i.e., by encoding knowledge to information which can be stored on data carriers thus can be transported across time and space"[3]. Knowledge consists of beliefs about reality and includes descriptions, hypotheses, concepts, theories or procedures, which are either true or useful.

Example: If the temperature in downtown Zurich is that low in the afternoon, then the snow on top of the ETH Hönggerberg will probably be frozen in the evening. I can easily bike up to the top, but I'd better wear a helmet because things could get slippery on the downhill.

In conclusion, in this thesis the concepts are distinguished pragmatically: Information is converted into knowledge once it is processed and reconstructed in the mind of an individual, and knowledge becomes information once it is articulated and explicated by an individual to a physical carrier, e.g., in the form of text, graphics, or signs. Based on this distinction the difference between information visualization and knowledge visualization can be defined:

Information visualization is the use of computer-supported methods to interactively explore and derive new insights through the visualization of large sets of information (Card, et al., 1999).

Knowledge Visualization in contrast examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons (Burkhard, 2004b, Burkhard and Meier, 2004, Eppler and Burkhard, 2005). Knowledge Visualization thus designates all graphic means that can be used to construct and convey insight.

Because a clear understanding of the field information visualization is essential to understand the new field Knowledge Visualization it is discussed in-depth in an individual section after the general theories. In the same way knowledge management, visual communication sciences, visual perception, and communication sciences are discussed and defined in individual sections.

Based on all insights from this thesis the in-depth definition of Knowledge Visualization is discussed in the conclusion at the end of this thesis.

[3] based on the definition "knowledge" by Beat Schmid, provided by the netacademy (www.netacademy.com), retrieved 5th of July, 2004

2.2 General Theories

This thesis is based on a dialectic argumentation. I implicitly refer to three general theories: Behaviorism, Cognitivism, and Constructivism.

2.2.1 Behaviorism

Behaviorism is an approach in psychology that states that observing behavior is the best means for investigating psychological and mental processes and for understanding mental functions. Leading proponents are Watson (1913) and Skinner (1938, 1945). The essence of Behaviorism for learning and the transfer of knowledge is that content should be split up into learning steps. In that way the learning targets are iteratively achieved. Criticism of behavioralistic learning theory states that it excludes the understanding, application, and evaluation of complex relationships.

2.2.2 Cognitivism

Cognitivism has two components: First, the belief that psychology can be fully explained by experiments, measurements, and scientific methods. Second, the understanding of mental functions in terms of information processing and mathematical models. Since 1960, Cognitivism has replaced behaviorism as the most popular paradigm for understanding mental function. Cognitive psychology, however, did not reject the methods of behaviorism.

2.2.3 Constructivism

Constructivism is based on the study of cognition. Constructivism states that learning is an active process in which learners construct new ideas or concepts based upon their current/past knowledge, and that insights arise from subjective experiences.

Much of the theory is related to child development research, especially by Piaget (1950). Piaget's theory supposes that persons develop schemas (conceptual models) by fitting information into existing schemas, thus altering existing schemas to grasp new information.

Bruner (1966) states that a theory of instruction should address four major aspects: (1) the students' predisposition towards learning, (2) the ways in which a body of knowledge can be structured so that it can be most readily grasped by the learner, (3) the most effective sequences in which to present material, and (4) the nature and pacing of rewards and punishments. In an example, Bruner (1986) demonstrates that children learn the concept of prime numbers more easily with a visual experiment where they can see that a certain amount of beans cannot be laid out in complete rows and columns.

Constructivists believe that knowledge has to be constructed from own experiences. Therefore teachers should not be instructors. This point is being criticized: Not all knowledge can be constructed by the learner himself. The learner needs knowledge on which he can build upon.

Regarding the transfer of knowledge, for the purpose of this thesis, constructivism has three consequences: First, knowledge is actively constructed or re-construced by each individual. And individuals need to accord meaning to knowledge instead of just accumulating facts. Second, knowledge should be linked to its future use. It should be embedded into realistic and relevant problems. In the Knowledge Visualization Model this point addressed with *Options to act.* Third, collaboration is important for social negotiation on meaning, for the testing of ideas, and the exchange and discussion of different perspectives. That is why the Knowledge Visualization Model stresses the iterative approach.

2.3 Knowledge Management

Knowledge Management is a management perspective that offers theories, strategies, and methods to manage, i.e., to identify, access, share, and create knowledge in organizations. It's aim is to help an organization to become more innovative, effective, and thus more profitable.

Knowledge management also tries to solve typical problems in organizations associated with knowledge such as:

- *Isolated knowledge sources*: Information is isolated, not accessible, not shared, or knowledge sources are unknown.
- *Identification of experts:* The identification of experts in organization is not systemized.
- *Repetition of the same mistakes*: Lessons learned from projects are not documented, therefore, the same mistakes are made repeatedly.
- *Reinventing the wheel*: Expensive methods are implemented parallel instead of collaborating or licensing existing technologies.
- *Information overload*: The increasing quantities of information may paralyze employees. They miss the big picture and cannot identify the relevant knowledge.
- *Intellectual properties*: Intellectual properties, e.g., patents, are not managed and fully exploited.
- *Brain drain*: The loss of a knowledge worker results in a loss of knowledge.

Knowledge Management has its roots in organizational learning (Argyris and Schön, 1978, Fiol and Lyles, 1985, Senge, 1990b), strategic management, and information science. The *knowledge-based theory* (Grant, 1996, Nonaka, 1991, Nonaka and Takeuchi, 1995, Spender, 1996) sees knowledge as a key productive and strategic resource which is embedded in an organizational culture, in systems, documents, and in the brains of individuals.

As a result of the knowledge-based perspective, research and management practice has already become more knowledge-focused, e.g., through establishing knowledge cultures, implementing knowledge strategies, introducing knowledge audits, communities of practice, and information management systems, or through sharing lessons learned from project debriefings.

In the past, different knowledge management strategies have been introduced and established, but these strategies and perceptions differ depending on the understanding of knowledge. To understand the most common knowledge management models, it is important to understand the different taxonomies of the concept knowledge and based on it the goals of the different perspectives. First, the different knowledge taxonomies are described, then the six perspectives on the management of knowledge are addressed. Finally the three established models in the knowledge management literature I refer to in this thesis are discussed. First, I discuss the knowledge taxonomies.

Knowledge Taxonomies

An understanding of the different knowledge taxonomies helps to explain the different perspectives and models in knowledge management:

First, Nonaka (1994), based on Polanyi (1962, 1967), distinguishes two dimensions of knowledge in organizations: a *tacit* and an *explicit* dimension. An example of tacit knowledge is riding a bike, which is hard to be explained or to be learned by studying books. An example of explicit knowledge is a telephone number which you can easily explicate, e.g., write into a database. Tacit knowledge forms the background necessary to develop and interpret explicit knowledge (Polanyi, 1975). As a consequence, there must be an overlap in underlying knowledge bases among individuals that are sharing knowledge (Ivari and Linger, 1999, Tuomi, 1999).

Second, knowledge can also be viewed as existing in the *individual* or the *collective* (Nonaka, 1994). Individual knowledge is created by and exists in the individual, whereas collective or social knowledge is created by and stored in groups. What is missing is a clear explanation for the interrelation of the various knowledge-types in this classification.

Third, knowledge can be divided into different types, such as declarative knowledge (*know-what/know-about*), procedural knowledge (*know-how*), causal knowledge (*know-why*), located knowledge (*know-where*), or relational knowledge (*know-who/know-with*).

Finally, a pragmatic taxonomy of knowledge in organizations tries to identify business relevant types of knowledge, which can include knowledge about processes, experts, competitors, customers, or products.

These different understandings of the concept knowledge result in different perspectives on knowledge management which are discussed next.

Knowledge perspectives

Knowledge can be seen from different perspectives. Based on Alavi and Leidner (2001), six perspectives can be distinguished, which all have implications on the understanding of knowledge management initiatives and goals. Theses perspectives and implications are described next:

First, knowledge can be seen by the distinction between data, information, and knowledge. Data are facts, information is interpreted data and knowledge is personalized information. The implication is that Knowledge Management focuses on exposing individuals to potentially useful information and facilitating assimilation of information.

Second, knowledge can be defined as a *"state of knowing"*. Polanyi refers to different types of knowing, i.e., skills or competences (Polanyi, 1967). This view is close to Ryle's, who introduces the labels "*knowing how*" and "*knowing what*" (Ryle, 1949). Machlup (1980) identified thirteen different states of knowing[4]. If knowledge is seen as a state of knowing then the implication is that Knowledge Management supports individuals to apply and expand their knowledge.

Third, knowledge can be defined as an *"object"* that can be stored and manipulated (Carlsson, et al., 1996, McQueen, 1998, Zack, 1998). The implication is that Knowledge Management focuses on the process of creating, sharing, and distributing knowledge and building information repositories.

Fourth, knowledge can be seen as a *"process"* of knowing and acting (Carlsson, et al., 1996, McQueen, 1998, Zack, 1998). The process perspective focuses on applying expertise (Zack, 1998). The implication is that Knowledge Management provides access to relevant information and aims to optimize the knowledge-intense processes, e.g., identifying, creating, and sharing knowledge. To do so, individuals are brought together.

Fifth, knowledge can be seen as a *"condition of access to information"* (McQueen, 1998), which is an extension to knowledge as an object. As an implication knowledge management systems should offer solutions to identify, structure, retrieve, and access relevant content. The implication is that Knowledge Management focuses on methods to identify, retrieve, and gain access to information.

Finally, knowledge can be defined as a *"capability to act"* with the potential of influencing future action (Carlsson, et al., 1996). Different scientists refer to this point: "*Knowledge is the capacity for effective action*" (Senge, 1990a), "*Knowledge is the capacity to act*" (Sveiby, 1997), "*Knowledge is the capacity for effective actions*" (Argyris, 1993). The implication of this perspective is that Knowledge Management focuses on the strategic advantage of knowledge, on building core competencies, and on creating intellectual capital.

In spite of these diverging understandings of knowledge, all perspectives have in common that knowledge management is seen as a dynamic and continuous task with three main objectives: (1) to optimize business processes from a knowledge perspective, (2) to introduce systems for

[4] Being acquainted with, Being familiar with, Being aware of, Remembering, Recollecting, Recognizing, Distinguishing, Understanding, Interpreting, Being able to explain, Being able to demonstrate, Being able to talk about, Being able to perform

storing, identifying, retrieving, and gaining access to information, and supporting individuals to collaborate, and (3) to develop a corporate knowledge culture that motivates employees to envision, create, and share knowledge, alone, in teams, or across units and regions.

To do so, different models and frameworks structure the field of knowledge management. They are discussed next.

Knowledge Management Models

Nonaka and Takeuchi (1995) propose the "*SECI Model*" (Figure 1) that classifies knowledge as either tacit or explicit, and either individual or collective. The model proposes knowledge processes that transform knowledge from one form to another: Socialization (from tacit to tacit), Externalization (from tacit to explicit), Combination (from explicit to explicit), and Internalization (from explicit to tacit).

	Tacit Knowledge	TO	Explicit Knowledge
Tacit Knowledge	Socialization		Externalization
FROM			
Explicit Knowledge	Internalization		Combination

Figure 1. Nonaka-Takeuchi learning cycle (SECI-model). (Redrawn by the author)

Probst et al (1997) propose a commonly used framework for both an individual and an organizational perspective. The framework distinguishes eight building blocks of knowledge management as seen in Figure 2.

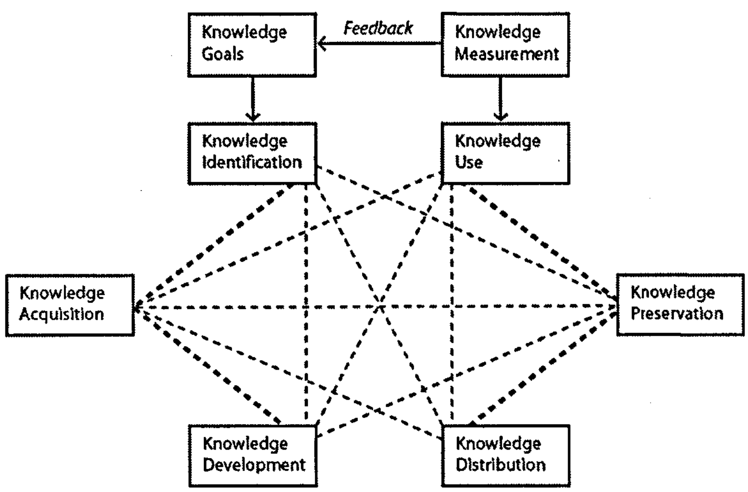

Figure 2. The eight building blocks of knowledge management (Probst, et al., 1997). (Redrawn by the author)

These building blocks structure the knowledge management process in logical phases, suggest points for interventions, and help to identify the source of knowledge problems.

Alavi and Leidner (2001) present a third structure and distinguish four knowledge processes: (1) the creation, (2) the storage and retrieval, (3) the transfer, and (4) the application of knowledge. This model is discussed in more detail:

(1) Knowledge Creation: Knowledge is created through social, collaborative, and cognitive processes. In Figure 3, each arrow represents a form of knowledge creation related to Nonaka's knowledge creation modes:

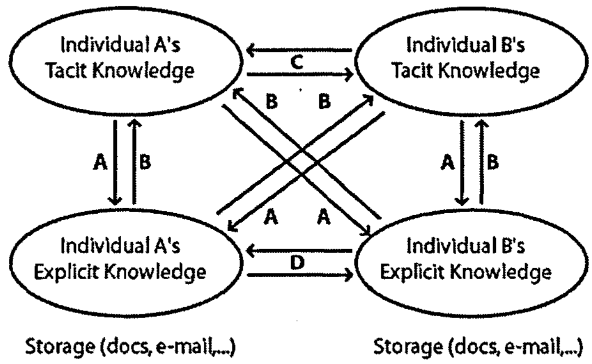

Figure 3. Knowledge Creation Modes (Alavi and Leidner, 2001). Each arrow represents a form of knowledge creation: Externalization (A), Internalization (B), Socialization (C), and Combination (D). (Redrawn by the author)

Externalization (A) refers to converting tacit knowledge to new explicit knowledge (e.g., the articulation of lessons learned). *Internalization (B)* refers to the creation of new tacit knowledge from explicit knowledge (e.g., learning and understanding as a result from reading or discussing). *Socialization (C)* refers to the conversion of tacit knowledge to new tacit knowledge through social interaction (e.g., apprenticeship). Finally, *Combination (D)* refers to the creation of new explicit knowledge by merging, categorizing, reclassifying, and synthesizing existing explicit knowledge (e.g., literature survey report).

(2) Knowledge Storage/Retrieval: Empirical studies have shown that organizations not only learn, but also forget (Argote, et al., 1990, Darr, et al., 1995). That's why the storage and retrieval of knowledge is important. The literature distinguishes between the individual and the organizational memory. Individual memory is constructed by observation, experience, and action (Argyris and Schön, 1978). Organizational memory is defined as "*the means by which knowledge from the past, experience, and events influence present organizational activities*" (Stein and Zwass, 1995). Organizational knowledge is stored in individuals or in networks of individuals and in data carriers (e.g., information repositories, databases, or expert systems).

(3) Knowledge Transfer: The transfer of knowledge occurs at various levels: Among individuals, from individuals to groups, among groups, among individuals/groups and an organization. The transfer of knowledge is a core process in knowledge management and is difficult to manage (Probst, et al., 1997). Based on Gupta and Govindarajan (2000), five elements can be distinguished for a successful knowledge transfer: (1) the perceived value of the sender's knowledge, (2) the motivation and willingness of the sender to share his knowledge, (3) the availability and richness of transmission channels, (4) the motivation of the recipient to acquire knowledge from the sender, and (5) the absorptive capacity of the recipient, i.e., the ability not only to acquire but also to use knowledge. To do so, knowledge must be recreated by the receiver, which brings us to the challenge: Individuals who need to transfer knowledge to one or more individuals, with similar or different backgrounds, not only need to convey the relevant knowledge, but also need to convey it in the right context. The transfer of knowledge can happen through different channels: formal (e.g., training session), informal (e.g., coffee break conversation), personal channels (e.g., apprenticeship), or impersonal channels (e.g., database).

(4) Knowledge Application: For an organization, the competitive advantage resides in the application of the knowledge, not in the knowledge itself. Putting knowledge to action is a key factor for successful knowledge management.

As we have seen in the last model, knowledge management can be divided into four main processes: the creation, the storage and retrieval, the transfer, and the application of knowledge. This thesis concentrates on one process: the process of transferring knowledge. This is such for different reasons: (1) The process of knowledge transfer is a key process for knowledge-intense organizations and poses various problems which can be solved by exploiting our innate abilities to process visualizations, (2) the process of knowledge transfer has not been studied enough by information visualization researchers, and (3) architects are experts in the visual transfer of knowledge.

Within the field of knowledge management, the research presented in this thesis underlines the important new aspect of **visualization** in knowledge intense processes, mainly **for the transfer of knowledge**. The theoretical framework and model are the first systematic approaches in regard to the use of visual representations in the field of knowledge management. Secondly, the case studies present innovative new approaches, evaluations, and applications for predominant problems in today's organizations.

2.4 Information Visualization

We know how to collect data and how to build data warehouses, but we still struggle to get the relevant information back out! The fact that information is available does not automatically mean that it is also useable.

Information visualization is a field of research that investigates the use of interactive computer-based methods for the analysis and exploration of large amounts of data using our innate abilities to effectively process visual representations. Information visualization is a field of study which is described by various researchers (Card, et al., 1999, Chen, 1999a, Spence, 2000, Ware, 2000). Card et al. (1999) define it, as "*... the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*". The origin of the field lies in the late 1980's when computers became affordable and powerful enough (computing performance, screen size) to support interactive graphics. At the same time, researchers started to use computers for scientific simulations or the automation of workflows and business processes. Both resulted in large databases of abstract data. As a first reaction, the computing discipline *scientific visualization* arose in 1987 with the first IEEE visualization conference held in 1990. Scientific visualization was the basis and starting point for the new field *information visualization* which also had roots in statistical graphics and user interface design. In contrast to scientific visualization, the focus here are abstract data which lack natural representations (i.e., financial data, genomic data, transaction data).

Information visualization builds on theories in information design, computer graphics, human-computer interaction, and cognitive science. These new applications allow the user to interactively explore abstract data with visual methods, ideally in the sequence discussed by Shneiderman's Visual Information Seeking Mantra (1996)): "*overview first, zoom-in and filter, then show details on demand*". Information visualization applications allow users to visually explore data in real-time and to discover patterns (e.g., trends, clusters, gaps, or outliers) concerning individual items or groups of items with the overall goal to derive new insights. Information visualization applications have three main characteristics: They are *interactive* (i.e., they use direct manipulation user interface techniques to apply operations such as filtering), *dynamic* (i.e., the visualization is rendered in real-time), and *they embed details in context* (i.e., they use focus and context techniques such as distortion or dynamic zooming).

What is the difference to database queries? Information visualization has to be seen complementary to database queries and information retrieval approaches. The main benefit compared to standard database queries is the power of our eyes to detect patterns, and hence it is a different and more effective method than database queries when little is known on the data, and if the goals are not clear. The second benefit is that information visualization applications are interactive, which means that users can constantly explore large amounts of data with interaction techniques (i.e., sliders and filters), and iteratively reformulate their goals while exploring the data visually.

Examples for information visualization applications are: (1) Tree Maps (Johnson and Shneiderman, 1991, Shneiderman, 1992), for space-constrained visualization of hierarchies using nested rectangles, Cone Trees (Robertson and Mackinlay, 1991), Table Lenses (Rao and Card, 1994), Hyperbolic 3D (Munzner, 1998). Throughout the years various new applications and concepts were developed, also by researchers in Switzerland such as (Brodbeck, et al., 1997, Brodbeck and Girardin, 2003a, Brodbeck and Girardin, 2003b) or Vande Moere (2002, 2004) who invented and implemented the *Infoticle* metaphor which introduces data-driven particles (= Infoticles) that help to explore large time-varying datasets.

Within the field of information visualization, the research presented in this thesis contributes (1) the important aspect of **transferring the derived insights to different recipients**, (2) the introduction of architects to use **complementary visualizations** which can extend the field, and (3) an example how an existing information visualization algorithm is being put into a real world context to solve a problem in document management, namely the retrieval of documents.

2.5 Visual Communication Sciences

Various isolated research fields investigate the effective design of information. However, these fields compete with rather than learn from each other which is one reason why no established framework or model exists. I believe that the whole field would be much more powerful and influential if the researchers agree on certain taxonomies or definitions, learn from each other, and identify synergies. It is not surprising that a clear name for this research direction does not exist, which I summarize using the title visual communication sciences. This section provides an overview on existing taxonomies and discusses three important fields: Information Design, Information Architecture, and Information Art.

2.5.1 Classification of Visual Representations

This section presents an overview on several classifications of visual representations, which are the base for my framework. Classifications of visual representations can either be functional or structural.

Functional classifications focus on the intended use of the visual representations, i.e., Tufte (1983, 1990, 1997). Bowman (1968) and Keller and Keller (1993) both communicate example-based visual solutions by use of a classification framework. Keller and Keller's investigations are conducted in the domain of scientific visualization, whereas Bowman's analysis is performed in the domain of non-interactive, static visual communication. Further examples can be found in Harris' and Nielson's research projects (Harris, 1996, Nielson, et al., 1997).

Structural classifications focus on the form rather than on its content; proponents are Bertin (1967), Rankin (1990), or Lohse et al. (1994).

Bertin (1967) developed a semiology of graphic representation methods, which helps make information transparent and comprehensive. With his visionary semiology, Bertin was among the first to systemize visual strategies to apply visual representations to reduce complexity and improve the transfer of knowledge. Bertin (1977) has suggested that there are two forms of data: data values (entities) and data structures (relations). Through his book, he aimed to break the still predominant situation, where children learn for years how to read, write, and calculate, but not to use simple visual representations to support the transfer of knowledge.

Rankin (1990) presents a classification of graph types, and distinguishes major categories such as: rectilinear Cartesian coordinate graphs, polar coordinate graphs, bar graphs, line graphs, matrix diagrams, tri-linear charts, response surface, topographic charts, and conversion scales.

Lohse et al. (1994) focus on how people classify visual representations into meaningful, hierarchically structured categories. In contrast to previous classifications, it is based on experimental data, rather than on the author's intuition to classify visual representations. In an empirical experiment, a group of 16 individuals tested visual similarities among sixty different visual representations. Ten categories were introduced to describe qualities of these representations:

- Spatial/non-spatial
- Non-temporal/temporal
- Hard to understand/easy to understand
- Concrete/abstract
- Continuous/discrete
- Attractive/unattractive
- Emphasizes whole/emphasizes parts
- Nonnumeric/numeric
- Static structure/dynamic process
- Conveys a lot of information/conveys little information

Users were asked to sort these 60 visual representations into groups of similar items. As a result, eleven categories of visual representations emerged. These are graphs, tables, graphical tables, time charts, networks, structure diagrams, process diagrams, maps, cartograms, icons, and pictures. The result is depicted through the tree diagram seen in Figure 4.

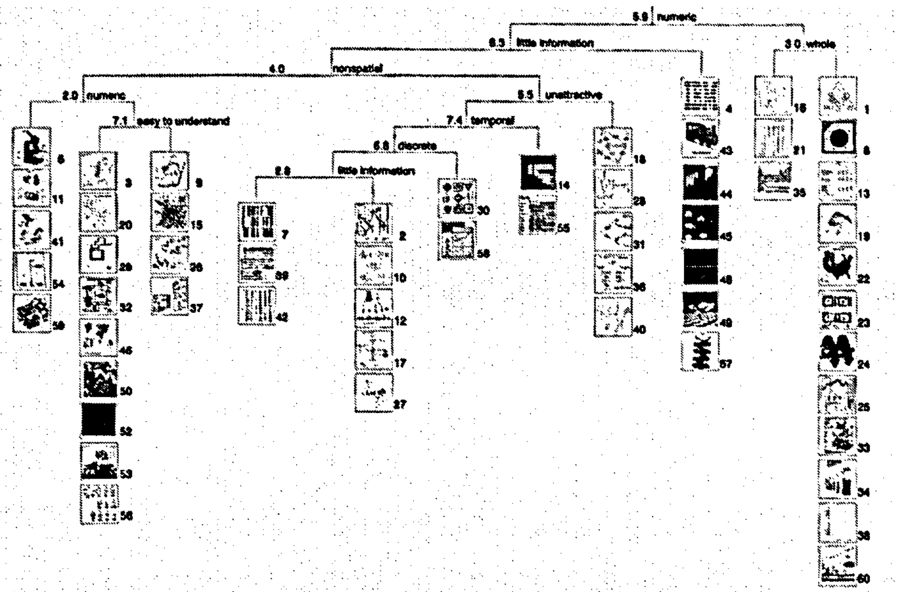

Figure 4. In the study by Lohse et al. (1994) eleven categories of visual representations emerged.

Apart from these taxonomies many new taxonomies were developed. Their main interest is to classify visualization methods in the field of information visualization:

Shneiderman (1996) proposes a task by data type taxonomy of information visualization with seven data types (one-, two-, three-dimensional data, temporal and multi-dimensional data, tree and network data)[5] and seven tasks (overview, zoom, filter, details-on-demand, relate, history, and extracts).

Card et al. (1999) constructed a data-oriented taxonomy for information visualization techniques, which is based on Card and MacKinlay (1997). This taxonomy divides the field of visualization into several subcategories: Scientific Visualization, GIS, Multi-dimensional Plots, Multi-dimensional Tables, Information Landscapes and Spaces, Node and Link, Trees, and Text Transforms.

In conclusion, the taxonomies and classifications aim to structure the variety of existing or novel visual representations. But there is no clear and simple taxonomy that structures visualization types that are used to transfer knowledge. What is missing in all taxonomies is the perspective of the recipient and the perspective of the different knowledge types that are

[5] Examples can be found at the "On-line Library of Information Visualization Environments" at http://otal.umd.edu/olive/

discussed in the knowledge management literature. A new framework (1) should help to identify new fields of research, (2) should be integrative, i.e., help to integrate existing classifications, (3) should mediate between the isolated fields (which demands to link to the existing taxonomies), and (4) should not only help researchers, but also practitioners, by providing checklists and relevant questions to be asked.

Within the field of visual communication sciences, the research presented in this thesis contributes this new and yet missing framework, which I call the Knowledge Visualization Framework. It further provides a model with guidelines for practitioners. In order to develop the framework and model, I analyzed various examples. These examples come mainly from the fields Information Design, Information Architecture, and Information Art are described next.

Information Design

Information design is the art and science of preparing information so that information is comprehensible, rapidly, and accurately retrievable, and easy to translate into actions.

The classic references in this field are from Tufte (1983, 1990, 1997). Tufte examines how large amounts of information can be presented in a way that is concise, compact, adequate, and easy to understand. In contrast to the research field of information visualization (Card, et al., 1999, Chen, 1999a, Spence, 2000, Ware, 2000), which creates interactive visual software applications, Tufte concentrates on printed graphical information. He discusses several examples (e.g., the Challenger disaster) and provides simple and ready to use advice and formulas (e.g., Maximize Data-ink; Minimize non-Data-ink).

In France, Jacques Bertin published the monumental '*Semiologie Graphique*' (Bertin, 1967), wherein he organized the visual and perceptual elements of graphics according to the features and relations in data as discussed above.

Robert Horn investigates visual communication, visual argumentation mapping, and visual cognitive maps, for instance to aid the policy making process. Horn introduced the concept of visual language, which he defines as a tight and thorough integration of words, images, and shapes (Horn, 1998).

The difference between information design and information visualization is that information visualization concentrates on computer-supported techniques whereas information design creates mainly static visual formats, such as maps, posters, and signs for orientation.

Information Architecture

Information architecture (Wurman, 1996) is a field of graphic design, interface design, interaction design, and human-computer interaction. In contrast to information design, the field of information architecture concentrates more on structural rather than presentational issues.

Another definition comes from the domain of architects with computer skills, which claim the same term. In contrast to Wurman they see information as a raw material (e.g., like a brick) that allows to create spaces, structures, and possibilities for interaction in the digital space (Engeli, 2001, Schmitt, 1999). These information architects apply their skills (e.g., to envision, structure, and think in concepts) to create novel structures, which allow navigation within information or information to be visualized in new ways. They perceive information as a new material that allows new virtual environments to be created.

One famous example, the project on which I had the chance assist, is the 3D trade floor visualization (3DTFV) by Asymptote Architecture (Moltenbrey, 1999). The project created an information space whereupon an abstract representation of the trading floors of the New York Stock Exchange was mapped with real time data streams, stock tickers, real-time CNN, three dimensional index charts, and a complex system to supervise technical and business alerts. The innovation of this project is twofold. It was among the first projects that applied the skills of architects to create an interactive visualization that is appealing, effective, and original. Second, it created a customized structure consisting of around fifty flat screens and an architecture on which the application has run. In a way, Asymptote Architecture realized what is discussed today: the extension of the rectangular screen to the architectural space. A variety of other projects can be found, for example the Virtual Guggenheim Museum by Asymptote Architecture (Drutt, et al., 2002), Data City (Maas and MvRdV, 1999), or ETH-World (Carrard, 2001).

Information Art

Various experimental applications, mainly created by innovative experiments coming from media institutes or multimedia design studios, present interesting approaches that break with the traditional user interfaces. The domain is sometimes referred to as information art, generative art, or info aesthetics. Such artists use the computer as a tool to generate experimental artistic objects. They combine graphic design and interface design, and programming. Such artists focus on the structures, deal with aesthetic and emotional qualities, and demonstrate possibilities of digital visual communication design. Most of them use tools such as

Macromedia Flash[6], Java, dynamic scripting languages, 3D worlds in VRML, or one of the various Game Engines, or they share codes and best practices in open source platforms[7].

Due to the experimental character of this area, it is difficult to document it, however, I suggest a visit to some currently interesting sites to get a better understanding of this area. The following sites are examples from various artists, such as Yugo Nakamura (www.yugop.com), Lia (www.dextro.org), Caseya Reas (www.groupc.net), Lisa Jevbratt (www.jevbratt.com), Shonerwisson (www.sw.ofcd.com), Jared Tarbell (www.levitated.net) or from exhibitions, e.g., *Documenta X* (http://www.documenta12.de/archiv/dx/) or *Abstraction Now* (www.abstraction-now.at).

In contrast to these experimental approaches, the field called info-aesthetics (Manovich, 2001, Manovich, 2004) tries to theoretically analyze the aesthetics of information access and the creation of new media applications that focus in aesthetic interfaces and deal with processing information.

In conclusion, these different fields provide various solutions and examples how the transfer of knowledge can be improved by using visual formats, but until today there is no general framework and model available that synthesizes the findings. This thesis aims to structure the field and provide the missing theoretical contributions.

2.6 Visual Perception

A majority of our brain's activity deals with processing and analyzing visual images. To understand perception, it is important to remember that our brain does not differ greatly from that of our ancestors, the troglodytes. At that time, perception helped for basic functions, for example for hunting (motion detection), seeking food (color detection), or applying tools (object-shape perception).

First I discuss the Gestalt principles, which are principles that explain how visual perception works:

Gestalt Principles
The *Gestalt School of Psychology* was founded in 1912 when the group of Kurt Koffka, Max Westheimer, and Wolfgang Kohler wanted to investigate the way we perceive form (Ellis, 1938, Koffka, 1935). The findings have been

6 www.macromedia.com

7 www.processing.org is an example of a non-proprietary visual sketchbook for digital artists

useful for understanding how we perceive groups of objects or parts of objects. The work of the Gestalt psychologists is still important, because it provides a clear description of many basic perceptual phenomena that are called "Gestalt laws", as seen in Figure 5.

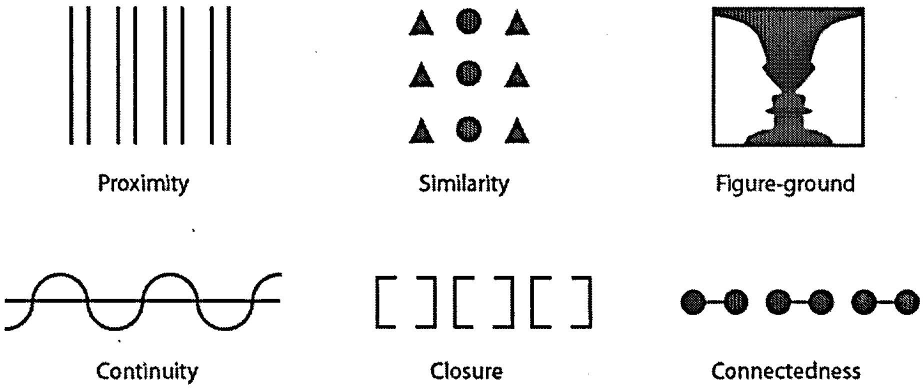

Figure 5. Gestalt Principles present how we perceive objects and groups of objects.

- *Proximity*: Elements tend to be grouped together according to their nearness
- *Similarity*: Similar items tend to be grouped together
- *Figure-ground*: Some objects (figure) seem prominent, and other aspects recede into the background (ground)
- *Continuity:* We tend to construct visual elements that are smooth and continuous, rather than abrupt changes in direction
- *Closure*: Items are grouped together if they tend to complete some entity
- *Connectedness, Symmetry*: Items will be organized into simple figures according to symmetry, regularity, smoothness, and connectedness.

Gestalt theory applies to all aspects of human learning, although it applies most directly to perception and problem-solving. The Gestalt laws provide valuable descriptive insights into form and pattern perception, but they offer few or no explanations for these phenomena. To understand how or why we perceive forms and patterns, we need to consider explanatory theories of perception. First I will summarize how visual information is being processed.

Visual Information Processing

Visual information processing can be divided into two stages as seen in Figure 6:

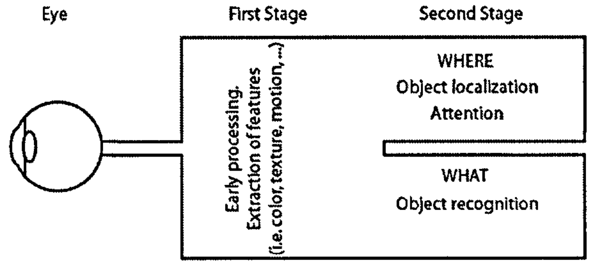

Figure 6. A schematic diagram illustrates the two stages of visual information processing. The second stage is divided into two visual subsystems. The diagram is based on (Ware, 2000) and simplified by the author.

In the ***first stage***, information is processed parallelly by the eye and the primary visual cortex where individual neurons in specific areas (called V1, V2, V3, V4, MT) are specialized to identify particular features (i.e., orientation, color, texture, contour, or motion). At this early stage, information processing proceeds pre-attentive and very rapid. Information is derived bottom-up. Example: If an icon on a website rotates, the motion detection neurons automatically react, whether we like it or not.

In the ***second stage***, information processing is divided into two functionally independent subsystems with complementary functional specializations. The idea of "*two cortical visual systems*" (Ungerleider and Mishkin, 1982) is that the visual processes underlie object recognition on the one hand, and object localization and attention on the other. One visual subsystem is more important for object identification (=what) the other for spatial localization (=where). In contrast to the first stage, the second stage is a top-down process. Some theorists suggest that between the first and second stage there is a intermediate kind of representation, i.e., feature maps (Triesman, 1980) or 2 1/2 D sketches (Marr, 1982).

Beyond the second stage, there are interfaces to other subsystems, such as the verbal linguistic subsystem, so that words can be connected to images and the motor system that controls muscle movements. Further details on the underlying cognitive components of picture processing are discussed by Farah (2000a).

This section introduced how visual information is processed, which is the foundation for understanding theories of visual perception.

Visual perception

The previous section does not explain how we visually perceive form. This subject is being investigated by visual perception research (Goldstein, 2001, Ware, 2000).

Perception is a set of processes by which we recognize, organize, and make sense of stimuli in our environment. (Goodale, 2000, Kosslyn and Osherson, 1995). It is clear that what we sense with our sensory organs is not necessarily what we perceive in our minds. The mind must create mental representations of objects, properties, or spatial relationships on the base of the sensory information. The way we represent these objects depends on our viewpoint in perceiving these objects.

In visual perception we sometimes cannot perceive what does exist (Figure 7) and sometimes we perceive things that do not exist (Figure 8).

Figure 7. We do not see things that are there, such as the Dalmatian.

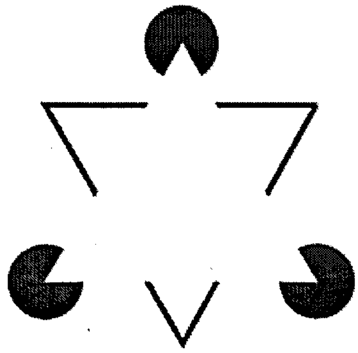

Figure 8. We do see things that are not there, such as the white triangle.

To explain perception, two fundamental approaches exist: Bottom-up theories (direct perception) and top-down theories (constructive perception). The two theories are complementary.

Direct perception (=bottom-up) states that all the information we need to perceive is in the sensory input we receive in the retina. Three main bottom-up approaches are differentiated: (1) The *Template theory* states that in our minds we have stored highly detailed templates for patterns we might recognize. To recognize a pattern we compare it with our stored templates and finally choose the template that matches to what we observe (Selfridge and Neisser, 1960). Critics state that for everyday situations, the perceptual system would barely work if it required exact matches for every stimulus. (2) The *Prototype-Matching Theory* is a best-guess class of related objects or patterns, which integrates the most typical features of a pattern. (3) The *Feature-Matching Theory* suggests that we match the features of a pattern to features stored in memory, rather than to match a whole pattern to a template or a prototype. An example is the findings of Hubel and Wiesel (1979), who discovered that specific cells in our visual cortex become activated when line segments have particular orientations.

Constructive perception (Bruner, 1957, Gregory, 1980, Rock, 1983), in contrast, states that an individual's perception is based on the combination of sensory information with prior knowledge and previous experience. Hence, successful perception requires the combination of sensory information with previous experiences. During perception, we quickly form and test various hypotheses based on what we sense, what we know, and what we can infer.

Above I introduced some theoretical background of visual image processing and visual perception. This background is helpful when we want to exploit our innate abilities to process visual representations, for example: (1) to address emotions, (2) to illustrate relations, (3) to discover trends, patterns, or outliers, (4) to get and keep the attention of recipients, (5) to support remembrance and recall, (6) to present both overview and detail, (7) to facilitate learning, (8) to coordinate individuals, (9) to motivate people and to establish a mutual story, or (10) to energize people and initiate actions by illustrating options to act.

Several studies prove the power of visualizations with regards to these functions. Some examples: (1) Miller (1956) reports that a human's input channel capacity is greater when visual abilities are used. (2) Our brain has a strong ability to identify patterns, which is examined in Gestalt psychology (Ellis, 1938, Koffka, 1935). (3) Visual imagery (Kosslyn, 1980, Shepard and Cooper, 1982) suggest that visual recall seems to be better than verbal recall. It is not yet clear how images are stored and recalled, but it is clear that humans have a natural ability to use images. (4) Several empirical studies show that visual representations are superior to verbal-sequential representations in different tasks (Bauer and Johnson-Laird, 1993, Glenberg and Langston, 1992, Larkin and Simon, 1987, Novick, 2001). (5) Instructional psychology and media didactics investigate the learning outcome in knowledge acquisition from text and picture (Mandl and Levin, 1989), or Weidenmann (1989), who explores aspects of illustrations in the learning process.

Concluding, this section introduced theoretical background that helps to understand, how our innate abilities to process visual representations can be exploited to create and share insights.

Visual Cognition

Visual cognition is defined as the use of mental imagery in thinking. Mental images can be derived from memories or they can be mental images of things we have never seen. This thesis does not analyze the mental processes of visual cognition in detail. However, it integrates the benefits of visual cognition, because these are tightly connected with the use of complementary visualizations. Kosslyn and Koenig (1992) state that mental imagery can be used in the following ways:

(1) The creative generation of images can be a valuable basis for *reasoning*, e.g., by combining familiar elements in new ways. (2) The use of imagery can support *learning skills*, e.g., in sports training. (3) An externalized mental image can be used to *comprehend verbal descriptions*, e.g., a floor plan that illustrates an instruction how to go to a certain place. (4) Images can further stimulate the *discovery* of unexpected patterns, new inventions, and creative concepts.

Within the field of visual perception, the research presented in this thesis, namely the empirical evaluation of the Tube Map Visualization (Burkhard and Meier, 2004) presents an evaluation of an application in a real-world context, which can be fruitful for visual perception researchers.

2.7 Communication Sciences

Communication Sciences can be divided into four major schools: *(1) Cultural Studies Schools* highlight the cultural and social contexts of communication, *(2) Critical Schools* focus on meta-economical and power questions, *(3) Information Theorists* are concerned with economical and technological aspects of communication, and *(4) Semiotic study* considers aspects of both the physical and the metaphysical area of all communications. Each influence distinguishes between individual point-to-point communication and mass communication. Due to the different influences and aspects of communication various specific communication models exist. In this section, I discuss six models that were important for the design of the Knowledge Visualization Model. Their critical display is necessary because in our Knowledge Visualization Model, I build upon their advantages.

Lasswell's model

Who
Says *what*
In *which channel*
To *whom*
With *what effect?*

Figure 9. Five elements in communication, especially in mass communication (Lasswell, 1948)

Lasswell was primarily concerned with mass communication, where especially propaganda studies drew his attention. In 1948, he carefully studied the US Presidential Elections, which was a basis for the creation of his model (Lasswell, 1948). Lasswell's model consists of five elements (Figure 9):

- *Who (= Communicator)*: Every form of communication is initiated by a conscious and voluntary act by someone.
- *Says what (= Message)*: The message is the content transmitted.
- *In which channel (= Medium)*: The channel or medium is the carrier of the message. Example: According to Lasswell written words are carried by paper.
- *To whom (= Receiver)*: The receiver is the person or audience that is being addressed.
- *With what effect (= Effect)*: Effect means a measurable change in the receiver re-action that is caused by the four former communication elements. According to Lasswell, changing one of these four (or all) will always affect the effect variable.

The main characteristic of the model is that it is based on the effect of the sender's message on the ignorant, passive receiver. In addition communication is not seen as a cycle; it is linear. Furthermore, Lasswell neglects the importance of the complex process of constructing, encoding, and decoding of meaning: a topic has to grow in the mind of the communicator, has to be explicated into a code message, and the recipient (if reached and if the message is accepted by him) has to decode that message.

Summarizing Lasswell's model sees communication as the linear transmission of messages, with a focus on 'effect' rather than meaning and context.

Shannon and Weaver's Model

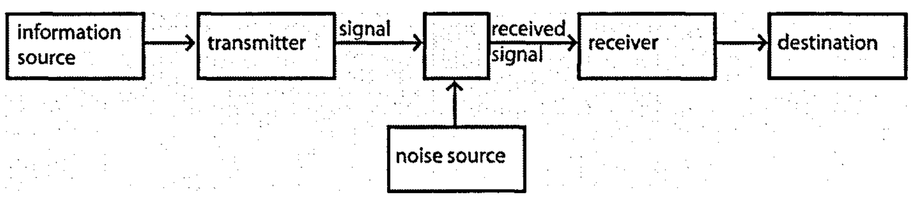

Figure 10. Shannon and Weaver's model of communication. (Redrawn by the author)

Shannon and Weaver's Mathematical Theory of Communication (Shannon and Weaver, 1949) is another widely spread cornerstone belief in Communication Sciences. Their model (Figure 10) too presents a linear process of communication, and focuses mainly on the medium. Although the primary focus is on the medium, this model might be seen as an extension to Lasswell's model: it inserts a new important element "noise source" and splits the medium into a sender and a receiver apparatus. This "noise source" is a first step towards recognizing that messages are read differently as they were coded, due to noise. Shannon and Weaver's understanding of noise however differs from the present understanding of noise in the Communication Sciences area: the former meant that the medium that carries the message is imperfect (e.g., radio interference), whereas nowadays noise is understood in a broader sense (e.g., background children's screaming, color blindness, etc.).

Here too communication is seen as a linear transmission, which considers that the recipient is still passive. This view highlights the factor medium from a technological/technical perspective.

Gerbner's Model

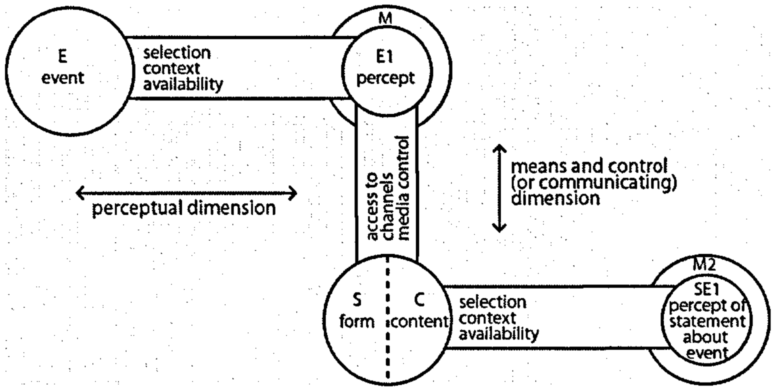

Figure 11. Gerbner's model (1956). (Redrawn by the author)

Gerbner's model emphasizes the dynamic nature of human communication. According to Gerbner (1956), the process of communication is divided in a horizontal and vertical dimension (Figure 11). Before communication takes place the sender needs to perceive and then mentally construct a message. As a result, humans do not communicate about objects with fixed identities, but about subjective perceptions. The communication process is selective and the message that is being constructed is being formed based on our selective mental image. As a consequence, there is always a gap when two individuals communicate, because the second individual only selects and constructs from the message sent by the first individual. In contrast to Laswell's and Shannon and Weaver's model, Gerbner's model does not claim that the message effect or the carrier are in the center. According to Gerbner, the mental representation in the message (interpretation of the content) is the basis for communication.

Concluding, the model of Gerbner reminds us that communication without dynamic human information processing does not exist.

Newcomb's model

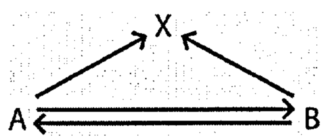

Figure 12. Schematic illustration of the minimal ABX system of Newcomb's model (1953).

Newcomb's (1953) *ABX Model* (Figure 12) presents a psychological view of communication between two individuals. The simple model consists of two communicators (A and B) with their personal "orientation" toward an "object of communication" (X). The object of communication could be an actual physical object, an event, an activity, an attitude, or a behavior.

Newcomb sees communication as a way in which people construct compromises about their environment. This relational system can be divided into four basic components: (1) A's attitude toward X, (2) A's attraction to B, (3) B's attitude toward X, and (4) B's attraction to A. According to the model, both A and B tend to balance their orientation to X towards each other. Example: If A and B have a positive attraction to each other, but A and B have different attitude about X (e.g., A dislikes and B likes smoking), then A will experience an imbalance. As a result, A is likely to revise his/her attitudes to regain balance. Possible solutions are: (1) A decreases in liking B, (2) A changes his/her attitude towards X, or A changes B's attitude about X to align with A's. Thus, both communicators are continually making predictions or estimates of their partner's orientations. A has perceptions of what B is thinking and feeling, just as B has perceptions of what A is thinking and feeling. Unique to this model is that there is no distinction between one communicator and one receiver: both are simultaneously communicator and receiver. Therefore the model is rather a dynamic cycle than a linear transmission model. Furthermore, the model also makes differences in encoding and decoding plausible.

The disadvantage of this model is that it is too simple and forgets other important components of the communication process: Newcomb forgets to accord significance to media carriers and to message contents. Newcomb's model displays the dynamic character of communication between humans.

Jakobson's model

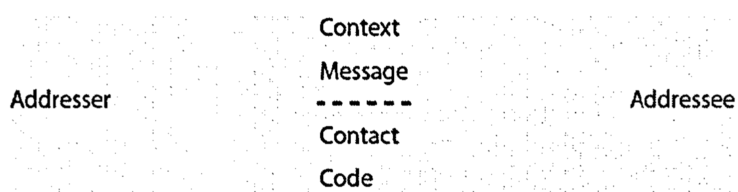

Figure 13. The constitutive factors of communication (Jakobson, 1960).

Jakobson was a Russian linguist. The design of his model (Jakobson, 1960) was based principally on the verbal communication process. The model highlights the importance of common codes and the social contexts involved. It outlines six constitutive factors in any act of verbal communication (Figure 13). This again is a linear transmission model, but it has a different focus than that of Lasswell and that of Shannon and Weaver: it deals with the message contents. It adds important features of messages like context, contact, and code. However, it neglects the notion of message carriers (media) because of Jakobson's verbal communication background. But even verbal communication has a medium; that of air waves.

Jakobson's model points us to the basic elements of a message contents.

Uses and Gratifications model

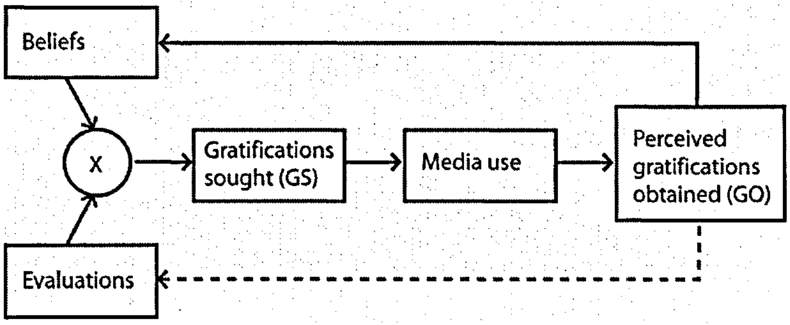

Figure 14. Palmgreen and Rayburn's (1985) expectancy-value model of media gratifications sought and obtained (McQuail, 1994). (Redrawn by the author)

The Uses and Gratifications model is the opposite of the linear transmission model initiated by the sender: communication is initialized by an active receiver that requests information. The receiver demands that information because he wants to use its content as a tool to satisfy his desires. The communicator is challenged to meet the expectations of the receiver. Important theorists here are Rosengren and Blumler and Katz. Whereas the linear transmission models claim the communicator to be the only initiator of communication, the linear Uses and Gratifications model stresses that the receiver is the primary actor. However, it accords too little significance to the status of the communicator and downplays the role of their innovation character.

The Uses and Gratifications model points to the receiver as constituent for the communication process.

Dynamic Transaction Model

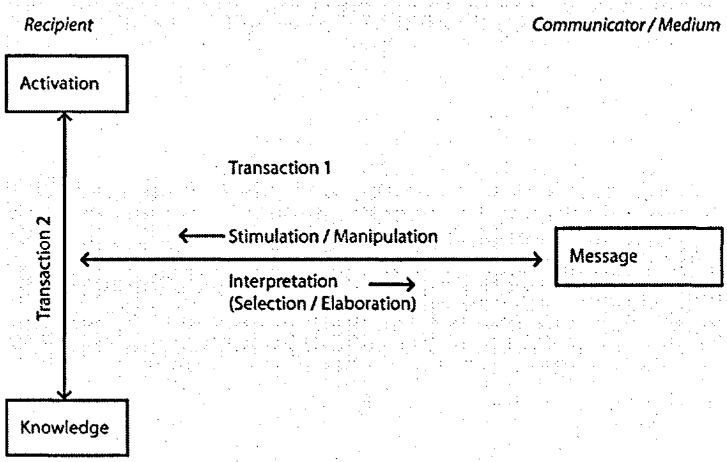

Figure 15. The Dynamic transaction Model in (Schenk, 2002). (Redrawn by the author)

In *Communication Sciences* the Dynamic Transaction Model (Figure 15) depicts a first attempt to combine the advantages of different viewpoints: Scientist like Bauer or Früh and Schönberg are not satisfied with the above models. They claim that all models have some truth, but none is complete. Therefore they connect them into one whole. The following quote rapidly makes their scope clear: *"In any natural media situation, individual receivers will choose which stimulus to attend or to avoid, will interpret its meaning variably and will react or not behaviourly, according to choice."* (McQuail, 1994). There are two dynamic transactions embedded in this model. An inter-transactional exchange occurs between the communicator and the receiver (Transaction 1). When the receiver tests and processes the new information internally to its past knowledge, this is the notion of intra-transaction (Transaction 2). The model thus clearly shows interaction between the communicator and the receiver, therefore one can consider the model a cycle. It also places value on the contexts of both the communicator and the receiver. The Dynamic Transaction Model combines an active dynamic communicator with an active dynamic receiver.

Conclusion

The six models presented were the basis for developing the Knowledge Visualization Model, which summarizes the transfer of complex information by use of complementary visualization and is described at the end of this thesis.

3. HYPOTHESES

3.1 Premises

The argumentation to prove and reject the hypothesis that complementary visualizations improve the transfer of knowledge is based on two premises: First, that knowledge can be transferred among individuals. Second, that an individual visual representation can help to transfer knowledge among persons. Architects use different visualization types for the transfer of knowledge.

3.2 Theoretical Hypotheses

This thesis investigates three ***theoretical hypotheses.*** In contrast to empirical hypotheses that can be proved or disproved by testing specific parameters, a theoretical hypothesis is more general and cannot be tested in a single experiment. A theoretical hypothesis may also be understood as a proposition. To prove and disprove the theoretical hypothesis, I refer to findings from other researchers and to my own data from the four case studies. In some of these case studies empirical hypotheses for specific situations were tested and evaluated. Together, the arguments from the literature and the findings from my own empirical evaluations allowed me to prove and disprove the theoretical hypotheses. It is important that the hypotheses investigate the potential of ***complementary visualizations*** rather than of an individual visualization. Complementary visualizations means the use of different visualizations that complement one another.

The theoretical hypotheses that are being investigated are:

1. The methods of architects to use *complementary visualizations* can be adapted to non-architectural domains, e.g., organizations.
2. The use of *complementary visualizations* improves the transfer of knowledge in organizations compared to an individual visualization, text, or numbers.
3. There is an optimal number of *complementary visualizations* for different knowledge transfer tasks.

Apart from these hypotheses, I tried to investigate and answer different research questions.

3.3 Research Questions

The research questions that are being examined in this thesis are:

1. *What is Knowledge Visualization?* The pyramid of data, information, and knowledge is a commonly used classification. Data visualization and information visualization exist, but when I started this thesis the term *Knowledge Visualization* did not exist. I tested diverse search engines on the internet in vain[8]. This gap was the starting point for my thesis. I wanted find out what Knowledge Visualization could be, to define Knowledge Visualization, and to establish Knowledge Visualization as a new research direction in business knowledge management. To do so, I needed to acquire the methods of scientific working and to study in depth the related literature in knowledge management, information visualization, and visualization sciences.

2. *Why does no established visualization taxonomy exist yet?* I studied the literature on visualization research. Various classifications do exist, but none of these is established. Can I create such a framework? Can the framework bridge the isolated fields and reveal synergies? Is it possible to systemize the fields so that visualization research is easier to grasp? This still missing framework should motivate visualization researchers to collaborate and overcome the situation, in which isolated visualization researchers fight each other and make it difficult for non-expert users to get an overview on this domain. To do so, I developed the framework for Knowledge Visualization.

3. *How can communication in organizations be improved when the stakeholders have different backgrounds?* Interfunctional communication - the communication between persons from different backgrounds and functions - interests me since I worked at Credit Suisse. Later at IBM, one specific visual metaphor allowed me to successfully communicate the business offerings to individuals with different backgrounds (such as staff, sales people, and customers), but I was interested to measure the effects in real-world scenario. To do so, I invented, implemented, and evaluated a new visual metaphor for the interfunctional communication of a project in an organization. This evaluation is described in the first case study: The Tube Map Visualization.

4. *Why does no effective search approach for the visual exploration of digital libraries exist? And what should it look like?* If we have an innate potential to exploit visual representations (e.g., to detect patterns) why

[8] For example, google.com, yahoo.com, lycos.com came up with no results.

does no effective search approach exist that allows digital libraries to be visually explored? If such an approach does not exist, how should it ideally look? And if even two or more individual visualization approaches exist, how would these visualizations be used complementary in a tightly coupled interface for the exploration for digital libraries? To do so, I developed and implemented an application that allowed such a new approach to be tested. The application finally allowed documents in a digital library to be explored, identified, evaluated, and disseminated. This application is described in the second case study: Metaview.

5. *How can architects improve communication with decision makers?* Architects are experts in the use of visual representations for the transfer of knowledge. However, they only use a limited set of visual formats. And there is an unwritten law to not use certain visualization types, such as conventional business diagrams as bar charts, line charts, decision trees, and other types. However, these diagrams are established among business decision makers. I wondered whether the transfer of knowledge to decision makers can be improved when architects use their visualization methods together with conventional business diagrams. To do so, in several real world situations I used these types complementary to the established formats. This potential for architects is described in the third case study: BKV4A (Business Knowledge Visualization for Architects).

6. *If the use of complementary visualization makes sense, is there something like an optimal number of complementary visualizations?* I tried to address, in one project, all items from the four perspectives from the Knowledge Visualization Framework. This allowed me, firstly, to get insights on the optimal number of complementary visualizations. Second, I was able to figure out which are the most promising combinations of formats. Third, I could get a feeling for the cost-value ratio of the use of complementary visualizations. To do so, I implemented all types in one real world project which is described in the fourth case study: Science City ETH.

7. *What are the benefits of visualizations?* I wanted to find out *why* a picture is worth a thousand words. To do so, I needed to understand our innate mechanisms for processing visual stimuli in the brain. Therefore I studied our visual system and investigated the related fields in the domains of neurosciences and cognitive psychology. Furthermore, I collected and structured arguments from literature to prove the hypotheses.

8. *What are the limitations of the use of complementary visualizations?* Because I am convinced that the use of complementary visualizations helps to transfer knowledge, I tried to also prove the opposite, the situation where the use of complementary visualizations leads to

distraction, misinformation, misinterpretation, or confusion. To do so, I collected and structured arguments that reject the hypotheses.

9. *Can the findings be generalized to a Knowledge Visualization Model?* If the various findings prove that complementary visualizations improve the transfer of knowledge, can the elements that contribute most to a successful transfer of knowledge be isolated and relationships be defined to a general model, a model for the use of complementary visualizations to improve the transfer of knowledge? To do so, I studied the communication science models and created as a synthesis of the dialectic discourse a model that complements the communication science models and that is ready to use by practitioners.

What is the relevance of these questions for architects? If architects are experts in the use of complementary visualizations, and if the use of complementary visualizations can be adapted to organizations and indeed improves the transfer of knowledge in organizations, then this would be a new job opportunity and value proposition for architects who do not want to work in architecture. If we look up the employment statistics of graduate architects, many of the graduates are not working in the architecture market anymore three or more years after the diploma. For them this new field can be helpful, because they can relate to it, instead of trying to explain one's individual strength. Therefore the new field Knowledge Visualization has importance for architects and should be an integral part in the education of future architects.

3.4 Focus and Periphery

3.4.1 Focus of the work

The focus of the thesis is to prove that complementary visualizations help to transfer knowledge among different individuals or stakeholders in organizations. The work aims to be *analytical*, thus to analyze and evaluate the chances of existing visualization methods, rather than inventing new visualization methods. The work aims to be *synthetical*, thus to derive a theoretical framework and a theoretical model. The work aims to be *dialectic*, thus to discuss arguments that prove and arguments that reject the hypotheses. Finally the work aims to be *original*, i.e., to make new contributions by establishing the new field Knowledge Visualization in the context of business knowledge management.

3.4.2 Periphery of the current work

Several subjects and fields were investigated peripherally to this thesis:

Visual Perception. One initial interest was to combine findings from information visualization and neuroscience, therefore I investigated related fields on visual image processing in the human brain. For me, as an architect, this field was difficult to enter, because it requires both a medical and psychological background. Nevertheless, I increasingly believed that it is important to the field of information visualization. However, I found that the work was already done, i.e., by Ware (2000) who is an expert in both domains.

Knowledge Creation. Knowledge management investigates various processes, however, I focused only on one process, the process of knowledge transfer (among individuals, among individuals from different backgrounds, among individuals and digital systems, and among different stakeholders. But, the use of visual representations can also improve other processes, e.g., the creation of new knowledge in groups by using visual representations. This aspect is very important but not the focus of this thesis.

Virtual reality, information art, information architecture. Both in my architectural studies and the training in architectural offices, I was fascinated by the qualities, chances, and challenges of virtual architecture, digital spaces for social interaction, and new ways to visualize complex issues. However, in this thesis I wanted to be analytic, synthetic, and solution-oriented, rather than option-oriented. I was not interested to invent another new visualization method, but to identify existing problems and to try to solve these problems by using the existing body of knowledge. Also, I was interested in measurable results, empirical evaluations, and a scientific argumentation, rather than proposing novel creative visualization methods for others.

Knowledge Transfer among Scientific Disciplines. The subject of investigation concentrates on knowledge transfer processes in real business situations and organizations, rather than knowledge transfer processes among scientists from different fields (e.g., the transfer of knowledge between an architect and a chemical engineer). The first reason for this is that the knowledge management literature I refer to mostly examines business knowledge management, and secondly that Knowledge Visualization in business situations were more challenging for me because various different stakeholders are involved.

4. KNOWLEDGE VISUALIZATION FRAMEWORK

First, this section illustrates why a new framework is important. Second, it presents a new visualization type taxonomy that is derived from the analysis how architects use visualizations to transfer and create knowledge. Third, it introduces three other decisive perspectives that complete the framework.

4.1 The Need for a Knowledge Visualization Framework

Three arguments make clear that a framework for Knowledge Visualization is necessary:

First, visualization research is not integrated into the context of communication sciences. In visualization research, the role of the recipient is not studied enough. However, for the transfer of knowledge the recipient plays the major role and therefore requires major attention. Successful visualizations need to be customized to the cognitive background of the recipient in a way that the recipient can re-construct knowledge as intended by the sender, on his own.

Second, visualization research is not integrated into knowledge management research. Knowledge management research distinguishes different knowledge types. Today's visualization research focuses primarily on one knowledge type (information, facts). Eppler (2004b) discusses this point: *"Apart from facts (to answer questions as what? who? when? how many?) knowledge communication needs to further transfer insights (to answer questions as why? and how?), experiences, attitudes, values, premonitions, perspectives, opinions, and predictions, in a way that the recipient can re-construct similar knowledge, as the sender intended"*[9].

Third, visualization research needs a general framework to mediate between the different isolated research areas that were introduced in the related work, for example information design (Bertin, 1967, Tufte, 1990), information visualization (Card, et al., 1999), cognitive art (Horn, 1998), information architecture (Wurman, 1996), graphics design, or advertising.

Therefore a mediating framework is needed. The framework should describe a mutual visualization taxonomy that can be understood both by practitioners and researchers. I found that structuring the way architects

[9] Translated by the author

use visual representations for the transfer of knowledge is promising for this yet missing simple taxonomy.

4.2 The Seven Visual Representations of Architects

This section presents the seven main visualization types that architects use, namely: Sketches, diagrams, plans, images, models, interactive visualizations, and stories. Each type is discussed next.

Sketch

A sketch, as seen in Figure 16, is defined as: "*Traditionally a rough drawing or painting in which an artist notes down his preliminary ideas for a work that will eventually be realized with greater precision and detail.*"[10] A sketch represents the main idea and key features of a preliminary study. Sketches are atmospheric, fast and universally accessible. Sketches help to quickly visualize an idea.

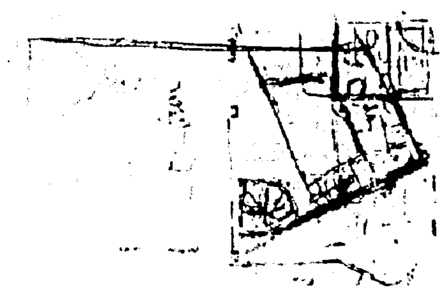

Figure 16. This sketch by Le Corbusier outlines the concept of a new building. [11]

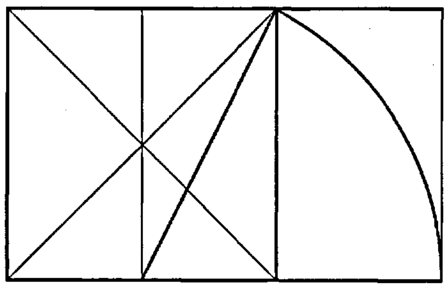

Figure 17. This diagram represents the construction of the Golden Section.

Diagram

Garland defines a diagram as a "*visual language sign having the primary purpose of denoting function and/or relationship*" (Garland, 1979). A diagram, as seen in Figure 17, is an abstract, schematic representation used to explore structural relationships among parts. Architects use diagrams to explain concepts and to reduce complexity.

[10] Sketch. Encyclopædia Britannica. Retrieved August 4, 2003, from Encyclopædia Britannica Premium Service. http://www.britannica.com/eb/article?eu=69864

[11] Retrieved August 4, 2003, http://www.strath.ac.uk/Students/Architecture/ciam/ciam1.html

Map
An architectural plan (Figure 18) presents an entity on a different scale. Drawings, like sections and plans, belong to this category. The floor plan of a building can show details like the thickness of a wall, whereas a plan in the urban scale might depict a house simply as the footprint of the building. Depending on the scale, architects start speaking of a map rather than of a plan. Maps generally have a scale, that determines the size of an object represented on the map in relation to its actual size. But some maps are not scaled, for example Subway maps. Geographic maps further bring three-dimensional inferences to a two-dimensional visualization surface. The features on a map depend according to the map's purpose: a road map presents roads, whereas a tube map shows the tube system.

Image
Kemp defines images as, "*representations which are primarily concerned with impression, expression or realism.*" (Kemp, 2000). An image (Figure 19) can be a rendering, a photograph, or a painting. In the context of mass-media, Doelker (1997) distinguishes different functions of images: they can be "*registrative, mimetic, simulative, explicative, diegetic, appellative, decorative, phatic, ontic or energetic*"[12].

Model, Object
Physical models (objects) bring together architectural plans and sections and enable a project to be seen from different perspectives. Physical models allow materials to be experienced and the design of complex buildings to be controlled (Figure 20).

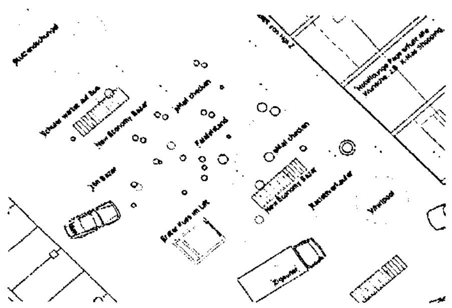

Figure 18. A plan or a map shows structural relationships and details in a different scale. E.g., the urban scale or the scale of a floor plan.

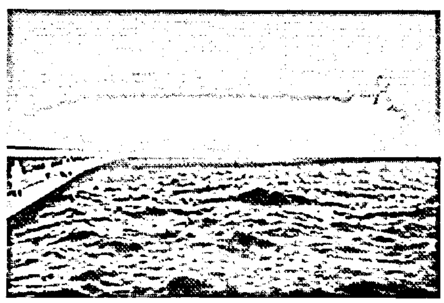

Figure 19. An atmospheric image of the "blur building" addresses emotions.[13]

[12] Translated by the author.

[13] Retrieved August, 2003, http://www.strath.ac.uk/Students/Architecture/ciam/ciam1.html

Interactive Visualization

Interactive visualizations are computer-based visualizations that allow users to control, combine, and manipulate different types of information or media. Figure 21 illustrates an interactive three dimensional interface that visualizes the data of the New York Stock Exchange, which we introduced in the related work.

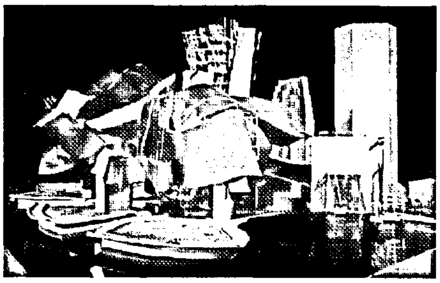

Figure 20. A physical model by Gehry helps to show relationships among parts. [14]

Figure 21. An interactive visualization allows supervising the New York Stock Exchange.[15]

Vision, Story

The last type is also different from the above because it is a non-physical type. Visions or Stories are imaginary, mental visualizations. Architects often imagine scenarios of potential influences of a new building or urban intervention. These visions help to discuss the ideas and concepts by externalizing them with stories or verbalized thoughts.

This section presented the seven main visualization types architects use: Sketches, diagrams, plans, images, models, interactive visualizations, and visions or stories. During this work the findings in the literature and the evaluation of the four case studies made clear that these types can also be adopted to transfer non-architectural contents, e.g., in organizations. But successful knowledge transfer demands three additional perspectives that need to be considered. Together these four perspectives build the Knowledge Visualization Framework which is discussed next.

4.3 Knowledge Visualization Framework

For an effective transfer and the creation of knowledge through visualizations, four perspectives (Figure 1) should be considered. They are based on four questions:

[14] Retrieved August 4, 2003, http://www.thecityreview.com/gehry.html

[15] Retrieved August 4, 2003, http://www.asymptote.net

- Why should knowledge be visualized? (aim)
- What type of knowledge needs to be visualized? (content)
- Who is being addressed? (recipient)
- What is the best method to visualize this knowledge? (medium)

These key questions lead to the Knowledge Visualization Framework as seen in Figure 21:

FUNCTION TYPE	KNOWLEDGE TYPE	RECIPIENT TYPE	VISUALIZATION TYPE
Coordination	Know-what	Individual	Sketch
Attention	Know-how	Group	Diagram
Recall	Know-why	Organization	Image
Motivation	Know-where	Network	Map
Elaboration	Know-who		Object
New Insight			Interactive Visualization
			Story

Figure 22. The Knowledge Visualization Framework consists of four perspectives that need to be considered when creating visual representations that aim to transfer knowledge: A **Function Type Perspective** answers why a visualization should be used, a **Knowledge Type Perspective** clarifies the nature of the content, a **Recipient Type Perspective** points to the different backgrounds of the recipient/audience, and finally the **Visualization Type Perspective** structures the main visualization types according to their individual characteristics.

4.3.1 Function Type Perspective

The *Function Type Perspective* distinguishes six functions of visual representations that can be exploited. The social, emotional, and cognitive benefits of visualizations can be summarized in the CARMEN-Acronym (Eppler and Burkhard, 2005):

- *Coordination.* Visual representations help to coordinate individuals in the communication process (e.g., knowledge maps, visual tools for collaboration, heuristic sketches). Social benefit.
- *Attention.* Visual representations get attention by addressing emotions (e.g., advertising) and keep attention (e.g., sketching on a flipchart) by identifying patterns, outliers, or trends (e.g., information visualization). Cognitive benefit.
- *Recall.* Visual representations improve memorability, remembrance and recall because we think in images (e.g., visual metaphor, stories, conceptual diagrams). Cognitive benefit.
- *Motivation.* Visual representations inspire, motivate, energize, and activate viewers (e.g., knowledge maps, mutual stories, instructive diagrams). Emotional benefit.

- *Elaboration.* Visual representations foster the elaboration of knowledge in teams (e.g., discussing scenarios of a new product by using heuristic sketches or a physical model). Cognitive benefit.
- *New Insights.* Visual representations support the creation of new insights by embedding details in context and showing relationships between objects (e.g., information visualization) or lead to a-ha effects (e.g., visual metaphors). Cognitive benefit.

4.3.2 Knowledge Type Perspective

The *Knowledge Type Perspective* aims to identify the type of knowledge that needs to be transferred. Such different types of knowledge are investigated in the field of knowledge management. For the framework, five types of knowledge are distinguished: Declarative knowledge (Know-what, e.g., facts), procedural knowledge (Know-how, i.e., knowing how things are done, which is captured in processes, norms of behavior, standards of practice, settings of equipment), experimental knowledge (Know-why, i.e., knowing why things occur which captures underlying cause-and-effect relationships and accommodates exceptions, adaptations, and unforeseen events), orientational knowledge (Know-where, i.e., knowing where information can be found, e.g., knowledge sources, libraries, databases), individual knowledge (Know-who, i.e., knowing who are the experts). Today, no classification exists that links visualization types to knowledge types.

4.3.3 Recipient Type Perspective

The *Recipient Type Perspective* aims to identify the target group and the context of the recipient. The recipient can be an individual, a team, a whole organization, or a network of persons. Knowing the context and the cognitive background of the recipient/audience is essential for finding the right visualization method for the transfer of knowledge. Today, graphic design and information visualization (Bertin, 1967, Tufte, 1990, Tufte, 1997) do not focus on this perspective.

4.3.4 Visualization Type Perspective

The *Visualization Type Perspective* structures the visualization methods into seven main groups that are derived from the architectural practice in visual knowledge transfer. The seven types are: Sketches, diagrams, images, maps, objects, interactive visualizations, and stories.

Sketches represent the main idea, are atmospheric, and help to quickly visualize an idea (Figure 23 and Figure 24). Sketches are used to assist the group reflection and communication process by making knowledge explicit and debatable.

For the transfer and creation of knowledge, sketches have five strengths: (1) sketches represent the main idea and key features of a preliminary study and support reasoning and arguing. (2) They are atmospheric, versatile, and universally accessible. (3) Sketches are rapidly created, and help to quickly visualize an idea. (4) They keep the attention (e.g., the use of a pen on a flipchart attracts the attention towards the communicator). (5) Sketches allow room for own interpretations and foster the creativity in groups.

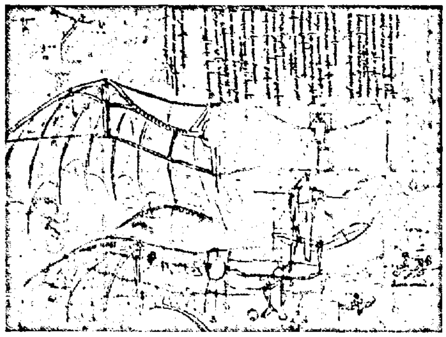

Figure 23. A sketch from Leonardo da Vinci represents the main idea of a new concept.[16]

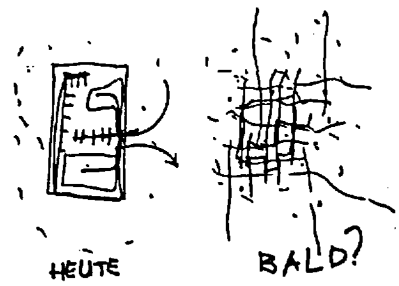

Figure 24. Various sketches helped to assist the group reflection processes in a workshop for new ideas.[17]

In contrast, **Diagrams** are abstract, schematic representations used to explore structural relationships among parts by denoting function relationship (Figure 25). The type of knowledge that is being conveyed by diagrams is analytic. Diagrams are therefore structured and systematic.

For the transfer and creation of knowledge, diagrams help to make abstract concepts accessible, help to reduce complexity, amplify cognition, explain causal relationships, reduce the complexity to the key issues structure, and display relationships.

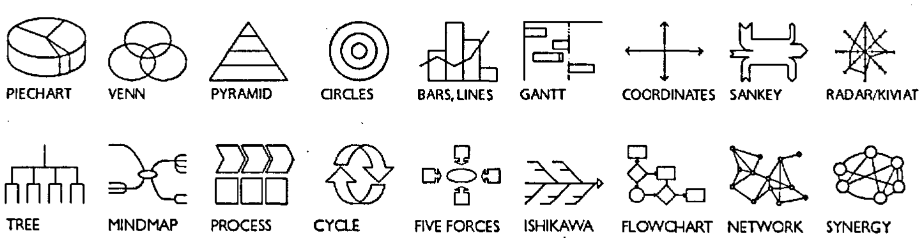

Figure 25. Diagrams are schematic depictions of abstract ideas which use standardized shapes to structure information and illustrate relations.

[16] Retrieved on the 20th of august 2004 from http://www.visi.com/~reuteler/vinci/fly3.jpg

[17] Science City ETH: http://www.sciencecity.ethz.ch

Apart from such diagrams new types of diagrams are currently being developed for the transfer and the creation of knowledge in teams, again by architects and urban planners. When it comes to complex factors, such as social, cultural, or economic factors in urban planning, the diagrams discussed above are not suitable to create new insights and to transfer such insights, therefore architects and urban planners were forced to develop new types of diagrams that allow a higher complexity to be illustrated or more variables in a single diagram to be represented. Today, almost every leading architecture or urban planning office[18] in the world has developed its own visual diagramming language for knowledge-intense processes or complex contents.

I am convinced that such new conceptual diagrams will claim an important and integral type of diagrams in future organizations, e.g., in business plans, business analysis (e.g., competitor or market analysis), or to illustrate business strategies.

Maps follow cartographic conventions to reference knowledge. A map generally consists of two elements: A ground layer which represents the context (e.g., a network of experts, a project, a city) and individual elements (e.g., experts, project milestones, roads). In the context of knowledge management, maps are called knowledge maps. They illustrate both an overview and details, and interrelationships among these details. Thus knowledge maps are graphic directories of knowledge-sources, -assets, -structures, or -processes. However, knowledge maps can also be fictitious and address visions or stories, for example to establish a mutual context in an organization. Figure 26 presents a fictitious map that improved interfunctional communication of a complex project in an organization, based on the power of visual metaphors. The Tube Map Visualization is discussed and evaluated in detail as one of the four case studies.

For the transfer and the creation of knowledge, maps help to present overview and detail, help to structure information, to motivate and to activate employees, to establish a common story, and to ease access to information.

[18] Examples: Asymptote Architecture (www.asymptote-architecture.com), Morphosis (www.morphosis.net), MVRDV (http://www.mvrdv.archined.nl), The Office for Metropolitan Architecture OMA with its research department AMO (www.oma.nl), Eisenman Architects, (www.eisenmanarchitects.com) or the UN Studio (www.unstudio.com).

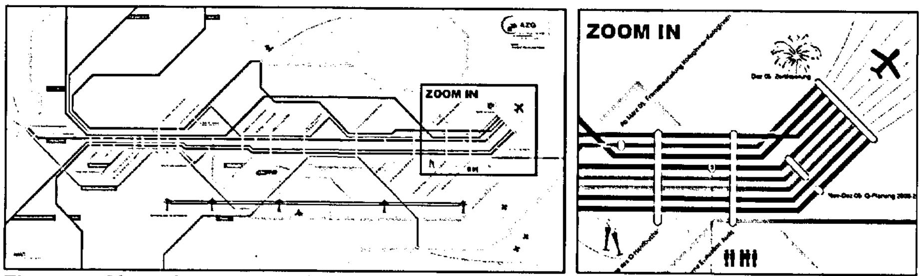

Figure 26: The Tube Map Visualization is a fictitious map transferred into a business context to improve interfunctional communication of a complex project. The ground layer used the metaphor of a subway system, shown as a tube map. The individual elements are subway lines (=target groups) and project milestones (=stations).

Images are impressive, expressive, or represent reality. Images address emotions and are inspiring, appealing, motivating, and energizing. Thus, they are widely used as a key instrument for advertising (Figure 27). Images can be grasped and recalled in less than a second and sometimes be remembered for decades (i.e., key images of the war in Vietnam or Iraq). The same effects can be used for the transfer of business related knowledge, e.g., by using visual metaphors (Figure 28). *"To convert tacit knowledge into explicit knowledge means finding a way to express the inexpressible. Unfortunately, one of the most powerful management tools for doing so is also among the most frequently overlooked: the store of figurative language and symbolism that managers can draw from to articulate their intuitions and insights."* (Nonaka, 1991). Visual metaphors support remembrance, lead to a-ha effects, and support reasoning and communication. They are instant and rapid, highly instructive, and facilitate learning. Eppler (2003a) discusses the potential of visual metaphors, and shows that in social sciences and philosophy various authors have proven that metaphors are an ancient and powerful tool to transfer insights.

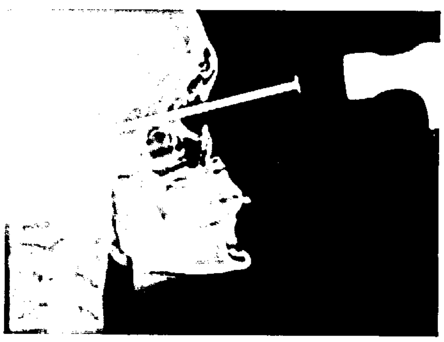

Figure 27. Images address emotions and are widely used in advertising.[19]

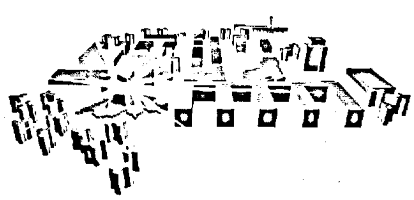

Figure 28. Images can clarify complex projects and motivate different stakeholders.[20]

[19] Image for a seminar on the effective use of visualizations: http://www.2sekmanager.ch

For the transfer of knowledge, images help get attention (e.g., advertising), inspire recipients (e.g., art), address emotions (e.g., advertising), improve recall (e.g., signs, visual metaphors), and/or initiate discussion (e.g., satirical comic).

Objects in Space exploit the third dimension and allow materials to be experienced. Objects in space are helpful for example for information points (Figure 29), knowledge fairs, or exhibitions (Figure 30), to complement physical and digital visualizations and to show the content from different viewpoints.

For the transfer of knowledge, objects help to attract recipients, support learning through constant presence, and/or allow integrating digital interfaces.

Figure 29. Objects in this Info-Structure attract people.[21]

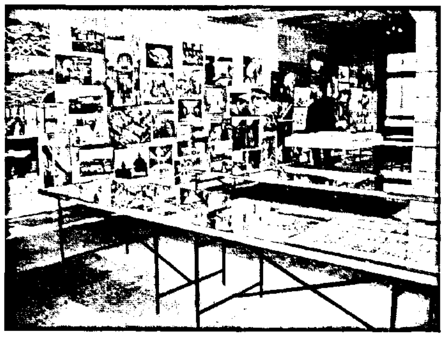

Figure 30. Objects and images complement each other, e.g., in an exhibition.

Interactive Visualizations allow the user to access, explore, and make sense of different types of information. An example of a visualization application (Figure 31) allows the data of a survey on the project Science City ETH to be explored. This application allows the results set to be filtered by using different sliders and is based on previous work, e.g., described in (Brodbeck and Girardin, 2003a). Another application, the Infoticle application (Vande Moere, et al., 2004), uses data-driven particles (*Infoticles*) to explore large time-varying datasets with reoccurring data objects that alter in time in an immersive environment (Figure 32). The animation of these Infoticles displays the behavior of individual data entries or the global context of the whole dataset.

To transfer knowledge, interactive visualizations help fascinate people, enable interactive collaborations across time and space and allow complex data to be represented and exploreed, or to create new insights.

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[20] Science City ETH: http://www.sciencecity.ethz.ch

[21] Figure 29, Figure 30: Science City ETH: http://www.sciencecity.ethz.ch

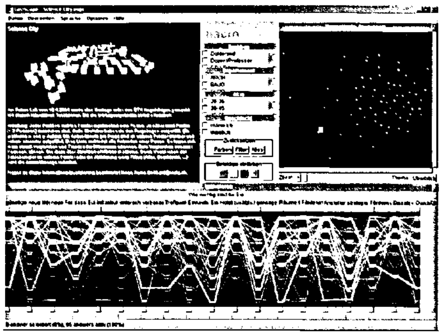


Figure 31. An interactive visualization of a survey based on the method described in (Brodbeck and Girardin, 2003a) allows to get new insights.[22]

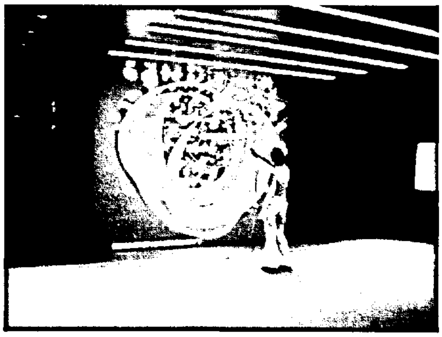


Figure 32. The Infoticle application allows to explore large time-varying datasets in an immersive environment (Vande Moere, et al., 2004).[23]

Stories, the last visualization type, are imaginary (not physical) visualizations that are efficient in transferring and disseminating knowledge across time and space. The use of stories (=storytelling) allows an illustrative mental image to be transported by using spoken or written language, and can be used in organizational practice (Loebbert, 2003).

To transfer knowledge, imaginary visualizations complement the other six visual formats and are valuable to establish a shared vision, a mutual story, which motivates and activates individuals.

[22] http://www.macrofocus.com
[23] http://blue-c.ethz.ch

5. FOUR CASE STUDIES

To test the framework and to evaluate different scenarios, four case studies are presented. First, I present an overview on these four case studies.

5.1 Overview on the Case Studies

Table 1. The four case studies test in different scenarios the Knowledge Visualization Framework. Each case study derives own empirical data.

TYPES	METAVIEW	TUBE MAP	BKV4A	SCIENCE CITY ETH
Function Type	Attention Elaboration New Insight	Coordination Attention Recall Motivation	Coordination Motivation Elaboration New Insight	All types
Knowledge Type	Know-What Know-Who Know-Where	Know-What Know-Why Know-Who	Know-What Know-Why Know-How	All types
Recipient Type	Individual	Organization	Group	All types
Visualization Type	Interactive Visualization	Map	Diagram	All types
Evaluation	User studies	Questionnaire	Expert Interviews	Expert Interviews

The questions that are being tested in the individual case studies are discussed in the following sections:

Metaview

Metaview presents a new approach for visual document search in digital libraries. With an increasing amount of digital documents, new search strategies become decisive. In the past, traditional libraries allowed open access to the books. This gave the users an overview of the books available. Today users explore libraries with computer-based interfaces. They facilitate keyword searches, but the users lose the overview. Studies show that users miss the overview in digital collections.

Metaview presents a visual overview of a digital library that can be filtered through keywords and other metadata and facilitates exploratory tasks (e.g., the analysis how the collection evolved over time) or top-down searches. The system complements today's text-based retrieval approaches; the framework integrates and structures isolated research results.

Metaview combines a collection overview with query-driven filtering to facilitate the exploration and retrieval of digital information. The hypotheses I test in this case study are: (1) Static collections: Users can benefit from this approach in static collections where no new documents are added. (2) Dynamic collections: Users have no difficulties orienting themselves in growing collections. (3) The new approach is complementary to classical information retrieval mechanisms and extends information retrieval in digital document collections and e-libraries, namely for the identification, evaluation, and dissemination of externalized knowledge.

Tube Map Visualization

The Tube Map Visualization is a visual metaphor for interfunctional communication of projects, e.g., where different stakeholders are involved. In an education centre for health care professionals, a quality development process needed to be established. Traditional project plans, flyers, and mails did not manage to get attention, to present overview and detail, and to motivate the employees for action. Because visual metaphors are effective for knowledge communication, I developed a customized format based on the tube system metaphor. The Tube Map Visualization illustrates the whole project: Each tube line represents a target group, each station a project milestone. The visualization was printed on posters and located at lively locations in the organization.

The Tube Map Visualization is a visual format that *complements* traditional Gantt charts, that are used as visual formats in projects. The evaluation with a questionnaire and interviews tested if a map improves the transfer of knowledge in a real-world situation. More specifically I tested whether: (1) the tube system metaphor improves understanding rather than leading to inferences (like misinformation, misunderstanding, miscommunication), (2) knowledge maps can be applied to non-architectural contexts, as quality development projects, (3) visual metaphors have a measurable impact in the communication of projects among employees from different backgrounds in an organization, (4) the pull-processes of employees are provoked by the map, and (5) the knowledge maps have social and cultural effects that can result in a higher motivation for the project.

The evaluation showed that the Tube Map Visualization is a powerful metaphor to communicate a complex project to different target groups and to build up a mutual story. The employees considered it useful, because it provides an overview and detailed information in one image and initiates discussion.

Business Knowledge Visualization for Architects (BKV4A)

Architects use complementary visualizations for the transfer of knowledge. But they do rarely use conventional but established business diagrams in the same way decision makers use them. This gap results in an ineffective knowledge transfer between architects and decision makers. I tested in this case study whether these business diagrams can be integrated into the visualization method alphabet of architects to improve the transfer between architects and decision makers. The real world scenario made clear that the combination of the formats resulted to a considerably improved communication and knowledge transfer, with a higher engagement of the decision maker in the presentations. These insights are therefore important for the education of future architects.

Science City ETH
In this case study I combined all visualization types I discussed in the Knowledge Visualization Framework and tried to figure out the potential and limitations of the individual visualization method. Furthermore, I tried to find rules for the best sequence of using them. This case study helped to refine the Knowledge Visualization Model and to derive the *Inverse U* for complementary visualizations discussed together with the Knowledge Visualization Model.

5.2 Metaview: Visual Document Search in Digital Libraries

This case study introduces a conceptual framework for the visual exploration of digital libraries and an implementation of such a system. A user study indicates that the system is promising for exploratory tasks and complements traditional keyword searches.

Situation
Current information retrieval paradigms can be divided in two major classes: *query-driven systems* and *data-driven systems* (Kleiboemer, et al., 1996). Query-driven systems return potentially interesting documents to a query provided by the user. Data-driven systems provide a task and query independent structuring of the collection which can be navigated. Conventional information retrieval systems are query driven, while systems that provide a topical taxonomy of the collection are data-driven.

Goal
I found no system that systematically combines both retrieval paradigms. Therefore I developed a complementary visualization approach where I combined the two retrieval paradigms into one system. Unlike the first case study where two different visualization types were used *complementary*, in this application the different visual representations are *coupled*. That means that changes in one visualization automatically modify the other visualizations in the interface and, in that way, help to explore the data.

Scientific contributions
The case study presents three contributions for the question of visual document search in digital libraries. First, I created a *framework for the visual exploration of digital libraries*, which is based on evaluation of the literature and my own studies. This holistic framework helps to structure the research in this field which today is isolated and distributed in different areas. It helps researchers in the fields of information retrieval, human computer interaction, and interface design to develop more effective and user-friendly documents retrieval systems. Second, to test the framework, I implemented a system for an existing digital library at the Swiss Federal Institute of Technology. Best current practices in information visualization

(Card, et al., 1999, Chen, 1999a, Ware, 2000) were integrated. Third, I conducted a qualitative user study to examine the effectiveness of my approach, study user behavior, and explore tasks and strategies for which my system could be useful. Two target groups were tested: managers and students. I found that the participants quickly understood the system, that both groups fulfilled the given tasks quickly and accurately, and that all participants considered the combination of a collection-overview and a query-driven filtering as effective and desirable. The participants indicated that the system is more suitable for exploratory tasks than traditional keyword searches. Participants liked seeing documents in context, revealing unforeseen relationships and the correspondence of size and color to meaning. Concluding, this case study introduces a system that combines a collection-overview with query-driven filtering as a complementary approach for exploratory tasks in digital libraries.

5.2.1 Related Work

In this section, I discuss evaluations of search result interfaces and implemented systems.

Evaluations of Search Result Interfaces

The need for improved search result visualization is described in an empirical study by Kleiboemer et al. (Kleiboemer, et al.). They evaluated the effectiveness of search result interfaces for novice users and compared a system with 2D graphical clusters, a system with 3D graphical clusters, and a system that shows textual clusters. Their findings indicate that only textual clusters are helpful.

Cugini et al. (Sebrechts, et al.) compared 3D graphical clusters, 2D graphical clusters, and textual clusters in a study with fifteen participants. Results for the time to locate targets: text clusters were fastest, next 2D graphical clusters and finally 3D graphical clusters. Anything involving text was faster with text. The spatial rotation in the 3D view led to a loss of the context. Visual features and color coding were considered as very helpful.

Chen et al. (Chen, et al., 1998) compared search tasks with Kohonen maps and Yahoo. Their results indicate that, starting with the Kohonen map, eight out of eleven participants could repeat the task in Yahoo. In contrast, starting with Yahoo, two out of fourteen participants could repeat the task in the Kohonen map. Among other things, in the map participants liked the correspondence of region size to the number of documents and the ease of jumping from one topic to another. Participants further wanted: (1) The integration of browsing and searching, (2) correspondence of color to meaning, (3) combined keyword and category search, and (4) hierarchical organization.

Systems
Various systems bring together the advantages of information visualizations and information retrieval technology. Nowell presents a list of such interfaces (Nowell, et al., 1996).

Envision (Fox, et al., 1993, Fox, et al., 2002), a digital library of computer science literature, provides an interface with several search result visualizations. It visualizes query-document similarity with relevance rank and estimated relevance of each document. However, Envision does not provide a collection overview with query-driven filters.

Chen illustrates how domain visualizations or visual co-citation analysis enable new ways of accessing scientific literature in digital libraries (Chen, 1998, Chen, 1999b, Chen, 2000) and describes various approaches for the mapping of scientific frontiers (Chen, 2003). His systems visualize linkage between the documents. Chen's approach is different from my problem formulation.

Sifer presents a visual multi-classification interface for the exploration of web site data (Sifer, 2003). The system enables fast and flexible exploration of the data. However, the system is not adapted for digital libraries and does not support query-driven filtering with different metadata.

Lin et al. contribute (Lin, et al., 2001, Lin, et al., 2003, White, et al., 2000) valuable research to the fields of associative search visualization and co-citation author maps. Their interfaces concentrate on the visualization of the immediate environment of the user, the query, related terms, and how they are related to each other. However, the systems do not provide an overview of the whole collection.

Klein et al. (Klein, et al.) present a coupled interface that offers intuitive search with a combination of a Scatter Plot and a Super Table. The system allows interactive filtering of collection overviews but does not fully exploit the correspondence of color and size to meaning and does not enable query-driven filtering.

Gridvis (Weiss-Lijn, et al., 2001) provides manually produced metadata for each paragraph or section level of a document. In a central grid, the metadata tags are assigned to the individual document sections. This creates a customized view of the document text. Gridvis is suitable for the *enhanced preview* which is described in the next section.

Roberts et al. present a multiple-view system with search result visualizations (Roberts, et al., 2002). Different glyph designs are used for visualizing the search result set. Several other search result visualizations for exploratory tasks exist, such as InfoSky (Kappe, et al., 2003) or information landscape (Weippl, 2001). None of these systems provide query-driven filtering of collection overviews.

From the analysis of the related work I found that first, a framework for visual exploration of digital libraries is missing, and second, that no system offers a collection overview with query-driven filtering. These findings were the basis for the Design Study.

5.2.2 Conceptual Framework for Visual Exploration of Digital Libraries

Based on the above and my own evaluations, I created the missing framework for visual exploration of digital libraries. I distinguished different types of metadata with relevance for exploratory tasks in digital libraries. Generally each document can be described with its unique properties as seen in Figure 33.

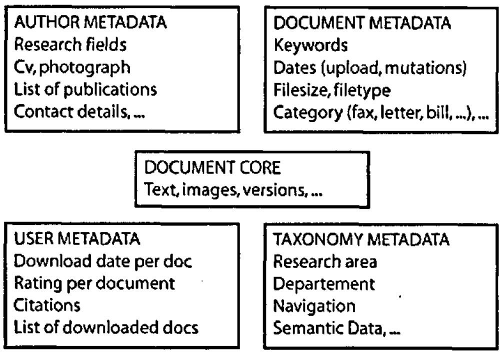


Figure 33. Relevant types of metadata for exploratory tasks in digital libraries.

Today's search methods concentrate on the "Document Core". I found that filtering collection overviews with other metadata (i.e., keywords, number of downloads, date) is a simple but effective strategy for the pre-selection of potentially interesting documents. Based on these types of metadata and the analysis of desires and current systems, I developed four views (View A-D) that facilitate exploratory tasks in digital libraries, as seen in Figure 34.

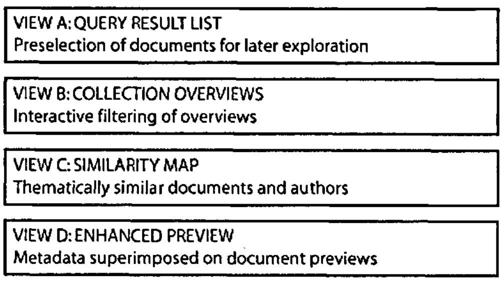


Figure 34. The Framework for visual exploration of digital Libraries couples four views that support specific exploratory tasks.

View A - Query result list: The query result set is presented in a list. Potentially interesting documents can be added to a selection list. Visual representations can be used to highlight keywords in the result set or to describe with a bar the potential relevance of a result. Example: Google[24].

View B - Collection overviews: This view allows a data-driven or top-down exploration of the library. The collection-overview presents the whole collection in one visualization and can be filtered with keywords and other metadata. This view combines the two retrieval paradigms: query-driven systems and data-driven systems. Example: Grokker (Groxis Inc., 2003).

View C - Similarity Map: Different interactive maps illustrate relationships between documents that are similar to one another, i.e., similar documents from different authors. Examples: Self Organizing Maps or Pathfinder Networks (Lin, et al., 2001, Lin, et al., 2003).

View D - Enhanced Preview: After using the Views A, B and C to pre-select potentially interesting documents, the user can evaluate one document after the other in the enhanced preview, as in a shopping cart. In this view relevant metadata is superimposed on the individual document, i.e., to highlight keywords in the document context or to visualize the structure of the document. Example: Gridvis (Weiss-Lijn, et al., 2001), Popout Prism (Suh, et al., 2002).

Coupling the Four Views: Ideally the four views are coupled (Ahlberg and Shneiderman, 1994) in a multiple-view interface. The individual views present the result set in manageable chunks and show the relevant metadata in the specific views. Coupled views ease cross-referencing among the different views and save the users work which reduces working memory load by allowing the user to switch between the views. Studies of multiple view visualizations (Baldonado, et al., 2000, Sutcliffe, et al., 2000) have shown improvement in user performance in various tasks, such as in the discovery of unforeseen relationships or improved user performance.

5.2.3 Design Study: Improving Text Based Search Interfaces

This section illustrates how an existing digital library at the Swiss Federal Institute of Technology (ETH) could be improved with this framework.

The Swiss Federal Institute of Technology has a digital library as seen in Figure 35. The collection currently consists of around 2500 documents in the pdf file format. The collection can be found at http://e-collection.ethbib.ethz.ch.

[24] www.google.com

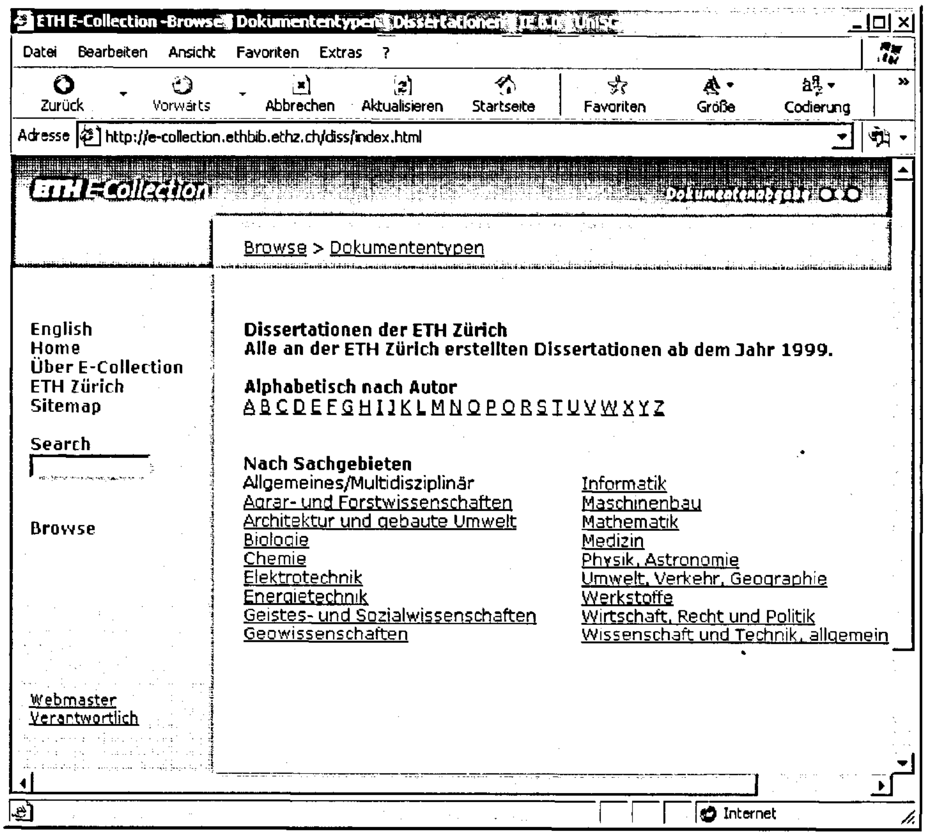


Figure 35. Today the ETH e-collection can only be explored with a keyword search and structured links. An overview is missing.

Problems: Information exploration in this interface has several weaknesses: (1) A collection overview is missing. (2) It is hard to find documents with similar content and identify relationships among research topics. (3) It is time-consuming to identify authors in the same subject area and to identify the research area of a specific author. (4) No additional metadata for the documents is provided. Solution: Applying the framework helps to improve the interface for exploratory tasks:

View A - Query Result List: In the result list (Figure 36), potentially interesting documents can be selected and added to the selection list which is located below the keyword field. The selection list saves the users work, and it enables the user to explore the documents in its context by switching to view B.

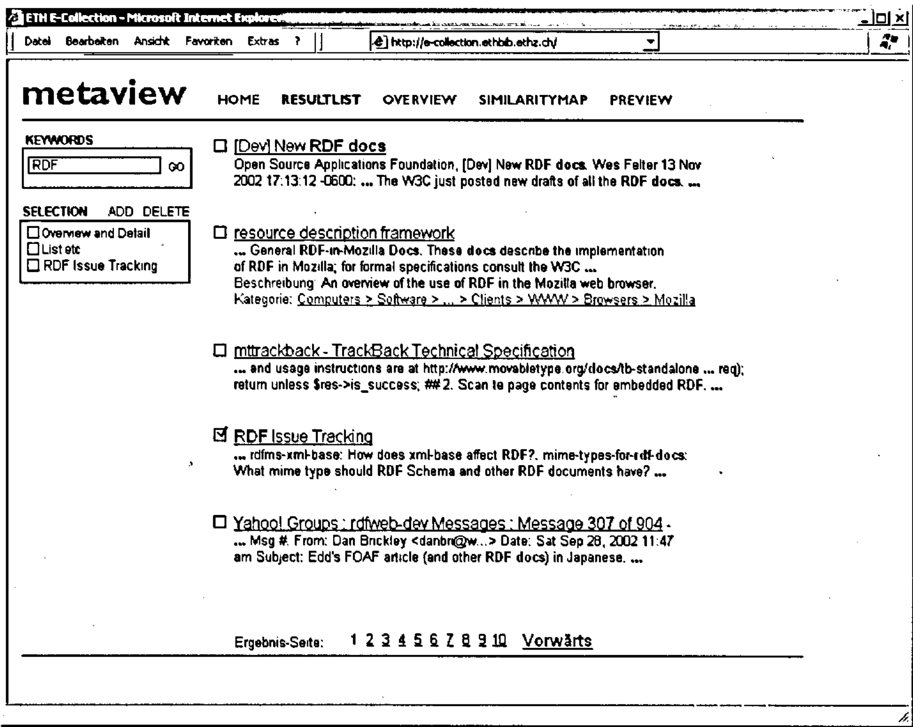


Figure 36. View A: In the result list interesting documents can be selected and added to a selection list.

View B - Collection Overview: For the collection overview, I have adapted an existing visualization method. I have chosen the tree map (Johnson and Shneiderman, 1991, Shneiderman, 1992) due to its wide acceptance, because it supports the principles of human perception and because the collection consists of a manageable number of documents (around 2500). In this tree map each rectangle represents one document. The hierarchy represents the organizational structure of the file system. The visualization is zoomable. Figure 37 presents the zoom-in to one area with around 100 documents. The interface is flexible and allows users to assign different metadata (i.e., number of downloads, rating per user, creation date, file size, etc.) to either the size or the color of the rectangles. In Figure 37, the size represents the number of downloads by different users; the color represents the user rating from 1 to 6. The filters on the left side allow the collection to be filtered with the metadata available. Filtered documents change the color to grey. In Figure 37, the user filtered the whole collection with the date by using the slider on the left side; pointing the mouse to one rectangle presents additional information (i.e., document title, age of the author, a graph of downloads over time...) in a tool tip. The overview can be further filtered by typing in keywords. By using keywords and filter sliders one can interactively reduce the numbers of potential interesting documents to a number that is manageable. Potentially interesting documents can be added to the selection list for further studies in the enhanced preview.

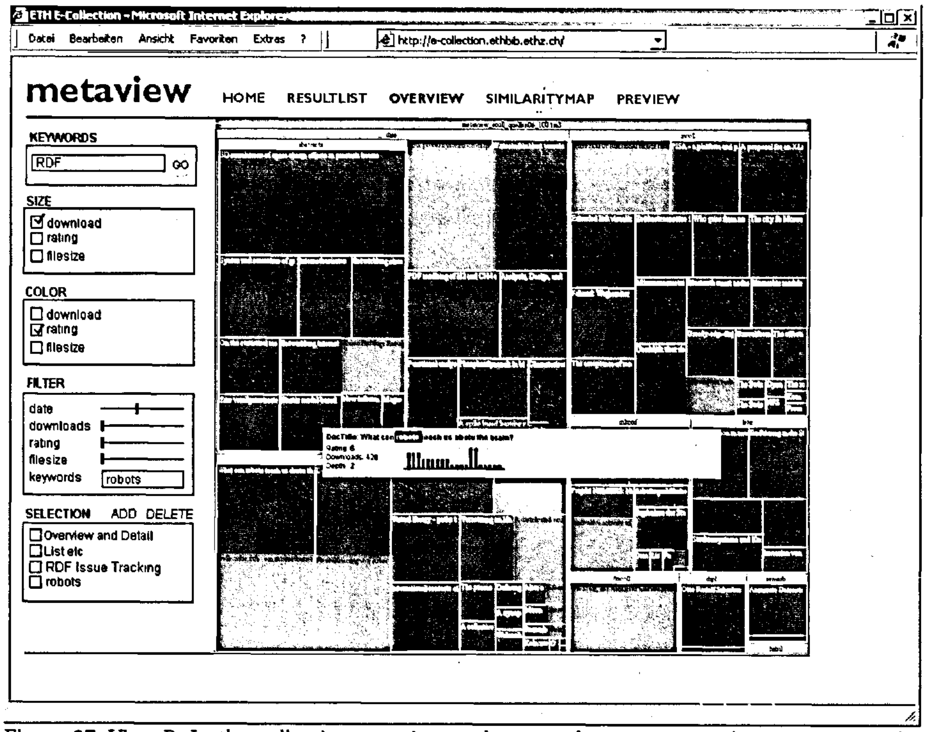


Figure 37. View B: In the collection overview each rectangle represents a document. Here the size represents the number of downloads, the color the user rating. A tool tip reveals information on the document.

View C - Similarity Map: An implementation of a similarity map or author co-citation map has not been implemented. Current best practice as discussed in the related work section can easily be integrated.

View D - Enhanced Preview: An implementation of enhanced document previews has not been implemented. Current best practice as discussed in the related work section can easily be integrated.

User Scenario

A user wants to know how many documents are new in her research field. She starts the search in the overview-view. First, she moves the date slider to the year 2002. Only documents later than 2002 remain colored, the others change to grey. Next, she enters keywords in the keyword field. As a result, only the documents that contain the keywords remain colored. Now she can quickly recognize that there are no new documents in her institute. But she can also see that one document was downloaded more frequently, because the size of the rectangle is ten times as big as the others. She further recognizes three colored documents in other institutes which she did not expect. It is clear for her that one document is not interesting for her because she knows the research focus of that particular institute. But the other two documents need to be evaluated. She therefore adds the two documents to her personal selection list by dragging the objects to the selection list. The next day she starts browsing the two documents from her selection list in the enhanced preview.

This section presented a design study to illustrate how the framework could be put into practice. The system is not fully implemented. However the novel part of it is implemented: the combination of collection overview with query-driven filtering. The next section presents an evaluation of this system.

5.2.4 Evaluation: Towards an Overview and Detail Search Interface

I have conducted a qualitative user study to examine the effectiveness of our approach, to study user behavior, and to explore tasks and strategies for which my system could be useful. I further tested two specific hypotheses.

Hypotheses
First hypothesis: *Combining collection overview with query-driven filtering facilitates exploratory tasks and thus is a benefit for users.* Second hypothesis: *Users have no problem to orient themselves in rapidly evolving collections.* I assumed that users do not get confused when the tree map selection interactively changes its appearance or if new documents are integrated.

Participants
Eight non-paid participants (6 males, 2 females) were recruited from different companies. Two target groups were tested: students (3 males, 1 female) and managers above 45 years (3 males, 1 female). All participants suffer from information overload and perform knowledge intense tasks in their jobs. All participants are frequent users of mouse-and-windows based systems (at least 30 hours per week) and frequent users of query-driven retrieval systems (i.e., www.google.com). Only two participants (1 male manager, 1 male student) were familiar with the tree map system.

Apparatus
The experiment was conducted on a Windows XP PC running a custom-based Java application, as seen in Figure 37. I would like to thank the HCIL Maryland[25] for providing the tree map source code for the prototype. The display was a 19-inch monitor, set to a 1280x1024 resolution. From the existing collection three static datasets were manually created. The first consisted of 26 documents, the second of 100 documents, the third of 1020

[25] http://www.cs.umd.edu/hcil/treemap/

documents. For the three datasets the keywords, file size, dates, and document paths from the original collection were extracted manually. For the number of downloads and the rating numbers were estimated.

Procedures

The participants were introduced to the existing e-document collection interface and instructed on the functioning of the new system with the smallest dataset (26 documents). After the instructions, the participants were allowed to explore both systems until they felt comfortable. Then the participants had to fill in the first part of a questionnaire which was followed by a short interview with structured open questions to get their first impression of the system.

After this interview the participants had to conduct a series of exploratory tasks with the second dataset (100 documents). For the last five tasks I switched to the third dataset with 1020 documents. Throughout the whole process the participants were observed and the accuracy and time needed to fulfill each task was measured manually. Some of the tasks the participants had to perform are listed here:

- Locate the most influential works in a specific area.
- Which area has the highest number of documents?
- In 1999, what was the most active research group on "Bluetooth"?
- Describe how the collection evolved over time.
- Which three documents on "le Corbusier" should be considered for a lecture for first semester architecture students?

After finishing all tasks, which took around 25 minutes, the participants had to fill in the second part of the questionnaire and answer what they liked, disliked, the strengths and weaknesses of the system, and for what tasks the system could be of interest. After that, the participants were interviewed again with structured open questions for another 10 minutes.

Findings: A Promising Approach for Exploratory Tasks in Digital Libraries

The findings from this study have implications for researchers in the fields of information retrieval, information exploration, and interfaces design in general. Next I discuss five findings:

Finding 1: Interactive filtering of the overview with keywords is desired. All participants quickly understood the added value of the system. They liked the collection-overview and query-driven filtering. All participants confirmed the advantage of this approach for exploratory tasks in digital libraries. Participants indicated that the system is more suitable for exploratory tasks than traditional keyword searches, and that they would like to test it with their personal digital libraries. In general the participants liked the system, because (1) it presents documents in a context, (2) it reveals unforeseen relationships, (3) size and color corresponds to meaning, and (4) it integrates browsing and filtering.

Finding 2: The participants could easily orientate themselves in growing datasets. I found that none of the participants had problems to orient himself in the growing datasets. Switching from the first dataset (26) to the second dataset (100), the participants could immediately orient themselves. The same happened when switching from the second dataset to the third dataset (1020). One participant even considered it easier to navigate in the bigger datasets. No participant considered it confusing when the rectangles changed size or position. The function to hide the filtered documents did not disorient the participants. It is clear that the position does not need to be static, which is a major insight from this study.

Finding 3: No clear preference for the ideal setting. I asked the participants which setting is most suitable as a standard configuration for what metadata should be represented by the size or color. The setting with the "number of downloads" as size and the "rating of the document" as color was preferred by four out of eight users. However, there is no clear preference. Further investigation is needed.

Finding 4: The managers were slightly slower than the students. Seven out of eight participants understood the functioning of the system within five minutes, one (manager) within 10 minutes. We found that one manager was slightly slower and one manager much slower in performing the tasks than the rest of the participants. However the two other managers were as fast as the students.

Finding 5: Different strategies for solving the tasks. All participants accurately solved the given tasks. By observing the participants I found that they used different strategies to solve the tasks. The interviews showed that the participants liked the flexible structure, which enabled them different ways of exploring the collection.

Discussion

The results support both hypotheses: (1) the participants considered the system as effective for exploratory tasks in digital libraries. (2) The participants did not have problems in orienting themselves in the growing datasets. I was astonished that people very carefully assigned the most suitable metadata for each task. I assumed that people would mostly work with one setting and concentrate on working with the filters. It is evident that they liked the flexible structure. Several issues are raised by the results. First, I believe that the framework should be refined in another research project. Second, further studies have to be done to test the online system with real download data and ratings provided by the users. Further evaluations have to be done to compare exploratory tasks with traditional keyword searches.

5.2.5 Conclusion

This case study introduced an approach for the visual exploration of digital libraries that combines a collection-overview and query-driven filtering. The introduced framework for visual exploration of document collections suggests four specific views that should be considered: (A) a query result list, (B) a collection overview, (C) similarity maps, and (D) enhanced previews.

The case study presented a specific implementation for a digital library of the Swiss Federal Institute of Technology. Users retrieve the documents in a context and reveal unexpected relationships. Using filters, the users can interactively reduce the numbers of potential interesting documents to a number that is manageable.

My evaluation indicates that combining a collection-overview with query-driven filtering is promising for the exploration of digital libraries, and that the system is more effective for exploratory tasks than traditional keyword searches. The contribution is therefore promising to complement today's search approaches. The system is currently being introduced as a complementary visualization and retrieval tool for a company that sells digital documents.

5.3 Tube Map Visualization: Interfunctional Communication of a Complex Project

In this case study I adapted the tube system metaphor to long-term projects and evaluated it's effectiveness to communicate a complex project to different stakeholders.

In the education centre for health care professionals, the new quality development process had to be communicated to the employees. Communicating the goals and motivating the employees for actions were important to achieve the quality certification in 2005. However, the employees addressed had different functions and backgrounds. As a consequence their information need diverged: Some employees needed details, some suffered from a general information overload. This situation made it difficult to communicate the appropriate amount of information.

The questions raised by the management board were:

- *Attention* – How can we draw the attention of the employees?
- *Overview* – How can we present an overview on the project that is appropriate to the information need of the different target groups?
- *Details* – How can we communicate the important milestones without unsettling the employees?

- *Strong Metaphor* – How can we create a logo and a metaphor for the project?
- *Motivation* – How can we build up a mutual story and initiate discussions on the project?
- *Discussion* – How can we support learning?

From my experience in visual knowledge communication, I believe that successful Knowledge Visualization implementations are tailored to the target users' experience and to the nature of the information need. I was searching for a suitable metaphor that is easy to understand and open for the various situations that can occur in long-term projects. The tube system metaphor seemed promising because: (1) it implies a dynamic and complex system where unpredictable occurrences can happen, (2) the tube system helps people to reach their targets, (3) the tube maps are appealing and fascinating for urban-minded people, (4) it presents both an overview and details in one image, and (5) it structures the information and enables to zoom-in to details on demand. "*Overview, filter, zoom-in and details on demand*" is important for effective user interfaces, as discussed in the information visualization mantra by Shneiderman (1996). The tube system was adapted to the process: Each tube line represents one target group; each station represents an individual or collective milestone, as seen in Figure 38. Each line (target group) stops at all the stations (milestones) where the target groups are involved. The stations are tagged with descriptions and a date so that the employees get detailed information and instructions (Figure 39) on the tasks of the project. The efficiency of instructions in communication is described by Wurman (2000). To reach all employees (also the employees with no access to computers) the Tube Map Visualization was printed on a poster (1,2m x 2,4m) and mounted on aluminum panels. These were placed at six different lively locations, e.g., next to the elevator.

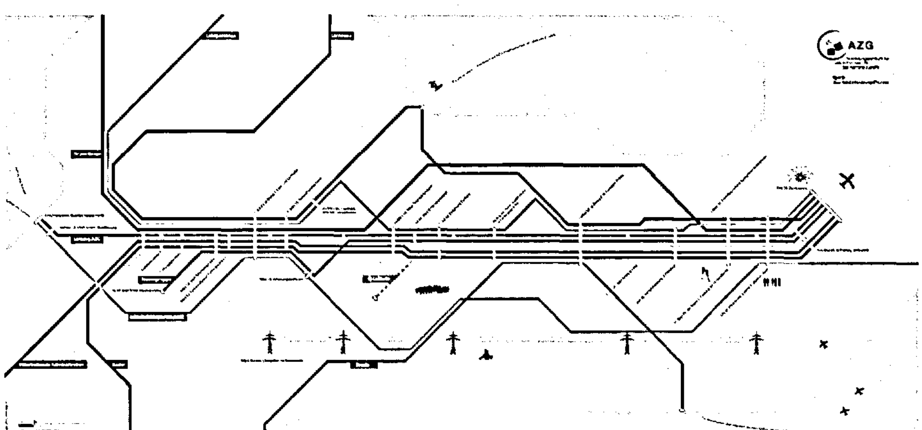


Figure 38. The Tube Map Visualization (1,2 x 2,4 meter) presents overview and detail on a three year quality development process. Each line represents one target group, each station a project milestone. The quality certification is the mutual target of the project. The map is aligned to a time line that runs from left to right.

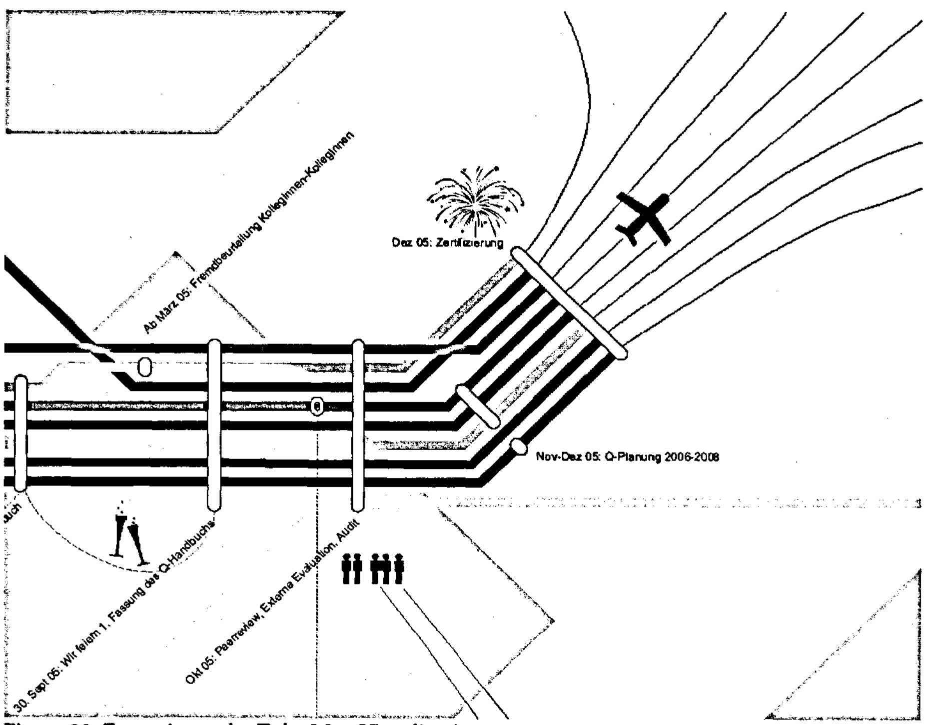


Figure 39. Zoom-in on the Tube Map Visualization.

The map was drawn with the software application Adobe Illustrator 10[26] and refined in several meetings with the management board. Initially I was thinking about computational procedures that generate the Tube Map Visualization, but I decided to draw the Tube Map Visualization manually because it helped optimize the aesthetic value which is essential to gain attention. The poster was created in three iterative steps. In three meetings the management board made corrections and added further information on the full-scale printouts. Full-scale printouts were used so that the managers could easily imagine the final map. After each meeting the designers transferred the corrections to a meaningful new version of the map. Positive feedback from the employees encouraged me to evaluate the effectiveness of the Tube Map Visualization for knowledge communication, which I discuss next.

5.3.1 Evaluation: Methodology and Results

I evaluated whether the Tube Map Visualization is an effective method for the communication of a complex project to different stakeholders. To do so, I tested several assumptions:

[26] http://www.adobe.com

- *Attention*: The employees are attracted to the Tube Map Visualization.
- *Overview*: The visualization presents an overview of the complex project.
- *Details*: The visualization presents the appropriate amount of information for each target group.
- *Strong Metaphor*: The different individuals understand the metaphor.
- *Motivation:* The employees build up a mutual story and discuss the project.

Target Group
The target group consisted of all employees that were exposed to the Tube Map Visualization. In total, 81 persons represent the whole population. Those persons have different education; most of them have diplomas in the area of health care professions.

Method
Two months after the introduction of the posters, a paper-based questionnaire was distributed among the 81 employees. The questionnaire consisted of two parts: Questions to the Tube Map Visualization and general questions (e.g., age, gender, or highest education). Comments could have been added to each question. At the end of the questionnaire, it was asked, what the participants liked and disliked mostly. The participation was voluntary and anonymous. The original questions were asked in German. For this thesis the questions are translated into English, as seen in Figure 40.

Response
45 out of 81 questionnaires returned, which means that the response rate is 0,56. 62 percent of the population is female, 29 percent male, and 9 percent did not answer the question to their gender. One person has a university degree. 76 percent have a diploma in the health care sector that is accepted by the Swiss Red Cross. 23 percent have a higher education similar to a university degree[27]. 76 percent are between 31 and 50 years old. The average time they are employed in this organization is 6.2 years.

[27] In German: „Fachhochschulabschluss“

5.3.2 Results

Figure 40 presents the results from the questionnaire:

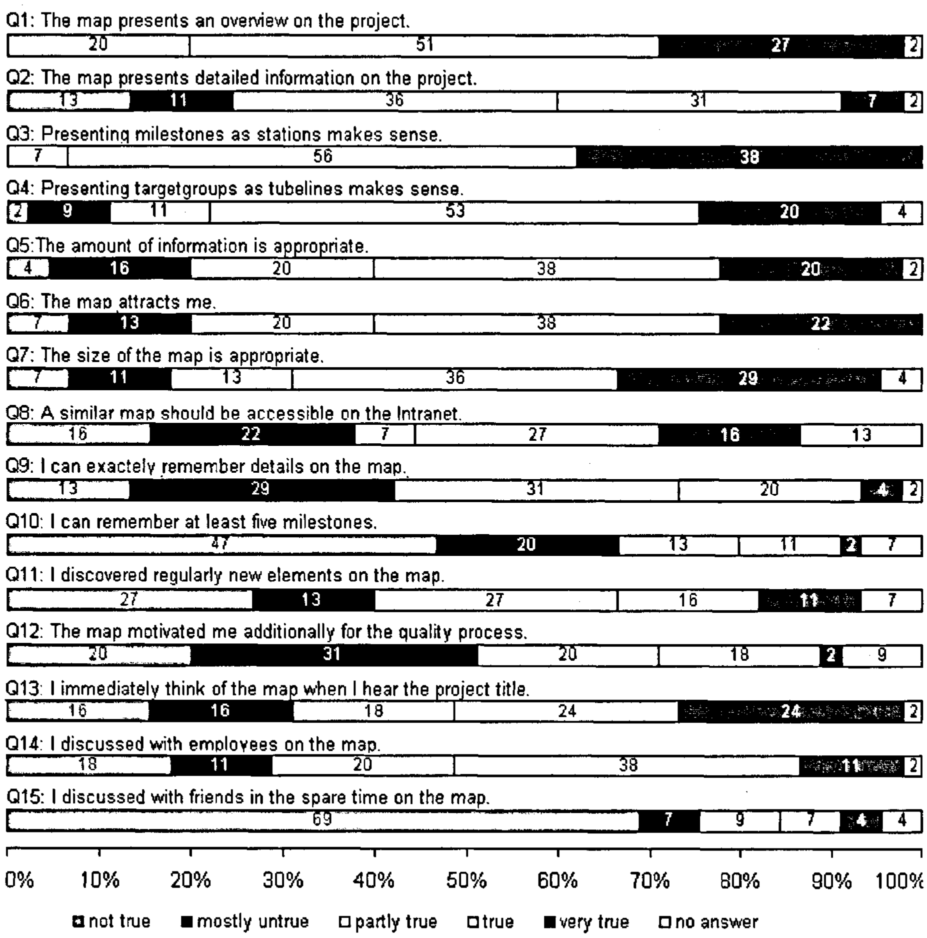


Figure 40. The results of the questionnaire. The numbers in the bars represent per cent (n=45).

Positive

Attention: Each person saw and studied the Tube Map Visualization. Each participant could answer all questions on the questionnaire.

Overview: The visualization helped the employees to get the missing overview on the project. Several employees made written comments that they could grasp the whole project thanks to this visualization and that it gave them orientation. The feeling of uncertainty was transferred into interest and motivation. 78 percent of the participants stated that the Tube Map Visualization gave them an overview, (51 percent = true, 27 percent = very true).

Details on demand: The employees considered the amount of information appropriate. However, the comments made clear that for some users there was too much, for the others not enough information. Question 2 and comments for question 2 showed that some employees wished further information. The results and comments show that the amount of data on such a map needs special attention and further investigation.

Strong metaphor: The employees understood the metaphor. Meanwhile the Tube Map Visualization is a synonym for the quality development process. The results of the questions 3 and 4 show that presenting milestones as stations and target groups as tube lines made sense for the employees. The employees liked the visualization. According to Question 6, 60 percent of the participants were attracted (38 percent = true) or very attracted (22 percent = very true) by the Tube Map Visualization.

Discussion: The location and size of the poster fostered discussion with employees and at home. The Tube Map metaphor was established as a mutual story for the quality development process.

Learning: Even if it was not required that the employees remember detailed dates, we were interested whether the employees remember details. 46 percent of the participants said that they remember milestones (Question 10). However, I did not verify any further whether these answers were correct.

Negative
Attention: Some employees considered the visualization as too predominant.

Overview: The comments of two participants said that they were initially confused by the metaphor.

Details on demand: The right amount of information to be presented remains the key issue. Few persons desired more detailed information to the individual milestones.

Discussion: Only 27 percent of the participants stated that they discussed the Tube Map Visualization in their spare time or at home.

Learning: Further studies with two focus groups have to be made to give answers how the Tube Map Visualization supports learning. The comments made clear that the icons on the map need a verbal description, which was missing on this map.

Discussion
The evaluation proved that the Tube Map Visualization is an effective tool for the communication of a complex project to different involved target groups. One disadvantage of the static posters is that they are not suitable if major changes and modifications occur in future. I consider an interactive map on the Intranet as a complementary visualization useful to offer

detailed information on selective milestones. 42 percent of the participants stated that a similar map should be accessible on the intranet (27 percent = true and 15 percent = very true). Further studies need to test whether the process of creating a map can be automated. The main disadvantage is that the printed posters are static. Major changes are difficult to update.

Face-to-face meetings with the persons involved in the management board showed that the map is also a valuable tool to unify the management board on the messages. They stressed how impressed they were, because the visual format helped them to discuss the details of the long-term planning in an effective and motivating way with other managers. As an unexpected side effect of the process of creating the map, they refined and discussed the whole project precisely and unified themselves on the goals and timeline, whereas at the beginning, the common understandings diverged. In short: The visualization helped to coordinate the managers.

5.3.3 Conclusion

In this case study I introduced a new metaphor of a project and an evaluation of its implementation in a quality development process in an organization.

The quality development process needed to be communicated to employees in an education centre for health care professions. Traditional visualization did not reach the goals. I adapted the metaphor of a tube map to illustrate the project. The Tube Map Visualization, printed on a poster, enabled management to get attention, give an overview, and motivate the employees to act.

I found in the evaluation that the iterative approach to create the image significantly improved the information and communication quality and unified the board on concise messages. Second, I found that the visualization attracts employees, gives them an overview, and motivates them for the project. The visualization fosters discussions and supports understanding. Third, it became clear that the employees would have liked a complementary visual approach where the Tube Map Visualization is presented both as a poster and on the Intranet.

In conclusion, the new scientific contribution of this case study is the introduction and proof that the Tube Map Metaphor is a helpful visual metaphor for the communication of complex projects where various stakeholders are involved. It is therefore a complementary visual format to Gantt Charts: Gantt charts are precise and structured and are mainly used for the planning of projects; Tube Map Visualization in contrast illustrate how target groups and tasks relate to each other and are mainly used for the communication of projects. The case study, therefore, shows a real-world situation where the concept of complementary visualization of architects was successfully adapted to a non-architectural content in an organization. The method is ready to be adapted by practitioners, as already happened in four cases.

In future studies that have already started, I want to make comparisons between Gantt Charts and the Tube Map Visualization. Secondly I want to create a software-based algorithm that allows Project Tube Maps to be automatically created. This research project has also already been started. The results of both contributions will be published in two articles in Summer 2005.

5.4 BKV4A: Business Knowledge Visualizations for Architects

The transfer of knowledge between planners (e.g., architects or urban planners) and business decision makers (e.g., investors, developers, marketers) can be improved if planners combine traditional visualizations with business Knowledge Visualizations. The presentation of an architectural or urban planning project is a decisive milestone, with the following challenges:

- *Information depth*: Trade off between an overview and details.
- *Limited time*: Limited time, attention, and capacity of the recipients.
- *Different background*: Difficulties of decision makers to understand the visual representations of planners.
- *Relevance*: Providing the relevant information for decision makers.

Today's planners use an enormous amount of time to illustrate a project, but almost no time to illustrate business relevant information that decision makers need for decision making. Issues such as revenue models, financial implications, risks, marketing potentials or effects for tourism are rarely mentioned or even visualized, which can cause three consequences: Information overload: Decision makers cannot identify the relevant information. Misinterpretation: Decision makers cannot understand, evaluate, and interpret the information. Misuse: Decision makers cannot use or misuse the information for decision making. I found that combining traditional visualizations with business Knowledge Visualizations is a promising approach that increases the communication quality (efficiency, motivation), increases attention, reduces information overload and as a consequence, improves decision making.

This case study first presents the tasks and visualization types of decision makers. Juxtaposing them with the visualization types of architects I presented earlier, reveals a major gap in the use of visual representations. Secondly, I present a scenario from my own experience in my own company where I evaluated and tested the approach that proves that this approach is a new value proposition for architects and thus should be considered in the education of future architects.

5.4.1 Visualizations of Business Decision Makers

In corporations it is imperative to increase financial returns. The tables 2-5 present an overview on tasks and targets of decision makers.

Table 2. Tasks in Strategy

TASK IN STRATEGY	TARGET
Strategic Planning	Formalized strategic planning processes and scenario planning.
PEST Analysis	Political, Economic, Social, and Technological factors in the macro-environment.
SWOT Analysis	Strengths, Weaknesses, Opportunities, and Threats in situation analysis.
Competitor Analysis	Determination of the competitor's objectives, assumptions, strategy, and capabilities.
Value Chain	Primary and support activities and their role in developing a competitive advantage.
Growth Share Matrix	"Dogs, Question Marks, Stars, and Cash Cows" of the BCG Diagram.

Table 3. Tasks in Economics

TASK IN ECONOMICS	TARGET
Demand/Supply Curve	Factors that may cause a shift in demand/supply. Price level determination. Effects of a shift in supply or demand to the equilibrium of price and quantity.
Opportunity Costs	The concept of opportunity costs and relative price.

Table 4. Tasks in Operations

TASK IN OPERATIONS	TARGET
Process Analysis	Analysis of business processes. Flow diagrams, performance measures, bottlenecks.
Work Breakdown Structure	Breaking down a complex project into individual tasks, facilitating resource allocation.
Gantt Chart	Visualizing the progression of a project in a chart.
Critical Path Method	A network model for project management.
Pert	A network model that allows for randomness in activity completion times.
Time-Cost Trade-offs	Types of project costs and trade-offs between project cost and completion time.

Table 5. Tasks in Marketing

TASK IN MARKETING	TARGET
Marketing Concept	Production concept, sales concept, advertising concept, PR concept.
Situation Analysis	Marketing situation: Company, Collaborators, Customers, Competitors, and Climate.
Market Definition	Market segmentation: Potential, available, target and penetrated market.
Market Analysis	Market size, growth rate, profitability, cost structure, distribution channels, trends.
Product Life Cycle	Different strategies and marketing mix decisions in different life cycle stages.
Marketing Mix	Marketing mix : Product, Price, Place, and Promotion.
Pricing Strategy	Pricing a product or service, including pricing objectives.

In each of the above disciplines there are conventions on the use of business diagrams. Figure 41 presents an overview of the most commonly used business diagrams which are discussed by other researchers.

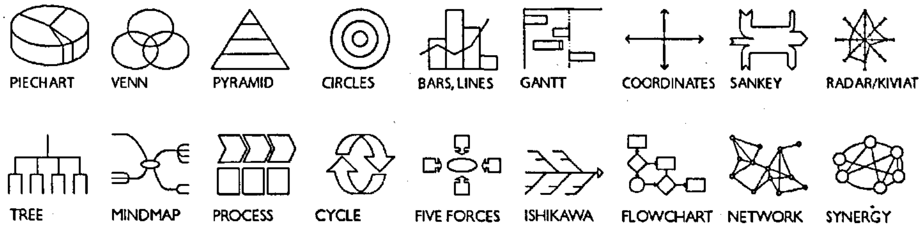


Figure 41. Overview on some diagrams business decision makers use.

Apart from business diagrams business decision makers use visual metaphors and clip arts.

This section presented the tasks and targets of business decision makers and the diagrams they use. Planners rarely use the above business diagrams. One reason for this is the missing know-how on the use of these diagrams. Another reason is that planners are not familiar with the tasks and targets as listed above. A third reason is that planners have no education to present business relevant information of a project. The juxtaposition of the visualizations that planners and decision makers use reveals a major gap: Both groups use different visualization types and both groups are not familiar with the visualization types of each other, however, both groups could benefit from each other.

In the next section I discuss an example where I tried to combine conventional formats of architects with business diagrams to test the hypothesis that the use of complementary visualization improves the transfer of knowledge to different target groups.

5.4.2 Knowledge Transfer in an Urban Planning Project in the City of Davos

This section presents new approaches how the company I founded in 1999,[28] communicated complex urban planning projects to decision makers. In presentations and workshops for different urban planning projects for the City of Davos, we combined traditional project visualizations with business Knowledge Visualizations to get the *attention*, the *interest* and the *desire* of the decision makers to finally initiate *action*. To do so we used various simple but complementary visual formats.

[28] www.vasp.ch

Attention - Visualizing the Situation

To illustrate a analysis of the situation an interactive visualization (Brodbeck and Girardin, 2003a), as seen in Figure 42, was used. It allowed different attributes of the cities in Switzerland to be explored. The visualization fascinated the recipients and revealed important relationships. The understanding of these relationships and seeing the "big picture" was important for the argumentation and the presentation of the different options.

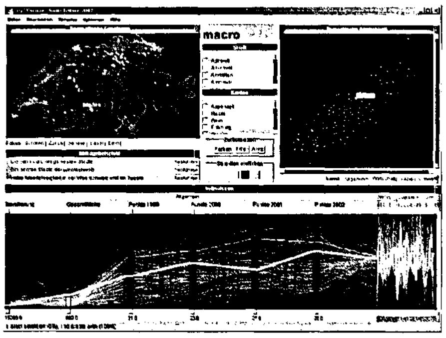


Figure 42. Attention: An interactive visualization helped to present an overview on the situation of the city and influencing factors.

Figure 43. Interest: To illustrate potential scenarios on the use of a public space, narrative texts were used to foster creativity without determining sole functions.

Interest - Visualizing Options

The visualization as seen in Figure 43 adapts the insight that storytelling is effective for the transfer of knowledge (Loebbert, 2003). Narrative keywords were integrated in the plans to present potential functions and social scenarios. In that way different scenarios and functions could be transferred. In contrast to the conventional denoting of a function (e.g., restaurant) the narrative keywords (e.g., red wine and BMW) address emotions, foster creativity and imagination, and increase remembrance.

Desire - Visualizing Potential Earnings

Potential earnings of different scenarios were approximately calculated and illustrated with a line chart (Figure 44). This very simple business chart had a tremendous effect: The decision makers were motivated to see that the office cares about their tasks and the discussion quality became considerably more constructive.

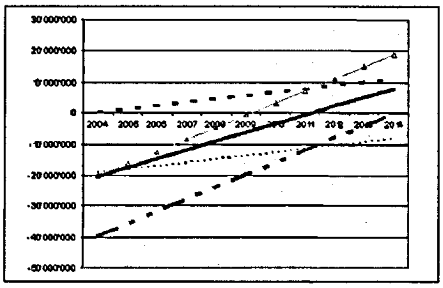


Figure 44. Desire: A line chart with the revenues of five scenarios was the breakthrough visualization to reach the business decision makers.

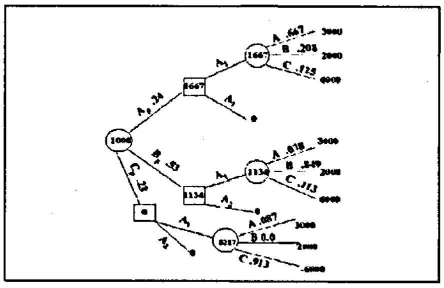


Figure 45. Action: In a decision tree different options and scenarios were presented. In that way decision making could be influenced and helped to make the relevant decisions.

Action - Visualizing Options to Decide

A decision tree as seen in Figure 45 structured the future decision that needed to be made. This chart is simple but effective. The decision tree helped to get the overview of the different decision-scenarios and supported structured decisions.

This section presented how decision making was improved by combining traditional formats of architects (that are not shown in this section) with additional visualization types.

5.4.3 Conclusion

Planners who combine traditional visualizations with business Knowledge Visualizations can improve the transfer of knowledge with decision makers. If planners illustrate business relevant issues, the information quality and decision quality can be improved. Further, this process reduces information overload, prevents misinterpretation, increases information quality, improves communication and as a consequence, improves decision making. This case study applied the Knowledge Visualization Framework and the use of complementary visualizations. Moreover bridging this gap means interesting work for planners. From my own experience with a start-up company, I saw that business decision makers need new and better visualization methods to present complex projects to different stakeholders. Developing visualizations to illustrate business related issues of complex urban planning projects is a skill of architects, but they have to be open to the language and the needs of business managers in order to create a value for them. Thus the approach has implications for the education of future planners and architects who do want to apply their expertise in other domains than architecture or urban planning.

In future research, I will investigate how a curriculum for such a course for architects would look.

5.5 Science City ETH: Visualizing a Planning Process

Science City ETH is the vision and project to realize a campus at the Federal Institute for Technology (Burkhard and Staub, 2004a, Burkhard and Staub, 2004b). For the planning, management, and communication process complementary visualizations were used (Burkhard, 2004a). Next, I introduce some formats for the seven visualization types.

Sketches

To transfer the main idea of Science City ETH sketches were used, both in workshops and in the planning team. Sketches as seen in Figure 46 and Figure 47 allow to analyze the status quo and to quickly imagine different scenarios. The sketches are atmospheric and help to improve group reflection processes. In the workshops the sketches helped to speed up the process and discuss the key issues both on a conceptual and detailed level, to structure and relate issues, and to evaluate scenarios. Such scenarios were either directly written on the prepared sketch or drawn on flip charts as seen in Figure 47. Photographs of the different sketches in the workshops helped the individual discussions to be quickly recalled later on. In presentations, different sketches were used complementary to images to address the important fact that Science City ETH is an open and participative program.

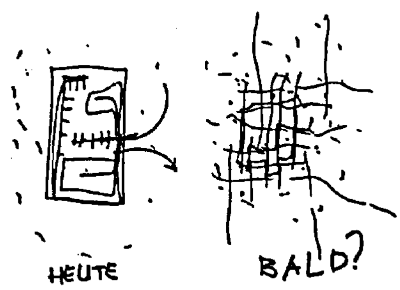


Figure 46. A sketch outlines the main idea.

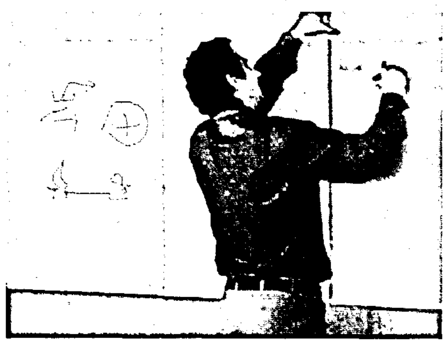


Figure 47. Sketches were used in workshops.

Diagrams

Conceptual diagrams were used to develop the project and to structure the planning and communication process. Figure 48 reduces the complexity of the project by isolating and relating key issues and breaking them down into arguments and tasks. This diagram helped to amplify cognition and to determine a shared consensus of the project. Figure 49 was a first diagram for the architectural master plan.

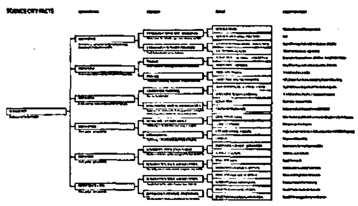


Figure 48. A tree diagram helped to structure the complex project.

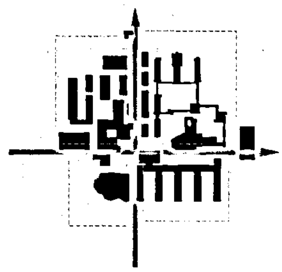


Figure 49. This diagram describes two streets that divide the campus.

Maps

The Science City ETH Map (Figure 50) is a map that was created for the exhibition in a gallery in Berlin and Barcelona. It measures 1,2 by 3,6 meters. The map illustrates central ideas and issues in Science City ETH and uses different graphic elements, such as plans, texts, arrows, hotspots, stories, symbols, etc. as seen in a zoom-in in Figure 51.

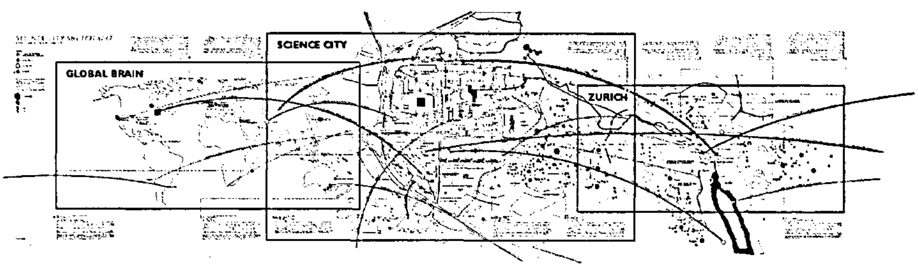


Figure 50. The fictitious Science City ETH Map presents influences, scenarios and stories on three levels - a global, a metropolitan, and a local level.

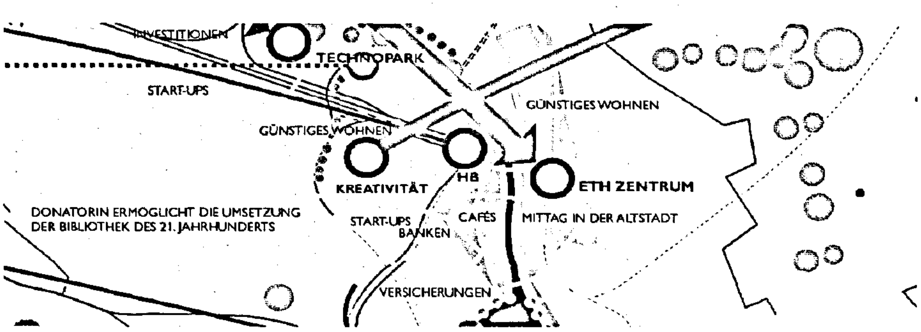


Figure 51. The map points to important local or conceptual hotspots, and illustrates relationships between the local, metropolitan and global scale.

Images

Images are impressive, expressive, or represent reality. They help to address emotions and to support recall. Therefore various images were used (Figure 52 - Figure 55), especially in presentations.

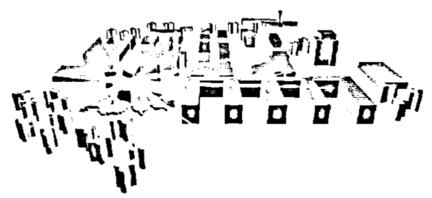


Figure 52. A diagrammatic image illustrates the existing structures (grey buildings) and potential new structures (orange buildings).

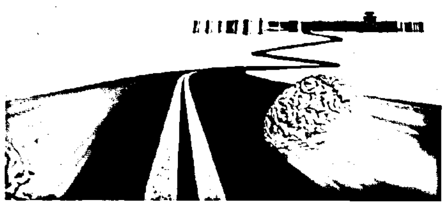


Figure 53. A metaphoric fictitious image shows that Science City ETH attracts brains from all over the world.

Figure 54. Science City ETH: A city upon a hill.

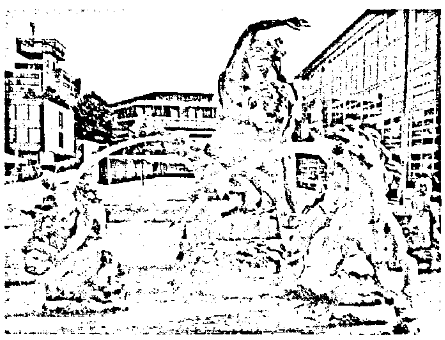


Figure 55. Science City ETH: Quality for living.

Objects

This *Infostructure* (Figure 56) was located at different central places at the ETH to attract and motivate people to explore the project. A physical plaster cast model of the new campus presented an overview (Figure 57) and got the attention of passers-by. As a counterpart the physical Science City Object (Figure 58) is a conceptual object that combines different concepts and metaphors in one aesthetic object produced with the latest 3D print technology out of silver or bronze. The object, as a communication tool, helps to create a series of unique images that help to create a brand identity and helps as a physical object to attract individuals, either in personal discussions or in keynotes. The same physical model and various complementary visualizations were used in an exhibition in a gallery in Berlin (Figure 59).

Figure 56. Different visualization formats are combined and presented in a small installation at busy places.

Figure 57. A physical model attracts peoples and illustrates relationships.

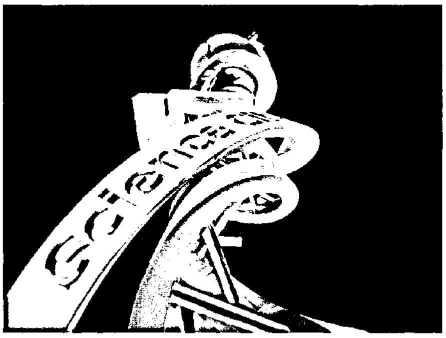


Figure 58. An image of a physical Science City object.

Figure 59. Exhibition in a gallery in Barcelona.

Interactive Visualizations

Another format I introduced was an interactive chart which represents the activity of a web forum (Figure 60), an information visualization application that visualizes the data of a survey among different individuals (Figure 61). This format illustrated the complexity and made relationships transparent.

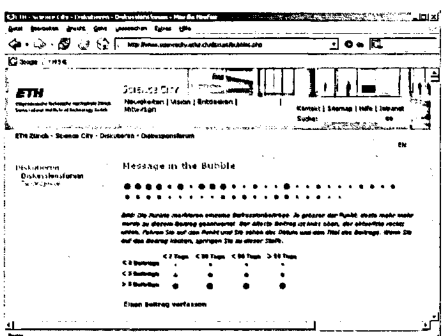


Figure 60. One page of the Science City ETH website illustrates the activity of the guestbook.

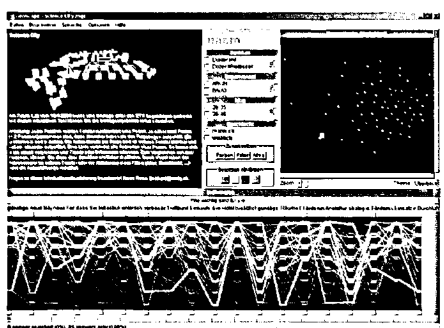


Figure 61. An information visualization application represents a questionnaire.

Further interactive visualizations were a video clip created in a workshop, and a virtual 3D World that allowed navigating through the master plan and imagining how Science City ETH could look like (Figure 62, Figure 63).

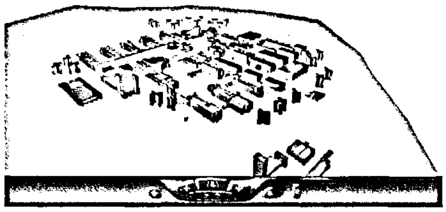


Figure 62. A software application allowed users to navigate through Science City ETH.

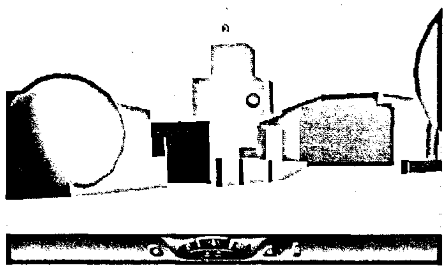


Figure 63. A software application allowed users to navigate through Science City ETH.

Stories

Storytelling was helpful to disseminate knowledge on the project and to motivate people for the project. In contrast to abstract descriptions of benefits, the stories were very easy to understand (Figure 65) and motivated individuals to tell them to others. The stories were written on boxes where small figures caught the attention of the viewers (Figure 64).

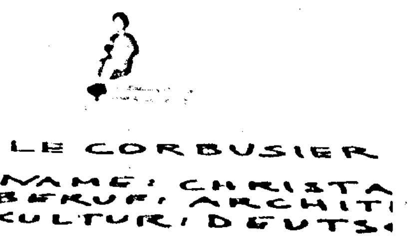


Figure 64. The stories were written on physical objects and presented as part of the Infostructures.

Louis Wellington: "Die Forschung ist mein Lebenselixir. Deshalb bin ich aus London nach Science City ETH umgezogen. Denn hier herrschen optimale Bedingungen, um meine Forschung voranzubringen: Zum Beispiel die Dichte an Spitzenforschern, die führende Rolle im Bereich Life Science, ..."

Figure 65. Different fictitious stories helped to better imagine the individual benefit per stakeholder. An excerpt of a imaginary story.

5.5.1 Evaluation of the Complementary Visualizations

These complementary visualizations helped to illustrate the complex contents of the Science City ETH project from different perspectives and customized for the different stakeholders. Important to all these formats is that each one did not generate more than four days of work. This allows the potential and limitations of these formats in a daily practice in organizations to be compared. For the evaluation, I interviewed various persons that were involved in the project and asked them to indicate benefits and limitations of the above visual representations. Next, I discuss some insights from these interviews.

Sketches: The sketches were mainly used in the design workshops (Figure 46, Figure 47). They were created by different stakeholders. Within these workshops the sketches were helpful to coordinate the groups and in presenting the findings to the other groups, however, they were not essential. After the workshop the photographs of some sketches were used as slides in keynote presentations and they were integrated into the Infostructures. In both cases the sketches underlined visually that different stakeholders were involved in the design process. However, if we compare this registrative function to photographs, photographs are the stronger format, because they address emotions and provide more contextual information. In conclusion, the sketches are simple and low-cost formats that can be used complementary to photographs.

Diagrams:. The diagrams we used were a tree diagram that structured the complex content of Science City (Figure 48) and an urban planning diagram of the development study Science City (Figure 49) that illustrate how the campus could be structured. The tree diagram was less important for the communication of the project or to coordinate people, however, it was essential to structure the content to a logical argumentation, which was needed when designing the exhibition in Berlin and at the same time writing the catalogue. The urban planning diagram helped experts to understand how the campus could look. But for non-expert users the diagram was difficult to understand. For them the renderings were more meaningful. In conclusion, diagrams were more important for internal use and for cognitive functions instead of mass communication purposes.

Maps: The fictitious Science City Map (Figure 50) was used to illustrate key-concepts of the Science City project, namely international knowledge exchange and collaborations. The huge plan was first used in the exhibition in Berlin. The effect was that people carefully studied the individual elements of the plan (Figure 51), which helped them to explore and better understand the complex and multifaceted project without reducing the complexity to a general and generic level of abstraction. The localization of the different ideas and concepts helped people to better imagine how living in Science City could look. As a consequence, the map allowed the viewer to build an individual mental model of the project, which then was explained by these persons to others by telling stories. Concluding, the fictitious map was helpful for various communication tasks and is a format that can be applied by organizations to map visions and strategies. Because it worked very well for all stakeholders, I will investigate in my future studies how knowledge maps can be used to visualize corporate strategies.

Images:. Various images were used in the whole communication process. (e.g., Figure 52-56). The images were used on the website, in the press, in presentations, flyers, and internal mailings. The images tried to use strong and warm colors to initiate positive associations and feelings. The effect of Figure 52 was very strong. This three dimensional rendering that is based on the two-dimensional diagram, helped people to better understand how Science City could look. As an effect, the image was suddenly used as a logo by different persons. However, it was not intended that the image that was only a scenario from the development studies became the logo. This later resulted in some effort to clarify that this was only a first step and did not represent the final Science City. Similarly this image focused on buildings. As a consequence, people believed that Science City is a building project, which is only one part of the whole project. In contrast to this image, we tried to use metaphoric images (Figure 54-56) that should be still valid in five years. These were helpful in keeping continuity in the visual communication. In conclusion, images stick in the brain and initiate emotions, which is why they should be used carefully. Instead of using one image, such as a strong logo, it is more effective to use various images complementary. In that way the content is visualized more interestingly, from more perspectives, and, through constant refinements, more precise and clear. As a result, the project is perceived as much more dynamic and in constant continuity.

Object: Objects were mainly used in the various exhibitions (Figure 57, Figure 59). The exhibition guides in the galleries in Berlin and Barcelona stated that individuals were attracted by the objects. Visitors were standing around the models and discussed and studied the three dimensional objects together. The Science City Object (Figure 58), even if it is not yet produced, resulted in intense discussions because of the potential discourse it could trigger. Where the images are already used, the Science City team is still considering the best moment to launch the physical object. In conclusion, objects are rarely used for the transfer of knowledge, which is in direct contrast to the effect we could see in the few examples we used. For this reason, I encourage researchers to investigate the effect of objects to transfer knowledge.

Interactive Visualizations: The interactive guestbook visualization helped individuals to quickly see when new comments were added to the forum (Figure 60). It helped individuals to see how the forum evolved over time and when new comments were added also in past threads. The visualization was a cognitive aid to supervise and track the guestbook. Another interactive format was the interactive survey visualization. It fascinated some recipients and target groups strongly, mainly researchers. It underlined the innovative character of the Science City project, however it was not suitable for mass communication purposes, due to a higher level of complexity and because it illustrates relationships among answers rather than a selected list of results. But integrated in the Infostructure, it complemented ideally the static visual formats as the sketches or images. The interactive walk-through was a VRML application that allowed users to virtually navigate through Science City (Figure 62, Figure 63). This application was, due to technical limitations, not as appealing as other formats. Secondly, for non-expert users it was difficult to navigate. A video might have been more effective for mass communication purposes in the gallery. In comparison to the other formats, it also takes much more time to create an impressive application. In conclusion, when using interactive visualizations one should not forget the goals. The incredible options can lead to a situation where individuals just want to show what is possible with such tools without concentrating on the transfer of knowledge. But if the goals are clear, it is a very effective method complementary to static formats as described above due to temporal and spatial independencies and because it can be interactively modified and extended by other stakeholders.

Stories: The use of figurative language from the very beginning was helpful to fill the abstract concept of Science City with life. Slogans and texts were motivating and fostered discussions. A further step was to introduce the fictitious portraits. These short stories (Figure 65) were highly effective to illustrate the individual benefits of the project, e.g., for the neighborhood, the politicians, the students, or other stakeholders. Together with the Science City map they were probably the two formats that inspired, motivated and had the most impact with regard to all stakeholders. In conclusion, the use of storytelling combined with spatial localization on a map is a fruitful and cheap strategy to communicate complex strategies to various stakeholders from different backgrounds.

5.5.2 Conclusion

In conclusion, this example has shown how different visual representations can be used complementary to transfer different types of knowledge to different stakeholders. The project has shown how important it is to use complementary visualizations in very early stages to get the attention of different stakeholders, to motivate them, to engage them, to coordinate, and to finally activate them to participate and support the project.

6. ARGUMENTS THAT SUPPORT THE HYPOTHESES

This section presents various supporting arguments for the three main reasons why complementary visualizations improve the transfer of knowledge. First, visualizations have *different advantages,* and thus serve different functions. By using complementary visualizations, these different functional aspects can be combined into one whole. Second, different recipients have *different information* needs, and the complementary visualizations help to reach those different stakeholders. Third, for the transfer of knowledge *different transfer processes* are involved. Each process can be supported with visual representations. The combination of complementary visualizations is a promising strategy for supporting the whole transfer process. As we will see in this section: All three main arguments are true, therefore the hypothesis can be verified.

In the subsequent section each main argument is funded by presenting supporting arguments from the literature and from my own case studies.

6.1 Argument 1: Different Advantages of Visualizations

Visualizations have different properties that can be exploited for the transfer of knowledge. Three main advantages can be identified: Different functions with regard to (1) the human visual system in general, (2) specific tasks with relevance for the transfer of knowledge, and (3) and different advantages of individual visualization types.

6.1.1 Supporting Argument A: Different Processing Levels of the Human Visual System

The human cognitive system has limits in processing complex information due to its limited capacity and duration of the working memory. If the visual-spatial system is used, the process can be improved. Next I discuss several supporting arguments that prove the existence of different functions of the human visual system that can be addressed with different visual representations.

Two Stages of Visual Image Processing

Visual information processing can be divided in two stages. In the *first stage,* information is parallelly processed by the eye and the primary visual cortex (Farah, 2000a, Ware, 2000). At this early stage information processing proceeds pre-attentively and very rapidly. In this first stage, individual neurons in specific areas of the primary visual cortex (the so-called areas V1, V2, V3, V4, MT) are specialized to identify particular features, namely orientation (e.g., of lines), color, texture, contour, or motion (Farah, 2000a, Ware, 2000). If colors or motion are carefully used, people will pre-attentively react.

The *second stage* of visual information processing is divided into two functionally independent subsystems with complementary functional specializations (Ungerleider and Mishkin, 1982). These are object recognition and object localization/attention, i.e., one system is more important for object identification (=what) and the other for spatial localization (=where).

One of the subsystems is face recognition: Humans are highly efficient at recognizing and interpreting faces. The face is an extraordinarily rich communication channel which conveys social and personal identity and reports a variety of expressions. Donath (2001) discusses the role of the face in mediated discussions. According to her, the face conveys four major types of social information: individual identity, social identity, expression, and gaze. Through faces we are very adept at recognizing people with their different expressions and as they change with age, at a varying distances and from various viewpoints.

Conscious versus Subconscious Image Processing

Image processing can be pre-attentive, conscious, unconscious, or subconscious. (1) *Pre-attentive image processing:* Pre-attention precedes conscious attention. The features that are pre-attentively processed can be organized into different categories (Ware, 2000): *Form:* Line orientation, line length, line width, line co-linearity, size, angle, spatial grouping, added marks, numerosity; *Color:* Hue, intensity; *Motion:* Flicker, direction of motion and *Spatial position:* 2D Position, stereoscopic depth, convex/concave shape from shading. Miller (1956) reports that a human's input channel capacity is greater when visual abilities are used. Humans not only have a great capacity to identify features, the brain has a strong ability to identify patterns, which is examined in Gestalt psychology (Koffka, 1935). (2) *Conscious image processing:* Several empirical studies show that visual representations are superior to verbal-sequential representations in conscious cognitive tasks, i.e., to illustrate relations, to identify patterns, to present both an overview and details, or to support problem solving (Bauer and Johnson-Laird, 1993, Glenberg and Langston, 1992, Larkin and Simon, 1987, Loftus, et al., 1992, Logan, 1992, Novick, 2001, Treisman, et al., 1992). (3) *Unconscious image processing:* Ehrenzweig (1975) discusses the role of the unconscious image processing and states, "*The existing literature hardly ever takes into account the possibility of unconscious perception processes which after all are our main concern.*" He describes how modern western art in the first half of this century is interesting for an investigation of unconscious form processes. Read (1934, 145) illustrates how some examples of modern paintings make the eye "wander", and that some examples do not comply with the teachings of the Gestalt Theory. The Gestalt Theory pays little attention to forms that are difficult to articulate.

Thus modern art can be a subject of investigation to figure out how our unconscious mind creates and perceives form. (4) *Subconscious image processing:* Image processing is done consciously and subconsciously. An example: Normally when we are in a room we do not realize the pattern of wallpaper, unless it disappeared or when individual items pop out and distract. Van Tonder et al. (2002) discuss an interesting finding in a Japanese Zen garden. They found that the "empty" space of the garden has an implicit structure which refers to the temple's architecture and contributes to the beauty and visual appeal of the garden. They assume that it was an intended feature of the composition. Such insights could be promising for different fields, e.g., to create calming visual interfaces (Lyons, et al., 2002).

Mental Imagery

In psychology the *mental image* is defined as an internal representation similar to that resulting from sensory experience, but arising from memory. The purpose of research in mental imagery has been to determine the existence of mental images, define their properties, and to establish how they are used in thinking. Several studies prove the existence of visual codes in memory. Shepard and Metzler (1971) measured the time it took for subjects to decide whether two complex block structures are similar or different. The results show that the decision time increased linearly with the difference in rotation between the two objects. Other researchers suggest a difference between visual and linguistic memory. Paivio (1971) was the first to suggest that visual imagery and verbal symbolic processes represent separate coding systems in memory. Paivio (1986) showed that the "imagery concreteness", i.e., the value of nouns to evoke an image correlates highly with the ability to remember. Example: 'Apple' leads to a more concrete mental image than the more abstract 'distance'. Kosslyn and Koenig (1992, 129) state that mental imagery can be used in the following ways: (1) Reasoning can be improved by the creative generation of images (For example by combining familiar elements in new ways). (2) Learning a skill can be supported by the use of imagery (For example in sports training). (3) A mental image can be used to ameliorate comprehension of verbal descriptions (For example a floor plan that assists an instruction to go to a certain place). (4) Images further can stimulate the discovery of unexpected patterns and lead to new inventions and creative concepts.

This section introduced the argument that visualizations have different advantages to be exploited because the human visual system has different processing levels and specialized areas which can be exploited separately. Therefore, the use of complementary visualizations is a fruitful strategy. Next I discuss different social, emotional, and cognitive functions of visual representations in general.

6.1.2 Supporting Argument B: Social, Emotional, and Cognitive Functions of Visualizations

Several empirical studies show that visual representations are superior to verbal-sequential representations in different tasks, i.e., to illustrate relations, to identify patterns, to present both overview and detail, or to support problem solving (Bauer and Johnson-Laird, 1993, Glenberg and Langston, 1992, Larkin and Simon, 1987, Loftus, et al., 1992, Logan, 1992, Novick, 2001, Treisman, et al., 1992). Visualization thus serves for different functions. Alesandrini (1992) presents five advantages of abstract images, that can be summarized with the acronym 'IMAGE': Images are Instant, Memorable, Automatic, Global, and Energizing.

To support this argument, I introduce a new classification that is more systematic than the acronym of Alesandrini and that is supported by various arguments. The classification was developed and introduced together with Eppler (Eppler and Burkhard, 2005). Visual representations have cognitive, social, and emotional benefits which are synthesized in the CARMEN acronym: Visual representations assist in Coordination, Attention, Recall/Learning, Motivation, Elaboration, and New Insights. The functions are discussed next:

Coordination
Visual representations can structure communication and coordinate individuals or discussions. Worren et al. (2002) describe how communication can be structured by using visual representations to *coordinate involved individuals* in discussions. In the evaluation of the Tube Map Visualization, I found that the main advantages of this format are the qualities to attract attention, to initiate discussions and to build up a mutual story. Another important aspect, which is often forgotten, is the power of using a pen on a flipchart. When drawing a sketch "live" people automatically look at this sketch, which helps to keep attention and to coordinate the discussion. This aspect - where one is looking - is called gaze and is an important channel of social information. Gaze is used in conversations to indicate understanding and attention. Gaze is a challenge for digital interfaces (Donath, 2001) with mediated faces or for videoconferencing, where the key problem is that no common space is shared.

Attention
Visual representations can support the two functions of attention: To get and to keep the attention of the audience. The initial step to transfer knowledge is to get the attention of the audience. To catch attention, images are highly effective. Miller (1956) reports that a human's input channel capacity is larger when visual abilities are used. We have seen that image processing is done *pre-attentively* and precedes text processing. In

displaying information we often have to point out something. To do so, preattentive features are helpful because we automatically react to them.

We further have an innate ability to quickly *process facial expressions.* Almost every aspect of the face allows people to be characterized and social and emotional cues to be interpreted at a glance. Faces are very useful for transporting emotional aspects. Russell et al. (1997) have conceptualized the relationship between the face and emotions. They discuss different basic emotions that the face reveals (anger, contempt, disgust, fear, happiness, sadness, and surprise). Observers of the face in general are able to read the underlying emotions from the facial expression. This is further discussed by Ekman (1997). Chernoff (1973) takes advantage of our ability to distinguish minimal differences among faces to compose multivariate statistical visualizations in faces: he maps data into facial features, e.g., nose length, eye tilt, head shape. Due to the emotional aspects faces carry, faces are often used in advertising. Apart from the use of faces, advertising proves with numerous examples that the use of visual representations catches attention.

These *eye-catching* effects were also evident in the evaluation of the Tube Map Visualization where this unexpected visual metaphor attracted the employees and motivated them to explore.

Visual attention in general is largely tied to *eye movements.* That is why we pay attention to that on which we fix our gaze. To do so, our eyes constantly make movements to seek information. Scanning the environment can be explained easily with the torch metaphor. Visual attention is like scanning a dark room with a torch: it demands continuous movements of the torch spot to investigate the room. This could be a reason why large maps (e.g., the Tube Map Visualization) get a high degree of attention: the eye is constantly scanning the map. The constant eye movements can lead to an enhanced concentration. That result is what we intend to achieve with regard to knowledge transfer: to get and keep attention. Images can strengthen the concentration of the viewer because the eyes focus on the image and that focus increases attention.

Recall/Learning

Visual representations improve learning and recall. Various evidence proves that visual representations support understanding, reasoning, and learning.

Visual representations are instructive: According to Wurman (2000) images are instructive and support the process of learning. Weidenmann (1989) explores aspects of illustrations in the learning process. Glenberg and Kruley (1992) showed that pictures improve comprehension. Visual information processing is different from linguistic information processing. One main difference is that images are automatically processed with a smaller cognitive effort (Kroeber-Riel and Esch, 2000). Kosslyn and Koenig (1992) describe how learning a skill can be supported by the use of visual imagery, i.e., in sports. Mayer (1994) discusses the role of illustrations as aids to knowledge construction and how learning can be supported via text and illustration. A series of experiments allowed four conditions under which visual aids have a strong effect on learning to be identified: (1) when the material is explanatory and has a cause-and-effect chain, (2) when the illustrations are explanatory and the illustrations consist of a series of frames depicting the states of the systems along with integrated verbal labels describing the state changes rather than a one-frame static picture, (3) when the students lack domain knowledge, and (4) when the test evaluates problem-solving transfer.

Dual-code theory: One major theoretical construct for such facilitator effects is the dual-code theory by Paivio (1971), which suggests that information could be stored either verbally or visually, and that the combination of both codes leads to better retention than either one alone. Paivio (1986) showed that the imagery concreteness correlates with the ability to remember. It further appears that words coded in both image and verbal mediators will be more easily remembered than words that are only verbally coded since more "links" exist to those words in memory. Mandl and Levin (1989) present different results in knowledge acquisition from text and pictures. Kosslyn and Koenig (1992) describe how mental images can support the comprehension of verbal descriptions, e.g., a floor plan which extends verbal instructions how to go to a certain location. In general, 1,5 to 2,5 seconds are necessary to grasp an image in a way that it can be recognized later on - in the same amount of time around ten words can be grasped (Kroeber-Riel and Esch, 2000). Glenberg and Langston (1992) indicate that pictures that are compatible with text facilitate learning.

Visual problem solving: Different studies show the general superiority of diagrams like hierarchies, matrices, and networks, in comparison to sentential representation for various learning and problem solving situations (Novick and Hmelo, 1994, Polich and Schwartz, 1974). Several empirical studies show that visual representations are superior to verbal-sequential ones to aid to an individual's understanding and problem solving (Bauer and Johnson-Laird, 1993, Beveridge and Parkins, 1987, Casakin and Goldschmidt, 1999, Glenberg and Langston, 1992, Holyoak and Thagard, 1997, Larkin and Simon, 1987, Novick, 2001, Novick and Hmelo, 1994). The above studies only represent a small subset of various studies that prove that visual representations support learning, comprehension, or reasoning.

Recall

Various evidence prove that visual representations of information improve people's ability to recall and understand it. Bellezza investigated this concerning the free recall of words (Bellezza, 1983, Bellezza, 1986). Bellezza (1986) concluded that the subjects recalled more words when they were presented in visual patterns. These patterns helped to retrieve the individual words. Visual imagery (Kosslyn, 1980, Shepard and Cooper, 1982) suggests that visual recall is more efficient than verbal recall. It is not clear how images are stored and recalled, but it is clear that humans have a natural ability to use images. Boers (2000) states that we think in images, and accordingly, can more easily remember by the use of images. Farah (2000b) and Langston et al. (1998) discuss mental imagery in general, whereas Paivio (1986) shows that the imagery concreteness correlates with the ability to remember. Kosslyn and Koenig (1992) describe how reasoning is based on the creative generation of mental images. Kosslyn and Koenig (1992) describe how learning a skill can be supported by the use of imagery, i.e., in sports. Worren el al. (2002) indicate that the use of visual metaphors increases remembrance. McDaniel and Waddill (1994) discuss a study where they found "*that illustrations embedded in text enhanced recall relative to an unillustrated text most generally for high ability readers. Average ability readers benefited from pictures but not as extensively as did high ability readers. Low ability readers benefited only very selectively from pictures, with the benefit restricted to recall of illustrated details*".

Motivation

Visual representations can energize the audience, can clarify the content or engage individuals. Learning can be regarded as remembering what we are interested in and thus motivational aspects are important in knowledge transfer tasks. Visual representations can energize viewers, e.g., they can motivate recipients to interpret and explore knowledge maps. In advertising, images have a higher value of entertainment than linguistic information. According to Kroeber-Riel and Esch this is the reason why they more strongly activate the audience (Kroeber-Riel and Esch, 2000). Successful managers and sportsmen know the power of mental imagery, i.e., when they imagine how they feel when they have achieved a certain goal. Kosslyn and Koenig (1992) describe how learning a skill can be supported by the use of imagery. Visualizations are helpful to perceive a mutual target or to create a mutual story. The evaluation of the Tube Map Visualization proved that envisioning the milestones and the goal of the project helped to motivate the employees. The use of fictitious stories (imaginary visualizations) can be highly motivating (Loebbert, 2003). This point also became clear in the evaluation of the Science City ETH case study where fictitious portraits of imaginary citizens of the future Science City ETH were helpful and motivated to search the individual advantage for different target groups.

Elaboration

Visual representations help us to elaborate knowledge, alone or in groups. The process of visualizing information leads to further understanding and appreciation of concepts and ideas, as one interacts with them. The use of other visual representations helps to elaborate concepts because these externalized visual representations allow us to extend our mental models and our capacity to think. A whole range of variables and parameters can be made visible and can reduce the cognitive load for the design and decision process. According to Greeno (1977), the difference between understanding and not understanding is in the nature of the representation - good understanding involves achievement of a coherent representation. He showed how the mental representation of problems is an indicator for ones understanding of the problems. Architects often elaborate a new building by discussing various sketches, diagrams, or study models. Such visual representations support group reflection processes and help teams to find solutions. When different authors are involved the individual contributions can easily be compared among each other. This is helpful because criticisms are much more objectively approached in comparison to oral-only discussions, where authors often get offended and take criticism personally. This practice applied to business situations would improve and speed up many meetings in organizations.

New Insights

Visual representations can reveal previously hidden relationships and lead to a-ha experiences. In the field of information visualization a great amount of studies prove that information visualization applications allowed new insights to be gained from data by identifying new perspectives or seeing patterns, outliers, or trends. A second important source are the visual metaphors, which can evoke sudden insights by seeing unexpected or previously hidden connections. Kosslyn and Koenig (1992) describe how reasoning is based on the creative generation of mental images and how new insights are derived by imagery.

This section introduced the argument that visualizations have different social, emotional, and cognitive advantages that can be exploited. Namely they serve for coordination, attention, recall, motivation, elaboration, and new insights. The use of complementary visualizations helps to exploit those individual advantages by combining different formats. This leads to a second proof of why the use of complementary visualizations is a fruitful strategy for the transfer of knowledge. Next, I discuss the individual advantages of different visualization formats.

6.1.3 Supporting Argument C: Different Functions of Individual Visualization Formats

If we consider a visual representation as a medium to transport explicated knowledge and if we remember Marshall Mc Luhans "*The medium is the message*" we can argue that different visual formats transport different messages or perspectives. By combining different visual representations, a message can be transferred from different perspectives, and hence transfer a more holistic image. In my framework I distinguish among sketches, diagrams, images, maps, objects, interactive visualizations, and stories. This section tries to collect findings for the individual strengths of each visualization type.

Sketch

For the transfer and creation of knowledge, sketches have five strengths: (1) Sketches represent the main idea and key features of a preliminary study and support reasoning and arguing. (2) They are atmospheric, versatile, and universally accessible. (3) They are rapidly created, and help to quickly visualize an idea. (4) They keep attention. (5) Sketches allow room for own interpretations and foster creativity in groups. Leonardo da Vinci developed and captured new insights and investigations in various domains, e.g., anatomy, mechanics, or architecture, in thousands of sketches and drawings. He used the method of depicting insights in the form of sketches, drawings, and diagrams as a tool of thought and to transfer insights. In the workshops of the Science City project, the sketches allowed different scenarios to be quickly visualized and discussed.

Diagram

For the transfer of knowledge, diagrams help to reduce complexity and amplify cognition, and explain causal relationships. Diagrams help to structure information. In contrast to sketches, they are precise and determined. Bauer and Johnson-Laird (1993) have shown that diagrams facilitate reasoning and problem-solving by illustrating complex relationships. Their hypothesis was that an external representation can ease deductive reasoning by supporting a subject to keep track of the possible alternatives. In their validation they claim that the subjects do not perform all the computations mentally, but they solve the problem by interacting with the representation. For the transfer and the creation of knowledge conceptual diagrams help to make abstract concepts accessible, reduce the complexity to the key issues, amplify cognition, and discuss relationships.

Maps

For the transfer of knowledge maps provide overview and detail, allow unknown areas to be explored, and information to be spatially structured.

Static maps: Eppler (1997) discusses maps in the context of knowledge management. The evaluation of the Tube Map Visualization discussed above and by Meier and myself (Burkhard and Meier, 2004), proved that a fictitious map of a complex project helps to get an overview and details on the project, motivates employees, and initiates discussion by establishing a mutual story. Smelcer and Carmel (1997) compare the use of tables and maps for decision making. They found that maps are more effective for problem-solving tasks, both concerning problem-solving time and error rates, especially when complexity increases.

Interactive maps: Peterson (1995) describes interactive maps and discusses tools for interactive and animated cartography and how these tools can be applied.

Mental maps: Results of experiments in cognitive psychology indicate a strong relationship between images and maps. Kosslyn's experiment (Kosslyn, 1980, Kosslyn, 1983) indicates that mental images are not copies of sensory impressions, like "*pictures in the head*", but rather seem to be intellectually processed and generalized representations analogous to maps. The zooming of mental images and the addition of more features is an interesting mental process.

Image
For the transfer of knowledge, images help to get attention, inspire recipients, address emotions, improve recall, or provoke discussions. In the context of mass-media, Doelker (1997) distinguishes different functions of images. They can be "*registrative, mimetic, simulative, explicative, diegetic, appellative, decorative, phatic, ontic or energetic*"[29]. Glenberg and Langston (1992) describe a situation where a picture was used to form a mental model, which improved comprehension.

Visual metaphors: Aristotle calls the metaphor a "*tool of cognition*". According to him, a metaphor provides rapid information, is highly instructive, and facilitates learning (Eco, 1984). The use of visual metaphors is effective for the transfer of knowledge (Nonaka, 1991). *"To convert tacit knowledge into explicit knowledge means finding a way to express the inexpressible. Unfortunately, one of the most powerful management tools for doing so is also among the most frequently overlooked: the store of figurative language and symbolism that managers can draw from to articulate their intuitions and insights."* (Nonaka, 1991). Eppler discusses the potential of visual metaphors for the transfer of knowledge (Eppler, 2003a, Eppler, 2004a).

Objects
For the transfer of knowledge, models help to attract recipients, support learning through constant presence, or integrate digital interfaces. The Infostructure, physical objects in the space used to communicate Science City, was successful in attracting people. The guides of the Science City exhibition in Berlin reported that the physical architectural models

[29] Translated by the author.

attracted the audience strongly, even if the room was full of huge and emotional images. The models were interesting because they could be explored and one could imagine being inside the model and thus being part of it. In marketing, companies sometimes give small gadgets with an inherent message to customers. If the given object is of regular use, for example a pencil, a mirror, or a flashlight, the company message will regularly be in the recipient's gaze. One step further are physical objects that represent a specific symbol or map an information structure to an object, for example a cube, where each of the six sides carries specific information or level of detail. Visual metaphors are very strong when they are combined with real objects. Nonaka (1991) describes how a beer can analogy allowed a mixed team at Canon to construct a new revolutionary mini-copier system. The key question of the task-force leader - How much does it cost to manufacture this can? - led the team to speculate whether the same process for making an aluminum beer can could be applied to the manufacture of an aluminum copier drum. By exploring how the drum actually is or is not like this beer can, the mini-copier development team was able to come up with the process technology that could manufacture an aluminum copier drum at the appropriate lowest cost.

Interactive Visualizations

For the transfer of knowledge, interactive visualizations and animations help to fascinate recipients, enable interactive collaboration, present complex data or different types of knowledge, and to investigate history. Interactive visualizations can be used as exploratory tools to detect similarities and/or differences in data. The field of information visualization presents various examples of interactive visual applications which aim to get new insights in abstract data. In the case studies, I discussed various systems that address the issue of visual information retrieval by combining the advantages of information visualizations and information retrieval, e.g., Envision (Fox, et al., 1993, Fox, et al., 2002), a digital library of computer science literature that provides an interface with several search result visualizations, Gridvis (Weiss-Lijn, et al., 2001), which provides manually produced metadata for each paragraph or section level of a document, or Roberts et al. (2002), which present a multiple view system with search result visualizations.

Another type of interactive visualization is *animations*. The most important aspect of an animation is that it depicts something that would not be evident if the frames were viewed separately. An animation can be defined as a depiction of those changes through time. Temporal animations depict change through a time variable. Tobler (1970) describes how an animation was used to depict the growth of a city. The Infoticle application (Vande Moere, et al., 2004) uses data-driven particles (*Infoticles*) to explore large time-varying datasets with re-occurring data objects that alter in time in an immersive environment. Animating these Infoticles allows the behavior of individual data entries or the global context of the whole dataset to be seen. Non-temporal animations show change caused by other factors than time, for example a "fly-through" animation. Mayer (1994) discusses the role of animations as aids for knowledge construction and how learning can be improved via narrations and animations. He claims that animations are effective for three main cognitive processes: (1) the conversion of the narration into a coherent verbal representation, (2) the conversion of the animation into a coherent visual representation, and (3) the linkage of the visual and verbal representations. The effects will be major when (1) the material is explanative, (2) the animation is explanative and depicts the changes in a system, or (3) the subjects are inexperienced. Mayer concludes that illustrations and animations can be effective only if (1) the material itself is comprehensible as a system in which a change in one part causes a change in another part, (2) illustrations or animations are effective when they allow the student to build a coherent mental model of the system, consisting of the main parts and there are causal connections among changes in the situation of the parts, and (3) illustrations and animations are most effective if the learner does not naturally engage into the cognitive processes of building referential connections between visual and verbal representations.

Cognitive psychologists have noted that even if an observer views a scene without moving objects, the observer's eyes will still be in continuous motion. Motion, either of objects in the environment or created by the movements of the eyes, is essential for perception. The perceptual system can be fooled to perceive motion when actually none exists. The film industry which projects 24 still images per second makes use of this principle. Motion then is a construction of the mind. Another approach to understand motion is Gibson's theory of ecological perception (Gibson, 1979). He argues that perception depends on changes in the display. He states that the flow in the structure provides information for perception, rather than the individual forms and shapes. His ideas have influenced work on the mental processing of computer-generated displays (Wagner, et al., 1992). Concluding, Baecker and Small (1990) suggest seven uses of animations for the user interface: (1) Identification: What is this? (2) Transition: Where do I come from, where am I going? (3) Choice: What can I do? (4) Demonstration: What can I do with this? (5) Feedback: What is happening? (6) History: What have I done? (7) Guidance: What should I do now?

Stories and Narratives

For the transfer of knowledge, stories are helpful to discuss future scenarios, visions and to establish mutual stories among individuals from different backgrounds. As described, Paivio's Dual-Code theory (Paivio, 1971, Paivio, 1991) suggests that information could be stored either verbally or visually, and that these codes together lead to better retention rather than either one alone. Peeck (1994) found that the effectiveness of pictures embedded in text significantly increases when a general instruction indicates that the learner should look at the pictures. Evidence that instructive captions (e.g., what to focus on, extract, or remember) has been presented in studies by Reinking, Hayes and McEneaney (1988), Weidenmann (1989), and Bernard (1990). In all three studies, picture-oriented instructions or cues enhanced the effect of the text illustrations in comparison with conditions that did not offer these instructions or cues. The instructions "*increase [the subjects'] attention to graphic aids to the extent that they are able to recall more information presented in graphic aids*" (Reinking, et al., 1988). A variety of books discuss the art of storytelling for the transfer of knowledge (Baker and Greene, 1977). Snowden (2000) is a leading researcher who investigates the role of storytelling in business knowledge management at IBM. Similarly, a variety of books discuss storytelling in the context of business knowledge management (Kleiner and Roth, 1998, Schnalzer and Thier, 2002). Finally, Loebbert (2003) points to the management of stories in organizations.

6.2 Argument 2: Different Information Needs

Different recipients have different information needs. Their motivation and capacity to absorb knowledge depends on the cognitive background (education, culture, values, ...), the time at disposition (e.g., a CEO has less time than a researcher), the mental capacity (e.g., information overload), personal motivation, relevance of the information, and the quality of the information. Using complementary visualizations allows a more flexible reaction to the recipients needs.

6.2.1 Supporting Argument A: Limited Capacity and Time

In organization, a lack of time and a general information overload are predominant problems.

Information overload: The amount of information constantly increases and this can lead to a situation where a user is paralyzed. This phenomenon is called information overload. A second pattern can be identified: Consumers get more accustomed to watching and accessing information passively. Gangloff (1995) illustrates the influence of the television: At the age of 18 years a student has already spent more time in front of the TV (13'000 hours) than at school (12'000 hours).

Information Quality: To be effective in the knowledge transfer process, information needs to be communicated in units. That makes it easy for understanding, activating, and entertaining (Kroeber-Riel and Esch, 2000). The quality of information is not only judged by its accuracy and clarity, but also by the impact it has on its audience. To increase the information quality information needs to be meaningfully structured. According to Wurman (1996) there only exist five ways to structure information: by location, by alphabet, by time, by category, or by hierarchy. He summarizes those ways in the LATCH-acronym. Wurman further discusses in Wurman (2000) the potential of instructions. With regard to instruction, it is also important to not only address what needs to be done, but also what should be prevented. Minsky addresses this point of negative knowledge: *"We tend to think of knowledge in positive terms and of experts as people who know what to do. But a 'negative' way to see competent is, never to make mistakes."* (Minsky, 1994). Eppler (2003b) discusses in depth how the value of information of knowledge-intense products and processes can be increased by managing the quality of the information.

Limited mental capacity. Apart from the information quality or the right amount of information, the mental capacity to grasp information is a limiting factor. It is therefore important to "reduce to the message" in knowledge transfer tasks. It is evident that mental capacity of different recipients can vary. This again demonstrates that it is crucial to know the audience.

Limited time: If the information quality is outstanding, the information is relevant to recipient, and the recipient has enough mental capacity to integrate the new knowledge, the most import question is whether the recipient has time. The different amounts of time (e.g., a CEO might have ten minutes time, in contrast to a student with two days time) influence the final visual format.

6.2.2 Supporting Argument B: Tradeoff between Overview and Detail

People like to have both overview and detail, however, the amount of detail differs greatly. Shneiderman's Mantra "*overview first, zoom-in and filter, then show details on demand*" (Shneiderman, 1996) for information visualization interfaces is also valid for Knowledge Visualization in general. It states that a system should present both an overview of the data, and allow the user to access details on demand. For interdisciplinary teams it is important to present both an overview and offer details on demand. The overview is important for decision makers such as managers, while presenting the details in context helps specialists to analyze the arguments for a detailed decision. The fact that some people prefer an overview, a holistic view on an issue, while others need a very detailed and well-structured approach to understand something can also be encountered when we present visualizations with both an overview and detail. An example for this approach is the Tube Map Visualization which presents the big picture in the tube system and added precise descriptions to the individual milestones.

6.2.3 Supporting Argument C: Importance of the Context

The context is very important because knowledge is contextualized information. So addressing the context is decisive. The context can be the organization unit, the culture, or the cognitive background of recipients. Knowing the frame of reference and shared assumptions of a problem allows new knowledge to be linked to something already known: "*You only understand something new relative to something you already understand, whether visually, verbally, or numerically.*" (Wurman, 1996, 17). Apart from the cognitive background, the cultural background of the audience can be decisive, for example when using visual metaphors with different meanings in different cultures. Apart from knowing the educational background, it also is decisive to know about the shared beliefs of the audience.

6.3 Argument 3: Different Knowledge Transfer Processes

The most proven technique for the transfer of knowledge is the direct transfer from face to face (Brown and Duguid, 2000). But even in the direct dialogue between individuals knowledge can not be transferred completely, and therefore it needs to be deconstructed by the sender into parts (*encoding*) in order to transmit sequentially. The recipient then has to *decode* this information and re-construct it into his own knowledge. In the direct dialogue, the recipient has the chance to steer the deconstruction to customized parts so that he can understand it.

6.3.1 Supporting Argument A: Temporal and Spatially Asynchrony

"Who needs your information, where and when?"

Different stakeholders: "Know your customer!" is the key of successful marketers and sales professionals. Understanding the customer and speaking his language is crucial to convince prospective customers. Analogous "Know your audience" is the key for effective knowledge transfer and Knowledge Visualization. The communication effectiveness rises when the language is adapted to the language of the audience as discussed in the ABX-model. Using different visualization types that allow choosing the most promising type to transfer knowledge to the specific stakeholder is and will be important for effective communication (e.g., if something is explained to pupils a visual metaphor could be the most promising visualization type, whereas for the same task, for a CFO, a business diagram might be more appropriate).

Different Locations: Globalization and information technology lead to the fact that knowledge transfer is not bound to a specific location; it can be done by videoconferencing or interactive collaboration tools across time and space.

Different Time: Globalization leads to the fact that in international collaborations the time difference needs to be considered. For the decision-making process it might be important to capture the way a team came to a certain conclusion. By using knowledge animations one can for example explore the history of a project.

6.3.2 Supporting Argument B: Different Knowledge Transfer Levels

The transfer of knowledge occurs at various levels: between individuals, from individuals to groups, between groups, and from individuals and groups to an organization.

Sub processes: Gupta and Govindarajan (2000) have conceptualized knowledge transfer in terms of five elements: (1) perceived value of the source unit's knowledge, (2) motivational disposition of the source (i.e., the willingness to share knowledge), (3) existence and richness of transmission channels, (4) motivational disposition of the receiving unit (i.e., the willingness to acquire knowledge from the source), and (5) the absorptive capacity of the receiving unit (= the ability not only to acquire but also to use knowledge) (Cohen and Levinthal, 1990). To do so, knowledge must be recreated in the mind of the receiver, which depends on the recipient's cognitive capacity to process the incoming stimuli (Vance and Eynon, 1998). Thus, the person responsible for the transfer of knowledge not only needs to convey the relevant knowledge at the right time to the desired destination, he or she also needs to convey it in the right context and in a way so that it can be used.

Different Methods: If we take a close look at the methods used to achieve these goals, we can distinguish a whole range of different text-based and IT-based solutions used in organizations, e.g., discussion boards, databases, corporate directories, intelligent agent software, etc., however, the capacities of our visual channel are rarely fully exploited.

Different Channels: Knowledge transfer channels can be formal (i.e., training sessions and plant tours) or informal (i.e., unscheduled meetings, informal seminars, or coffee break conversations). Informal mechanisms may be effective in promoting socialization but may preclude wide dissemination, while formal transfer mechanisms may ensure greater distribution of knowledge but may inhibit creativity. Personal channels (i.e., apprenticeships) help for distributing highly context specific knowledge whereas impersonal channels (i.e., databases) are effective for externalized knowledge.

6.4 Proof for the Hypotheses

The above arguments and supporting arguments make clear that the transfer of knowledge can be improved when more than one visual representation is used, and when the various visual representations complement each other.

First, various supporting arguments were presented to prove that visualizations have *different functions* and thus can serve for different functions. When we want to exploit more than one of these functions it rarely is possible through a single visualization. More visualizations should be used. When using different visualizations, they have to be complementary, i.e., each one exploits another function. That is the first reason why complementary visualizations improve the transfer of knowledge.

Second, different recipients have *different information* needs. As soon as we address more than one individual, the backgrounds, mental capacities, interests, or needs diverge. Some only want to have an overview, whereas others prefer detailed knowledge, i.e., to see relationships in a diagram. When addressing a specific person, the visual representation can be customized to the recipients' background. But when we try to address two or more individuals that have varying interests and cognitive backgrounds (e.g., in interfunctional communication), it is likely that different visualizations have to be made to translate the same knowledge into a customized visualization for each stakeholder. In short alternative visualizations help to reach different stakeholders, however, these alternative visualizations need to be coupled and interlinked, because otherwise misinformation could occur if an addressed recipient accidentally gets two different visualizations. As a consequence, visualizations have to be used complementary. That is the second reason why complementary visualizations improve the transfer of knowledge.

Third, for the transfer of knowledge *different transfer processes* are involved. Each process can be supported with visual representations. As soon as we want to use the potential of visualizations for the various sub processes of the knowledge transfer and for the various knowledge management processes where visualizations are beneficial (i.e., identification, retrieval, creation, application), we have the option to use different visualizations. Then again with regard to the cost-value ratio of using visualizations complementary, it does not make sense make them replaceable or interchangeable; they need to be used complementary. Thus to support the whole transfer processes, the combination of complementary visualization for different processes is a promising strategy. That is the third reason why complementary visualizations improves the transfer of knowledge.

Each of these three arguments is grounded and proven by various supporting arguments. Each of those supporting arguments is proven by evidences from a wide variety of researchers with different methods and from my own empirical data. Because each supporting argument is scientifically proven, each argument is verified too. As a consequence, the hypothesis is true. Therefore I have proved that the use of complementary visualization improves the transfer of knowledge.

7. ARGUMENTS THAT REJECT THE HYPOTHESES

Visualization can cause drawbacks with regard to specific contexts. One should thus not neglect the risks inherent in using visualization formats: Diagrams and maps are sometimes difficult to maintain, views could be invalid, and recipients may be invalid, or the reality could be distorted through misinterpretations. This chapter illustrates that an individual visual representation and that complementary visual representations too can be dangerous or ineffective for the transfer knowledge. Visualizations may be hard to read, may distract, distort, manipulate, or simplify wrongly.

7.1 Argument 1: Missing Information

In designing a visualization, the information can be reduced unintentionally or consciously. This can result in missing but valuable information. The amount of missing information can greatly vary based on the visual format that is chosen. For example: Video reveals identity but is not the same as being there. Studies indicate that in transmitting facial information via video, something is lost during the process. Rocco (1998) indicates that people often need an initial face-to-face meeting to establish the trust needed to communicate efficiently online.

The absence of textual clues, headings and descriptions may lead to a wrong interpretation of the visual representation.

7.2 Argument 2: Misinformation by the Author

7.2.1 Unintentional Misuse by the Author

The misuse or wrong use of visualizations by an author can cause significant drawbacks. Instead of clarifying, it could lead to a decreased information quality, which can result in not understanding, contradictory meanings, or misunderstanding. The reasons can be manifold: (1) use of a wrong visualization type, (2) a wrong implementation of the right visualization type, or (3) the correct use and implementation, but neglecting that the audience has a different connotation regarding the chosen visualization type.

Glenberg and Langston (1992) showed that an invalid image is worse than no image. In any case, recipients form a model based on what they perceive, which is a false model when the image is wrong.

7.2.2 Intentional Manipulation by the Author

The intended misuse of visualizations by the author can have manipulative effects. A simple example is to point the audience to wrong conclusions by only presenting a subset of a statistical chart and by fading out the context. Such manipulations are a dangerous tool and could have significant effects for the construction of meaning. While powerful effects of visualizations stick in the mind, it can be hard to forget such manipulative images. Pörksen (1997) discusses the negative aspects of images: They can lead to distortion, distraction, manipulation, wrong simplification, or misinterpretation.

7.2.3 Modifications by Ghost-Designers

The education on visual communication and a coherent use of visual representation is marginal in our society. As a result visual formatting is often delegated or outsourced to specialists or third parties. If these external persons do not fully understand or even misinterpret the content it can result in a distortion and modification of the information. The implementers change the message by leaving out important aspects, stressing wrong topics, or illustrating wrong relationships.

In the Tube Map Visualization it was observed that the involved managers had different ideas of the final result. As a result, the outcome could have differed depending on the involved managers. In a large group the final result may be suboptimal through various changes and too many compromises.

7.3 Argument 3: Misinterpretation by the Recipient

7.3.1 Different Preferences

Even if the visual channel is an effective channel, not every individual prefers the visual channel. The literature distinguishes between different learning types that are based on sensual preferences: vision (sight), audition (sound), olfaction (smell), gustation (taste), touch (haptic). Examples: Complex visualization can distract from the content or can be seen as ornaments (Tufte, 1990). Great visual representations may loose the effect (e.g., attention) when they are seen too often.

7.3.2 Addressing the wrong context

Recipients may perceive the same image differently based on their experience and cultural or cognitive backgrounds. In certain situations visualization can be misplaced, for instance too funny for a serious business context, or they can convey different meanings in a foreign culture. Images without text may lead to misinterpretation or misunderstanding. Authors who copy the visual representation might misuse its original meaning by adding new textual explanations. The use of visual metaphors may lead to communication problems (Blackwell and Green, 1999). Visual representations can lead to wrong interpretations and unintended associations. Similar visual representations can exclude individuals who can not link the visualizations to previous knowledge. Furthermore, when visual representations are used in the wrong context it can result in an interference which can result in misinterpretation. Different cultures share different understanding of symbols.

7.3.3 Missing skills

Cartesian line graphs are a preferred method of displaying multidimensional scientific data in various sciences. Bell and Janvier (1981) point out that many pupils from secondary schools are weak in interpreting global graphical features of diagrams. McDermott et al. (1983) have shown that this is problematic even among many university students in the sciences. Maichle (1994) conducted a study on the cognitive processes in understanding line graphs and concluded that for instructional practice, teaching students to read and interpret graphs flexibly and skillfully is decisive. Peeck (1994) found that the effectiveness of pictures embedded in text significantly increases when a general instruction indicates that the learner should look at the pictures.

7.3.4 Deficits of Visual Perception

Illusions, diseases, or deficits of visual perception may lead to an unsuccessful knowledge transfer.

As we have seen in the related works section, people can see things that are not there and, on the contrary, cannot see things that are there. The eye can fool us which can result in misinterpretation. Apart from perceptual illusions, different diseases and deficits of the visual perception system exist:

A common deficit is *color blindness*. About ten percent of the male population and one percent of the female population suffer from a form of color vision deficiency. If color is widely used for information coding, this could exclude a class of people from certain professions.

A more rare disease is *agnosia*, which is usually associated with brain lesions. Agnosia results in deficits of form or pattern perception. This causes insufficient ability to recognize objects that are in the visual fields of afflicted persons. People who suffer from *visual-object agnosia* can sense all parts of the visual field, but they are unable to get a meaning out of the objects they see. People with *simultagnosia* are unable to pay attention to more than one object at a time, whereas people with *spatial agnosia* have difficulties in understanding and handling of spatial relationships. People with *prosopagnosia* cannot recognize human faces, including their own.

7.4 Argument 4: Cost-Value Ratio

Another drawback of visualization methods may be the cost-benefit ratio:

7.4.1 Cost Intensive

In general, the creation of a concise visual representation can be expensive. For some knowledge transfer tasks the same amount of money could be spent more efficiently by using other methods. However, outsourcing visual formatting may drop the costs and render visualization competitive.

7.4.2 Time Consuming

For non-expert designers and visually low educated persons, the creation of concise and appealing visualizations can be time-consuming without any guarantee of a good, or perfect, result. Novice designers might be unable to reduce the message. Due to technological euphory: a designer may not concentrate too much on the form (Tufte, 1990); as such he does not convey the right message and puts too much time and effort in the tailoring of this message.

7.4.3 No Added Value

For some recipients a visual format may be a significant help, for others it might not add any value. Mayer (1994) found that visual aids have been more effective for students who lack prior knowledge of technical domains than for students who possess high levels of prior knowledge.

7.4.4 Modifications

A very important aspect, that is often forgotten, is the time and cost that modifications implicate. Modifying or updating visual formats can become difficult when the software that was used to create the visual format is not available anymore or if the expert disappeared.

7.5 Rejection of the Hypotheses

The arguments above make clear that the use of individual visual representations has a variety of contraproductive variables. First, if a trained or untrained author creates a visual representation it can lead to misinformation or misinterpretation. Second, when a trained or untrained author uses a visual representation, customized for one target user, another recipient might see but not understand the visualization. With each visualization added, the room for interpretations increases and the message that should be transferred may becoming vaguer. As a consequence, attention is achieved but inference and misinterpretations lead to a diffusion of the key information which can lead to information paralysis. Third, even if the first two effects do not occur and the use of complementary visualization indeed supports the transfer of knowledge it is not automatically said that the same goals would have been possible with non-visual formats. i.e., if the same amount of time and money would have been used for other means, the transfer of knowledge might be just as effective.

That is why the use of complementary visualization does not automatically lead to a better transfer of knowledge. As a consequence, the hypothesis needs to be rejected.

8. SYNTHESIS: THE KNOWLEDGE VISUALIZATION MODEL

Research on cognition and learning clearly demonstrates that there is no such thing as direct knowledge transfer from one individual to another. People acquire knowledge in a complex process where prior experience and several other factors have major influences on the process of constructing meaning. The arguments presented make clear that humans have different abilities to interpret visual stimuli, that different visual representations can serve different functions, and that different formats have different specific strengths and weaknesses. That is why the combination of different visual representations can exploit the specific functions more radically, and thus for the transfer of knowledge in general, it is more effective than one sole visualization. However, juxtaposing the arguments I can conclude that the use of complementary visualization is a strategy with chances, but also with limits. The dialectic argumentation and the findings from the case studies allow deriving a general model for Knowledge Visualization. The Knowledge Visualization Model identifies and relates the features that contribute most to a successful communication when complementary visualizations are used to transfer and create knowledge. The Knowledge Visualization Model is presented next.

8.1 The Need for a Knowledge Visualization Model

Such a *Knowledge Visualization Model* is necessary for four reasons: First, communication sciences models are too general with regard to the use of visual representations. Second, visualization scientists do not offer a holistic model for the transfer and creation of knowledge through visual representations. Third, the Knowledge Visualization Model complements the Knowledge Visualization Framework. Together they can achieve the goals of Knowledge Visualization, discussed above. A fourth reason in favor of the Knowledge Visualization Model is that it can easily be extended to communication cycles using other media complementary, which proves an important contribution to the domain of *Communication Sciences* in general.

This Knowledge Visualization Model is the first model to serve for the domain of *Communication Sciences* as well as for that of *Knowledge Visualization,* and that of *Visual Communication Sciences.* Moreover, the model is useful for practitioners considering the salient features necessary in order to improve the transfer of knowledge thanks to the use of complementary visualization.

The value of this model is that it systematically highlights the essential features of *Knowledge Visualization* and their interrelatedness and that it is integrated into the context of *Communication Sciences* theory.

8.2 The Knowledge Visualization Model and Its Features

The Model as seen in Figure 66 is based on five questions:

- Why externalize something into visual representations (aim, effect)?
- What needs to be visualized (relevance)?
- Who does it address, who does it serve (audience)?
- Why should it interest the recipient (benefit)?
- How should it be visualized (efficiency)?

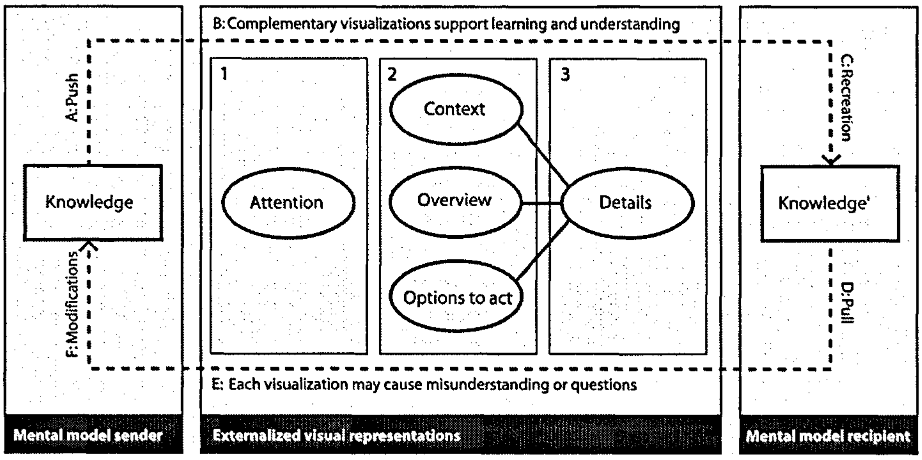


Figure 66. The Knowledge Visualization Model with a sender, complementary visualizations as a medium, and a recipient.

The *Knowledge Visualization Model* (Figure 66) is divided into three parts: a sender, a medium, and a recipient. These three parts are all interlinked in an interactive communication loop.

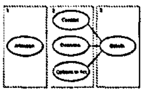
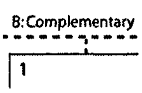
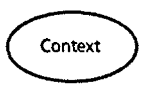
This model contains interpersonal (between individuals) and intrapersonal processes (in the mind of an individual) processes. The sender's mental model of a knowledge excerpt is externalized into various explicit complementary visual representations. These visual representations serve as knowledge mediating tools to communicate the knowledge excerpt to a recipient. The mediating visual process includes three sub processes (1,2,3 in the Figure above) that need to be achieved sequentially.

First, complementary visualizations have to catch the attention of the recipient, for instance an emotional provocative image is embedded. Second, a complementary visual representation needs to illustrate the context, an overview, and the options to act. Finally complementary visual representations can point to selected details. This ideally happens in a dynamic dialogue with the recipient. By using these complementary, visualizations the recipient can re-construct the excerpts of the sender's knowledge. However, due to different assumptions, beliefs, or backgrounds, inferences can occur and this leads to interruptions and failures in the knowledge re-construction. If the receiver is aware of misinterpretation or misunderstanding, or simply desires more information, questions may arise, and a feedback loop may be initiated. The sender then has to refine or modify the used visual representations, has to add further complementary visualizations, or has to use other formats in order to achieve a concise re-construction of the knowledge as intended, and thus make successful communication possible. Note: The model aims to promote the use of complementary visualizations, but of course sometimes the same model can be used for a sole visualization, which serves all purposes. The individual elements are discussed in the tables 6-8:

Table 6. Elements from the sender

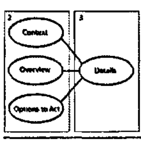
Mental model sender	In psychology, the mental image is defined as an internal representation similar to that resulting from sensory experience but arising from memory. The **Mental model** of the **sender** is built up from three components: knowledge, a push-process, and a modification process. The transfer process starts with an individual that wants to transfer parts of his knowledge by a push-process. He has a mental image of what he tries to transfer and creates one or more visual representations based on it. A visual representation is a medium to transport this knowledge to the recipient. Important for a successful knowledge transfer is "the motivational disposition of the source (i.e., its willingness to share knowledge)" (Gupta and Govindarajan, 2000).
Knowledge	The sender makes some of his **knowledge** available for transfer to a receiver. His knowledge totality however is not static: First, the sender might receive recipient feedback, and secondly, he himself might be a receiver in other communication processes.
A:Push	For the **push-process** the sender uses one or more complementary visual representations for the functions discussed in B.
F:Modifications	The sender might get feedback from the recipient, which can result in **modifications** or additional visual representations. This shows the dynamic and iterative character of the model.

Table 7. Elements from the medium, which are complementary externalized visualizations.

	This model concentrates on **complementary visualizations.** The individual elements in this model are only significant with regard to the use of complementary visual representations. However, it may also be possible that one sole visualization can serve for all purposes, or that various images might be necessary to illustrate one element (e.g., overview).
	**These aspects** have to be seen in a **sequential temporal order.** First a visual representation has to catch the attention of the recipient (e.g., an emotional image), then the context (e.g., a logo), the overview on the knowledge (e.g., knowledge map) and options how the recipient can benefit from the knowledge or how he can put it into action. Only when the recipients can see by whom (trust), what (content, context) is transferred and why it is important to him (relevance), he is motivated and ready for the third stage: details.
	**Complementary visualizations support. learning and remembrance** means that the recipients are given a tool to reconstruct the knowledge. Example: an overview visualization might help to understand details. In general, complementary visualizations help an individual to understand a content from different perspectives via different channels.
	The first stage (1) to be achieved is the catching of the recipient's **attention.** Attention does not only mean reaction; it means an interest of the recipient, a moment where the recipient is open to the knowledge of the sender.
	In the second stage (2) different issues need to be depicted, but the order does not matter here. Generally the **context** has to be illustrated, so that a recipient automatically sees that the knowledge is important to him or her.
	Next, an **overview** presents the key frame of the content. To see the big picture helps to integrate knowledge.

Next, **options to act** are to be displayed before details; for several reasons: (1) According to Gupta and Govindarajan (2000) a key-element for knowledge transfer is the capacity of the receiving unit to absorb: this is the ability not only to acquire but also to use knowledge. Cohen and Levinthal also stress this point (Cohen and Levinthal, 1990). Presenting options how this knowledge can be used, and which individual advantages they implicate, helps to improve the motivation and the activation of the individual. (2) Gibson's affordance theory (Gibson, 1979) assumes that perception is designed for preceding action: we do not perceive points of light, rather we perceive bundles of light as possibilities for actions (e.g., handles are for pulling, tools for manipulating, surfaces for walking,). Translating this theory into the domain of Knowledge Visualization means that visualizations should display options to act. (3) According to Constructivist Theory knowledge should be linked to its future use; It should be embedded into realistic and relevant problem displays. (4) Wurman (2000, 200) illustrates that most people want to follow instructions and that most of the knowledge visualizer's work involves giving instructions to employees or customers. To improve the design of instructions Wurman presents six building blocks: Purpose (reason), objective (destination), core (procedure), time (duration), expectation (anticipation), and failure (error). This last point is also discussed by Minsky (1994) who argues that a large part of human knowledge comes forth from negative experiences. Thus only encoding knowledge in positive rules (if X happens, do Y) misses much of expertise because knowing what to do also requires to know, what not to do.

Only in the third stage (3) it is important to present **details**: This means that the context, the overview and the options to act precede the detailed knowledge.



The connection lines represent the tight **interrelation between the stages 2 and 3.** This interrelationship is interactive and depends both on the information needs of the recipient and the knowledge of the sender.

Visualization may cause misunderstanding/ misinterpretations or questions. This indicates that a recipient may need additional explanations for the individual visualizations, may demand modification of the content of the knowledge excerpt or extra contents, or may wish for alternative formats.

Table 8. Elements from the recipient

Mental model recipient	A recipient who is being addressed can react either positivly, which means the initiation of a feedback loop, or negativly, which means that he blocks the start of the feedback loop (for example because of information overload or no perceived further value of the source unit's knowledge). The motivational disposition of the receiving unit, i.e., its willingness to acquire knowledge from the source, is a further important element in the transfer of knowledge discussed by Gupta and Govindarajan (2000).
C:Recreation	A recipient has to re-create the sender's knowledge into his own knowledge thanks to the visual media tool and its embedded knowledge content.
Knowledge'	Successful knowledge transfer means that the knowledge is integrated into the knowledge base of the recipient. But due to the recipients different backgrounds, the recreation results in a modified version of the knowledge excerpt sent.
D:Pull	As the different visual representations may lead to further questions, the recipient becomes active and seeks further knowledge (pull-process), starting the feedback loop.

8.2.1 Conclusion

The Knowledge Visualization Model identifies and relates the key aspects of complementary visualizations that contribute most for the transfer of knowledge.

This model focuses on five main features that need to be considered when using complementary visual representations: Attention, context, overview, options to act, and details. The model is grounded in the dynamic transaction model discussed in the related work on communication science, wherein the knowledge transfer or communication process is an iterative, dynamic process where both the sender and recipient influence each other.

The purpose of the Knowledge Visualization Model is to bridge the gap between communication scientists and visualization experts/scientists by integrating the most important features for the transfer of knowledge through use of visual representations into the context of established communication sciences models. Second, it helps to identify the key issues that need to be considered to improve the effectiveness of the knowledge transfer. This sequence – where first the attention, then the context, then the overview of the content and the options to act (e.g., how to use the knowledge, where to buy a product, or who to ask for details) and then a dynamic push- and pull- process for details – is a new and important feature. In this way information overload can be prevented, and motivation can be increased.

8.3 The Optimal Number of Complementary Visualizations

The third hypothesis is that an optimal number of complementary visualizations for different knowledge transfer tasks does exist. In the analysis of various examples, namely the case studies, I could identify four different situations for the use of complementary visual representations. These four situations can be visualized with a curve, as seen in Figure 67.

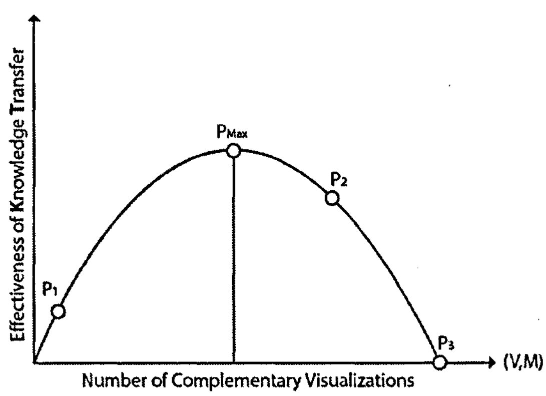


Figure 67. The Inverse U-curve is a theoretical construct that allows testing of four scenarios on the use of complementary visualizations.

The Inverse U-curve (Figure 67) is a theoretical construct that allows testing of four scenarios on the use of complementary visualizations: The effectiveness of the transfer of knowledge rises with the sum of complementary sets of (V,M). (V,M) means a visualization type on a media type (e.g., a sketch on paper or a sketch on a screen are two different representations). Four different situations can be distinguished:

P_1: Additional complementary visualizations improve the knowledge transfer efficiency. The additional visual representation complements the already used sole visualization.

P_{max}: The optimal number of complementary visualizations is used. The cost-benefit-ratio is optimal. Each visualization is necessary and important to help a recipient re-construct knowledge as intended.

P_3: Too many visual representations are used. The knowledge transfer efficiency is not optimal and too much time, effort, and money are spent. This can happen when additional visual representations cause misinformation, misunderstanding, or misinterpretation or lead to contradictory statements, e.g., old formats, different meanings when different authors depict the same content.

P4: The knowledge transfer does not happen. It can happen that so many visual representations are used that a recipient gets confused to a degree where he suffers from information overload, where he does not trust the information anymore; the whole effort of using visualizations was not worth it; The knowledge transfer did not happen and was not improved by the use of complementary visualizations.

Finally, we can consider different areas defined by these points (Figure 68):

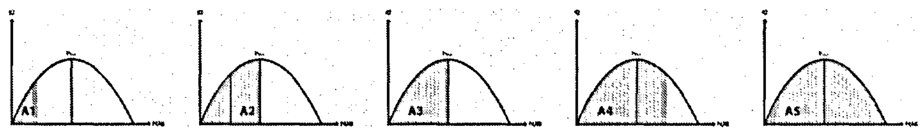


Figure 68. Five different states can be defined which create the areas 1-5. The area represents the effort/costs of complementary visualizations.

Area one (=A1) represents the situation where one new visual representation was used to complement a visual format to improve the knowledge transfer. This situation was analyzed in the Tube Map Visualization case study. The additional visual representation improved the efficiency to transfer knowledge, but it also created extra effort and costs.

Area two (=A2) defines the situation where an individual visualization existed and where additional visualizations improved the transfer of knowledge. This situation was described in the BKV4A case study, where I have shown that extending the visual formats of architects with business Knowledge Visualizations is fruitful to improve efficiency, but again this costs extra effort.

Area three (=A3) defines a situation where no visual representation existed in the beginning and where the optimal number was implemented in one step. This situation was examined in the Metaview case study, where different visualizations types were coupled to offer a new approach for document retrieval in digital repositories, which previously was done with text-based systems without visual representations.

Area four (=A4) illustrates a situation where too much effort was spent on visual representations. In my fourth case study, the use of additional visual representations did not improve the knowledge transfer efficiency in two particular situations, however this is only seen from the knowledge transfer efficiency aspect. In the example of Science City ETH, I have shown that additional visualizations helped to motivate people to collaborate and therefore a certain amount of visualizations which opened a dialogue were important. In this case study we found in the evaluation that few visual formats (e.g., the VRML landscape) did not contribute greatly to the transfer of the knowledge.

Area five (=A5) describes the situation where a huge effort is undertaken without any positive effect, i.e., the knowledge transfer does not occur. Here I did not present a case study.

In conclusion, the Inverse U for Complementary Visualizations is a theoretical construct that can help to distinguish different situations which can occur when using complementary visualizations. In contrast to this abstract concept practical guidelines are presented next.

8.4 Guidelines for Applying the Model

To design effective visualizations, different principles should be considered. These principles are derived from my work experiences.

Know your Data. A designer must first understand and evaluate the content that is to be communicated through a visualization and decide whether the content data are complete, reliable, and relevant.

Know your Audience. A designer should be aware of the diversity in the audience: the different needs and various social, cultural, and educational backgrounds. People think, understand, and solve problems in different ways. It is important to know whether an individual, a group, an organization, or a network is being addressed.

Prevent Misinterpretation. The visualization should prevent misuse, misinterpretation, and misunderstanding. It is important to address the context, to present the overview, and to display options to act. Visualizations could further be combined with text to prevent the above negative effects.

Compress your Knowledge. To increase the information quality and prevent information overload, a designer should concentrate on the quality, rather than the quantity; thus concentrate on the essence. Tufte suggests compressing as much information into a space as small as possible.

Present Overview and Detail. Shneiderman's Mantra "*overview first, zoom-in and filter, then show details on demand*" (Shneiderman, 1996) for information visualization interfaces is also valid for Knowledge Visualization. A designer should present both an overview of the data and allow the user to access details.

Be consistent. Complementary visualizations should be consistent with regard to the logic, the way in which the user interacts with it (e.g., in interactive applications) and to the use of visual elements. Elements such as color, shape, size, symbols, and fonts should be similar for similar types of data in all visualizations.

Avoid decoration. The visualization should provoke thought about the content rather than the visualization itself, therefore, one should be careful with decorations or the use of elements such as clip-art or strong colors.

Don't distract your audience. Do not use visualizations to distract your audience unless this is your intention. Many visualizations (i.e., clip art) do nothing but divert the attention of the user, and distract the user from their knowledge acquisition or problem-solving tasks.

Use natural representations. Natural representations mean that the visualization can be associated with the real-world, which allows a recognition-based approach to be used instead of one that requires recall. This is important because recognition-based tasks are faster and require less energy.

Motivate your audience. Visual representations should be designed to envision, to lead to thinking, and to encourage users to elaborate knowledge. Use imaginary visual representations to establish a shared vision.

9. CONCLUSIONS

9.1 Summary of the thesis

This thesis introduced the research area **Knowledge Visualization** by presenting our innate visual abilities which can be exploited by using visualizations to transfer and create knowledge. It presents a dialectic argumentation, a theoretical model, a theoretical framework, and four new approaches. Each approach tests a specific hypothesis on how the potential of *complementary visualizations* can be exploited to improve the transfer of knowledge.

The thesis has proven that Knowledge Visualization is powerful for the transfer of knowledge, that it reduces information overload, and that it leads to better understanding and remembrance. Knowledge Visualization thus solves the predominant problems in organizations, namely that in less time more complex contents are to be communicated to more diverse audiences.

The thesis adapted the methods of architects to use complementary visualizations to the field of knowledge communication and knowledge transfer in general. It then tested these adaptations in the domain of business knowledge management, in four case studies, and posed proving- and counterarguments for the hypothesis that complementary visualizations support the transfer of knowledge, especially for individuals with different backgrounds.

The thesis introduced the new field Knowledge Visualization as an achievement parallel to writing this thesis both in the scientific community and for practitioners. With twelve published scientific articles on knowledge visualization (Burkhard, 2004a, Burkhard, 2004b, Burkhard, 2004c, Burkhard, 2005a, Burkhard, 2005b, Burkhard and Meier, 2004, Burkhard and Meier, 2005, Burkhard, et al., 2005a, Burkhard, et al., 2005b, Burkhard, et al., 2005c, Eppler and Burkhard, 2005, Stott, et al., 2005) I initiated a scientific discourse in the fields of knowledge management, information visualization, and communication sciences[30]. This clearly

[30] That this thesis serves as a main building block to establish the new field Knowledge Visualization can be seen in the facts that I was asked to introduce and lead a symposium "Knowledge Visualization" in an important international information visualization conference (Infovis 2005) and second that the definition of Knowledge Visualization, written together with Martin Eppler, will appear in the encyclopedia of knowledge management.

shows that (1) there is a difference between the two fields information visualization and the new introduced field Knowledge Visualization, (2) my goal to establish the new field and to contribute to the domain of information visualization has been reached, and (3) the goal to establish this new focus in the context of knowledge management and information visualization research has also been reached.

I believe that the main reason for these positive signals is that my research is analytical and inclusive rather than exclusive. This means that the framework and the model are tightly coupled to existing taxonomies in a way that they can be easily integrated and accepted. Thus, they help mediate between the different fields of knowledge management, information visualization, information design, and communication sciences.

This work aimed to organize arguments from cognitive science, evaluations, and further sources to both prove and counter the hypothesis that complementary visualizations improve the transfer of knowledge. This dialectic approach is also helpful for pointing to the limits and dangers of visual representations and allowed principles to be created which are guidelines that can be extended.

The thesis, as discussed in the chapter Motivation, reached the goals that were the starting point for this thesis: to establish the new field of *Knowledge Visualization* by presenting original theoretical and practical contributions.

The five theoretical contributions are the **definition of Knowledge Visualization**, the concept of **complementary visualizations**, the **dialectic analysis**, the **first Knowledge Visualization Framework**, and the **first Knowledge Visualization Model.**

The four practical contributions for predominant key problems were invented, implemented, evaluated, and discussed through scientific publications. Each case study presents a research contribution for the fields I refer to: (1) a new metaphor for interfunctional communication (Tube Map Visualization), (2) a new visual document search paradigm (Metaview), (3) a new approach to improve the transfer of knowledge between planners and decision makers (BV4A, and (4) an application of the framework in one scenario (Science City ETH). The evaluations of the case studies allowed relevant empirical data to be derived to test the theoretical contributions.

In conclusion, the findings and insights, both in theory and in practice have implications for researchers in the realm of knowledge management, information visualization and visual communication sciences.

9.2 Conclusions

9.2.1 Conclusion with regard to the Hypotheses

In conclusion, the three **theoretical hypotheses are true:**

First hypothesis: The methods of architects to use complementary visualizations can be adapted to non-architectural domains, e.g., organizations. I have proven, with different applications in different settings, that the methods of architects to use complementary visualizations can be adapted for non-architectural knowledge transfers, i.e., in the context of organizations. Therefore, a new value proposition for architects who have the ideal background for becoming Knowledge Visualization experts has been opened. This because (1) they can think in different conceptual levels and can see a problem from different perspectives, (2) they are trained to mediate among different fields of research, and (3) they think in structures, can envision alternative solutions, and have an eye for aesthetics.

Second hypothesis: The use of complementary visualizations improves the transfer of knowledge in organizations compared to an individual visualization, text, or numbers. The use of complementary visualizations improves the transfer of knowledge in organizations. Knowledge Visualization offers a systematic approach on how visual representations can be used for the transfer of knowledge in order to increase its speed and its effect. The transfer of knowledge occurs at various levels: between individuals, from individuals to groups, between groups, from individuals and groups to an organization. Gupta and Govindarajan (2000) conceptualized knowledge transfer and state that one key issue is how recipients not only acquire and assimilate but also use knowledge (Cohen and Levinthal, 1990). To do so, knowledge must be recreated in the mind of the receiver, which depends on the recipient's cognitive capacity to process the incoming stimuli (Vance and Eynon, 1998). Thus, the person responsible for the transfer of knowledge not only needs to convey the relevant knowledge at the right time to the right destination, he also needs to convey it in the right context. In all of these processes visual representations can improve the individual processes therefore, the second hypothesis is also true. The use of complementary visualizations improves understanding rather than leads to inferences (such as misinformation, misunderstanding, or miscommunication). However, this is only partially correct, because miscommunication, misunderstanding, and misinterpretation may occur when visual representations are wrongly encoded by the author or wrongly decoded by the recipient. In addition, one has always to be aware on the cost-benefit ratio. For each task it has to be considered whether a visual representation is required, because not only the time and budget for the creation, but also the time and budget for modification are of importance.

Third hypothesis: There is an optimal number of complementary visualizations for different knowledge transfer tasks. I have shown in the Knowledge Visualization Model and the Inverse U for Complementary Visualizations that there are situations where the use of complementary visualizations supposes a signification effort and cost without positive effects for the knowledge transfer efficiency. Therefore there always exists an optimal number of complementary visualization for different knowledge transfer tasks, which has been conceptualized with the Inverse U of Complementary Visualization. But I also found that the optimal number can be one or zero visualizations (e.g., for the final quotation of stock).

9.2.2 Conclusion with regard to the Main Goal: Knowledge Visualization

My introduction of the term Knowledge Visualization (Burkhard, 2004b) allowed the difference between Knowledge Visualization and Information Visualization to be discussed. This first introduction also helped to differentiate *Knowledge Visualization* and *Knowledge Domain Visualization* (Börner and Chen, 2002, Chen, 2003). Today the following definition of Knowledge Visualization is being accepted by information visualization, Knowledge Visualization, and knowledge domain visualization experts: "*Knowledge Visualization examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons*". (Burkhard, 2004b, Burkhard and Meier, 2004, Eppler and Burkhard, 2005). Knowledge Visualization thus designates all graphic means that can be used to construct and convey insight. Based on this consensus, an elaborated definition of the field finally found entrance into the Scientific Encyclopedia of Knowledge Management (Eppler and Burkhard, 2005). This is an important milestone because the Encyclopedia defines key concepts in the field Knowledge Management which will influence future researchers strongly.

But even if Knowledge Visualization is now accepted, what, in conclusion is the difference to information visualization? This question is answered in the next section.

9.2.3 Conclusion on the Difference between Information Visualization and Knowledge Visualization

Information visualization and Knowledge Visualization both exploit our innate abilities to effectively process visual representations, but the contents and the processes differ. Information visualization aims to visually explore abstract data and to derive new insights. Knowledge Visualization, in contrast, aims to improve the *transfer and the creation of knowledge* *among people* by giving them richer means to express what they know. While information visualization *improves information retrieval, access and presentation of large data sets*, in particular in the interaction between humans and computers, Knowledge Visualization primarily aims at enriching knowledge-intensive communication between individuals, for example by relating new insights to already understood concepts, as is the case with visual metaphors.

Early precursors of information visualization created static paper-based visualizations (i.e., a map or a drawing) (Bertin, 1967, Tufte, 1983, Tufte, 1990, Tufte, 1997), but recently the research area information visualization is being claimed by a more computer-based community (Card, et al., 1999, Chen, 1999a, Spence, 2000, Ware, 2000), which concentrate on computer based visualization methods as discussed above.

However, four limitations can be identified: First, non-computer based visualizations disappeared from the research field information visualization. Second, knowledge types (e.g., insights, experiences, tacit knowledge) that cannot be put into a digital carrier (i.e., a database) are ignored. Third, the role of the recipient is not studied enough. Fourth, applying the new methods to knowledge and business processes, and real problems, is not investigated systematically.

These issues were the starting point for a new research direction: *Knowledge Visualization.* Researchers in this field therefore often have a background in knowledge management, psychology, didactics, architecture, or communication studies.

In general, researchers in the fields of information visualization and Knowledge Visualization both exploit our innate abilities to effectively process visual representations, but the way of using these abilities differs in both domains.

Next, I try to differentiate the fields by discussing ten differences concerning the goals, the origin, and the techniques of both fields.

Goal: Knowledge Creation versus Knowledge Transfer
Information visualization aims to use computer-supported visual applications for exploratory tasks in large amounts of data, with the goal of getting new insights. Knowledge Visualization, in contrast, aims to use one or more visual representations with the goal to improve the transfer of knowledge among people and to improve the creation of knowledge in groups.

Benefit: Information visualization aims to improve information access, retrieval, and exploration of large data sets. Knowledge Visualization, in contrast, aims at augmenting knowledge-intensive processes (e.g., knowledge transfer, communication) among individuals by using one or more visual representations.

Content: Information visualization concentrates on explicit data such as facts or numbers, while Knowledge Visualization also cares for other knowledge types, such as experiences, insights, instructions, assumptions – knowledge types that answer questions such as why, who, or how.

Recipients: Information visualization typically supports individuals to get new insights. Knowledge Visualization, in contrast, concentrates on supporting individuals or a group of individuals to transfer knowledge and to create new knowledge in collaborative settings.

Influence: Information visualization provides new insights for the fields of information science, data mining, data analysis, and for problems such as information exploration, information retrieval, human-computer interaction, interface design. Knowledge Visualization provides new insights for the fields of visual communication science, knowledge management, and for problems such as knowledge exploration, -transfer, -creation, -application, learning, information quality, information overload, design, interface design, visual communication. However, some of these points also apply to information visualization.

Origin: Computer Science versus Architecture Studies

Proponents: Information visualization researchers typically have a background in computer science. Knowledge Visualization researchers, in contrast, mainly have a background in knowledge management, psychology, design, communication studies, or architecture.

Contribution: Information visualization is more technology-oriented; researchers in this field mainly create new technical methods. Knowledge Visualization is more solution-oriented and tries to apply novel, but also traditional visualization methods, to solve predominant problems. Only if no method exists or works, new methods are invented. Knowledge Visualization is integrative and offers urgently needed theoretical structures for the whole field of visualization research, with the aim to improve collaboration among these isolated fields.

Roots: Information visualization is a young field of research that only became possible with the introduction of computers. Knowledge Visualization is an even newer term, but grounded in cultural and intellectual achievements, e.g., of architects and philosophers, which use complementary visual representations to transfer and create knowledge, e.g., Eco reminds us of Aristotle on the power of metaphors (Eco, 1984, 100). The practice of architects of using complementary visualizations is a source for further investigation with relevance for knowledge management, communication science, and information visualization researchers. There are three reasons: (1) Architects combine, structure, and integrate different concepts. (2) Architects intuitively use complementary visualizations for knowledge-intense tasks. (3) Architects are experts in interfunctional communication (e.g., among decision makers, site constructors, local authorities). (4) Architects constantly think in and switch among different conceptual levels (e.g., urban scale or detail of a house).

Technique: Interactive Applications versus Visual Representations
Means: Information visualization uses computer-supported methods. Knowledge Visualization, in contrast, uses computer-supported, but also non-computer supported visualization methods, such as early information visualization proponents, architects, artists, or designers.

Complementary Visualizations: Information visualization combines different visualization methods using the same medium in one interface by tightly coupling them. This concept is called multiple coordinated views. Knowledge Visualization combines different visualization methods using one or more different media (e.g., a software application, a poster, or a physical object) with the aim to illustrate knowledge from different perspectives and to exploit different functions of visual representations. In Knowledge Visualization this concept is called complementary visualization. Complementary visualization is defined as the use of at least two visual representations that complement each other to enrich knowledge-intense processes. This concept is derived from the professional practice of architects and urban planners, which use complementary visualizations to envision, think, innovate, communicate, disseminate, and document complex knowledge (Burkhard, 2004b, Burkhard, 2004c).

This juxtaposition of the ten points is not exclusive, and should rather be seen as a starting point for others to extend the arguments. It is a first attempt to find synergies between both fields by describing the individual strengths and weaknesses. The juxtaposition makes clear that information visualization and Knowledge Visualization can benefit from one another and together they can improve learning, and/or the creation and transfer of knowledge.

9.2.4 General Conclusion

"If fish were to become scientists, the last thing they might discover would be water." (Samuels, 1970). Similar to the prelude wherein Samuels addressed the failure of researchers to study one of the most widely adopted instructional aids, pictures, I have to conclude I was confronted with almost the same phenomenon. In the literature of knowledge management the process of knowledge transfer and knowledge creation hardly took (with few exceptions) the potential of visual representations for the transfer and creation of knowledge into account. This thesis highlighted this gap, and presented the basis to establish the new and important research area Knowledge Visualization. I did so by juxtaposing both pros and cons of visual representations in general and the use of complementary visualization more specifically.

The research presented mediates between theoretical contributions: a dialectic argumentation, a framework and a model, which all focus on bridging the gap, and mediates and merges isolated research areas that investigate in knowledge transfer. Apart from this theoretical focus, I also tried to establish solutions for practitioners, because I am still concerned that humans learn how to write and calculate but not how to communicate visually. This is in contrast to the fact that we have entered the visual age.

My main motivation, as described in the introduction, to introduce and establish the new field Knowledge Visualization, finally grew into a passion to establish the importance of visual communication in society and education.

What I learned while researching and writing this thesis is to radically investigate my passion.

9.3 Future Trends

Based on the findings and the conclusion, in the next section I present an outline of future trends in Knowledge Visualization. Some of these areas belong to my future studies:

9.3.1 Knowledge Visualization in Strategic Management, Advertising and Marketing:

Today budgets for professional visualizers in organizations are allocated mainly for the fields of advertising or corporate identity. Advertising has its expertise in drawing attention, addressing emotions, and illustrating products or services. Corporate identity has expertise in the use of a visual language to support the creation of a corporate brand. Both fields are important, but they do not fully exploit the potential of visualizations. If it comes to the transfer and creation of knowledge, especially of business relevant, complex or abstract knowledge, Knowledge Visualization is a powerful complement to these fields, but often budget and time is only allocated when it is already too late. In my practical experience I have seen that Knowledge Visualization helps in early stages of projects. In the fields of strategic management, marketing, public relations, and advertising imaginary visualizations or mental images (i.e., stories or metaphors) are already used to envision and illustrate strategies, mutual targets, or values. Storytelling in management to create and disseminate knowledge is fruitful, for example as discussed by Loebbert (2003). I believe that these stories can be visualized and combined with other visualization formats to trigger and accelerate the creation and dissemination of knowledge. I believe that Knowledge Visualization can become a mediator of the essential knowledge between strategic management, advertising, marketing, public relations, and corporate communication, because it combines imaginary (i.e., stories), physical, and digital visualizations. I believe that the time and the budget for Knowledge Visualization will be integrated in future initiatives wherein the transfer and creation of knowledge is important.

9.3.2 Knowledge Ambienting: Moving Knowledge Visualization Off the Screen

The fact that imaginary visualizations (such as stories) are essential for Knowledge Visualization makes it clear that visualization is already leaving the screen and entering other realms. While visualizations to create and disseminate knowledge in organizations were originally seen as static objects, I can now identify two trends:

First, new displays, media, and carriers of information are being developed. Current user interfaces display information as "painted bits" on rectangular screens. New approaches with its roots in *Ubiquitous Computing* (Weiser, 1991) or *Augmented Reality* (Feiner, et al., 1993, Wellner, et al., 1993) attempt to change the paradigm of "painted bits" into "tangible bits" (Ishii and Ullmer, 1997). As a consequence, the richness of human senses and skills can be used for a much richer multi-sensory experience of digital information. Computer generated visualizations, which today are presented on screens or by video projections, will soon merge with virtual space. An example of this trend is the blue-c[31] project at the Federal Institute of Technology in Zurich. It presents a tele-immersive space for 3D collaboration in virtual environments (Gross, et al., 2003).

Second, visualizations are becoming more dynamic and interactive, as discussed in the section on knowledge animation. Visualizations are therefore no longer simple static objects for the transfer of knowledge in the classic sender-recipient model. They establish an iterative, collaborative process where the visualization (and new knowledge) is dynamically co-created.

These two trends will offer new opportunities for the creation and transfer of knowledge in organizations.

[31] http://blue-c.ethz.ch

GLOSSARY

The following glossary provides helpful definitions for Knowledge Visualization. The definitions of the terms have to be interpreted in the context of this thesis.

Case study. An empirical inquiry to investigate a phenomenon within it's real-life context, used to demonstrate behavioral phenomena and to document inductive reasoning.

Cognition. A way of looking at human behavior that emphasizes research on how the brain takes information in, creates perceptions, forms, and retrieves memories, processes information, and generates integrated patterns of action.

Cognitive Psychology. The study of the mental processes by which information from the environment is modified.

Complementary Visualizations are the use different visual representations that complement each other and allow to illustrate a content from different perspectives, which allows to improve the transfer of knowledge among individuals.

Conceptual diagrams are schematic depictions of abstract ideas with the help of standardized shapes such as arrows, circles, pyramids, matrices, etc.

Data. Raw, unrelated numbers or entries, explicated on a medium (e.g., in a database). Data are numbers, characters, images, or other outputs from devices.

Diagram. A diagram is an abstract, schematic representation used to explore structural relationships among parts, to explain concepts and to reduce complexity.

Gestalt principles provide descriptions of many basic perceptual phenomena.

Grounded Theory. The Grounded Theory approach is a qualitative research method that uses a systematic set of procedures to develop an inductively derived grounded theory on a phenomenon. The method can be used, if there is not enough theory about the research question.

Heuristic sketches are ad-hoc drawings that are used to assist the group reflection and communication process by making unstable knowledge explicit and debatable.

Image. A visual representation which is concerned with impression, expression, or realism.

Immersion. The feeling of being in an environment, e.g., in a virtual environment, a film, or a book.

Information. Information is data in a context and can be explicated and stored in an information system.

Information Art. Experimental applications that break with the traditional user interfaces and create digital aesthetic structures or impressions.

Information Architecture combines interface design, interaction design and virtual reality to create digital structures which allow for representational, navigational, or exploratory tasks.

Information Design is the art and science of preparing information so that information is comprehensible, rapidly, and accurately retrievable, and easy to translate into actions.

Information Overload is a state where information can no longer be accommodated and integrated by an individual due to the amount of information or limited time.

Information Exploration. A conceptual approach to explore data, mostly visually with visual techniques in the realm of information visualization.

Interactive visualizations are computer-based visualizations that allow users to control, combine, and manipulate different types of information or media.

Information visualization is the use of computer-supported methods to interactively explore and derive new insights through the visualization of large sets of information.

Interfunctional Communication is the communication to persons from different functions or organizational roles which have different cultural or educational backgrounds.

Knowledge emerges when someone combines different information to accomplish a specific task. It is justified true belief, know-what/-how/-who/-why/-where, that is stored in the brains of individuals, and that needs to be re-constructed and integrated by every individual itself.

Knowledge domain visualization focuses on identifying and visually presenting the dynamics of scientific frontiers in a multidisciplinary context and allows new ways of accessing knowledge sources by visualizing linkage, relationships, and the structures of scientific domains.

Knowledge Visualization examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons. Knowledge Visualization thus designates all graphic means that can be used to develop or convey insights, experiences, methods, or skills.

Knowledge maps are cartographic depictions of knowledge sources, structures, assets, and development or applications steps. Knowledge maps do not directly represent knowledge, but reference it for easier identification and assessment.

Knowledge animations are interactive applications that consist of interactive mechanisms that foster the re-construction of knowledge or the generation of new insights.

Mental Image. In psychology, the mental image is defined as an internal representation similar to that resulting from sensory experience but arising from memories.

Metadata. Data about Data. Data which provides context to make it more valuable.

Perception is a set of processes by which we recognize, organize, and make sense of stimuli in our environment.

Sketch. Represents the main idea and key features of a preliminary study. Sketches are atmospheric, fast and universally accessible. Sketches help to quickly visualize an idea.

Visual Cognition is defined as the use of mental imagery in thinking. Mental images can be derived from material stored in memory, or they can be mental "drawings" of things we have never seen.

Stories are imaginary, mental visualizations used to imagine and discuss scenarios of potential interventions (e.g., of a new building or urban intervention).

Visual metaphors are graphic depictions of seemingly unrelated graphic shapes that are used to convey an abstract idea by relating it to a concrete phenomenon.

Visualization. An externalized visual mean or mental model used to represent information.

CURRICULUM

Remo Aslak Burkhard studied architecture at the Swiss Federal Institute of Technology (ETH). During his studies he worked for the 3D Trade Floor Visualization Project of the New York Stock Exchange at Asymptote Architecture in New York. Before, during and after his studies, he worked in several companies in Switzerland and abroad in different functions including Bank Leu and IBM.

In 1999, Remo Aslak Burkhard founded the company vasp datatecture burkhard (www.vasp.ch), which after the studies grew and was recreated with his associate Michael Meier as vasp datatecture GmbH. Today vasp is market leader in the field of Knowledge Visualization in Switzerland and had projects for companies such as SwissRe, UBS, IBM, Ciba, Helsana, Accenture, Unique, and various smaller companies.

Since 2003, Remo Aslak Burkhard has been at the Institute for Media and Communications Management located at the University of St. Gallen were he is building up the Competence Center for Knowledge Visualization.

In his spare time he likes traveling to urban hubs such as Tokyo, Mexico City, Shanghai, Dubai, and Science City.

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