TECHNISCHE UNIVERSITÄT WIEN

VIENNA UNIVERSITY OF TECHNOLOGY

DISSERTATION

INTERACTIVE CEILING

Ambient Information Display for Architectural Environments

ausgeführt zum Zwecke der Erlangung des akademischen Grades
eines Doktors der technischen Wissenschaften

unter der Leitung von
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Wien, Oktober 2008

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Ambient Information Display for Architectural Environments

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Doctoral Thesis, October 2008
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ABSTRACT

In the information society of today, we are interacting with computing devices on a daily basis. While they are a valuable tool for retrieving information, it can sometimes be frustrating for users to access this information. This is especially the case when they want to maintain a constant awareness of information. The concept of ambient display suggests the integration of computing technologies into everyday environments to support monitoring of information at the periphery of users' attention. This thesis investigates the architectural ceiling for ambient display of information that is non-obtrusive, always available, and can be accessed by simply looking upwards. Various related fields are investigated that provide an important foundation for the research work described in this thesis, such as historical ceiling frescos, interactive architecture and ubiquitous computing. Using an explorative research approach, five feasibility studies were conducted to explore application scenarios and develop proof-of-concept prototypes for interactive ceilings. The results from the studies and insights from the literature review are conveyed in a framework for ceiling interaction, which serves as a tool for design and research in the field of interactive ceilings. Based on the literature review and the experience from developing the prototypes, design guidelines are suggested to further guide future research in this field. A conclusion derived from this work is that interactive ceilings are especially suited for visualizing spatial data, such as sound or environmental conditions, since they allow for visually mapping their location in space onto the ceiling. Further the aesthetic integration into the existing architectural environment is of vital importance to assure user acceptance.

KURZFASSUNG

Im Zeitalter der Informationsgesellschaft sind wir ständig von digitalen Geräten umgeben. Diese Geräte stellen nützliche Werkzeuge für die Beschaffung von Information dar, sind aber in ihrer Bedienung oft frustrierend, speziell wenn es notwendig ist, ein konstantes Bewusstsein über Information aufrecht zu erhalten. Das Konzept von Ambient Displays beschreibt die Integration von digitalen Technologien in alltägliche Umgebungen, um ein Bewusstsein über Information an der Peripherie der Wahrnehmung zu unterstützen. Die vorliegende Arbeit untersucht speziell die Eignung der architektonischen Decke als Ambient Display, das Information in unaufdringlicher Form darstellt und immer verfügbar ist. Dabei stützt sich die Arbeit unter anderem auf relevante Gebiete, die die Basis für die ausgeführte Forschungsarbeit bilden, wie zum Beispiel historische Deckenfresken, interaktive Architektur und Ubiquitous Computing. Unter Anwendung eines explorativen Ansatzes wurden fünf Machbarkeitsstudien durchgeführt, um Anwendungsszenarien zu untersuchen und Konzeptprototypen zu entwickeln. Die Ergebnisse von diesen Studien, sowie Erkenntnisse von der Literaturrecherche, wurden in Form eines Frameworks zusammengeführt, das als Werkzeug für das Design und die wissenschaftliche Untersuchung von interaktiven Decken dient. Basierend auf der Literaturrecherche und den von der Entwicklung der Prototypen abgeleiteten Erkenntnissen wurden weiters Design Richtlinien vorgeschlagen, die zukünftige Forschung in diesem Bereich leiten sollen. Eine Schlussfolgerung der Arbeit ist, dass interaktive Decken speziell zur Visualisierung von räumlichen Daten, wie zum Beispiel Schall oder Umgebungsbedingungen, eignen, da sie die visuelle Abbildung der Position, an der die Daten auftraten, ermöglichen. Des weiteren ist die ästhetische Integration in der architektonischen Umgebung von wesentlicher Bedeutung, um die Benutzerakzeptanz sicherzustellen.

Contents

PREFACE

Most of the research described in this thesis was conducted while I was working at the Research Group for Industrial Software (INSO) at the Vienna University of Technology. The idea to investigate the architectural ceiling in an ubiquitous computing context evolved during a visit at the In Situ group at the Universitè Paris Sud. My work further benefited a lot from my six month stay at the Design Lab at The University of Sydney. Travel has brought me to many different places, meeting many people, who helped shaping the topic. I particularly want to thank the following people for their help and support during the last four years.

I want to thank my supervisor, Thomas Grechenig, for his support and encouragement with my thesis topic. I also owe him for providing me with the opportunity to work in a multidisciplinary group and giving me the freedom to pursue my sometimes unconventional research ideas.

I am much obliged to Andrew Vande Moere, my advisor at The University of Sydney. The opportunity to work at his group in Sydney allowed me to further explore some of the aspects that build the basis of this thesis and to approach it from other perspectives. He also provided me with valuable feedback throughout the process of writing this thesis. It would not be of the same quality without his advice.

I would like to thank all my colleagues at INSO, the lecturers and fellow students at the Design Lab in Sydney, as well as the Nordsee group for many inspiring discussions. Special thanks to the DSHG group, consisting of Karin Kappel, Jürgen Spangl, and Jörg Summer, for the regular feedback and review sessions, which were an important guidance especially during the last year.

I further owe the following people credit for their help with parts of the projects described in this thesis. The ambient display model

presented in section 4.4 is based on research work that was conducted together with Karin Kappel and Andreas Lehner. Gerhard Rzepa provided me with valuable knowledge and support on the electrical engineering part of the sound allocation prototype described in section 3.4. Sonja Mayrhofer assisted me with setting up and conducting the study on emotional awareness, described in section 3.2.

Many thanks to my friends and colleagues, who volunteered to review the thesis. Their input was of great help for leveraging the quality of this work.

1 INTRODUCTION

Advances in technology promote the integration of computers and wireless networking technology into everyday objects. *Ubiquitous computing*, also called *calm computing*, describes a vision, where computing technology disappears into the environment, calmly assisting us in our daily activities (Weiser, 1991). Computers will increasingly inhabit everyday objects, such as clothes, coffee cups, light switches, furniture, or walls, that provide us with clues about *our environment, our loved ones, our own past, the objects around us, and the world beyond our home* (Weiser, 1996).

Ubiquitous computing applications therefore have the potential to provide a remedy to the problems of information overload. In our society, we are constantly surrounded by information technology. Electronic devices provide us with information and support us in our activities. While we increasingly depend on these devices, they are also often perceived as being annoying, sometimes frustrating, and distracting due to their obtrusive nature.

Architectural ceiling. In this thesis architectural ceiling describes the overhead upper surface of a room. It can be made of different materials, but typically does not feature windows or other openings.

In contrast, ubiquitous computing applications stay in the background and only provide us with information when we desire to or really have to consult this information. A crucial step towards this vision is that computing technologies are seamlessly integrated into our everyday environment. Designing spaces *where people can live, communicate, and interact without the technology interfering* still remains a challenge (Eriksson, 2006).

In this thesis the architectural ceiling is suggested as an information display, which augments everyday spaces with ubiquitous computing technologies to provide passers-by or inhabitants with information about their context, the building, or other people sharing the space.

A model for interactive systems. Giannetti (2004) defined the following categories for interactive systems: active, reactive, and interactive. An active system only allows users to control which content is displayed. A reactive system reflects external stimuli, such as user behavior or environmental conditions. An interactive system allows users to influence its output or to add new information in the case of more complex systems.

The umbrella term *interactive ceiling* is introduced to describe this concept and applications that employ the ceiling as information display. The term interactive here is used to emphasize the fact that there is a conversation taking place between people and technology. This does not imply that applications have to actively engage people into interactions. The concept of interactive ceiling also includes applications that are reactive, meaning that the information display's behavior is a *direct reaction to external stimuli, for instance user control or altered environmental conditions* (Giannetti, 2004). Using interactive ceiling as umbrella term also reflects one of the basic concepts of *tangible bits* – interactive surface (Ishii & Ullmer, 1997). Tangible bits is one of the contributing paradigms and is described in section 2.3.3.

1.1 Motivation

Information display. An information display provides people with information related to their context, the building, or other people sharing the same space. The representation can be high- or low-resolution and two- or three-dimensional. Information displays can be active, reactive, or interactive.

We daily interact with numerous objects and devices, which are located at arbitrary places in our environment. Common places, where interaction happens, are tables (e.g. desktop computers, books, or table lamps) and walls (e.g. flat panel TVs, clocks, or wall calendars). Only few applications require us to interact with the ceiling – in fact, only two examples can be found in the traditional home. The first one are lights, which typically inhabit ceilings. However, interaction and mediation of lights are very rudimentary, and we actually rather interact with switches that sit on walls. The other interface that sometimes can be found on architectural ceilings are ceiling fans, which usually allow interaction through a suspended string. These two examples are solutions to low-level problems, namely darkness and heat.

The dangling string, described by Weiser and Brown (1995), shows that ceilings also offer solutions to higher-level problems, such as awareness. The dangling string is an eight foot plastic string attached to an electric motor mounted onto the ceiling. The motor is electrically connected to an Ethernet cable and its speed is controlled by the network traffic on that cable, allowing peripheral surveillance of the network traffic (figure 1.1). Ishii and Ullmer (1997) also suggest to use ceilings as information display to connect the physical and virtual worlds. Tangible bits, in contrast to graphical bits, embody digital information in physical objects and environments.

The dangling string was one of the first prototypes for ambient display, which was later formalized as the concept of conveying information at *the periphery of a user's attention* (Mankoff et al., 2003). Ambient displays present information in an unobtrusive and aesthetically pleasing way and therefore reduce information overload. The architectural ceiling provides a natural opportunity for ambient display, since it literally sits at the periphery of human perception.

Figure 1.1: The dangling string, which represents the traffic on an Ethernet network.

1.2 Aim and Objectives

The aim of this research is to investigate the architectural ceiling as ambient information display in everyday environments that conveys information at the periphery of human perception.

To achieve this goal this thesis targets objectives at three levels. (1) The first one is to review ceilings in architecture, which covers historical (such as ceiling frescos) to contemporary (such as large-scale media displays) examples. (3) The second objective is to study application scenarios that investigate different aspects of using the ceiling as information display. This objective includes considerations in regards to user experience, evaluation, and implementation of interactive ceiling applications. (3) The third objective is to create a framework, which guides research and design of interactive ceiling applications.

The outcome of this research provides answers to the following questions:

- For which tasks can the ceiling be used to visualize information?
- What kind of information can be displayed on ceilings?
- Which interaction techniques can be applied for interactive ceiling applications?
- What are the design constraints for interactive ceiling applications?

1.3 Methodology

There is hardly any literature available about interactive ceilings. This research therefore requires the application of an explorative investigation approach (Bortz & Döring, 2003). The goal of such an investigation is to develop theoretical and conceptual assumptions that might eventually lead to the formulation of hypotheses. This is done by using qualitative research methods, such as interviews or user workshops. While qualitative approaches to information systems have gained acceptance, there is still a lack of detailed guidelines for methodological frameworks (Avison, Lau, Myers, & Nielsen, 1999). The research described in this thesis is loosely guided by *Verplank's Spiral* (Davenport, Holmquist, & Thomas, 1998), which supports the explorative approach. In this spiral model a project starts with a *hunch*, which is a vague idea of what to do. This leads to a *hack*, a first technical implementation, and makes it possible to *try* if the hunch actually works. If it does, it is further developed into *ideas* that lead to multiple *designs*, which can be implemented as *prototypes* and subsequently be *tested*. Eventually a set of *principles* arises from these evaluations, and if there are promises of further applications in industry, consequently a *production plan* and finally *products* will be designed (figure 1.2).

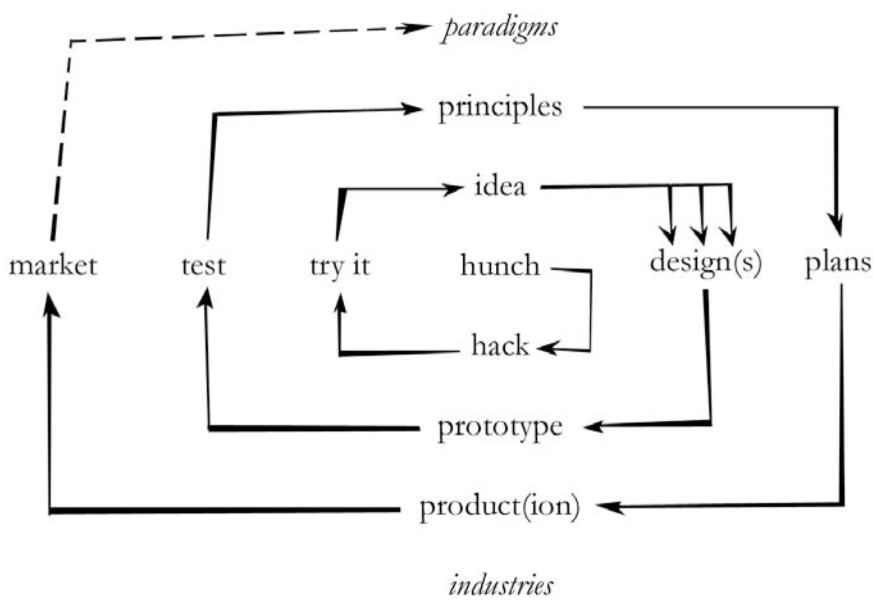


Figure 1.2: Verplank's spiral (Skog, 2006).

1.4 Significance

The design of the ceiling is currently not receiving enough attention in both contemporary architecture (Marc Aurel Schnabel, personal communication, June 2008) and research on ubiquitous computing environments (Hess & Tomitsch, 2007). This research work initiates a reconsideration of the ceiling particularly for information display. Interactive ceilings add to the perceived quality of architectural space and can, depending on the application scenario, also reduce information overload by relocating non-critical information into the periphery.

The contributions of this research work are: (1) five studies that give insights into application scenarios and implementation aspects, (2) a framework to guide design and research of interactive ceilings, and (3) design guidelines for interactive ceiling applications.

1.5 Organization

This thesis is structured into five chapters. Chapter 2 starts with an investigation of characteristics and attributes that constitute the psychology of ceilings. Next, architectural configurations of ceilings and the use of ceilings in and for arts is discussed. This also includes the use of media displays in contemporary architecture and approaches towards an interactive architecture. The chapter concludes with an extensive overview of research projects in the field of ubiquitous computing and ambient display.

In chapter 3 five studies on interactive ceiling applications are presented. The first study describes an application that projects a graphical representation of the short term weather forecast onto the ceiling. The application can be configured to display the current weather, the weather forecast for the current day, or the forecast for the following day.

The second study spans a number of design prototypes to explore various approaches for employing the ceiling to support implicit communication between distant couples. The designs include spatial representation of sound or activity, as well as more engaging approaches, such as creating patterns of light through interacting with the ceiling. Qualitative interviews were conducted to collect background information and evaluate the prototypes.

The third study investigates ceiling-based design prototypes for visualizing ambient sounds for deaf and hearing-impaired people in a home environment. The design was guided by results from expert interviews and a questionnaire. The prototypes were evaluated in a workshop with deaf and hearing-impaired people.

In the fourth study a low-resolution version of a display that covers the entire ceiling of a room is presented. The prototype developed in this study acts as an ambient display for sound levels within a space and allows for implicit interaction between passers-by and the space.

In the last study three different interaction techniques are compared in a controlled experiment: free hand pointing, laser pointing, and ball activation. The first two techniques are borrowed from ubiquitous computing environments. The third technique provides a more playful approach to ceiling interaction, where users can select an item by throwing a ball at the ceiling. The techniques were evaluated using a wizard of oz prototype.

Chapter 4 introduces the CIx (Ceiling Interaction) framework to guide design and research of interactive ceilings. The framework consists of three components: the architectural display model, the ceiling display model, and the ambient display model. The origins of the models and their application is discussed in detail in this chapter. A set of design guidelines is introduced as supplementation to the CIx framework.

In the last chapter general conclusions are derived and related to the research aim and objectives.

2

THEORY AND RELATED WORK

This chapter sets the stage for the research of this thesis. It provides an overview of theory and related work from different disciplines that contribute to the framework and interactive ceiling applications described in the following chapters. General aspects of ceilings, the use of ceilings in architecture and art, and the paradigms of ubiquitous computing and ambient display that propose the integration of information technologies into everyday environments are covered within this chapter.

2.1 The Psychology of Ceilings

In his book *The Design of Everyday Things* Norman (2002) refers to a British designer, who noticed that the kinds of materials used in the construction of passenger shelters for a railway company affected the way vandals responded. He therefore suggested that there might be a psychology of materials. Norman used this approach to describe what he calls the psychology of everyday things. He claims that there are several principles that affect the way we interact with things, which constitute a form of psychology. In the same way as a passenger shelter has a psychology, ceilings of rooms also have a psychology. A shelter made of wood has a different affordance than one that is made of glass, hence they have different psychological constitutions. Flat wooden surfaces encouraged vandals to write on them, glass in contrast was smashed by the vandals (Norman, 2002). A ceiling, though it is a flat surface, does not have the affordance to write on it – not even if it is made of wood. This is due to one of the characteristics of ceilings, namely that it is usually not possible to touch them without using any tools, such as a ladder. In contrast, objects fixed onto the ceiling tend to hang down, which affords the action of pulling. Interfaces such as pull cords used as switches (figure 2.1) and lights that allow changing of their height exploit this characteristic.

Ceilings further feature specific attributes, such as height, size, and color. These attributes influence the psychological expression of ceilings. For example, a dark ceiling emphasizes a feeling of oppression, which is due to the fact that a dark color lowers the experienced height of the ceiling (Wharton & Ogden, 1898), while a light-colored ceiling gives an impression of open space. In the hallways of the house where I live the kind of material and a low-enough ceiling height indeed seem to motivate the action of breaking, similar to the shelters made of glass. These hallways feature so-called dropped ceilings made of lightweight tiles (see figure 2.14 for an example) and the material used for the tiles has a similar appearance as styrofoam. It seems that vandals just cannot resist the affordance of this material combined with the provoking low height of the ceiling and the tiles therefore need to be replaced constantly.

Figure 2.1: Suspended pull cords to control ceiling fan and light.

In this section characteristics and attributes that constitute the psychology of ceilings are introduced. These characteristics and attributes are important issues that need to be considered when designing interactive ceiling applications.

2.1.1 Characteristics of Ceilings

Ceilings are a subform of walls. They share many characteristics with walls, but also have many that are specifically valid for ceilings. There are various kinds of ceilings (some of them are described in section 2.2.2), which exceed by far the possibilities for wall constructions. It is therefore necessary to differentiate between general characteristics and those that depend on the specific form of the ceiling. Architectural trends and advances in construction technologies have led to so many varying configurations of ceilings that it is possible to find an exception for any of the characteristics presented in this section. A classification of all ceiling concepts and their characteristics would exceed the scope of this work and would not add any valuable insights to its contribution in the context of interactive ceilings. The term *ceilings* in this chapter therefore only refers to ceilings that comply with the definition given in the chapter 1.

Ceilings of rooms, in their basic form, feature the following general characteristics:

Ceilings are situated in space above our heads. Most of the time, i.e. while we sit, stand, or walk, ceilings are located above us. The distance to the ceiling surface may vary, but in general we do not see the ceiling, while focusing on other tasks. We do, however, perceive the ceiling at the periphery of our perception, depending on its distance and size. This characteristic also means that we can move the ceiling into the focus of our attention by simply looking upwards.

Ceilings support a clear view. The view onto other surfaces in rooms, i.e. walls and floors, is often interrupted by furniture or other objects. It is often not possible to see every corner and every bit of the floor from one position inside the room. The same is true for walls, where doorways, tables, or other furniture might prevent a clear view. In contrast, it is always possible to see every part of a ceiling, independent of the position inside the room. Ceilings that feature hanging objects, such as lights or ceiling fans, are exceptions, since those objects might prevent partially the view onto the ceiling.

Ceilings are not covered by objects. It is common to put objects on walls, such as pictures or wall clocks. Those objects cover the wall at least partially, dividing it into several parts of different sizes. It is, in contrast, very uncommon to mount objects onto the ceiling (the flat screen TV above the bed might be a rare exception). The ceiling therefore constitutes a large surface that is only divided by the surrounding walls.

Ceilings do not have any openings. Rooms usually feature openings as connecting elements to the outside, such as windows and doors. Typically windows and doors are located on walls. Ceilings usually do not have similar openings. Exceptions are roof windows, which are sometimes found in the upmost floor or in large halls, and attic doors that are accessed through a ladder.

Ceilings stay clean and clear. Due to their height ceilings get less dirty than other surfaces. It is impossible to walk on them and also very difficult to touch them or even streak them with an object, which might cause stains. Due to gravity it further stays free of dust. People often tend to spread all kinds of objects and artifacts around the floor, covering it partially or even entirely. Gravity also keeps ceilings clear from this kind of room "pollution".

It is difficult or impossible to touch ceilings. Depending on the actual height of a ceiling it is difficult or even impossible to touch it without any supporting tools, such as a chair or ladder.

When lying down, the ceiling moves into the main perception. As stated above ceilings are generally located above our heads and therefore outside of our main perception. However, when lying down on the back, it moves into the center of our vision. In this case ceilings are very similar to distant walls.

2.1.2 Ceiling Attributes

There are many attributes that are important for the design and construction of ceilings from an architectural point of view. In this section only those attributes that will be important later-on throughout this thesis are discussed. Further details on other attributes can be found in Alexander, Ishikawa, and Silverstein (1978) and Durm, Ende, Schmitt, and Barkhaufen (1895).

Size and height. These are the basic attributes of ceilings. Together they describe the size of volume of the space that is covered by the ceiling. A large ceiling should be accompanied with a large room height, or else it would feel as the ceiling is pressing heavily on our heads, propagating a feeling of oppression (Wharton & Ogden, 1898). Exceptions are long and narrow spaces, where people only pass through. Small-sized rooms should have a lower ceiling that balances oppression and open space. A small room with a very high ceiling would not allow people to feel comfortable. The height of ceilings also depends on the dedication of space (see below). Public rooms and rooms where many people gather should have a higher height, while rooms for one or two people should feature a lower ceiling (Alexander et al., 1978). The size of ceilings typically also correlates with the dedication of space.

Color and patterns. The color of a ceiling can affect the subjective impression of a room's size of volume. This also depends on other colors used inside the room, especially on the color of the floor. A light-colored floor in combination with a dark ceiling visually lowers the height, while a light-colored ceiling above a dark floor seems to raise the subjective height of a room (Wharton & Ogden, 1898). Ceilings may also feature patterns (e.g. ceiling wall papers, section 2.2.3, page 42) or paintings (e.g. frescos, section 2.2.3, page 38). Both, however, also give an overall impression of color which again affects the visual height of space. Color, patterns, and paintings also have to harmonize with the room's physical size and height.

Shape. Typical standard ceilings have a rectangular shape and a flat even surface. The geometry of the ceiling largely depends on the shape of the room. The form of the surface itself can vary. Only in some cases the room type determines the form of the surface. For example, in attics ceilings are often constructed as inclined flat surfaces. A traditional type that is especially used for large public rooms or halls are vaulted slabs (section 2.2.2). Modern construction technologies (e.g. stretch ceilings, section 2.2.2) allow for the design of almost any shape. The shape of a ceiling can also influence the visual height of a space and further affects its acoustics.

Structure. Structural elements are usually covered by the visual surface of the ceiling, but can sometimes be used as decorative element (e.g. wooden beams). So-called dropped ceilings (section 2.2.2) consist of a metal grid and lightweight tiles. The metal grid is always visible and also represents a structural attribute. Such ceilings have a different character, because of the visible structure and also because of the dynamic character of the tiles, which are not fixed and can be replaced or moved easily. Visible structural elements (such as beams) can affect the degree of comfort that people experience in a space (Wharton & Ogden, 1898).

Type of dedication. The dedication of ceilings depends on the dedication of the room itself. There are three typical types that can be found in buildings – private, public, and semi-public spaces. Private spaces are usually inhabited by few people, typical examples are apartments and one-or-more-family houses. Public spaces are typical large spaces where people gather, such as museums, churches, libraries, or other public institutions. Typical semi-public spaces are offices, where people both gather and work, but they usually do not live in these spaces. Those spaces are middle-sized (compared to private and public spaces), but their actual size can vary, depending on their specific purpose (e.g. office room versus meeting hall). The type of dedication influences ceiling height and size and vice versa (see above).

Orientation. In regard to orientation, there are two types of architectural spaces in buildings – *places* and *passageways*. On a larger architectural scale this resembles plazas and streets in cities (Petersen, Krogh, Ludvigsen, & Lykke-Olesen, 2005). Places within buildings can

Figure 2.2: The wooden ceiling in one of the royal rooms at the Alhambra in Granada (Spain) features the Latin words *plus oultre*, representing the motto of Charles V, King of Spain at the time the ceiling was erected, to *go beyond*. The words are arranged circularly, not only for aesthetic reasons – this also makes them legible from different viewing angles.

have different embodiments, such as halls, rooms, or alcoves, depending on their dedication. Passageways are typically represented by hallways. What is important, is that every space has either a static or dynamic characteristic regarding the flow of people through space. People usually do not gather in hallways, they only use them to get from one point to another. Hallways therefore connect two or more places and represent a certain direction (similar to streets in cities). A typical example for *place* is the living room, where people gather, meet, rest, eat, or sleep – activities that take place over a longer period of time. In case of lack of connecting passageways, places can also become temporary passageways. Ceilings are sometimes designed to reflect the orientation of the space they cover. Despite the fact that ceilings possess an orientation, people might approach them from different directions. In the case of places this can be any direction, in case of passageways there are usually only two directions from which the ceiling is approached. This makes it difficult to display readable text on the ceiling. The wooden ceiling found at the Alhambra in Granada (Spain) shown in figure 2.2 demonstrates a possible solution to this: the text is repeated circularly to assure its legibility no matter from which side it is approached.

Field of view. Size and shape of ceilings determine their field of view. A large-sized rectangular ceiling provides a larger view than the ceiling of a small room. The reason for this is that a large overhead surface fills a larger area of the peripheral vision. Therefore a large ceiling is visible from more viewing angles than small-sized ceilings are. Ceilings of rambled rooms reduce the field of view due to their non-rectangular shape and people would have to move around to see all parts of the ceiling.

(In)visibility. As described above, ceilings are situated in the space above our heads and therefore not immediately visible. We only perceive the ceiling or parts of the ceiling at the periphery of our perception. The actual part that we see depends on our position inside the space, but mostly on size and height of the ceiling. A large low ceiling would be almost totally visible at our periphery. The visibility decreases if the height enlarges or the size becomes smaller. A rather high ceiling with a large surface might still be visible, while a ceiling of the same height and a smaller size would totally disappear from our periphery.

2.1.3 Human Perception of Spaces and Ceilings

Although we often do not consciously notice the ceiling when entering a room, it has a strong influence on how we perceive that space (Rasmussen, 1964). Henry (1992) defined three components of spatial perception: *(1) the sizes of the individual spaces, (2) the relative configuration of the spaces to each other and (3) the qualities and attributes (i.e. the feel) of individual spaces*.

Size of individual space. This component is defined by the attribute shape and size, which were already introduced above. People do not consciously measure the height and size of every room they enter, but they unconsciously *feel* it, which leads to a certain feeling of comfort or unease. If people are asked to express the size of a room they might say things like that *it is twice as large as my kitchen*, or *I could line three couches up from wall to wall* (Henry, 1992). A frame of reference for expressing the height of space might be one's body height (for lower rooms) or another common room into the space at hand (for high rooms). As stated above the color of the ceiling has an impact on the perceived room height. Mirrors are another way to virtually increase the height of spaces with low ceilings (see figure 2.3 for an example).

Relative configuration. People unconsciously build a mental map, when they experience a new environment, which is constantly refined and updated over time (Henry, 1992). This allows people to store spatial information in their memory, which is crucial to find ones way in unfamiliar environments. The second component is therefore defined by the way people explore and remember spaces, where the relation of spaces to each other represents an elementary role.

Figure 2.3: A mirror installed at the ceiling of a room leverages the perceived size of volume of an architectural space.

Feel of individual spaces. The third component describes how people feel when they experience a space. The basic characteristics of the space – shape and size – can make them feel *large or small, claustrophobic, public or private, open and inviting or chilling* (Henry, 1992). The perception of how a place feels is very subjective and can differ largely among people. It is therefore not possible to define objective attributes that describe the felt quality of space.

2.2 Ceilings in Architecture

This section discusses ceilings in an architectural context. The term architecture in the context of this thesis not only refers to the physical structure of an architectural environment, but also spans other spatially related disciplines. The section starts with a discussion of the ceiling as a conceptual notion. This is followed by a short history of ceilings in domestic architecture and an overview of physical structures of ceilings. The largest part of the section presents an introduction to ceiling art and decorations, which is mostly based on historical examples. Suspended objects, such as lights, fans, or signs, are briefly discussed and the remainder of the section covers fields that combine architectural concepts with information technologies. This includes media architecture, interactive architecture, and interactive art.

2.2.1 Ceilings as a Concept

In architecture, ceilings are the overhead boundaries of rooms. A ceiling either separates the room from another room, which sits above, or constitutes the border to the exterior. Only in some cases a room is directly constrained by the roof. Ceilings have to comply to static (permanent weight, live load, horizontal forces, and possibly dynamic forces), functional (fire, thermal, and noise protection), and design (visual appearance and decorations) constraints (Durm et al., 1895).

From a structural perspective ceilings can be classified into three categories (Durm et al., 1895): (1) ceilings, which do not have a room above and therefore do not have to hold a floor; (2) ceilings, above which there are one or more further rooms and which therefore also serve as a supporting floor to these rooms; and (3) ceilings, which represent the substruction for a balcony, terrace, etc.

For the research of this thesis it is important to stress that the ceiling is not only the underside of the floor, although timber ceilings in northern countries of Europe were treated this way centuries ago. In terms of decoration the three categories above do not seem to have any immediate importance. Accepting that the ceiling is an entirely different concept to the floor dissolves the relevance of these categories. Ceilings from all categories might feature the same style, no matter which constructional purpose they serve. It is of course important to consider the type of ceiling when planning and

Ceiling vs. underside of floor. Until the sixteenth century, the same word was used for both floor and ceiling in French (Wharton & Ogden, 1898), which indicates that the ceiling was not treated as a surface on its own, but rather as the underside of floors.

constructing the basic structure of a building. Different kinds of ceiling construction exists (Durm et al., 1895), which might be as well relevant for the decoration of houses, insofar as sometimes the exposure of structural forms is desired.

Apart from many specific configurations, the basic character of ceilings can be classified into *flat*, *vaulted*, and *curved*. In fact, the form of the ceiling is of far more importance to the general effect of the room than its decoration. Wharton and Ogden (1898) discuss positive and negative effects of different configurations and give insights to their application at the end of the 19th century.

But before moving on to a deeper discussion of the history of ceilings in architecture, it is necessary to ensure a common agreement of the term *ceiling*. What do we actually conceive as being a ceiling? The most common sense in our culture is identical with the definition given above: a ceiling represents the bounding of a room. However, this consequently leads to the question of what is being considered as a room? Even in our culture, a room does not necessarily have to be rectangular in shape, enclosed by walls featuring one or more exits and closed by a ceiling. Rooms might reflect all kinds of shapes, which are mirrored by the ceiling. From another perspective, one might say that the ceiling determines the shape of the room. But this is not always true. Apart from following the general geometry of a room, ceilings might be vaulted or curved. In some cases not even the general geometry might be the same, as it is the case for example with attics.

Different rooms and therefore different types of ceilings are prevalent in different cultures. Native American tepees, for example, which have a conical form, do not feature a ceiling at all. In fact the concepts of walls and ceiling become one. The same might be true for igloos, which are dome-shaped and typically built from blocks of solid snow. People from Ancient Egypt believed that the sky was an enormous ceiling, or overhead platform, along which the waters of the heavenly ocean flowed (Edwards, 1891).

One attribute that defines a ceiling, on which probably most people would agree, is that the ceiling is situated above our heads. This definition is only possible due to our directional senses and gravity. We know where up and down is. If somebody would turn us around with our eyes covered or in a dark room, we would still be able to sense whether our feet are pointing towards the floor or ceiling. These directional senses are different for different life-forms. Triops (Notostracans), which belong to the oldest living animal species on earth, sense the directions of up and down based on the source of light. When a light source is held beneath an aquarium filled with Triops, they will turn around and continue swimming on their back.

One might argue that this is all very far away from the topic of ceilings, but we might be able to gather inspirations and learn new concepts or implications for architectural configurations. The turnOn prototype from the Austrian architects group AllesWirdGut (Awg, 2004) for example moves away from a strict separation of floor and ceiling, turning the room into a round wheel that can be placed in different operation modes (figures 2.4 and 2.5). turnOn features a sleeping room, a working room, and a kitchen. The different living modes are activated through walking, which turns the object. What was the ceiling before becomes the floor and what was used to stand on before turns into the ceiling. Ceilings therefore suddenly possess a much greater role than being pure decoration. They hold an important functionality that does not interfere or impose on the inhabitant, but can be activated by turning the room.

Figure 2.4: The turnOn prototype from AllesWirdGut architects group.

This short discussion points out that there are application areas that go beyond the traditional perception of architectural space. However, in this thesis the term *ceiling* will only be used for surfaces that serve as boundaries to rooms in western culture, if not explicitly stated otherwise.

2.2.2 Configurations of Ceilings

Various configurations of ceilings can be found in historical and contemporary architecture: high ceilings, low ceilings, flat ceilings, vaulted ceilings, curved ceilings, etc. The design of ceilings is influenced by different aspects, for instance the context in which the room that the ceiling covers is used. The construction technique influences the visual appearance of ceilings. Thus, the configuration of ceilings changed over time, depending on the construction techniques that were available and trends of different epochs.

Ceiling Heights

In the early days of human history the height of ceilings was determined by practical aspects. For instance, low ceilings held body heat and were therefore easier to keep warm on cold days. High ceilings, in contrast, had the advantage of reducing the effect of smoke

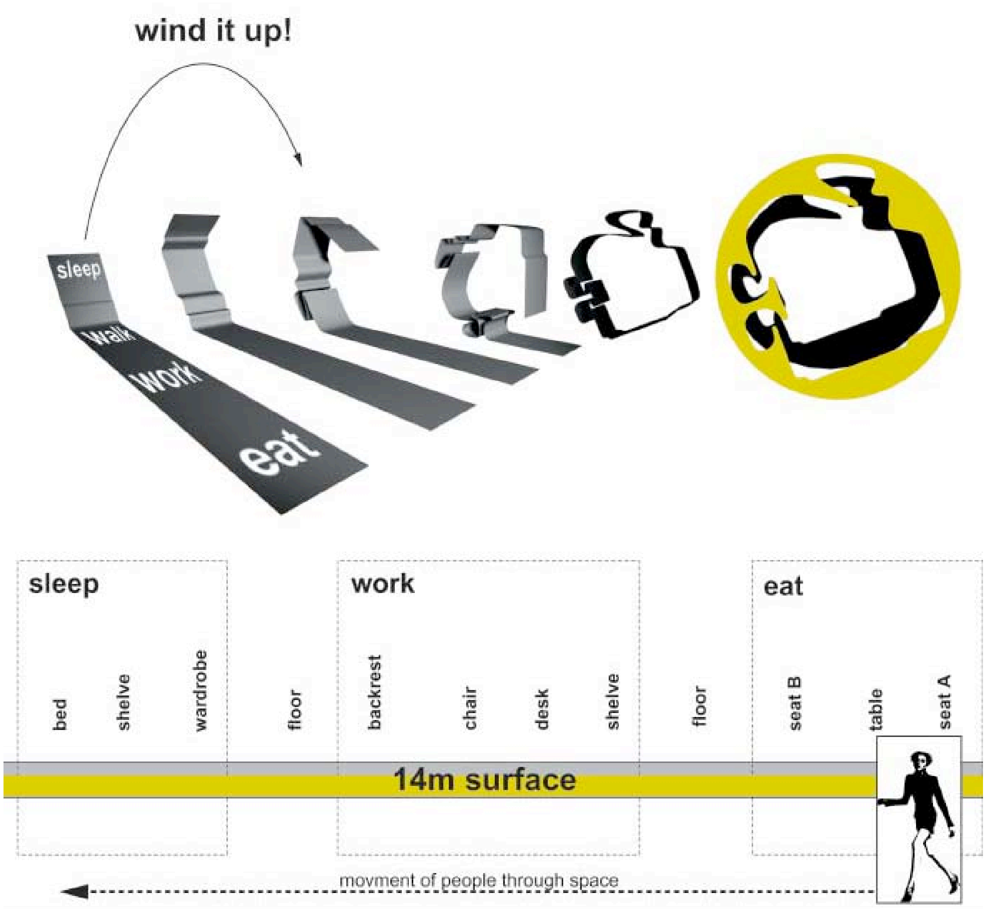


Figure 2.5: The turnOn concept features three different living modes – eating, working, and sleeping. Modes can be changed by movement through space.

from heating, lighting, and cooking. They also kept buildings cooler during hot summer days.

High ceilings suggest a wealthy living style, while low ceilings can create a cramped impression (Rasmussen, 1964). This is also the reason why we can still find houses from the last centuries that feature high ceilings. Public buildings, such as town halls, museums, churches, and shopping centers, still use high ceilings to create the impression of wealth and to impress visitors, but also to balance the size of the rooms or halls. Public places usually have to accommodate large crowds and it is therefore important to create an expansive atmosphere.

Meyers-Levy and Zhu (2007) demonstrated the influence of ceiling height on the type of processing that people use for problem solving. They conducted three experiments and concluded that a high ceiling induces freedom-related concepts, whereas a low ceiling resulted in refinement-related concepts. These concepts are derived from a comparison of small and contained chapels versus awe-inspiring cathedrals (Meyers-Levy & Zhu, 2007). Thus the concepts of freedom and refinement translate to openness and restrictedness respectively. The conclusion from this research is that the ceiling height has to match the intended purpose of the architectural space. Depending on the purpose either of the concepts might be desired.

Figure 2.6: Composition of supporting wooden beams and floor and ceiling with fill for insulation.

The height of rooms can also be extended visually, for instance by installing vaulted ceilings or large windows that start right above the floor. This creates the optical illusion of a higher ceiling, which in turn has an impact on how people experience space (cf. section 2.1.3).

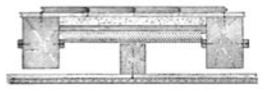


Figure 2.7: Beam ceiling with different beams for floor and ceiling support to improve thermal and noise insulation.

Ceiling Construction

This section gives an overview of ceiling construction from a historic perspective. Durm et al. (1895) describe three different construction types of ceilings: beam ceilings, vaulted slabs, and ceilings built from other construction materials.

Figure 2.8: Iron beams as supporting elements and plaster as filling.

Beam ceilings. The first construction type describes ceilings that consist mainly of supporting beams. They are simpler than other types of ceilings in terms of their construction. Beam ceilings are backed through walls or free-standing supporting stands. Timber-based beam ceilings consist of supporting beams, an intermediate ceiling to absorb sound and for thermal insulation, the actual ceiling of the covered room, and for the most part a floor, resting on the supporting beams (figures 2.6 and 2.7). Beam ceilings that consist of iron and timber use a combination of the two as supporting elements (figure 2.8). Another composition that is used for beam ceilings combines iron as supporting beams with stone or plaster. There are also beam ceilings that are built from iron and mostly use corrugated metal sheets as building material.

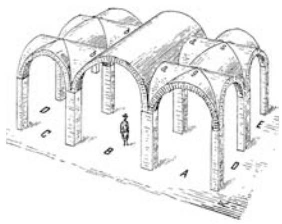


Figure 2.9: Cascading of several cross-shaped vaults to cover a wide-stretched room.

Vaulted slabs. The second construction type was common during the 19th century and in the beginning of the 20th century. Vaulted slabs consist of double-T-carrier as supporting elements and bricking or stonework as fills. Durm et al. (1895) list several types of vaulted slabs, including cross- shaped vaults, fan-vaulted ceilings, and domes (figures 2.9, 2.10, and 2.11).

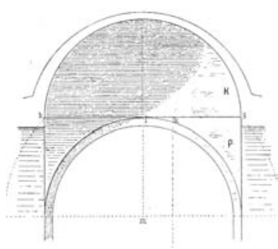


Figure 2.10: Cross section of a dome.

Ceilings built from other construction materials. The last construction type includes glass ceilings, skylights, and corrugated metal sheet ceilings. Ceilings made out of glass sometimes also serve as a floor for the room above. In this case the glass provides a view to

Figure 2.13: The glass ceiling of the ancient roman bath in Vienna (Austria), Praterstern.

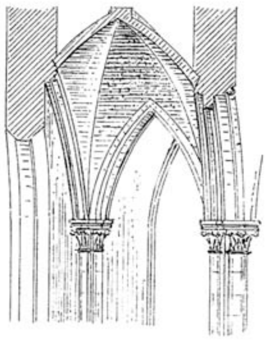


Figure 2.11: Gothic cross-shaped vault.

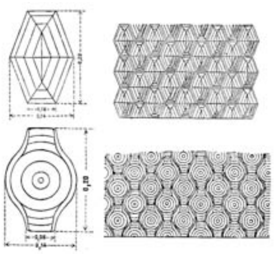


Figure 2.12: Different styles of glass blocks.

the upper room or rather allows light from the room above to enter the room. The view might be blurred or distorted, depending on the kind of glass material used (figure 2.12). Glass ceilings that also form the roof of a building and skylights provide a sky view and light up the room. Glass as building material for ceilings is usually used for translucent coverings of large halls (figure 2.13) or hallways, only lately it is increasingly used in houses. For glass ceilings that span a larger surface iron beams or grids are integrated into the ceiling as supporting elements.

The Visible Part of Ceilings

In most cases the structural part of the ceiling is covered by an additional layer that hides construction elements and provides a smooth surface that is visually pleasing and also allows the application of paint or other decorations. Additional layers can also improve sound and thermal insulation, balance acoustics, and allow for spatial adjustment of room proportions.

The visible part of ceilings can be either classified according to its visual appearance or to the treatment, i.e. the material and technique used. Types of the visual appearance of ceilings are: coved, lean to, open beam, and dropped or suspended (Durm et al., 1895). Dropped ceilings are more contemporary than the construction types above.

Figure 2.14: Dropped ceilings made of metal grids clad with lightweight tiles – containing light fixture elements (left) and used to conceal piping, wiring, and ductwork (right).

They are further most interesting for the context of this thesis and are therefore discussed in detail below.

Dropped (or suspended) ceilings consist of a grid of metal t-shaped channels suspended drom the main ceiling structure. Each cell of the grid is filled with lightweight acoustic ceiling tiles. Tiles are typically white, but can also be painted any color. Light fixtures that have the same size can be inserted into the grid as desired (figure 2.14, left). This type of ceiling is used as secondary ceiling that offers both enhanced sound absorption and a space to hide piping, wiring, or ductwork (figure 2.14, right). Adding a special insulation material above the panels improves sound insulation. Special tiles made from mineral fibers can be used if fire safety is a concern. Dropped ceilings offer great flexibility due to their dynamic character. Tiles can be removed and replaced by other elements easily and the plenum offers plenty of space to hide technology.

Rabitz or gypsum plasterboard ceilings are also sometimes used for dropped ceilings and provide a space to hide mechanical equipment. Rabitz ceilings consist of a wire-cloth that is suspended from the ceiling and filled with plaster. This type of dropped ceiling does not allow for easy access to the plenum, since it is built as a continuous surface. However they also allow for adding invisible installation of wiring to existing constructions.

Most ceilings consist of timber ceiling joists and are clad with drywall or plaster. More decorative ceilings may be clad or covered with wood paneling or pressed metal. Other types of ceiling surfaces are directly fixed onto the main ceiling structure (e.g. whitewashed ceilings). These ceiling types do not allow for easy installation of additional wiring since they are lacking a plenum. Instead they provide better

Figure 2.15: Stretch ceilings consist of PVC-foil and allow individual composition in terms of color and surface.

stability and can hold heavy objects, for instance chandeliers. They are therefore generally better suited for the installation of hanging objects.

A recent trend are stretch ceilings, which can be even or curved, are made of a PVC-foil and can be fixed onto the ceiling in any composition (figure 2.15). They first appeared in the middle of the 1960s in Sweden, but can actually be traced back to the ancient states of Egypt, Greece, and Rome, where a thin fabric was fixed in one plane onto the ceiling to create a feeling of comfort in the stone cavities of that time. Modern stretch ceilings come in a wide range of colors and even patterns are available (figure 2.16). They provide fire safety, moisture resistance, high durability, stability, and are easy and fast to install. Stretch ceilings are used in offices, apartments, shops, bars, pools, and sport halls.

Figure 2.16: A stretch ceiling with paint finish attached to the ceiling above a pool.

2.2.3 Ceiling Art and Decorations

Since humans began to create art some 40,000 years ago, the ceiling has always been an important platform for the exposure of art. There were periods when the ceiling was less conceived as an important design element (like in the middle of the 19th century), but there were also periods when ceilings were covered with impressive artwork (for example during the Renaissance).

Cave Art

Figure 2.17: The ceiling in the Altamira Cave in Spain, where the first Palaeolthic cave art was discovered in 1879.

Cave paintings were discovered on open air rocks, on walls, floors, and also on ceilings of caves (figure 2.17), and date back to 40,000 BC. The first cave painting was discovered in the 1860s, but they were accepted as an art only later (Johnson, 2003). The best artworks that are known today were created by the Magdalenians in Europe. The paintings were drawn with red and yellow ochre, hematite, manganese oxide and charcoal and mostly feature animals, such as bisons, horses, and deers as a theme.

Historians today still know least about cave art of all forms of art (Johnson, 2003). A recent controversial theory claims that cave painting might be an early form of graffiti, but it is still commonly believed that cave art was created by respected elders or shamans (Viegas, 2006). The most likely reason that people at that time devoted so much attention and resources to cave art over such a long period, is probably that they found satisfaction in it. It gave them entertainment, fun, excitement, sensual and spiritual relief, and added to their knowledge (Johnson, 2003). Caves with featured paintings might have

Figure 2.18: The ceiling in one of the rooms inside the tomb of Sethi I, which is painted as an astronomic ceiling, containing stars and heavenly constellations.

been an intellectual instrument, which encouraged discussion or storytelling. It might also have played a creative role not merely in general education but more specifically in the development of sophisticated language, being capable of communicating thoughts on an ever widening range of subjects (Johnson, 2003). In this sense, the ceiling was treated as a surface to hold pictures, in no way different than the walls.

Ancient Egyptian Art

Another ancient society which created remarkable pieces of art and also used the ceiling as decorative element is that of Ancient Egypt. In Ancient Egypt art and paintings played an important role. Tombs for example were decorated with rich paintings to make the afterlife of the deceased a pleasant place.

Every Egyptian temple was built like a microcosm. All the parts of the temple structure had its specific symbolism. In its entirety it was a model of the universe. Pillars, walls, gardens all had a symbolic meaning and represented a copy of an element in the universe. The ceiling in the roofed halls consequently symbolized the sky of this temple microcosm (Wilkinson, 1999). It was typically decorated with stars and flying birds representing different protective deities (figure 2.18). The same principles were applied for mortuary temples, tombs, and palaces.

Baroque Ceiling Frescos

Fresco is a term used for several related painting types. Egyptian wall paintings in tombs are amongst the oldest frescos. The most well-known examples were created in the Medieval and Renaissance periods. This section gives a brief overview of baroque ceiling frescos in general (based on Bauer, 2000) and the work of Italian baroque artist Andrea Pozzo in more detail (based on Burda-Stengel, 2001).

Two different techniques were used for fresco paintings: Pigment mixed with water and painted on wet, fresh, lime mortar or plaster is called the *bun fresco* technique. Paintings, where pigments are mixed with a binding medium and applied to dry plaster are called *a secco* paintings. Bun frescos have some advantages over a secco paintings, such as better durability, but are more difficult to create. The different techniques do not have any effects on the visual appearance (apart from damages through time) and the semantical meaning of the painting and therefore will not be discussed further.

Fresco painters considered the base onto which they applied their paintings not as something that had to be covered, it rather evolved as part of the artwork during the painting process. The brightness of the lime mortar or plaster determined the luminosity of the firmament.

The conceptual planning of ceiling frescos was, similar to other painting genres of that time, determined by the requirements of symbolism. Thus, they were created as instruments for silent poetry, rhetoric, or homily.

Baroque ceiling frescos and contemporary ceiling art. Burda-Stengel (2001) investigated the reason that Pozzo was still such an important artist, even though he was not part of the upper category of roman baroque artists. He discussed Pozzo's works from different view points and also compared it to contemporary video art.

Andrea Pozzo (1642-1709) is an important baroque artist and featured in most comprehensive books about baroque art. His most famous work is the well-known ceiling fresco in the roman church of Sant'Ignazio (figure 2.19), although his work cannot be compared to that of other artists of the roman baroque era. Pozzo never reached the quality that makes frescos by other, more popular artists, such as Pietro da Cortonas or Gianlorenzo Berninis, so unique. Compared to their work, the protagonists in Pozzo's paintings appear like untalented actors from one of the performances, for which he also created the stage designs (Burda-Stengel, 2001).

Pozzo's fresco in the church of Sant'Ignazio is considered as an extreme example of baroque art because of several aspects that distinguish it from other frescos, which may be of higher quality (Burda-Stengel, 2001). Firstly, the fresco of Sant'Ignazio is of such a

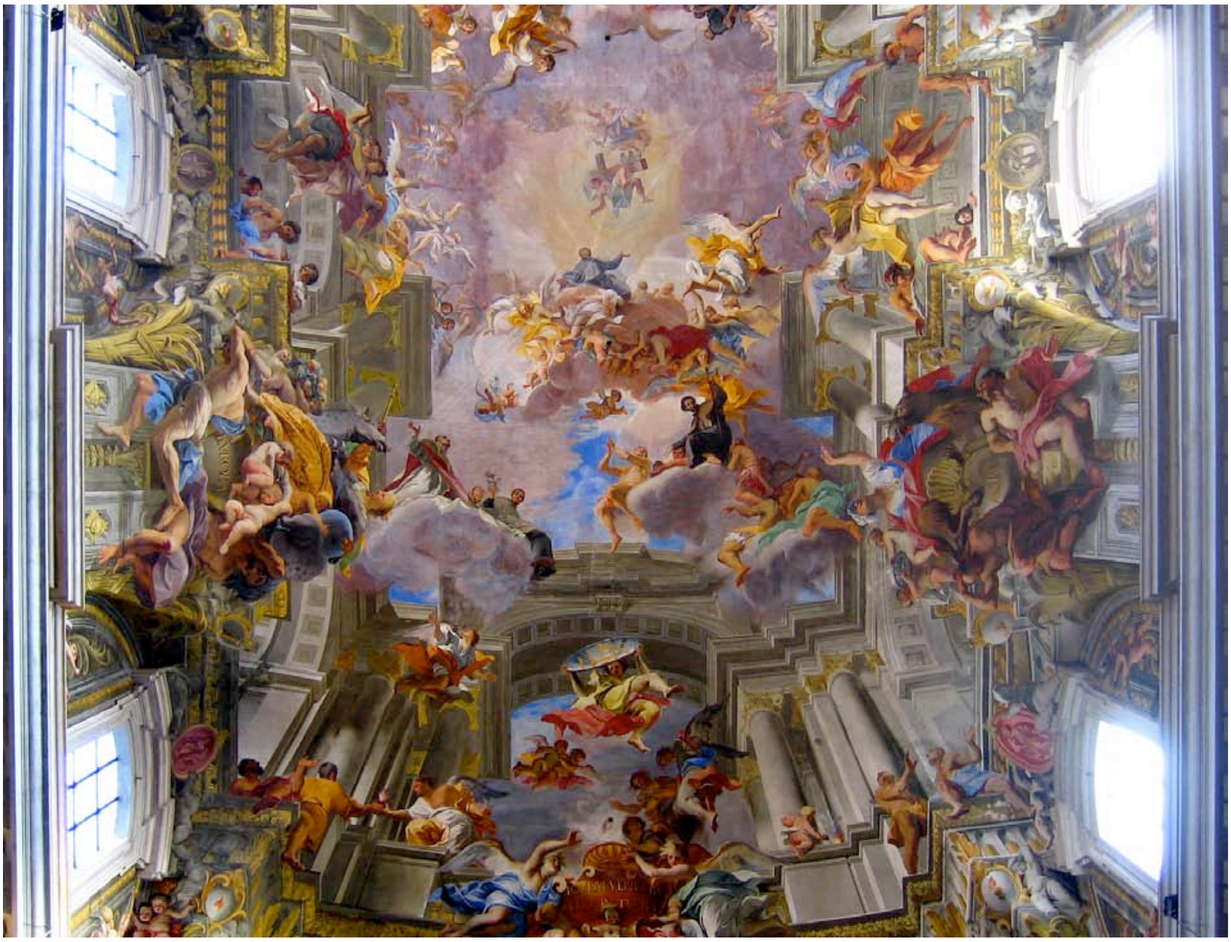


Figure 2.19: The ceiling fresco in the church of Sant'Ignazio (Andrea Pozzo, 1685-1694).

scale that it has only few pendants. Secondly, the fresco appears to virtually extend the real architecture of the church. It adds another structural level to the actual space and seems to open up into the sky. This illusion only works from one specific viewpoint, identified by a marble plate integrated into the church's floor. The fact that the viewer has to enter an exact position, guided by the architecture of the church, and that the illusion appears to be perfect from this specific point makes Pozzo's work particularly interesting for the context of this thesis.

Pozzo painted the trompe-l'œil dome of Sant'Ignazio (figure 2.20)on a canvas, 17 m wide, and the painting seems to prolong the real architecture in a such a realistic illusionistic perspective that it is difficult to see what is real and what is not.

Trompe-l'œil means "trick the eye" in French and describes the use of perspective in art for creating optical illusions of three-dimensional imagery.

Another remarkable painting by Pozzo is the fresco at the corridor of the Camere di San Ignazio (1681-1686). Both the Iganzio corridor and the ceiling fresco at Sant'Ignazio create a perfect illusion viewed from

Figure 2.20: The trompe-l'œil dome of Sant'Ignazio (Andrea Pozzo, 1685-1694): painted on a 17 m wide canvas this painting creates a perfect illusion of a real dome when viewed from a specific viewing angle.

the correct point of view. The ceiling height in the Ignazio corridor is much lower than that of the church and moving away from the spot immediately results in a distorted view of the fresco. This tranisition from perfect illusion to a distorted image occurs more slowly inside the church of Sant'Ignazio. However, still the viewer quickly realizes that his position inside the space affects the way he or she perceives the image. Pozzo was a virtuoso and perfectly knew how to create illusionistic perspectives. He published his artistic ideas in a noted theoretical work, entitled Perspectiva pictorum et architectorum (2 volumes, 1693, 1698). Still his perspective paintings only work from one specific viewing angle and appear to be poor from other perspectives. Burda-Stengel (2001) concludes that this must mean that Pozzo was well aware about this limitation of his work and rather treated it as an integral element than a limitation. The viewer becomes part of his painting and can affect its visual appearance by moving through space. This technique resembles contemporary closed-circuit video installations, where visitors are recorded with a camera and their image is integrated into the projection, influencing the visualization through interaction between the visitors and the art installation (Burda-Stengel, 2001).

In fact, it can be said, that the painted ceiling at Sant'Ignazio allowed for basic interaction. Viewers were able to change the impression of the painting by simply changing their distance to the perfect view point in the middle of the church. Though this was a very rudimentary interaction, it allowed them to actively influence the way they perceived the painting. Once they stood on the right spot it appeared to be a perfect illusion, it was impossible to tell where the real architecture ended and the fictive architecture began. Moving away from this spot allowed them to discover what was only an illusion and what was part of the real world.

Burda-Stengel (2001) discusses a number of issues that result from the fact that the truth of the painting (i.e. an undistorted view) is only visible from one view point. For instance, he argues that the viewing of the painting is a very individual experience, in contrast to the service, which Burda-Stengel (2001) correlates with assumptions of the Jesuit's belief.

Pozzo was well aware of the different viewing approaches that stem from the different ceiling heights. In the Ignazio corridor, which is rather low, long, and drawn-out, it is impossible for the visitors to view the corridor ceiling in an holistic view. Congruously Pozzo chose to paint the ceiling cluttered into small framed single pictures that can be viewed one after another. The homogenous character of the pictures was further chosen to avoid a hierarchical order. In contrast, the painted ceiling at Sant'Ignazio can be viewed as an entire large image due to the immense ceiling heigth.

The techniques that Pozzo used for his illusionistic perspectives were based on Leone Battista Alberti's (1404-1472) scientific study on perspective. Alberti's most important point was that all parallel lines appear to come together in one vanishing point (Burda-Stengel, 2001). Another fundamental part, which Pozzo omitted, were frames that allowed the viewer to perceive the picture like looking through a window. Or as Alberti described it, a window onto the real world through which he sees what he wants to paint. Since modern visualization devices, such as cameras and computers, produce pictures in a one-point perspective style, Alberti's system is still

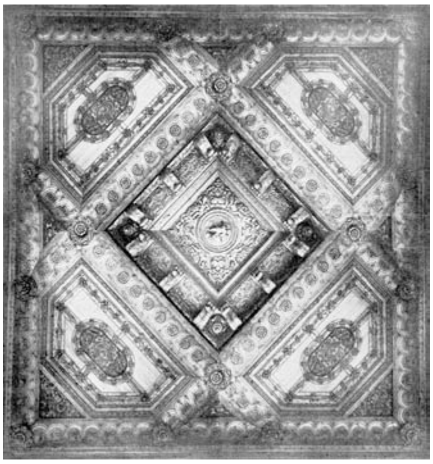
Figure 2.21: Example of stucco decoration: drawing-room at Easton Neston Hall, England (1702).

relevant for the way we perceive the world. What he defined as window, now represents the monitor.

Ceiling Decoration

Wharton and Ogden (1898) identified two different influences which have shaped the development of the ceiling in Europe: the timber roof of the north and the brick or stone vault of the Latin builders. In northern countries the decoration naturally followed the rectangular subdivisions specified by the timber floor above. Floors in the south, however, were mostly built from stone and ceilings were treated as flat and undivided surfaces that allowed free application of ornament.

Examples of timbered ceilings from the Renaissance period can be found in Italy as well as in England or France (Burda-Stengel, 2001). In Italy, where classical ornamenting was predominant, architects applied the decorative treatment as used for stone vaults to the flat or coved Renaissance ceiling. The tendency towards exposing structural forms only appeared in the very end of the 18th century. Roman architecture especially influenced architects in England, who abandoned the timbered ceiling with its structural subdivisions for a flat plastered ceiling. Lacking guidance of a proper application of the



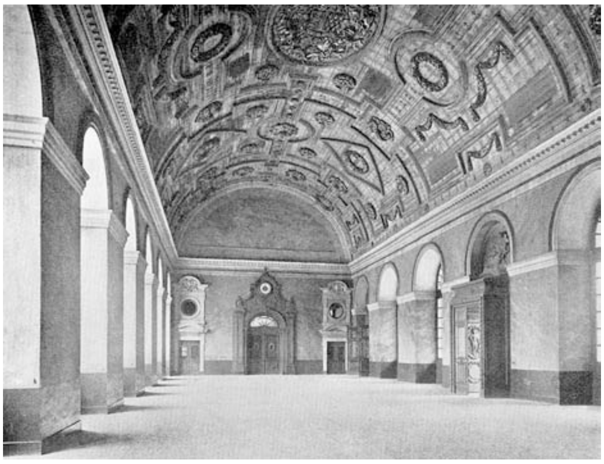


Figure 2.22: Carved timber ceiling, Villa Vertemati, XVI century – Showing influence of stucco decoration (left) and ceiling in the Palais de Justice, Rennes, Louis XIV period – wooden ceiling imitating masonry vaulting and stucco ornamentation (right).

Italian style, ceiling decorations first resembled wall paper patterns, until the architectural character was restored by Inigo Jones, who was one of the first Englishmen to study architecture in Italy (Wharton & Ogden, 1898). (See Figure 2.21 for an example of an English stucco ceiling.)

The twofold tradition of northern and Latin ceilings and the interpenetration of the two styles has resulted not infrequently in stucco panels that exactly reproduced the lines of timber framing and timber ceilings made in imitation of stucco (figure 2.22) during the Renaissance.

Figure 2.23: An example of chinoiserie decoration, inspired by Chinese art: the ceiling in the Château of Chantilly in France.

An affordable decorative ceiling element that imitated exquisite European plaster work and was popular in North America in the late 18th century were tin ceilings. They consisted of sheets of tin that featured embedded patterns, typically painted white to resemble molded plaster. Tin ceilings were incorporated into residential living rooms and parlors as well as offices, where painted tin was often used as wainscoting. In the 1930s however they began to lose their popularity.

In the beginning of the 18th century a lighter style of composition for ceiling decoration appeared in France, often influenced by Chinese art (figure 2.23). This style better suited the petits appartments, which became popular in France at that time, than the rich Roman decorations (Wharton & Ogden, 1898).

While artful and rich decoration were popular during the Renaissance period and until the beginning of the 18th century, Wharton and Ogden (1898) already identified a change towards a lightweight and simple architectural style at the end of the 18th century:

> *In moderate-sized rooms which are to be decorated in a simple and inexpensive manner, a plain plaster ceiling with well-designed cornice is preferable to any device for producing showy effects at small costs.* (Wharton & Ogden, 1898)

2.2.4 Suspended Objects

The architectural ceiling provides a platform for the installation of objects, such as lights, fans, and signs. Ceiling fans and electrical lights were introduced to homes around the same time, when power became inexpensive and readily available. In the 1920s ceiling fans were not only installed for ventilation, but also for decoration, which added to their success. Different types of fans were developed over time (e.g. the Diehl Electrolier, a fan with an adapted light kit), but no informational value can be attributed to ceiling fans. In contrast, lights not only provide lighting, but also convey information about people using the space based on whether lights are switched on or off. For instance this provides information about whether somebody is at home (in a home environment) or still working (in an office environment). Both types of suspended objects are relevant to consider when designing interactive ceiling applications. In fact, the dangling string, which was already introduced in chapter 1, as well as the Pinwheel installation (Ishii, Ren, & Frei, 2001), presented in section 2.4.2, and the 7-segment display by realities:united, described in section 2.2.7, can be considered as suspended objects that provide people within an environment with additional information.

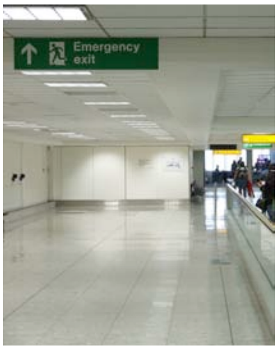


Figure 2.24: Suspended navigation sign at an airport in London.

Hanging signs are typically used as navigational clues in public environments (figure 2.24). The reason why they are installed at the ceiling is simply that the ceiling is visible from various viewing angles within a space. Another advantage over placing them on the floor is that they do not suffer from people walking through that space and therefore have a higher durability (figure 2.25). (Compare the characteristics described in section 2.1.1.)

2.2.5 Media Architecture

Media architecture describes the integration of digital media into the built architecture, creating an *architecture of images*, sometimes also

Figure 2.25: Floor signs at a train station in Vienna to aid people navigating through the environment. The picture to the right shows a similar sign at another station, with a high pedestrian through traffic.

termed *mediatecture* (Fahmi, 2001). This creates a hybrid interface, where the physical world as an interface is augmented with virtual information: digital media – typically images or videos – which is displayed on digital screens.

The most ubiquitous representatives of media architecture are applications that turn the façade of buildings into large-scale screens. This form of architectural display is usually referred to as media façade. The Blinkenlights project (CCC, 2001) is an early example of a media façade. It is unique, since it was one of the first projects to use the existing infrastructure of a building – in this case the lights – for turning the building's façade into a display. The Blinkenlight media façade featured a very low-resolution display, nevertheless it was possible to run movies on it, since the building was visible from a large-distance.

The content running on media façades can be categorized into *abstract* or *semantic* programs (Gernot Tscherteu, personal communication, July 2008). In this context an abstract program describes a visualization that does not use any images or text. Such visualizations are usually more difficult to read for passers-by since they need to interpret the displayed information.

Media architecture is also found on the inside of buildings, where other surfaces, such as the floor or the ceiling, are used for media display. OMA's original design concept for the Seattle library featured real-time navigational cues on the floor, exploiting the spatial nature of a library to support visitors in their orientation (OMA/LMN, 2005).

OMA. The Office for Metropolitan Architecture (OMA) is an international partnership focusing on contemporary architecture, urbanism, and cultural analysis. (http://www.oma.nl).

One of the most impressive and well-known media ceilings is the

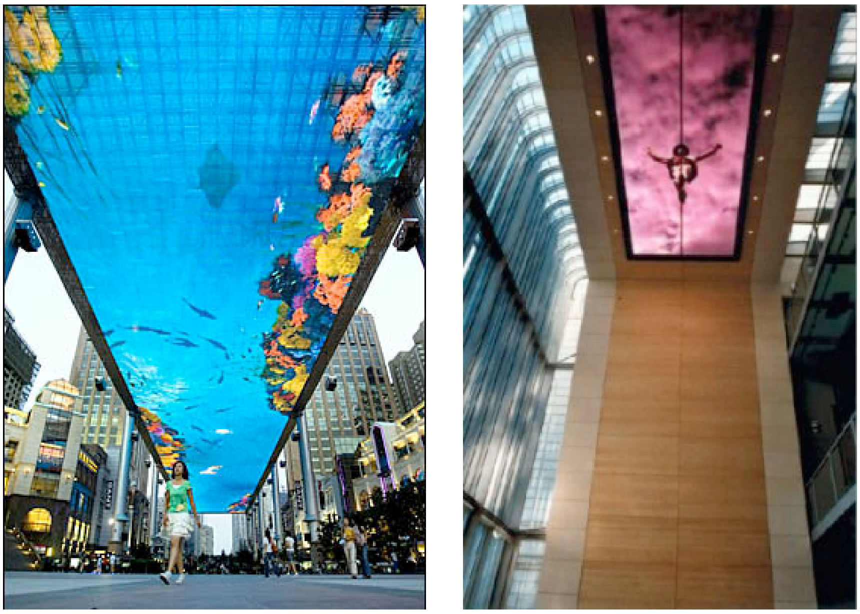


Figure 2.26: Media display ceiling covering a new shopping mall in Beijing (left) and multimedia sky above the winter garden of the Bertelsmann residence in Berlin (right).

Fremont Street Experience in Las Vegas. Another similar impressive example is a display of 250 meters length installed in the ceiling of a shopping mall in Beijing, showing a fake fish tank and other animations (figure 2.26, left). Both ceiling displays aim to add to the experience of the architectural environment, but are not based on any environmental data or user input. Thus they represent active systems according to the model for interaction by Giannetti (2004). The multimedia sky above the winter garden of the Bertelsmann residence in Berlin (figure 2.26, right) is an example of a large-scale media ceiling that conveys information relating to the environment: the display shows weather data retrieved from a nearby weather station. It therefore represents a reactive system.

Media architecture applications that use the ceiling for representing digital information are valuable examples of possible application scenarios and showcase the use of new display technologies in that context. However, their usefulness is of very limited nature, seen from the users' perspective. Their main purpose is often only to create a landmark or to attract attention.

2.2.6 Interactive Architecture

The interactive architecture movement is similar to media architecture, but puts more emphasis on the interaction between people and the

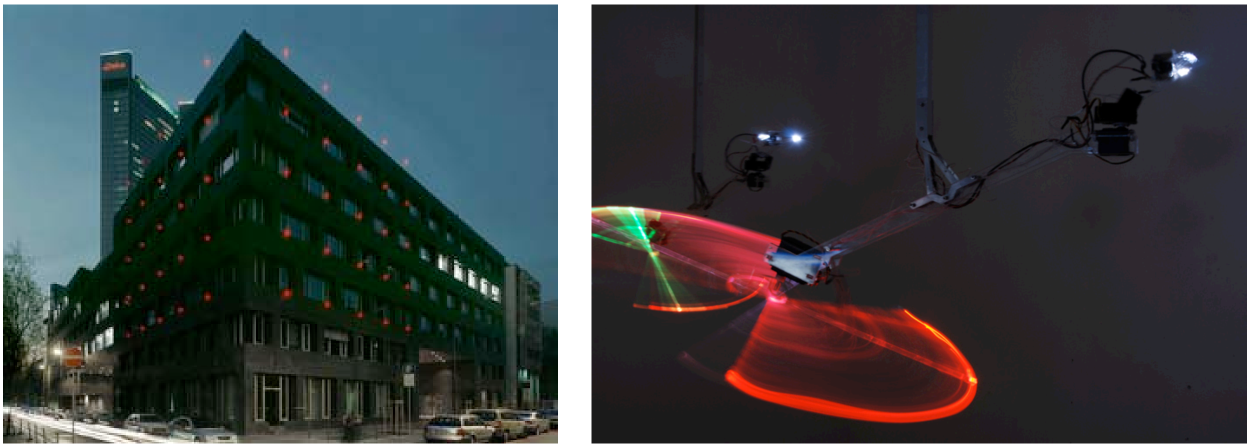


Figure 2.27: The intersite project, which reflects urban sounds through lights patterns (left), and the performative ecologies installation, where robots suspended from the ceiling try to engage passers-by into conversations (right).

environment. It has also a longer history, dating back to 1958, when interactive architecture projects were displayed as part of pavillions for the Brussels Expo (Bongers, 2002).

Architects use information technologies as supplementing building material to create real-time changes through means such as light, sound, water, or even moving elements of the building (Bongers, 2002). In contrast to media architecture applications, interactive architecture installations are often of explorative and temporary character, i.e. they are built as installations that run for a predetermined time span.

The intersite installation (Wollscheid, 2004), shown in figure 2.27 (left), consist of light nets that cover the façades of two different buildings, reflecting traffic noise and voices of passers-by through changing light patterns and intensity. Like in this example, designers of interactive architecture installations are often working as both artists and architects, which allows them to merge the concepts of the two streams.

Another example is the performative ecologies installation (Glynn, 2007). It features three autonomous robots suspended from the ceiling that continuously search their environment for inhabitants and try to engage them in non-verbal communication by performing different gestural patterns (figure 2.27, right). The robots remember and teach each other about which performances were most successful. This project explores the use of information technologies to turn

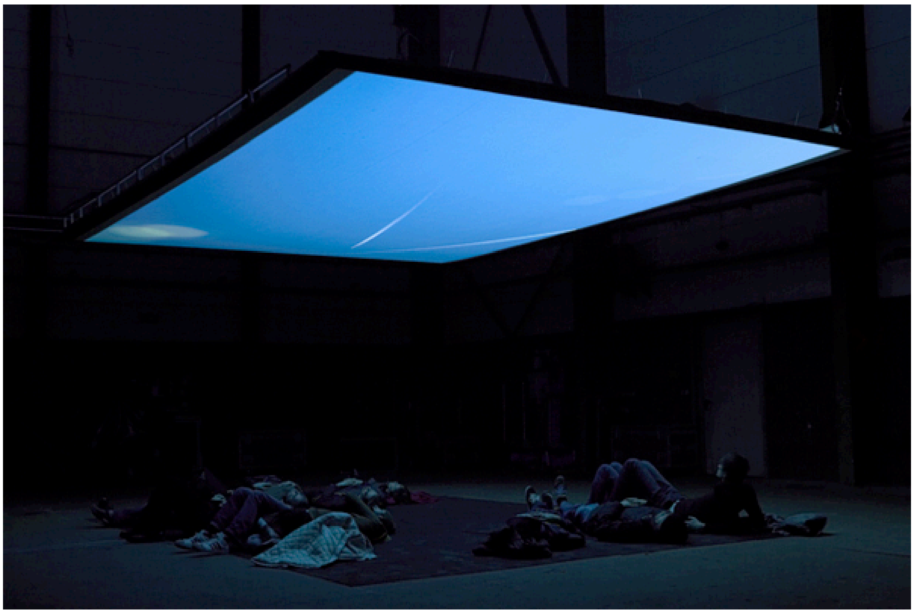


Figure 2.28: The Oberlicht installation: a slide show of real-time generated selection of photographs inspired by historical ceiling frescos.

architectural space into a social space, that seeks conversations with passers-by.

Although there are no projects in the field of interactive architecture that particularly employ the ceiling for information display, it is relevant for its creative approach that might reveal unsought application scenarios.

2.2.7 Interactive Art

There are many interactive art projects, which contributed directly or indirectly to the development of new computing paradigms. Artists increasingly make use of information technologies, such as sensors, robotics, and network technologies, to create interesting and often provoking installations. In fact, this field and its influences on new paradigms would deserve a treatise itself. In the context of this thesis, there will be discussion of three projects that employed the ceiling for representation of information, and therefore add to the foundation of this work.

The first of the projects, the Oberlicht installation was exhibited at the Academy of Art and Design in Offenbach, Germany (hfg, 2006). The work was inspired by the historic context of ceiling frescos and an analysis of concepts like atmosphere, traces, and perspective. The installation projected images of the sky onto the ceiling, which provided people within the exhibition space with a view onto a (virtual) ceiling (figure 2.28). The slide show of images was generated in real-time from a selection of photographs.

The installation takes an interesting approach in transferring the concept of historical frescos, which often featured a painted sky (cf. figure 2.19), into a digital context. The projection creates an unusual space that is subject to constant rearrangement over time. Unfortunately the patterns which determine the selection of photographs is not specified. Therefore it is difficult to say whether the installation also reacted to people within the space, therefore adapting to its environment. The project is also interesting from a technological point of view: the image is back-projected onto a suspended ceiling, thus visually lowering the height of the room.

The second project, black shoals, was initially designed to be installed in the ceiling of a restaurant next to the London stock exchange (Autogena & Portway, 1999). The installation is based on a night sky where stars represent the top 4.000 traded companies worldwide. The world's stock market is reflected by an animated night sky. Stars light up brighter when their stock is traded and distances between stars correspond to the affinities of their respective companies. A second, virtual layer is established through the introduction of artificial creatures, that build an ecosystem, which lives among the data determined by the financial, real world. Figure 2.29 shows the installation of the dome projection and an image of the visual representation.

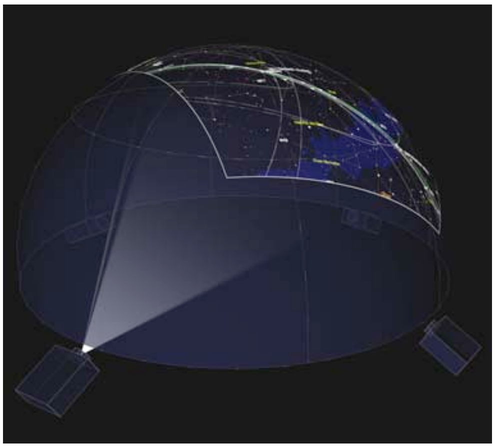


Figure 2.29: In the black shoals installation stock market activities are represented through stars projected onto a domed ceiling. The right image shows the Enron nova (top) and Biotech cluster (bottom).

Figure 2.30: The contemporary architecture installation by realities:united uses industrial fluorescent tubes as light source that also displays information (the current time in minutes).

The contribution of the black shoals project in the context of this thesis lies in its approach to use stars for representing information on the ceiling. Stars are naturally associated with the sky, which in turn is associated with the ceiling. This link has already been employed in history, consider Ancient Egyptian ceiling art, presented in section 2.2.3 for an example (figure 2.18).

Both projects, Oberlicht and black shoals, represent the reoccurring use of natural metaphors in different epochs, which in turn demonstrates the importance of historical work on ceiling-based art. People have been thinking about possible uses of this space again and again throughout different centuries. The best inspirations for contemporary applications might therefore be found by reviewing historical work.

The third project is quite different in its approach, showing yet another direction for ceiling-based representations. It was created by realities:united for an exhibition at the New York based Artistsspace gallery (realities united, 2007). They arranged industrial fluorescent tubes suspended from the ceiling to form two digits of 7-segment display (figure 2.30). The installation serves two purposes: it is the only light source for the room, where it is installed and shows the current time in minutes. The overall light intensity of the installation is kept on a constant level to achieve a subtle change of display.

This installation is unique in its technological approach: it uses room lighting to display information. By this it employs an element that has traditionally inhabited the ceiling to add another quality to the space. Thus, no new technology is introduced, but rather an existing technology is rearranged and reused.

2.3 Ubiquitous Computing

In the 1950s computers filled rooms (figure 2.31). They were expensive and computing time was a scarce resource. People who used those computers for compiling their programs had to share time slots. There was no human-computer interaction in a direct sense. They had to transfer their programs, printed on punch cards, to specially trained technicians, who inserted the cards into the computer. The results were delivered on printed paper.

In the decades that followed, the computer became – due to advances in technology – smaller in size and better in terms of power. Computers were equipped with keyboards and later with pointing devices. People could now type in their programs through directly interacting with the machine. With the introduction of the desktop metaphor the computer became available for an even wider audience.

Now there is again a paradigm shift happening. Computers continue to decrease in size and start inhabiting everyday objects, such as washing machines or cars. Phones became wireless and mobile already a while ago and today mobile phones are ubiquitous in most parts of the world. PDAs (personal digital assistants), digital cameras, and other electronic devices are joining them and aim to assist us in our daily lives.

This trend and advances in wireless communication and sensor technologies led to the notion of *ubiquitous computing* (Weiser, 1991). The idea of ubiquitous computing is that computers dissolve into our

Figure 2.31: IBM Selective Sequence Electronic Calculator (SSEC), 1948.

environment, calmly assisting us in our daily activities. This assumes that computer technology becomes ubiquitous and does neither require specially trained skills to interact with it nor continuous primary attention. Weiser (1991) compares this to writing, which he claims may be the first information technology. Today this technology is ubiquitous. We can find it not only in books, magazines, and newspapers, but also on street signs, food packages, and billboards. The information is always there but does not require our attention and therefore does not distract from other primary tasks. Only if we need to access the information it is ready for use at a glance.

Machines that fit the human environment instead of forcing humans to enter theirs will make using a computer as refreshing as taking a walk in the woods. (Weiser, 1991)

Traditional personal computers demand continuous attention. In contrast, ubiquitous computing applications stay out of our way and only suggest to provide us with information when appropriate. Therefore context awareness is a key issue in ubiquitous computing. Scale and connectivity are also issues of crucial importance. Only if computers decrease in size they will be able to weave themselves into our environment. Connectivity is necessary to enable different devices in a similar environment to interact with each other and to exchange information about current states and contexts. However, it is important to point out that no means of artificial intelligence are necessary to allow our environment to react intelligently to the users' needs.

Figure 2.32: The PARCTAB Systems consists of small computers, called tabs. They feature constant connectivity and can be tracked through receivers.

To lay a foundation for the vision of ubiquitous computing, Weiser (1991) developed three different prototypes together with his colleagues from Xerox PARC (Xerox Paolo Alto Research Center), which they called tabs, pads, and boards. *Tabs* have the smallest scale and constitute embodied Post-it notes. They allow people to store digital information around their desks. Tabs can also identify themselves through receivers in any environment, like in a building. Active badges are tabs that allow tracking of people or objects in an office building (Want, Hopper, Falcao, & Gibbons, 1992). *Pads* have about the size of a sheet of paper and can be used in a very similar manner for taking notes. *Boards* resemble bulletin boards, white boards, or flip charts. They are large-scale displays that allow people to interact collaboratively in an office or even remote.

Ubiquitous computing was often misunderstood due to its misleading name. *Ubiquitous*, which means *omnipresent* is often interpreted as anytime and anywhere. However, this would not describe a new vision, but just another term for traditional mobile or wireless computing. Therefore it is important to stress that ubiquitous computing is not simply about making computers small enough, so that we can carry them with us everywhere and equipping them with wireless network technologies, so that we can use them all the time. IT (information technologies) industries picked up the term *ubiquitous* to promote their products, but used the term in a wrong sense as well. This is also why Weiser later used the term *calm computing* to counteract this misinterpretation. Several years later Ishii (2004) suggested the term *transparent interface*, since *transparent* or *invisible* better describes what Weiser meant when he was talking about ubiquitous.

Ubiquitous computing does not depict a next step in computer evolution, where computers are shrinking in size and becoming integrated into more and more mobile devices, such as digital cameras or PDAs. Ubiquitous computing can be rather seen as a step off the beaten track, as something that is evolving in parallel to other advances in computing technologies. Ubiquitous computing will never be able to replace all human-computer interfaces that are commonly used today (e.g. the keyboard for typing). However, it might be able to replace or augment some of them, enriching the experience of interacting with computers.

2.3.1 Technological Objectives

Alcañiz and Rey (2005) described the following objectives for ubiquitous computing applications, which are mainly derived from a technological perspective.

Terminal and user interface issues: If the devices used in an ubiquitous computing environment require a display, it should have a good quality. It should be intuitive and clear even with limited display size. Different means of data input should be available, such as gestures, handwriting recognition, or speech recognition.

Low-cost devices: Computers that we use today are expensive, but also very powerful. In contrast, computers used in ubiquitous computing environments usually serve very specific purposes. Therefore they have different requirements concerning processor power and hard disk space than today's general purpose computers. This allows keeping ubiquitous computing devices low-cost, which is an essential issue, since many devices per user are necessary in an ubiquitous computing scenario.

High bandwidth: Connectivity between devices is one of the three key issues in ubiquitous computing. Therefore a high bandwidth is required to allow continuous communication between different devices that share the same environment. Communication networks in ubiquitous computing environments are also very dynamic, since the devices might change their locations continuously. This characteristic requires network topologies that allow locating the position of devices and building up ad-hoc networks.

Invisible file systems: Computers in ubiquitous environments should be invisible. They should be able to understand the users needs and support their mental model of task executions. This also means that users should be able to interact with such computers in a natural way, without knowing specific file names, formats, or locations.

Automatic installation: Installation routines are often a source of problems and require user intervention. In ubiquitous computing environments it should not be necessary to change the configuration in order to run a program on another device. It should be possible to simple move applications between different computers, without going through the troubles of configuring the system or taking care of the right operation system.

Personalize information: Information presented on a ubiquitous computing system should be personalized depending on the current user. This assumes that every device knows the personal profile of every user.

Privacy issues: Ubiquitous computing can generate serious privacy risks, since the system can record sensitive data about users, like their actions, their preferences, their location, etc. This is a very important problem and not only a technical issue, but also a social concern. If people do not trust a system they will not use it. This topic has been addressed by several research projects, e.g. Dey, Lederer, and Mankoff (2002) and Nguyen and Mynatt (2002).

2.3.2 Contributing Paradigms

Advances in information technologies and new ways of thinking about human-computer interaction have also led to the formulation of other research paradigms, besides ubiquitous computing, that share similar objectives.

Ishii and Ullmer (1997) presented their vision of HCI (human-computer interaction), which they called *tangible bits*, at the CHI (computer-human interaction) conference in 1997. Their research was based on earlier work on *graspable user interfaces* by Fitzmaurice, Ishii, and Buxton (1995) and led to the notion of *tangible user interfaces* (TUIs). The idea of TUIs has evoked great interest in the HCI community and started many discussions about new approaches to HCI. Dozens of TUI applications and attempts to classify TUIs have been developed in the last years. For a good overview of the state of the art in TUIs and a taxonomy for the classification of TUIs see (Fishkin, 2004).

Tangible bits – in contrast to graphical bits – represent both, digital information and a control to interact with or manipulate this information. Physical artifacts (sometimes also called *phicons*, which stands for *physical icons*) represent digital information, changing the state of an artifact (e.g. through moving) manipulates the information. TUIs therefore take advantage of our skills for manipulating physical objects, skills which we already developed at a very early age and which we employ throughout our everyday life. This allows for more intuitive interfaces than the indirect manipulation of data through a pointing device and the distant screen.

Ishii and Ullmer (1997) define three concepts for tangible bits, which are also key for the work described in this thesis (figure 2.33).

1. *Interactive surfaces:* Every architectural surface, such as walls, ceilings, floors, desktops, and doors, can represent an active interface between the physical and virtual worlds.
2. *Coupling of bits and atoms:* Enhancement of everyday objects, such as cards, books, and dishes, with digital information.
3. *Ambient media:* Using ambient media, such as sound and light, for peripheral background interaction with digital information.

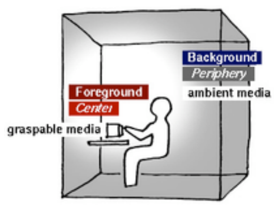


Figure 2.33: The three key concepts of tangible bits: interactive surfaces, coupling of bits and atoms, and ambient media (Ishii & Ullmer, 1997).

Ambient media is a very important aspect that also strongly correlates with the ideas of ubiquitous computing. Ishii and Ullmer (1997) stated, that while HCI research at the time they presented their vision of tangible bits focused mainly on foreground activity, people are subconsciously receiving information from their periphery all the time. This allows them to switch focus immediately if anything unusual happens in the background. Weiser also underlined the similarities of his work on ubiquitous computing and tangible bits, suggesting that tangible bits might serve as an overall umbrella name (Ishii, 2004).

Ambient intelligence is a research movement that has its origins in Europe. The Information Society Technologies Advisory Group (ISTAG) is funding most of the projects from this research area. Philips Research also conducts research in that direction and has set up the AwareHome – a lab, where they develop and test new ambient intelligence prototypes (Marzano & Aarts, 2003).

Ubiquitous computing and ambient intelligence share similar intentions. It is therefore difficult to clearly define differences between the two paradigms. The ISTAG states that the vision of ambient intelligence seeks to fulfill three key concepts: ubiquitous computing, ubiquitous communication, and intelligent user friendly interfaces (Ducatel, Bogdanowicz, Scapolo, Leijten, & Burgelman, 2001). This implies that ambient intelligence covers a larger range of applications, where ubiquitous computing is one contributing part.

During a scenario planning exercise, launched by the ISTAG, the following five technological requirements for ambient intelligence were identified (Ducatel et al., 2001):

- The hardware has to be unobtrusive.
- Provision of a seamless mobile/fixed communications infrastructure.
- Availability of dynamic and massively distributed device networks.
- Human interfaces have to be designed so that they allow natural feeling and intuitive use.
- The technologies should be safe and secure.

Those requirements supplement the ones for ubiquitous computing, which were outlined above.

Pervasive computing is another notion that is related to ubiquitous computing and often used to describe similar concepts. It is also more environment-centric than traditional computing paradigms, such as desktop-based or mobile computing (Saha & Mukherjee, 2003). Pervasive computing devices have the capability to receive information from the environment in which they are used (Lyytinen & Yoo, 2002). Another important aspect is that they can detect and connect to other devices that enter this environment. In this respect, pervasive computing represents a similar vision to ubiquitous computing. Lyytinen and Yoo (2002) claim that applications from those two realms differ in terms of level of mobility, but an investigation of recent publications in the two fields suggests that they are used for describing the same concept: the integration of embedded computing technologies into context-aware environments.

2.3.3 Interactive Surfaces

The concept of *interactive surface* is one of the three basic concepts of tangible bits (Ishii & Ullmer, 1997). As stated above it describes that every architectural surface can represent an active interface between the physical and virtual worlds. In the context of this thesis, the notion of interactive surfaces covers surface-based applications that are either reactive or interactive systems (Giannetti, 2004).

This section presents some representative examples from the fields ubiquitous computing and ambient intelligence, which are based on this concept. Most projects found in literature exploit the wall as an interface. The table, which is treated as architectural surface in this section, has also been used as interface in many projects. Tangible table and multi-touch table applications have received a lot of attention within the research community recently. Floor and ceiling are utilized only in few projects. In 2007 a survey of interactive surfaces originating from research projects and interactive art revealed 90 table-, 51 wall-, 17 floor-, and 6 ceiling-based projects (Hess & Tomitsch, 2007).

Walls

It is a fine line between large-scale displays and interactive walls. Large-scale displays have been used in research for quite some time, since they represent a special case of desktop computer screens. Figure 2.34 shows the Spatial Data Management System (SDMS), an early representative of this category (Donelson, 1978). In this system a wall-size projection was used in combination with a traditional screen, providing detail and context view for a navigation application respectively. The SDMS was designed for the integration into an architectural environment. However, users were sitting while working with the system, which resembles the metaphor of the desktop

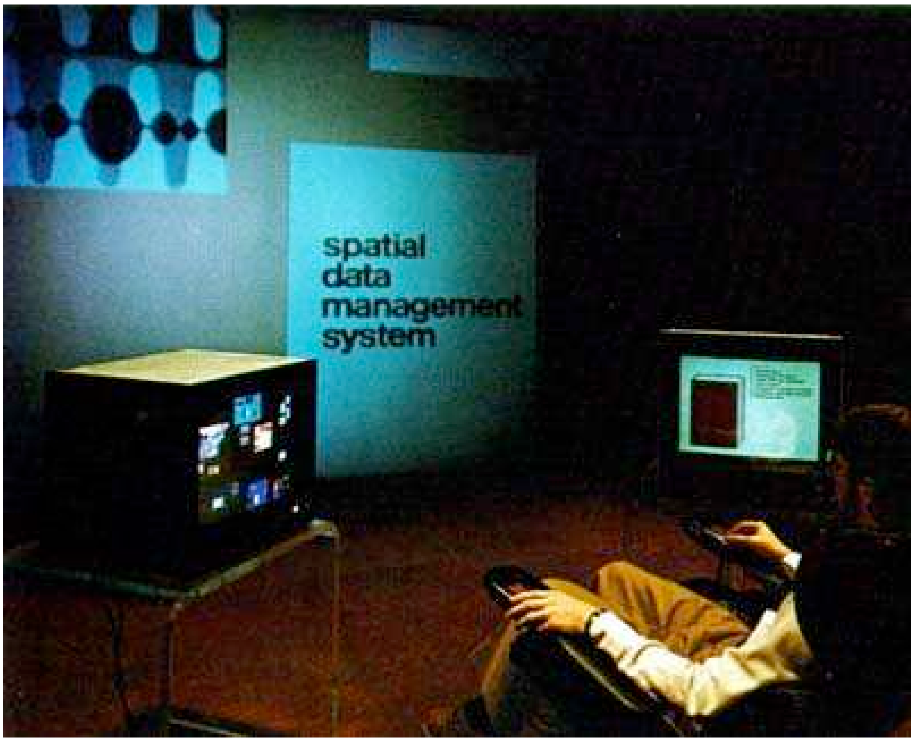


Figure 2.34: The Spatial Data Management System: A wall-size projection screen shows the detail view of a large data surface. A small display is used to provide a context view.

computer. It therefore is closely related to traditional graphical user interfaces rather than following the concept of ubiquitous computing. Still the SDMS represents an important contribution to interactive surfaces, since it was one of the first attempts to exploit the wall for information display.

Another approach to large-scale displays from an HCI perspective is their investigation in terms of interaction. Interacting with such a display introduces new challenges: when users are close, they have difficulties in keeping track of the entire display area, if they are located further away, it is impossible for them to directly touch the display.

Different interaction techniques have been investigated for close-up range interaction, such as throwing virtual graphical objects across the screen to other users (Geißler, 1998). The techniques were developed for the DynaWall system, which is one of the components of the i-LAND project (Streitz, Geißler, & Holmer, 1998). The DynaWall is 5 meters wide and 2.7 meters high. It represents an interactive wall, but

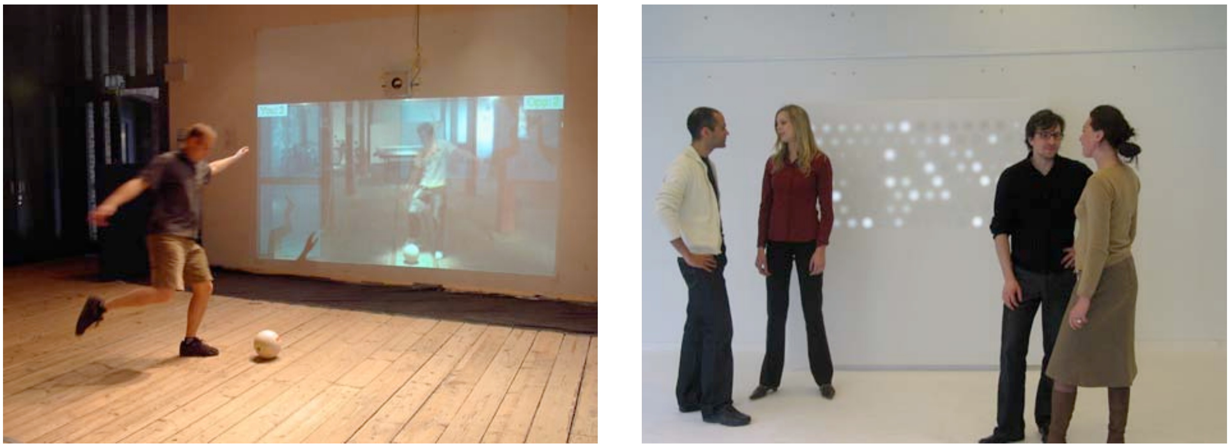


Figure 2.35: An interactive wall that allows people to collaboratively play a game over a distance (Mueller & Agamanolis, 2005) (left) and the Hello.Wall, which displays information about people passing by through light patterns in one of its modes (Prante et al., 2004) (right).

is still close to traditional desktop screens in its functional purpose, since it was developed as a work place.

Techniques for distant-range interaction are discussed in detail in section 2.3.4, since they are of fundamental relevance for interactive ceilings.

The sports over a distance project introduces yet another interaction technique with a distant wall display: people can interact with the display using a ball (Mueller & Agamanolis, 2005). The display itself features a live video stream of another user at a remote location. Figure 2.35 (left) shows the installation, which allows users to collaboratively play a long-distance game. This approach is interesting since it emphasizes the social interaction between people. It employs the architectural wall as a window to another (remote) space, changing the experience of space and engaging (long-distance) interaction.

The Hello.Wall project demonstrates another approach for using walls in ubiquitous computing environments: it does not only support interaction, but also reacts to people passing by (Prante et al., 2004). Light patterns reveal information about passers-by (figure 2.35, right). Hello.Wall represents an example for the concept of ambient display, which is explained in section 2.4. Interactions with the wall takes place on three levels, which are indicated in figure 2.36. When users reside in the ambient zone the wall displays general information. Once they enter the notification zone they are identified by the system, which displays user-related information on the wall. Users that are very close to the wall can interact with specific parts of the display.

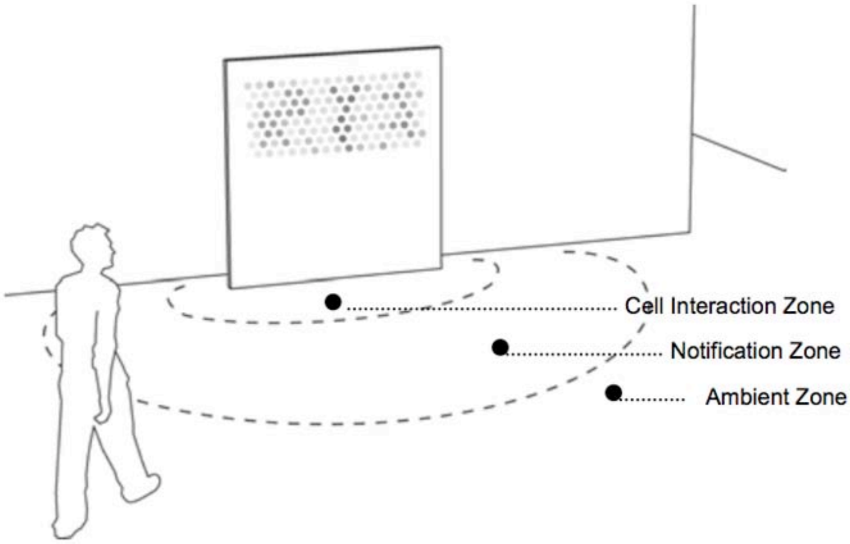


Figure 2.36: Three zones of interaction for interactive wall displays (Prante et al., 2004).

The three zones – ambient zone, notification zone, and interaction zone – defined by Prante et al. (2004) can be used as general classification approach for interaction within architectural environments. They also summarize the different uses of walls in ubiquitous computing environments: interactive walls can allow for interaction, act as a display that reacts to people in the environment, or display general information in an ambient mode.

Floors

Interactive floors have been less explored from a research perspective than walls. A reason for this is that the wall suggests itself more obviously as a display. People are used to interact with vertical screens. Interacting with (and perceiving information from) a wall is therefore more intuitive than it is for floors. Another reasons is that it is more challenging to install an interactive floor. Similar to walls, projectors can be used to create a floor display. However, application designers have to deal with the fact that users are casting a shadow when they get close or onto the interactive floor. This can affect the user experience and how users engage with the application. It is easier to avoid shadow casting in wall projections through optimized placement of the projector or by using a back-projected display. The use of custom-made displays is also more problematic for interactive floors since they have to be robust enough so that people are able to walk on them.

Figure 2.37: The iFloor displays questions and answers posed by people in a library environment (Petersen et al., 2005) (left). Memory pavement visualizes traces of people in urban space over time (Frenchman & Rojas, 2006) (right).

Petersen et al. (2005) developed a series of applications to investigate floor interaction. The iFloor application is used in a library setting. It allows visitors to post questions and send answers to each other through mobile phone text messages or e-mail. The items are displayed on the floor (figure 2.37, left) and controlled through body movement, which turns into a playful challenge when more than one person interacts with the floor. In another application the authors explored a vision prototype that allows people to place and pick up information from the floor through bouncing a ball on the floor. A gesture-based remote control is used to interact with the MediaSurface prototype. This prototype allows users to distribute digital documents on different surfaces in the home, including interactive floors.

A natural and intuitive way of interacting with digital information displayed on the floor is stepping on it. Magic carpet is a sensitive floor which enables people to influence sounds by moving over it (Paradiso, Abler, Hsiao, & Reynolds, 1997). The Z-Tiles system also allows people to interact with the floor through walking or stepping on it, but provides a more modular approach (Richardson, Leydon, Fernstrom, & Paradiso, 2004). The system consists of nodes which can be connected to build an interactive floor of any size (figure 2.38). Using footstep force has even been explored for the identification of people walking on the floor by comparing the data received from a force sensor with stored footstep profiles (Paradiso, 2003).

Interactive floors can be classified conceptually into *plazas* and *streets* (Petersen et al., 2005). This classification is derived from the function

Figure 2.38: Z-Tiles – modular building blocks for floor interaction (Richardson et al., 2004).

of spaces in urban environments. Interactive floors as plazas support drop-by interaction and provide access to information from various directions. They are well-suited for collaborative applications in public space. Interactive floors as streets give unidirectional access to information, which makes them suitable for individual and more efficient interactions.

None of the interactive floor applications presented in this section were developed for ambient display and all support user interaction. This is due to the natural affordance of floors: they are made to walk on them and walking on a floor represents interaction. The memory pavement, developed as part of the Zaragoza Digital Mile project (Frenchman & Rojas, 2006), is an exception. It is designed for a public urban environment and visualizes traces of pedestrians through the city (figure 2.37, right). This provides an ambient display of traffic within pedestrian zones. Thus, interactive floors can also support ambient display of information. However the presented landscape of interactive floors shows that ambient display represents only a small application area, while all interactive floors support some kind of interaction (Hess & Tomitsch, 2007).

Ceilings

As stated earlier the ceiling has only been vaguely investigated as an interactive surface so far. Ishii et al. (1998) developed an application that translated the motion of a hamster wheel to the motion of a solenoid in a shallow water tank. This produced water ripples which appeared as shadows on the ceiling. What is interesting about this approach is how it uses shadows instead of a digital screen or projection for turning the ceiling into an interactive surface.

Meagher et al. (2007) investigated the integration of sensors into the ceiling for measuring environmental conditions, such as humidity or temperature. The sensors control light patterns to visually reflect air quality within an architectural environment (figure 2.39). The goal of the project is to allow people working in open space environments to select their work place based on a ceiling-based representation of environmental conditions.

There are only few projects, which investigated ceiling interaction. For instance, the Multimedia Bed (Lieberman & Selker, 2000) supports playing a constellation game on the ceiling. Gesture recognition is suggested as interaction technique (figure 2.41), but no information is available how the interaction was actually implemented. The

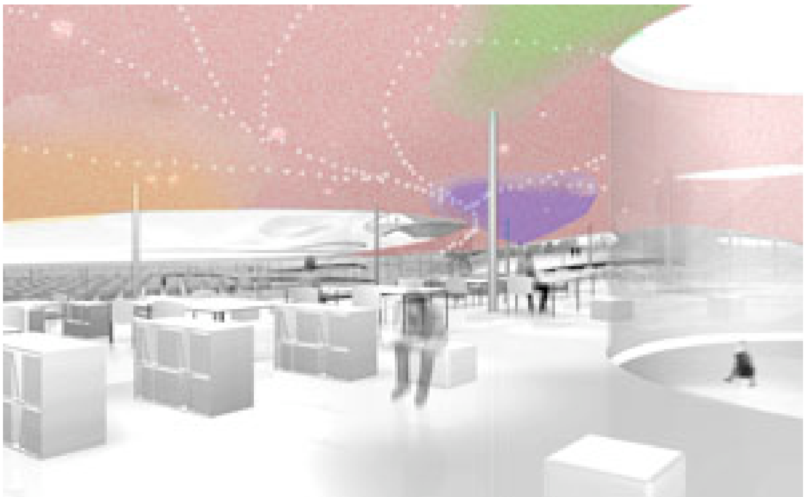


Figure 2.39: Display of environmental conditions in an open space environment (Meagher et al., 2007).

Multimedia Bed also enables users to read while lying in their bed and is proposed as alarm clock in a mode, where the display would show a sunrise. Employing the ceiling as a bed interface has also been investigated to enable bed-ridden manually impaired users interacting with computer systems (Pieper & Kobsa, 1999).

Figure 2.40: The Hanging Twines interface for controlling media devices (Butz et al., 2005).

The Hanging Twines are inspired by suspended cords used as switches (figure 2.1) to provide a tangible interface for media control (Butz et al., 2005). Plexiglas rods hanging from the ceiling are mapped to functions for controlling a media application (figure 2.40).

In contrast to floors, ceilings are lacking natural affordances for interaction. In fact, it is difficult, most of the time impossible, to reach the ceiling for directly interacting with it. This explains why all applications found in the survey on interactive surfaces (Hess & Tomitsch, 2007) that employ the ceiling do not allow for interaction. In contrast interactive ceilings provide a natural opportunity for ambient display of information, which is one of the founding theories of this thesis.

Other Surfaces

Other interactive surfaces in ubiquitous computing environments include doors, tables, or any other furniture. For instance, a fridge door is used as interactive surface in the augmented reality kitchen project (Bonanni, Lee, & Selker, 2005). When a user is sensed in front of the fridge, an image of the content within the fridge is projected onto the door. The augmented reality kitchen features several other

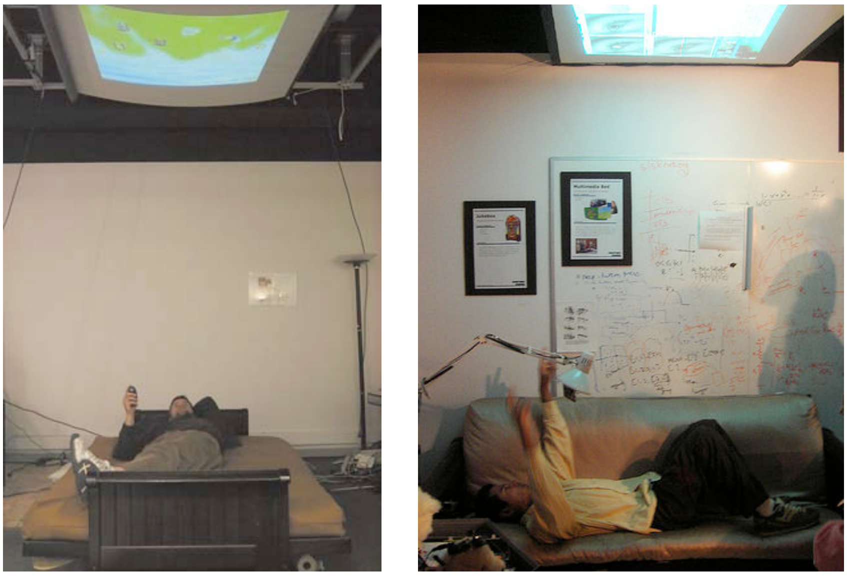


Figure 2.41: The Multimedia Bed allows ceiling interaction from the bed (Lieberman & Selker, 2000). Gestures are used for example to control a game.

interactive surfaces, integrated into furniture, such as cupboard doors and the kitchen bench.

Tables have been extensively investigated as interactive surfaces, particularly as tangible interface. The Sensetable is one of the first and most well-known examples (Patten, Ishii, Hines, & Pangaro, 2001). It tracks the position and orientation of multiple objects on the table. Tangible tables can be used for various application scenarios, most successfully they have been used for applications to generate or modify musical tracks, e.g. (Patten, Recht, & Ishii, 2002) or (Jordà, Geiger, Alonso, & Kaltenbrunner, 2007). Both projects allow for interaction with digital content through physical objects. More recently multi-touch has been investigated for interacting with table-based applications, also called tabletop interaction (e.g. Han, 2005).

Chatter is an interactive table that reacts to sound frequencies with changing light patterns. Volume is visualized through brightness of the pattern. This allows for example deaf or hearing-impaired people to learn the connection between patterns and acoustic events, such as the ringing of a doorbell, which would support them in identifying events happening in their home environment.

While the Chatter table represents an example for a reactive system according to the models for interaction defined by Giannetti (2004), most table-based applications are interactive systems. It is difficult to give a general statement about the characteristics of other surfaces from this category due to their variety in terms of embodiment, location, and visual appearance. What is important to note, is that interactive surfaces on furniture, such as tables, are different to walls, floors, and ceilings, in terms of mobility. Tables also influence the experience of an architectural space, which should be considered when designing an interactive table, but due to their mobility this is of less concern, or at least seems to be less reflected by research projects, which often treat the table as a computing interface similar to the desktop computer.

Figure 2.42: The first mouse developed by Douglas Engelbart in 1963.

2.3.4 Pointing Interaction

During the last decades the mouse has persisted as pointing device for interaction with desktop computers. It has become so ubiquitous due to its intuitive navigation control and its eligibility for interaction patterns, such as drag and drop. The mouse as interaction device has seen an evolution and the development of many variations since the introduction of the first mouse by Douglas Engelbart in 1963 (figure 2.42), but in its main functionality it remained the same. Trackballs, TouchPads, and other recent pointing devices still support the same basic operations, which are *point and click*. Touch screens map the same functionality, but provide more intuitive direct manipulation. The reason for this is that it is more appealing to tap with a finger or pen on objects on a screen, since it mimics real world interaction (Vogel & Balakrishnan, 2005).

Current trends show an increasing of displays in size and resolution while decreasing in costs. This suggests that very large displays will soon inhabit surfaces in our everyday environments, such as walls or doors. Such large displays allow users to work up close with detailed information or to interact with the contents of the entire display. Vogel and Balakrishnan (2005) name *sorting slides/photos/pages spread over the large displays, or presenting a large drawing to a group while navigating/ panning/highlighting* as examples for tasks that are best performed from a distance. Further, there are situations, where users cannot easily approach the display and need to interact from a distance.

Another trend that we can identify is that the number of interactive devices in our homes that are controlled remotely is increasing. Furthermore, it can be anticipated that consumer devices like TV sets, VCRs, and stereos will still exist as separate devices in the near future

(Ringwald, 2002). Home automation systems already exist, which allow remote control of various things, such as window blinds. Consequently, the number of remote controls in our homes will continue to increase. Usability problems of current remote controls (Nielsen, 2004) and the fact that it is difficult to keep track of a high number of remote controls motivate the introduction of a general device for interaction with these devices. Apart from commercial universal remote controls, there are some research projects, that for example provide universal remote control of devices based on PDAs or laser pointers that also support point and click interaction. Some approaches rely on displays incorporated into the pointing device, others provide on-screen (e.g. on the TV) menus for interaction.

In all cases the basic operations for interaction are pointing (either to select an object or a device) and clicking (to either confirm a selection or invoke an operation). Derived from the classification by Vogel and Balakrishnan (2005) the following categories for remote point and click interactions can be defined: *hand-held indirect pointing*, *laser pointer-style devices*, *body and hand tracking*, *direct hand pointing*, *selection with the hand*, and *eye tracking*.

Figure 2.43: The GyroPoint device has a built-in gyroscope that supports operation in the air (Mackenzie & Jusoh, 2001).

Figure 2.44: The RemotePoint device features a joystick for navigation (Mackenzie & Jusoh, 2001).

Hand-held Indirect Pointing

Solutions that allow distant indirect pointing are devices that are either of isometric or isotonic nature. An isometric input device does not require movement of the device itself which makes it less tiring than operating a freely held isotonic device. Both, isometric and isotonic devices can be operated facing towards the remote screen, but this is not a requirement of the devices per se. A disadvantage of these devices is that transition from distant to up close interaction may feel awkward since they have no direct mapping when used on a touch-enabled surface (Vogel & Balakrishnan, 2005).

GyroPoint, a product of Gyration, Inc., is an example for an isotonic device (figure 2.43). It supports two different modes. Firstly, it can be operated like a regular mouse. Secondly, it features an integrated gyroscope that allows sensing of movement in the air. The angular movement of hand side-to-side or up-and-down translates to a two-dimensional motion of the cursor on the remote screen. Applications for the GyroPoint include computer pointers, TV remote controllers, robotics, factory automation, and auto navigation (Mackenzie & Jusoh, 2001). *RemotePoint* (from Interlink Electronics) represents an example for an isometric device. It features a built-in joystick on its upper side for navigation and a trigger-like button that is operated with the index finger for selection (figure 2.44).

Laser Pointer-Style Devices

Laser pointers as input devices mimic a gesture that we use when communicating (Vogel & Balakrishnan, 2005). When pointing at a specific thing with the index finger one can imagine a laser beam emitting from the tip of the finger along the vector of the finger's direction. This so-called *ray casting* technique is fast for selecting large targets, but hand jitter can make the selection of small items difficult.

A general problem of remote pointing techniques such as laser pointer interaction is that they are lacking a button or other mechanism for validating a selection. To overcome this, most systems use a cursor dwell in combination with a visualization that shows the user whether a "click" has been registered. Since it can easily happen that users unintentionally make a selection, these systems often also allow to redo the selection by leaving the area of selection. Another problem which is specifically relevant for laser pointer interaction is hand jitter, which was already mentioned above. This jitter makes it difficult to point at small items. There are also techniques that can be used to minimize the influence of hand jitter (Olsen & Nielsen, 2001).

Figure 2.45: The Optical Tweezers system is a laser pointing device that uses three infrared beams to allow left and right button interaction in addition to cursor movement (Matveyev & Göbel, 2003).

Olsen and Nielsen (2001) developed a system that uses laser pointers for interaction with distant wall-sized displays. They use a web cam pointing at the screen to track the dot produced by the laser pointer and translate it into mouse cursor movement. In their work they demonstrated how laser pointers can be used for interacting with various graphical user interface widgets. The *Optical Tweezer* system (Matveyev & Göbel, 2003) relies on an infrared laser pointer, where the laser beam is split into three distinctive beams (figure 2.45). This eliminates several disadvantages of laser pointer interaction. Firstly, the dot produced by the laser, which may interfere with objects on the screen, is not visible to the user. The system instead calculates the position of the cursor based on the position of the three invisible infrared beams that are tracked by an infrared camera and displays an on-screen cursor. Secondly, Matveyev and Göbel (2003) use an algorithm to determine whether a left or right click has occurred from the relative position of the three infrared beams.

Body and Hand Tracking

Nickel and Stiefelhagen (2003) investigated the use of a stereo-camera for tracking a user's face and hands. This allowed them to identify different pointing gestures. They further found out that determining head orientation improves recall and precision of pointing gestures.

Tracking of the entire body has also been investigated for interacting with playful visualizations on large display (Krueger, 1990) and even for group interaction to enable for instance collaboratively playing games on a large-scale screen (Aminzade, Pausch, & Seitz, 2002).

Direct Hand Pointing

Various approaches for direct hand pointing have been investigated (Hinckley, Pausch, Goble, & Kassell, 1994), which provide different solutions for implementing the mouse click. Hinckley et al. (1994) used gloves with integrated buttons to allow users activating a selection. Another solution is the combination of direct hand pointing with speech recognition to issue commands (Corradini & Cohen, 2002). The use of fingers for selection gestures has also been investigated but the problem with this approach is that those subtle gestures are difficult to track with current technologies (Vogel & Balakrishnan, 2005). In the recent past, direct hand pointing has been mainly used to enable interaction within virtual environments.

Eye Tracking

Eye gaze has been investigated to control cursor movement on traditional desktop computers, but also for large-scale displays (Skaburskis, Vertegaal, & Shell, 2004). Again, the problem with this technique is to issue the mouse click in an intuitive and also reliable way. The advantage of this interaction technique is that sensors for eye tracking are commercially available. There are several systems available, which are deployed for eye gaze tracking in usability testing, i.e. they are designed for traditional desktop computer screens. Eyebox2 is an eye tracking technology developed by Xuuk Inc. to measure the number of people looking at billboards or video screens (Xuuk, 2007). It is therefore designed to work over a distance, which makes it applicable for interactive surfaces in ubiquitous computing environments.

Discussion

There is a broad body of literature on pointing techniques available. Many techniques have been explored within virtual environments. Despite the different context, they can also be used for interaction with architectural environments, particularly with interactive surfaces. The choice of the appropriate interaction technique depends on various parameters. For example, device-based interaction devices are usually not suitable for public environments, where people drop in and out of interactions on a frequent basis. Another important parameter is whether the application requires people to issue select or other commands.

All techniques presented in this chapter are suitable for interaction with interactive ceiling applications. Again, the choice depends on the context, purpose, and character of the application. The character also determines whether the application is an interactive or reactive system. For instance, body tracking might be well-suited for a reactive system where the representation is influenced by people moving within the architectural space. However, it is less suitable as interaction technique in an application that requires a more efficient interaction, such as selecting options or setting parameters.

Direct hand pointing, laser pointing, and a novel technique that allows for playful interaction were subject to a controlled experiment for determining user preferences in the context of interactive ceilings. Details about the study are presented in section 3.5.

2.4 Ambient Display

We are increasingly surrounded by information technology. Today computers are everywhere. During the last decades they have changed in size and now inhabit our mobile phones, PDAs, digital music players, etc. Most people have multiple computers that they use. They carry around many of them everywhere they go. All these devices regularly need our attention: a phone call, a text message, a reminder for an event, etc. Additionally our everyday environment is increasingly equipped with digital screens: advertisement displays in the streets, information television in subways, screens that announce the departure or arrival of trains or planes, etc. Information technology therefore has led to the phenomenon of *information overload* (Berghel, 1997). We are surrounded by digital information almost everywhere we go. This digital "pollution" is distracting and causes high cognitive load.

Ubiquitous computing sets out on the quest to remedy the information overload side effects caused by the information technology age. As described in section 2.3 the idea is that the computer disappears into our daily environment and calmly assists us in our activities. Computers should rather dissolve into the background than being integrated into distinct objects, as they are now. This would allow people to interact with digital information in a more natural and casual way.

Ubiquitous computing is also the underlying concept from which the notion of *ambient display* emanates. Ambient display refers to the visualization of information at the periphery of human attention (Mankoff et al., 2003). An ambient display provides specific bits of information without requiring full attention of the user. Only if an event occurs that needs immediate response, the user is alerted to focus on the ambient display.

Ambient display vs. peripheral display. The concept of ambient display is sometimes also described as peripheral display. The term ambient display puts a stronger emphasis on the aesthetic quality of the display. Ambient information systems can be both, either ambient or peripheral displays, and also include notification systems (Pousman & Stasko, 2006).

The first ambient display that was mentioned by Weiser and Brown (1995) was developed by the artist Natalie Jeremijenko. The *dangling string* consists of a servo motor and a wire, which is fixed onto the motor and hanging down from the ceiling (figure 1.1). The motor is connected to the ethernet network and the network traffic controls the speed of the motor. Low network usage therefore causes the string to rotate only calmly, while heavy traffic puts it into fast rotation, which eventually even leads to a sound produced from the rotating wire.

An example for a non-digital ambient display is an office window. Offices sometimes have windows that lead to the hallway. People working inside the room do not pay deliberate attention to these windows. However, they do perceive anything that is going on in the hallway at their periphery. For example, they would notice if many people start rushing down the hallway, which might mean that it is lunch time, or that there is a meeting scheduled, which they may have to attend as well. If the hallway is dark and empty one would notice that it is late and that the office is almost empty (Weiser & Brown, 1995). Another example are peripheral sounds that enter through the window into a room. When we get up in the morning, incoming sounds could possible give us hints about the weather: blowing wind would tell of stormy weather, rain drops knocking at the window glass would vividly announce rain, and tweeting birds would announce a sunny day.

The latter example was also incorporated into a digital ambient display (Ishii, Mazalek, & Lee, 2001). A bottle placed on a table "contains" the weather forecast. When the tap of the bottle is removed, a sound is effused from the bottle. The character of the sound is mapped to the weather forecast for that day. This project later evolved into the music bottles project, which is described below.

2.4.1 Characteristics of Ambient Displays

There is no general definition of ambient display that is commonly accepted and used by the research community. Some definitions are quoted below to give an overview of the field. They also describe characteristics of ambient displays.

> *Ambient displays are aesthetically pleasing displays of information which sit on the periphery of a user's attention. They generally support monitoring of non-critical information to the domain of ambient displays. Ambient displays have the ambitious goal of presenting information without distracting or burdening the user.* (Mankoff et al., 2003)

> *Ambient Displays take a broader view of display than the conventional GUI, making use of the entire physical environment as an interface to digital information. [...] Information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movement, sound, color, smell, temperature, or light. Ambient*

> *Displays are well suited as a means to keep users aware of people or general states of large systems [...]* (Wisneski et al., 1998)

> *[...] Ambient Displays are designed not to distract people from their tasks at hand but to be subtle, calm reminders that can be occasionally noticed. [...] the displays also frequently contribute to the aesthetics of the locale in which they are deployed. [...] typically an ambient display conveys only one piece of information. Peripheral displays, conversely, may present multiple information items.* (Plaue, Miller, & Stasko, 2004)

> *Ambient Displays are ubiquitous computing devices that provide a continuous stream of information in a peripheral, non-obtrusive way. Ambient Displays are particularly good at monitoring and displaying in a simple manner the status of a complex system, but can provide us with any information about the world that we do not need or want to directly attend to. [...] Ambient Displays reduce a user's cognitive load by alerting the user to an interesting development, rather than requiring the user to occasionally check the status of an information source.* (Ames & Dey, 2002)

> *Ambient Displays are designed to display information without constantly demanding the user's full attention. Ambient Displays are envisioned as being all around us and thereby moving information off the more conventional screens into the physical environment. They present information via changes in light, sound, movement of objects, smell, etc.* (Streitz et al., 2003)

The main characteristic of ambient displays is that they have pointed aesthetic goals and present a very small number of information elements (Pousman & Stasko, 2006). The following characteristics are derived from the quotes above and define the term *ambient display* for the context of this thesis.

- Ambient displays are integrated into our environment and are perceived at our periphery.
- Ambient displays embody information that does not require constant attention of the user.
- Ambient displays are designed to reduce the cognitive load on users.

- The mediation of information is not constrained to visual embodiment. It can also happen through changes of other sensual variables, such as temperature, odor, or sound.
- The design of ambient displays is aesthetically pleasing and environmentally appropriate.

These characteristics already give an idea of what is important when designing ambient displays. To better understand the design constraints for ambient displays it is further necessary to look into the state of the art in ambient display design. Additionally heuristics and guidelines exist to guide the design and evaluation of ambient displays. The following sections present both state-of-the-art ambient displays and theoretical work from that field. The examples presented below are categorized according to their representation, which can be one of the following: physical artifact, integrated, or screen-based.

2.4.2 Ambient Displays as Physical Artifacts

Ambient displays that are designed as physical artifacts introduce new objects. They can be based on existing real world objects, but their only purpose is to represent information at the periphery of users' attention.

The large-scale Pinwheels installation exhibited in a museum in Tokyo was based on 40 computer-controlled pinwheel units (figure 2.46). The pinwheel represents an existing object that is put into a different context to provide people within an architectural space with information *through subtle changes in movement and sound* (Ishii, Ren, & Frei, 2001). The installation was designed to create an awareness for people's activities in both physical space (e.g. traffic of people) and cyberspace (e.g. e-mails).

The Bus Mobile is another example for an ambient display as physical artifact that is suspended from the ceiling (Mankoff et al., 2003). It shows the arrival of different bus lines in form of a mobile. The height of a bus sign indicates how close the according bus is (figure 2.47).

Figure 2.47: The Bus Mobile displays arrival time for busses. (Mankoff et al., 2003)

Strong and Gaver (1996) developed three ambient displays to support simple, implicit, and expressive communication for distributed couples. The first one, Feather, consists of a mobile picture frame and a feather. Lifting the picture frame while traveling triggers a fan at the home. The turning fan causes the feather to drift, giving the person at

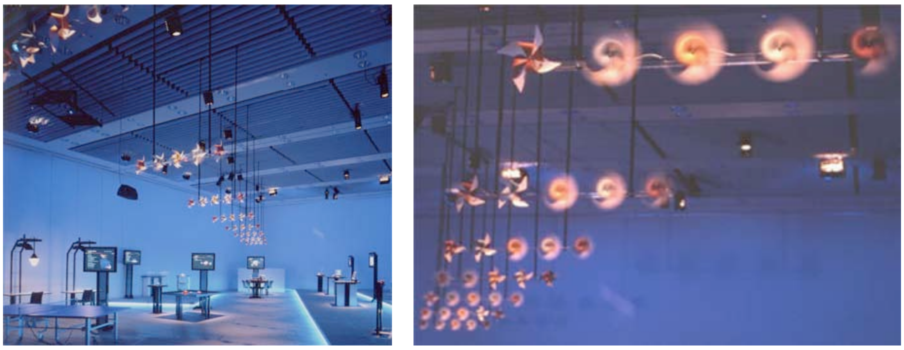


Figure 2.46: The Pinwheel installation at a museum in Tokyo provides peripheral awareness of people's activities (Ishii, Ren, & Frei, 2001).

home a feeling of intimate connectedness. Scent is a variation of Feather. Interacting with the picture frame starts a heating element, which causes the vaporization of essential oil. The third prototype, Shaker, consists of two objects. Shaking one object causes subtle vibrations of the other object.

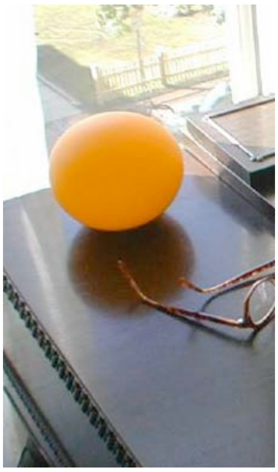


Figure 2.48: The Ambient Orb: a glass orb that displays information through color.

The inTouch system (Brave & Dahley, 1997), another ambient display to support implicit communication, provides a physical link between distant people through tactile feedback. It consists of two objects, each made of three rollers. When one of the rollers is rotated, the corresponding roll on the other object moves as well. This gives people the illusion that they interact with the same physical object over a distance.

The Ambient Orb is a commercially available ambient display made of a glass orb (Ambient Devices, 2004). It receives information, such as weather forecast or stock market, from a wireless network, and displays it through color (figure 2.48). For example if it is configured to display stock market information, it glows yellow when the market is calm, red to indicate that the market is going down, or green to show it is going up.

2.4.3 Integrated Ambient Displays

Ambient displays from within the second category are integrated into existing objects that also serve another purpose. They therefore augment our everyday environment to provide information at the periphery of users' attention.

The short-term weather forecast display employs the window within buildings as peripheral display, which provides graphical weather forecasts (Rodenstein, 1999). To achieve this the window, which

Figure 2.50: Two examples for remote communication: the RemoteHome features interactive walls indicating activities (left, Schneidler et al., 2002) and the Habitat table showing objects placed on the table in the remote location (right, Patel & Agamanolis, 2003).

retains its original functionality, is augmented with a digital projection of graphical images.

Forecast (Materious, 2005) is another ambient display that enhances an object, namely an umbrella, to provide weather information in a peripheral way (figure 2.49). Again, the original functionality of the object is retained and the information conveyed by the ambient display is related to the object's context.

Figure 2.49: Forecast: an ambient display integrated into the handle of an umbrella to inform users about the weather forecast.

The RemoteHome applies the concept of ambient display in a home environment (Schneidler, Jonsson, & Petersson, 2002). Walls and other architectural elements are augmented with information technologies to provide a feeling of connectedness between distributed couples. For instance patterns of lights integrated into the walls show activities within a room (figure 2.50, left).

Habitat (Patel & Agamanolis, 2003) was also developed to provide implicit communication in a home environment. The system projects images of objects that are located on a table onto the table at the remote location (figure 2.50, right).

Ambient displays have also been integrated into sleeping environments to support implicit communication between distant couples through aural, visual, and tactile modalities (Dodge, 1997). The system consists of pillows that translate motion into heartbeat and physical presence into warmth. Dialogs and breathing are translated into movement of a curtain and visually enhanced through shadows.

The Hug (Gemperle, Disalvo, Forlizzi, & Yonkers, 2003) is a similar

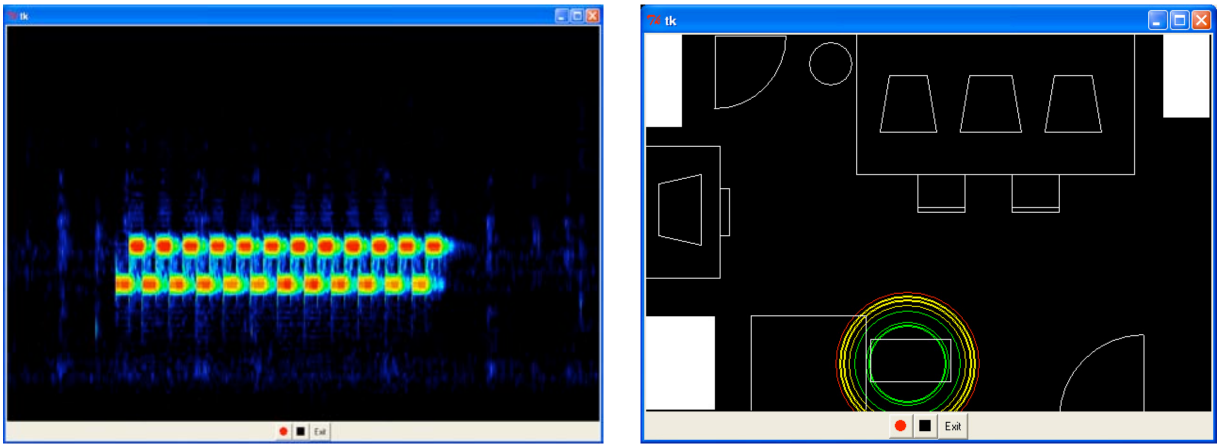


Figure 2.51: The Single Icon and Spectrograph applications, representing the sound of a ringing cellphone through. (Ho-Ching et al., 2003)

system, which augments a pillow. It translates a hug into heat and tactile vibration to support implicit communication between distributed family members.

Rüüg (Thompson, Friedland, & Cargiuolo, 2005) is a plush rug that sends input from walking or sitting to a remote rug, which displays this input with color change. The system consists of heat-sensitive dye and heating-elements beneath the rug, thus providing a simple low-resolution display. It was developed to communicate presence and physical activity, thereby creating a sense of remote connectedness between close friends.

The Hello.Wall (Prante et al., 2004), which was already introduced in section 2.3.3, is also an ambient display, integrated into the environment, in this case the wall.

2.4.4 Screen-based Ambient Displays

The third category covers ambient displays that are based on screens, which are placed into everyday environments. Some representatives for this category are described below.

The GroupCast display (Mccarthy, Costa, & Liongosari, 2001) is integrated into the hallway of a building. It displays information about interest of people passing the display, which might stimulate conversation between people sharing the same interests.

Ho-Ching et al. (2003) built two different approaches for ambient displays that supported monitoring and notification of sounds. In a follow-up project Matthews, Fong, and Mankoff (2005) developed

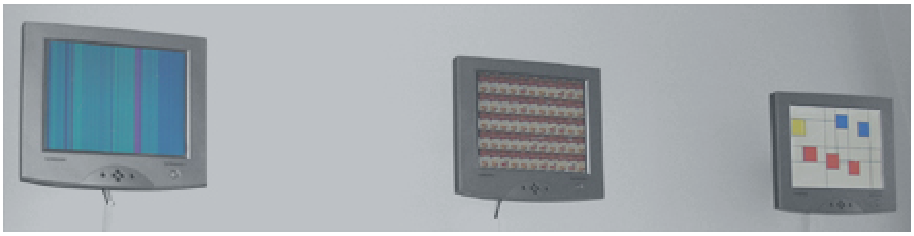


Figure 2.52: Informative Art: three prototypes for ambient displays showing information, such as activity, time, and weather (from left to right), inspired by paintings of well-known artists. (Redström et al., 2000)

several functional prototypes, which they evaluated in different studies. The Single Icon application displayed recognized sounds as icons and unrecognized sounds as rings (figure 2.51, left). Pitch and volume of unrecognized sounds were encoded through color and number of rings. The Spectrograph with Icon application additionally displayed a black and white spectrograph (figure 2.51, right). This spectrograph served as a footprint and aimed to help identifying sounds through a more detailed representation of volume and pitch. Both prototypes used the sound recognition system from Malkin, Macho, and Temko (2005) for sound identification.

A common approach for screen-based ambient displays is their implementation as pictures that can be hung on the wall like paintings. Informative Art (Redström, Skog, & Hallnäs, 2000), which adapts well-known art to present different kind of information in an aesthetically pleasing way (figure 2.52), is one representative for this approach, the InfoCanvas (Miller & Stasko, 2001), which can be configures to display e-mail traffic, website usage, etc., another.

2.4.5 Heuristics, Guidelines, and Taxonomies

The short overview of ambient displays given above demonstrates the large variety of possible application scenarios. Heuristics and guidelines have been developed to define the design space of ambient displays. This involves the introduction of design dimensions. Heuristics can be applied for both designing and evaluating ambient displays, while guidelines specifically aim at guiding the design process. In contrast, the strength of a taxonomy is its applicability for categorizing existing applications. This eventually guides future directions in research by pointing out potential or under-researched areas.

Ames and Dey (2002) published a set of design dimensions for ambient displays: intrusiveness, notification, persistence, temporal context, overview to detail, modality, level of abstraction, interactivity, location, content, and aesthetics. They based the dimensions on their experience from building ambient displays and suggested their application for evaluating ambient displays.

Mankoff et al. (2003) proposed eight heuristics specifically for evaluating ambient displays, such as *match between design of ambient display and environments*. The motivation for their work was to provide a low-cost evaluation technique, but the heuristics can as well guide designers of ambient displays. The proposed heuristics highlight important aspects of ambient displays without directly corresponding to design dimensions.

Matthews, Dey, Mankoff, Carter, and Rattenbury (2004) described three key characteristics, derived from a survey of existing ambient displays and cognitive science literature. They further developed a toolkit to support the development of peripheral displays, which facilitates the incorporation of the key characteristics. The characteristics they found were: abstraction, notification, and transitions. They also suggested five levels of notification: demand action, interrupt, make aware, change blind, and ignore.

Brewer (2004) introduced guidelines as a set of questions that designers have to consider, such as for example, *How quickly does the information change* and *Is the information already displayed in some way or is it intangible*.

Pousman and Stasko (2006) proposed a taxonomy for ambient information systems. It is based on four design dimensions: information capacity, notification level, representational fidelity, and aesthetic emphasis. They classified 19 research systems and three consumer ambient displays along these dimensions. The metric for each dimension ranks from low to high. The resulting diagram, displayed in figure 2.53 shows the distribution of existing ambient information systems along the four axes, pointing out trends and clusters.

The overview of these heuristics, guidelines, and taxonomies shows the existence of different approaches to guiding design and research of ambient displays. Some approaches only refer to the information representation, while others consider the entire ambient display. This

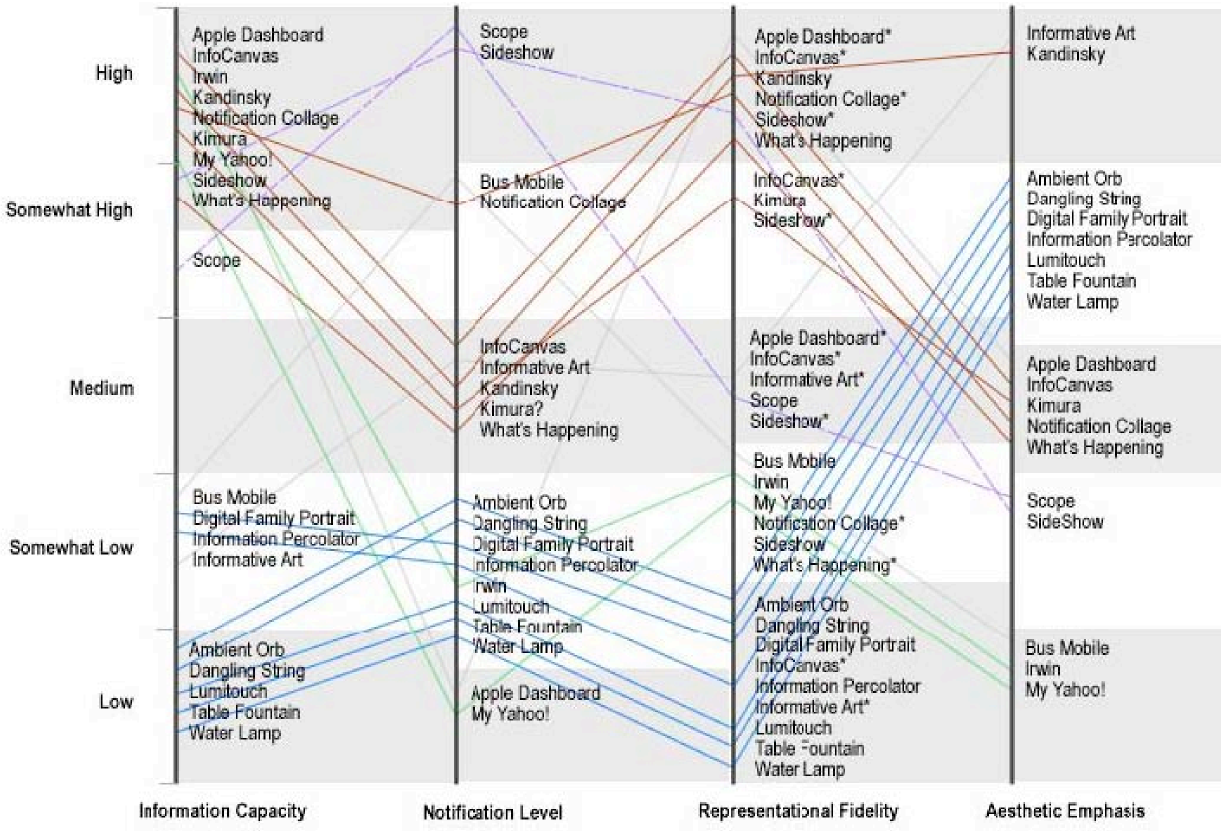


Figure 2.53: Classification of 19 ambient displays. Colors point out groups of systems that are similar. (Pousman & Stasko, 2006)

results in a high number of design dimensions and attributes that need to be considered when designing ambient displays. The ambient display model introduced in section 4.4 is an attempt to bring the most important ones into an integrated perspective.

2.5 Conclusion

Four important foundations for the concept of interactive ceiling were identified during the review of related work: (1) general aspects of architectural ceilings, (2) the use of the ceiling in architecture, (3) the ubiquitous computing paradigm, (4) and the concept of ambient display. The foundations and their contribution for interactive ceilings is summarized below.

The first foundation is defined by an investigation of the *psychology of ceilings*, which revealed attributes and characteristics of ceilings. The attributes are partly linked to the characteristics. While the characteristics describe features of the architectural ceiling, attributes represent parameters, which are determined when the ceiling is constructed. Some of those parameters, such as color, pattern, or even height, can be set by interactive ceiling applications, thus changing the perception of the space. Human perception of space also represents the third component of this foundation. The ceiling largely determines how humans experience space. For example a dark ceiling lowers the ceiling, creating a claustrophobic impression.

The second foundation constitutes the largest part of this chapter. It started with a general discussion of the *architectural ceiling* as a concept, where the meaning of ceiling in the context of this thesis was clarified. The review of the history of ceilings showed how and why ceiling height has changed over time. In the early days it was mainly influenced by practical concerns, such as air circulation to dispense smoke from fire used for heating and lighting. In recent history the ceiling height has been reduced for environmental and energy reasons, also due to high costs of land. It is therefore necessary to visually raise the height for a positive experience of space. In architecture this can be done through vaulted ceilings and large windows that start right above the floor. Vaulted ceilings and other types of ceilings were discussed next in this section. The conclusion here was that dropped ceilings provide a good platform for installing technology into the ceiling, since panels can be easily replaced. They also provide space to hide cable work or other installation material. Other ceiling types, such as vaulted ceilings, and also visible beams, can make it more difficult to install an interactive ceiling application.

The review of historical ceiling art represents an important part of the second foundation. The review revealed that the ceiling as a medium for expression has a long history that dates back to the first days of human evolution. Most interesting in terms of their contribution to this thesis are examples of ceiling frescos that convey information and/or represent elements that are associated with the sky, such as stars or the sky. Here, the work of the Italian artist and architect Andrea Pozzo, was discussed in detail, since his ceiling frescos demonstrate how the ceiling as a structural element can be augmented and turned into a conceptual layer that affects the way we experience space.

The discussion of media architecture showed that the integration of media into the built architecture has seen quite some coverage from a commercial perspective, but only marginal impact on a research level. The survey of media architecture applications revealed that the architectural ceiling has already been used for information display, the most well-known example being the Fremont Street Experience in Las Vegas. However, those examples represent active systems and therefore mainly create an ambience, rather than engaging people in reactive or interactive ways.

Interactive architecture and interactive art were included in this section, since they are representative for a contemporary examination of architectural concepts and information technologies in the lights of art, often in whimsical ways. Projects from these fields often have the goal to provoke visitors, which frees them from empirical research constraints, but has in turn the potential to inspire new scientific application scenarios.

The contribution of the third foundation, *ubiquitous computing*, is the concept of integrating computing technologies into everyday environments. The contribution of the respective section in this thesis is a survey of interactive surfaces, categorized into interactive walls, interactive floors, interactive ceilings, and other surfaces (such as tables). This survey showed that most projects currently employ tables as interactive surface, followed by walls, and floors. Only few projects were found that use the ceiling as interactive surface.

The last foundation is the concept of *ambient display*, which suggests the visualization of information at the periphery of human perception. A number of ambient display projects were presented for the purpose of demonstrating the concept. The categorization of these projects revealed different types of representation: physical artifact, integrated ambient display, and screen-based representation. The concept of ambient display links back to the first foundation, where one of the ceiling characteristics was that ceilings sit at the periphery of human perception. The ceiling therefore provides a natural opportunity for ambient display of information.

3

INTERACTIVE CEILING APPLICATIONS

This chapter starts with a discussion of the methods used for the studies on interactive ceiling applications. Accordingly, five studies that were conducted as part of this thesis research are described and discussed in the context of the CIx framework. In the first study the ceiling is employed as interface for displaying weather forecast. The second study provides an evaluation of a number of approaches for mediating emotional awareness through the ceiling. The third study investigates the ceiling for displaying ambient sounds for deaf and hearing impaired people. In the forth study a responsive ceiling display is used for representing sound levels within a built environment. The last study is a controlled experiment on different techniques for ceiling interaction.

The design method used for the studies discussed in this chapter is a mix of several HCI methods. There is a lack of technology and empiricism in the field addressed by this thesis. This requires the application of appropriate methods from closely related fields as well as general methods aiming at research of unexplored areas. An explorative investigation approach was chosen for the research work of this thesis (Bortz & Döring, 2003). The goal of such an investigation is to develop theoretical and conceptual assumptions that might eventually lead to the formulation of hypotheses.

The prototypes described as part of the studies represent probes into the design space to investigate the scientific feasibility of ceiling-based applications. They were developed following a combination of user-centered design methods and Verplank's spiral (Davenport et al., 1998). The specific methods are described in the respective sections.

The spiral model works well to formalize the development process from something that might be interesting to explore (a hunch) over prototypes to products, which might eventually lead to new paradigms (figure 1.2). Since the ceiling for information display represents a given parameter for the studies, it was crucial to start with a vague idea of what to do, which had to be tried out in the form of a hack before leading to further designs, which were then tested with users in some of the studies. The underlying methodology is therefore a composition of bottom-up (technology-driven) and top-down (idea-driven) approaches.

3.1 Study I: Weather Forecast

The first study investigates the architectural ceiling for displaying non-vital information, such as the weather forecast, as a peripheral visualization. The application scenario was inspired by the observation that information about the weather trend for the current day is typically most relevant in the morning before leaving the home. This is the moment when we decide whether we should wear a coat or take an umbrella with us. Information technologies allows us to receive this information through the Internet or the TV. Both require explicit interaction with a device. The weather forecast ceiling displays information as an ambient visualization on the ceiling in the hallway (Tomitsch & Grechenig, 2007b). Inhabitants can pick up this information on their way to the bathroom, when they pass the hallway, or before leaving the house, when they put on their shoes.

3.1.1 Motivation and Goals

The idea for this prototype emerged from the metaphor of the natural sky, which is described in section 4.3 as part of the CeDis model. In outdoor environments the sky provides us with clues about upcoming weather conditions. For example, dark clouds might tell about an arriving storm or rain clouds at the distant horizon might imply that it will be raining soon (figure 3.1). It is possible to receive this information by looking outside of the window from within a building, but this usually only provides a view into one direction and a very short-term forecast.

Therefore the specific goals for this study were: (1) investigating the visual impression of a ceiling projection, (2) creating an augmented architectural environment that provides people within a building with a short term weather forecast, (3) approaching requirements for the visual design of ceiling-based visualizations, and (4) collecting experience with the technological constraints for ceiling projections.

3.1.2 Method and Materials

The goals were approached according to the spiral model by Verplank (figure 1.2). The initial hack consisted of a Processing sketch, which retrieved information about the local forecast via the Yahoo! Weather RSS feed (available at http://developer.yahoo.com/weather/).

Processing is a Java-based toolkit that follows a simple approach to programming and is therefore especially popular among designers. For more information see http://www.processing.org.

In this hack the background color of the image represented the forecasted temperature. The color was adopted from the ambient orb (Ambient Devices, 2004; section 2.4.2). Trying out this prototype showed that the colored background produced a too obtrusive projection and also had a negative impact on the aesthetics of the visualization (figure 3.2, left and middle). Consequently, the final design and prototype encodes the temperature into the graphical representation for the weather condition (rain, snowfall, etc.). A blue ceiling anticipates a cold day, while a yellowish color promises a warm day. Animated water ripples (figure 3.2, right) or snow flakes floating over the ceiling inform about rain or snowfall respectively.

The prototype can be configured to display either the current weather conditions, the short-term weather forecast, or the forecast for the next day. The modes are mapped to keyboard buttons, but the design idea eventually foresees the possibility to change modes through direct interaction with the ceiling-based visualization. A wizard of oz prototype that demonstrates possible interaction techniques is presented in section 3.5.

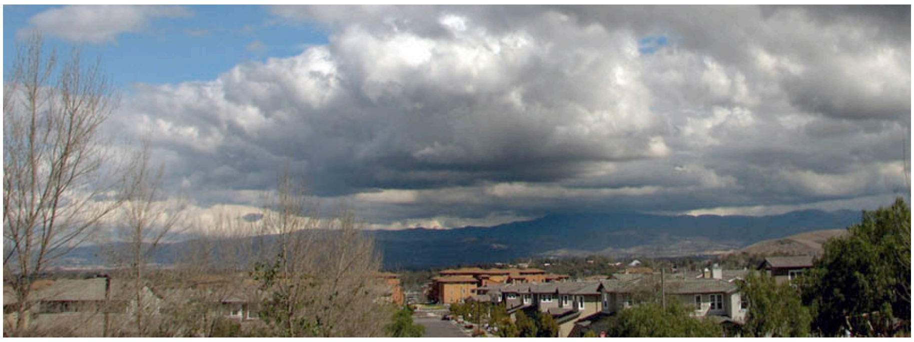


Figure 3.1: In outdoor environments the sky provides peripheral awareness, e.g. about upcoming weahter conditions.

Figure 3.2: The first prototype for the weather forecast application showing warm (left) and cold temperature with rainfall (middle), and a revised version, where temperature was color-encoded into the graphical representation of the predicted weather condition (right).

The prototype was installed in the hallway of our office and informally tested through interviews with colleagues passing by.

3.1.3 Results and Discussion

The weather forecast installation aroused considerable attention from people in the office. In fact, it received more attention than it was designed to, which had an impact on its quality as ambient display. This was probably due to two reasons: Firstly, the ceiling projection was a new and unusual experience within the office environment, and therefore people were curious to learn more about it. This would probably change if the application was installed for a longer period of time. Secondly, the animated water ripples (during the installation the weather forecast predicted rain) were moving too fast, resulting in a high notification level (cf. section 4.4.2). In the case of the weather applications the notification levels have to be set somewhere between *change blind* and *interrupt*, depending on the displayed information. People should not become interrupted by a slight change in the forecasted temperature, but it is important to make them aware of predicted weather conditions that require an action. For example, if the forecast predicts heavy rain, they might need to think about taking their umbrella before leaving the house.

The chosen graphical representation for the different weather conditions was probably too abstract, though it was placed on the semi-abstract level of the corresponding dimension (section 4.4.2), since people were asking about the meaning of the animated ripples. The level of abstraction was chosen for aesthetic reasons. My assumption was that once learned the abstract representation would be easy to remember. The appropriateness of the abstraction level can therefore only be evaluated in a longer study.

Using a projector to simulate a ceiling display worked well for this particular application, since it did not require spatial mapping of data onto the ceiling. The projection had also an appropriate size for being installed into a hallway or hallway. Section 3.6.2 provides a discussion on technologies that allow for a larger projection area.

Other ambient displays have already been proposed to communicate the weather forecast at the periphery of human perception, such as the ambient orb (figure 2.48) or the forecast umbrella (figure 2.49). The ceiling-based visualization of weather in a home environment has the advantage that it exploits the ceiling as a large surface for displaying this information. It is hard to miss color changes on a room's ceiling, but it might be fairly easy to lose sight of the umbrella's handle when it's stored away. An advantage of the artifact-based approaches is however that they are portable and therefore easy to relocate. Installation and operation costs of ceiling displays are considerably higher too, but this issue is discussed in detail in section 3.6.2.

3.2 Study II: Emotional Awareness

The second study investigates the architectural ceiling as a (non-verbal) implicit communication space for couples living apart from each other. It is based on previous work in this area (Strong & Gaver, 1996; Brave & Dahley, 1997; Schneidler et al., 2002; Patel & Agamanolis, 2003) (see section 2.4.)

Implicit communication is information encoded by the way people interact with each other through means such as gesture, body language, and voice (Schmidt, 2000; Strong & Gaver, 1996).

3.2.1 Motivation and Goals

Technology-mediated communication allows us to communicate with family members and friends across the street or across the world (Etter, Röcker, & Gilgen, 2006). However, current communication devices only afford explicit communication and require people to have a reason for contacting someone (Etter et al., 2006). Especially in intimate relationships people have the desire to receive and give a feeling of continuous connectedness (Vetere et al., 2005). While current technologies, such as SMS (Short Message Service) or instant messengers, have the capability to supply this desire up to a certain extend, the lack of everyday knowledge about intimate friends creates a sense of emotional distance (Thompson et al., 2005). Continuous and asynchronous connectivity can potentially improve the feeling of togetherness in relationships and awareness among distributed family members (Tollmar & Persson, 2002).

Developing new means of enhanced communication is a relevant issue, since current trends of the job situation in the European Union (EU) show that mobility is an important requirement for professional development. A recent study (Krieger, 2006) on mobility revealed that the lack of direct contact with family or friends is the main reason that discourages people from moving to another EU country (figure 3.3). Schneider, Limmer, and Ruckdeschel (2002) identified five issues that are important for mobility. One of them were expectations about relationship and family in respect to proximity, distance, togetherness, and personal freedom. Two third of the participants stated that mobility had mainly negative impacts on the relationship. They argued that the need for intimate closeness and time spent together represent a disadvantage of job mobility. This can eventually lead to the end of the relationship.

> *Interactions that add to the consolidation of a relationship get a raw deal. There is no room for time to exchange experiences, discuss problems, ... or for spending time together.* (Schneider et al., 2002)

Accordingly job mobility can have a negative impact on the quality of a relationship. The motivation of this study was therefore to investigate the potential of ambient ceiling visualizations to improve the feeling of intimacy and togetherness over a distance. The assumption was that an environment that supports implicit communication can counteract the lack of direct contact with family or friends (cf. figure 3.3). The study's goals were:

- Finding out whether there is a need for implicit communication in long-distance relationships,
- Collecting design requirements; and
- Evaluate design scenarios for ceiling-based emotional awareness applications.

3.2.2 Method and Materials

This study consisted of two parts. The first part was an interview about current ways of communicating with a distant partner. The

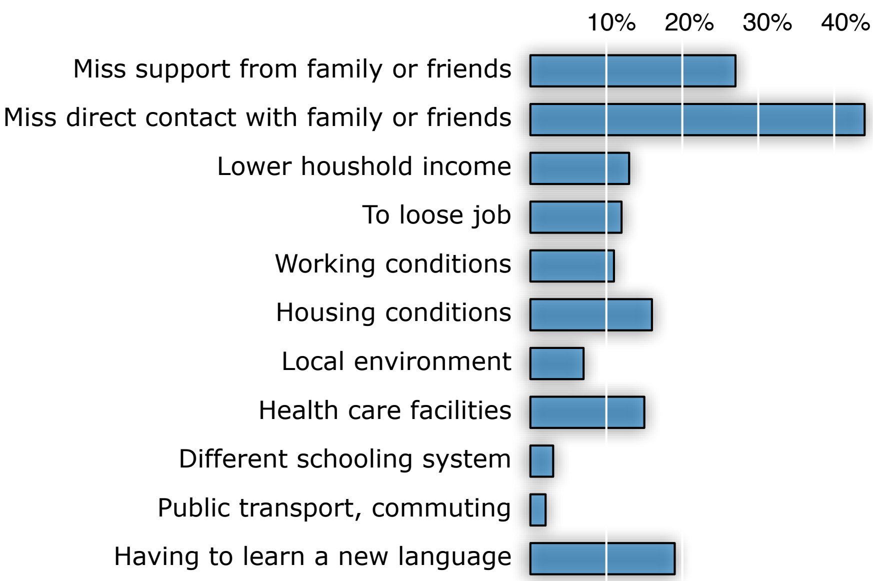


Figure 3.3: Factors that discourage people to move to another EU country, based on (Krieger, 2006).

second part was another interview about the use of new technologies for implicit communication. Two existing research projects (Habitat and InTouch, see section 2.4) were introduced to explain and discuss the concept of implicit communication. This was followed by a walkthrough of eight design scenarios that were prepared for the study (see below).

Participants and Setting

Six people (3 male, 3 female; aged between 22 and 36 years), that lived in long-distance relationships at the time the interviews were held, took part in the study. Since some of the interview partners were living abroad, two interviews took place via phone and two via an online platform (a combination of an online questionnaire and a messenger). The remaining two interviews were conducted face-to-face.

Design Scenarios

The design scenarios were based on an analysis of related research projects (section 2.4). The process was further guided by the design nuggets formulated by Agamanolis (2003) and the AmDis model described in section 4.4. The design scenarios convey the visual part of different ceiling-based approaches and discuss interaction modes, but have not been actually built as working prototypes. The prototypes therefore serve as proof-of-concept scenarios for applications in this area.

Scenario 1: Activity

The first scenario determines activity in the remote home and accordingly causes changes in the ceiling-based visualization. Activity directly relates to clouds projected onto the ceiling. If there is no activity, a clear blue sky is displayed. The more activity the more clouds are displayed (figure 3.4).

Scenario 2: Location

The second scenario represents the location of the distant person through an abstract ceiling-based visualization. The location is spatially mapped onto the ceiling and displayed as simple pattern. Number of people within a room and amount of activity determine the size of the pattern (figure 3.5).

Scenario 3: Sound I

The third scenario employs the metaphor of rain to visualize the sound level in the distant home. The room features a ceiling-based

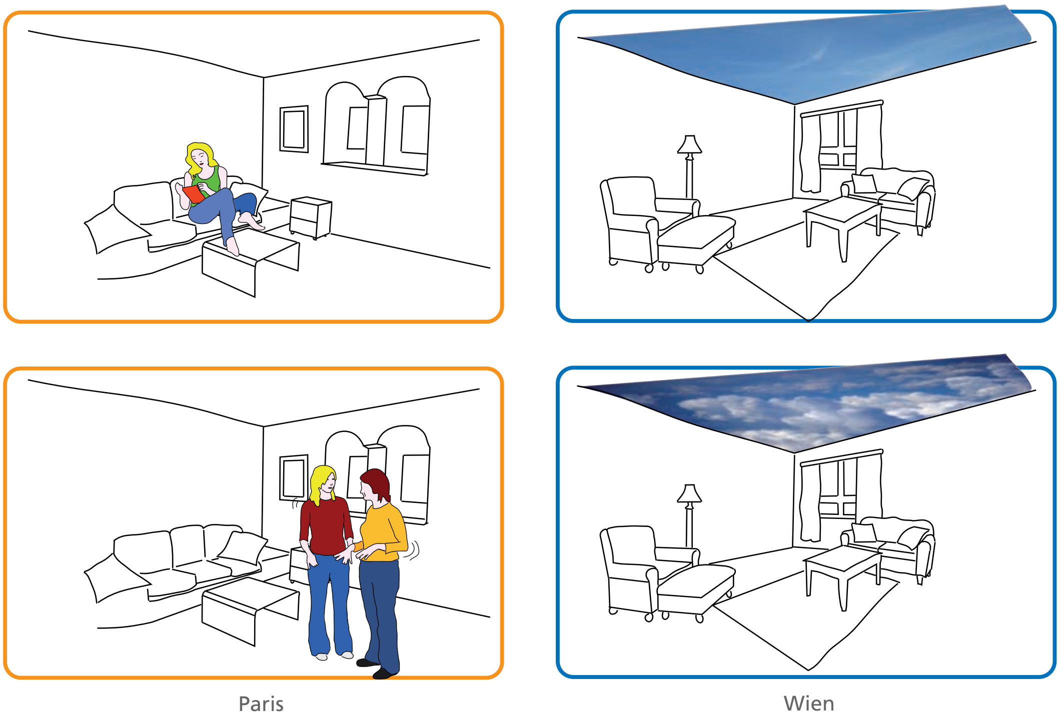


Figure 3.4: Scenario 1 demonstrates an application, where the level of activity is represented by animated clouds projected onto the ceiling.

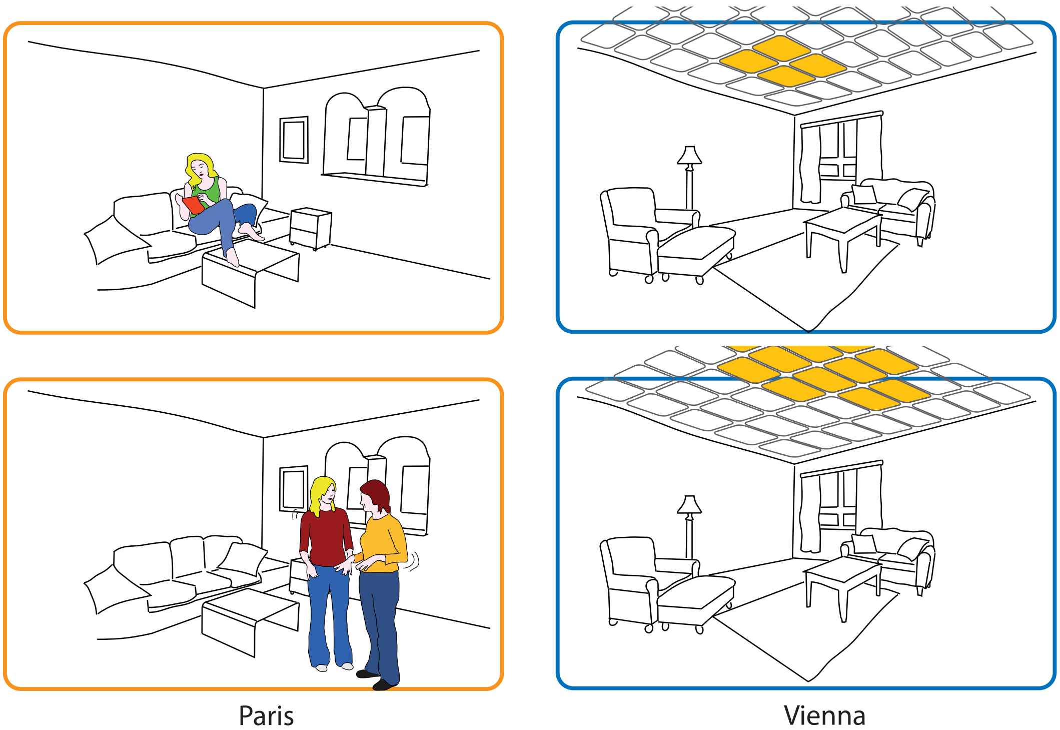


Figure 3.5: In scenario 2 the location and activity of people is represented through patterns of light.

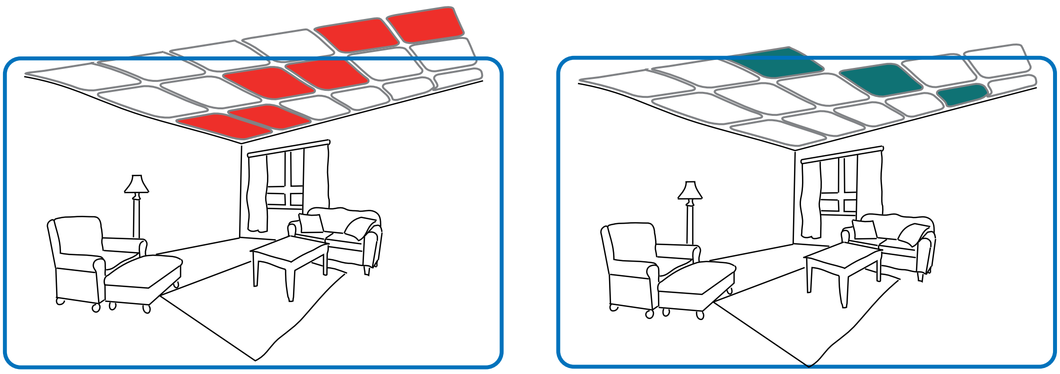


Figure 3.6: Scenario 5 displays the use of light patterns to mediate an awareness for the mood of the distant person.

visualization of a water surface. Rain drops falling onto the water and creating sound ripples convey the current sound level (figure 3.7).

Scenario 4: Sound II

The fourth scenario visualizes the sound level in the distant home, similar to scenario 3. Instead of displaying a water surface covering the entire ceiling, only ripples are displayed. The number and size of ripples is determined by the current sound level (figure 3.8).

Scenario 5: Mood

The fifth scenario uses projected light patterns to reflect the mood of the distant partner (figure 3.6). A physical cube served as tangible interface for input, since it is not only difficult to measure the mood of a person, but would also go beyond the scope of this thesis. The cube featured labels on each side, corresponding to certain emotional states: sad, inspired, angry, tired, amazed, happy, and ashamed. Each emotional state is represented by a colored pattern of squares.
Figure 3.9 shows a proof-of-concept installation of this scenario in an office environment. The applications aims at creating an awareness of the other person's mood over a distance, based on research that proves that different colors may cause different reactions in human beings (Sanchez, Kirschning, Palacio, & Ostròvskaya, 2005). The colors to represent the different modes were adopted from Sanchez et al. (2005), who investigated the effect of different colors in the context of an online messenger: grey (sad), marine blue (inspired), purple (angry), turquoise (tired), red (amazed), yellow (happy), and pale green (ashamed).

Scenario 6: Text

The sixth scenario allows distant couples to send text messages, which are displayed on the ceiling in the remote home. Messages are sent

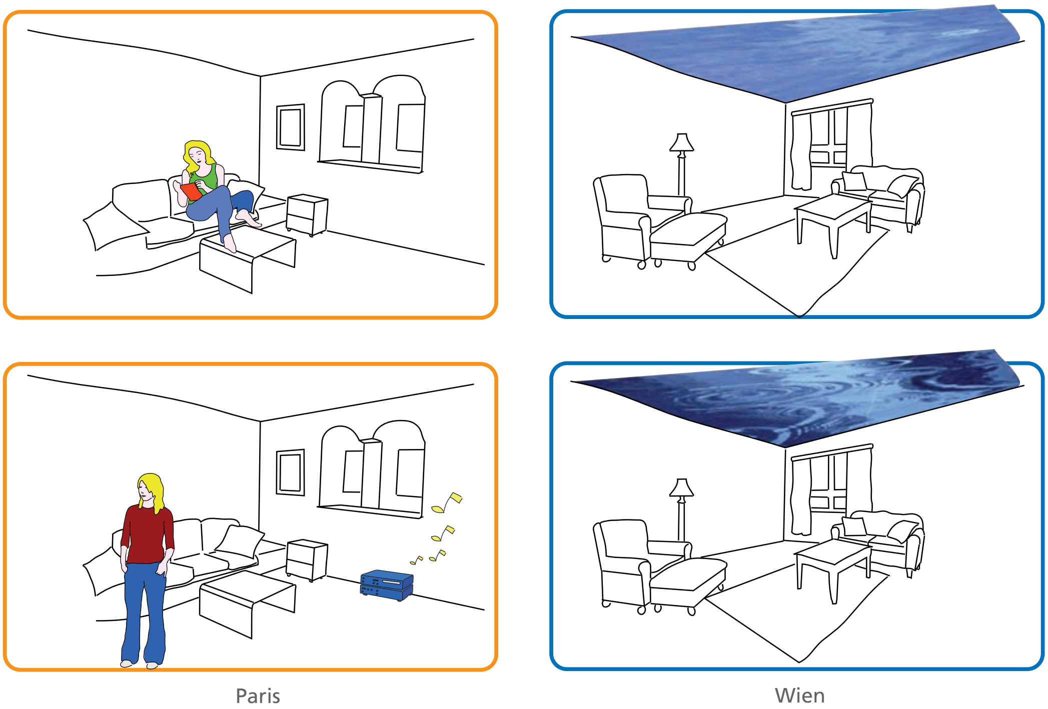


Figure 3.7: Scenario 3 describes an approach for sound awarness, where sound recorded in the distant room creates water ripples on the ceiling.

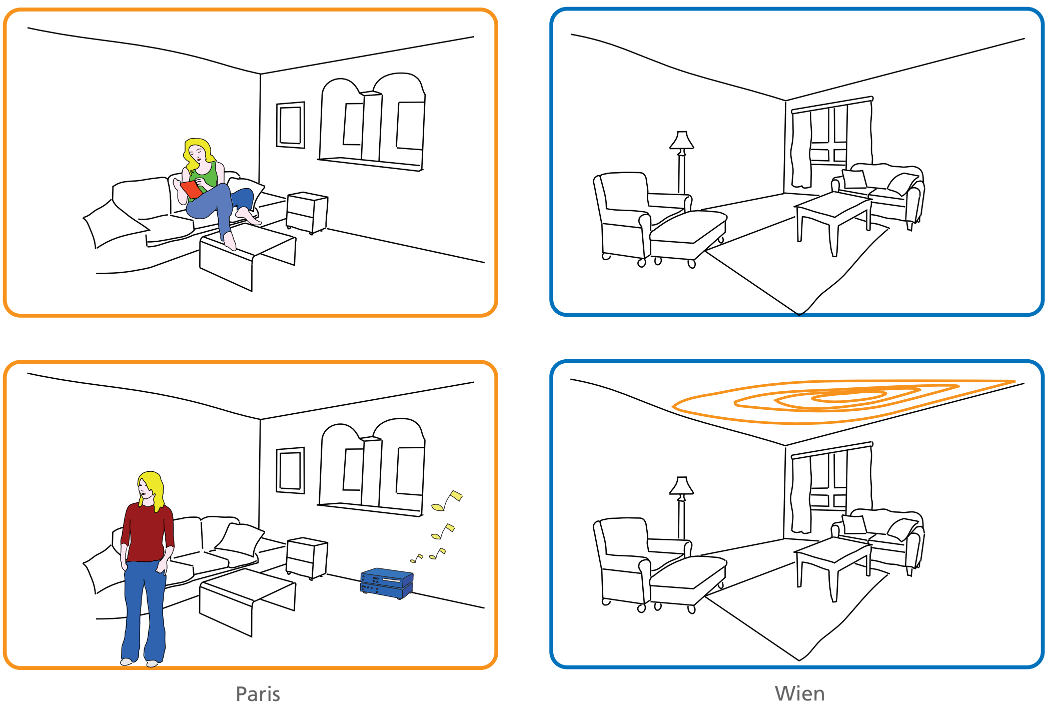


Figure 3.8: Scenario 4 also shows the use of ripples for conveying sound recorded in the distant room, but uses a more abstract representation.

Figure 3.9: Proof-of-concept installation of scenario 5: the left image shows the mood *happy* and the right image represents a *sad* mood.

using the mobile phone and fade over time. This prototype touches the problem of displaying directional data on the ceiling, i.e. data that is only readable from one particular direction (cf. section 2.1.2, Figure 2.2).

Scenario 7: Interaction

The seventh scenario enables interaction over a distance in an entertaining way. Users can throw a ball at panels attached to the ceiling, creating patterns of light. This design scenario allows distributed couples to create their own symbolic language, expressing states of mood or exchanging messages. (For an investigation of this interaction technique see section 3.5.)

Scenario 8: Table Mirror

The last scenario is inspired by the Habitat project. An image of the kitchen table is visualized on the ceiling above the table in the remote home. This gives people a sense of the other persons' current activities, e.g. whether they are drinking a coffee, having dinner, or reading a book.

3.2.3 Results and Discussion

All interview partners lived in a long-distance relationship. Two of them even lived on different continents. Both, mobile and non-mobile people were included in the study. They saw their partner from one time per week to every three months.

One of the participants used a variety of communication technologies, including phone, SMS, e-mails, and letters. The others either used e-mails or their phones to communicate with each other, depending on the available infrastructure and expenses of the respective service. SMS and letters were only rarely used (a few times a month).

All participants expressed a desire for more communication. Three of them said that they would like to have video phones, so that they could see their partner. Overall, participants were most interested to receive information about the mood of their partner. This was followed by the desire of being able to send a non-verbal expression of thinking at each other. Activity and location awareness were of minor interest.

All participants except one rated the scenarios described above on a 5-point Likert scale. Overall scenario 5 (mood) received the best rating. This also correlates with the results from above concerning the ranking of non-verbal kinds of information. The possibility to send text messages, which are displayed on the ceiling (scenario 6) was rated second, followed by ball interaction over a distance (scenario 7). The other scenarios – activity (scenario 1), location (scenario 2), sound (scenarios 3 and 4), and table mirror (scenario 8) – were less attractive for our participants.

Though the study involved only six people, results showed some shared tendencies towards certain applications. However, there were also subtle differences between participants concerning specific applications. For example, scenario 8 was rejected by all but one. The reason for these variations lies probably within the fact that relationships are built upon different expectations. Intimate communication between couples depends on the individual characteristics of the partners. An investigation of these characteristics is problematic since *there is no generally accepted language for describing and discussing intimacy* (Vetere et al., 2005).

Participants were mostly skeptical when asked whether they would like to use one of the applications. A reason for this is probably that it was difficult for them to imagine how the applications would look like, when installed inside a room. Some of the participants stated that they felt uncertain about the perception of a ceiling-based visualization and they were afraid that they might be distracted in their primary task. As one participant stated, *I would like to try it, to see the actual experience.* She further said, that some of the applications would increase the curiosity to know what the other person is currently doing, since the information is displayed in an abstract manner.

An interesting result was that an awareness of the current mood of the partner can trigger an explicit action. As one of the participants put it: *You know how the partner feels and you can act accordingly and call him.*

A strong opinion against scenarios 1, 2, 3, and 4 was that the participants were worried about having the feeling of surveillance. This contradicts the findings of another study, in which an ambient display was evaluated, which showed the presence of a distant person through a light (Tollmar & Persson, 2002). The explanation for this is probably the fact that this study involved family households. The factor of surveillance is likely to be of more serious concern between couples, as one participant stated *Looks like surveillance. If the partner has someone visiting and one becomes aware of this, then you're rather curious who is visiting and why.* This also explains why scenarios 5, 6, and 7 received a higher rating than the others.

According to this study interactive ceiling applications that reflect the emotional state of the distant partner have the highest probability of being accepted. Participants were also interested in applications that both entertain and give them a feeling of remote awareness at the same time.

Remote awareness technologies will never be able to replace the experience of physical presence or face-to-face communication. They can however enrich the experience of communicating and living together over a distance Vetere et al. (2005).

While applications for location, activity, or sound awareness appear to be inappropriate approaches for couples, there seems to be a potential of such systems for interfamily communication. One of the participants, who works abroad, told us that once during a family meeting his parents turned on the headset and he could listen to their dialogs via Skype while working. He did not actually participate in their communication but experienced their virtual presence at the periphery of his attention.

More information about the interviews, which were part of a larger study on the impacts of job mobility on relationships, can be found in (Tomitsch, Grechenig, & Mayrhofer, 2007) and (Mayrhofer, 2008).

3.3 Study III: Ambient Sounds

The study discussed in this section investigated the application of ambient ceiling-based visualizations for providing deaf and hearing-impaired people with graphical representations of ambient sounds (Tomitsch & Grechenig, 2007a).

3.3.1 Motivation and Goals

Ambient sounds represent things happening in our vicinity and thus constantly provide us with important clues about our environment. Matthews et al. (2005) identified different classes of ambient sounds: serendipitous events (e.g. children playing in the next room), problematic things (e.g. fire alarm), and critical information (e.g. knocking on the door). In their study they revealed that deaf people have difficulties to keep track of this kind of information. Assistive technologies exist that help them to stay aware of specific events, such as a telephone call or the doorbell. However there is no tool available that consistently provides them with visualizations of all sounds in an environment (Matthews et al., 2005). For example, Matthews et al. (2005) found out in one of their interviews that a deaf couple once triggered the fire alarm while cooking and did not notice this until a hearing friend informed them. Deaf parents have difficulties to maintain awareness about their children's activities (Clarke, 2001). Such situations cause additional stress for deaf people (Clarke, 2001).

The study was motivated by the following facts:

- In a previous study deaf people stated to prefer large-scale displays for the representation of ambient sound visualization (Matthews et al., 2005).
- Recent advances in technology promote the integration of ambient technologies into the home, although it might take another decade until the technology for such an application will actually be available on the market.
- The ceiling has the advantage that it sits at the periphery of human perception. This approach exploits the fact that deaf people have enhanced visual attention to the periphery (Bavelier et al., 2001). The ceiling also allows spatial representation of sound sources.
- The ceiling is always present and always available. This is an

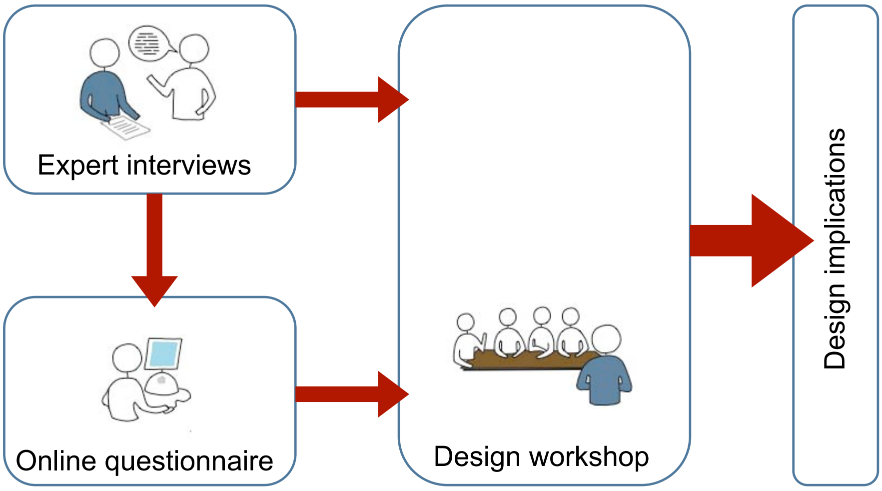


Figure 3.10: Study outline showing the dependencies between the methods used.

> advantage over an ambient sound display application that runs on a desktop computer, since people move around and are not always near their desks (Matthews et al., 2005).

The goals were to collect general background information about the importance of ambient sounds for deaf and hearing-impaired people, to evaluate a set of design prototypes, and to develop design implications for ambient sound display.

3.3.2 Method and Materials

The design process of the ambient sound application was guided by expert interviews, an online questionnaire, and insights resulting from a design workshop (figure 3.10).

Expert Interviews

The expert interviews were held at a local association for deaf and hearing-impaired people, called WITAF (formerly *Wiener Taubstummen-Fürsorgeverband*, now *Wissen, Information, Tradition, Aktuelles, Forderungen von Gehörlosen für Gehörlose*, which is the German abbreviation for Knowledge, information, tradition, news, and demands from and for deaf people). The interview partners were a social worker, who had been working at WITAF for several years, and a technical assistant, who was responsible for installing assistive technologies at people's homes. The objective of the interviews was to develop a common understanding for the situation of deaf people and to gather initial design ideas. The interviews also had the purpose to

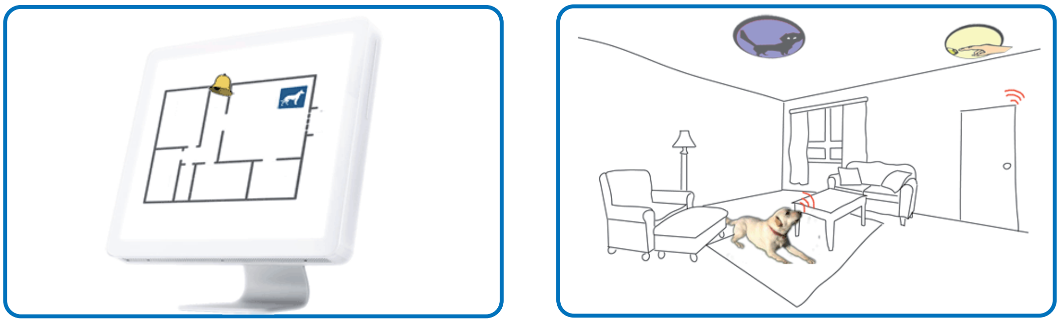


Figure 3.11: Sketches used in the questionnaire to illustrate a desktop-based versus ceiling-based approach for ambient sound display.

initiate a personal contact to the people from WITAF, which was a crucial factor for the success of the successive steps of the design process.

Questionnaire

The goal of the questionnaire was to collect information about assistive devices people currently use. It also aimed at verifying the assumption that especially people familiar with new information technologies, such as the Internet, would be interested in ambient sound displays. Previous work (Chan, 2002) as well as results from the expert interviews indicated that deaf people have difficulties with filling out long questionnaires. The questionnaire used in this study therefore consisted only of short closed questions and was developed in cooperation with the social worker at WITAF. The first part consisted of a questions regarding devices deaf people currently use and their preferences, e.g. whether they preferred vibration or flashlight for notification. The second part introduced two sketches of ambient sound systems (figure 3.11) to determine whether they would be interested in such an application. The questionnaire was distributed through WITAF mailing lists.

Design Workshop

The goal of the design workshop was to collect information about the target audience and to develop design ideas in a participatory design process. It was held during one of WITAF's club evenings, to make sure participants were familiar with the environment. The workshop was structured into three parts. The first part was a demonstration of a simple application that projected a visualization onto the ceiling, which reacted on acoustic input. The second part introduced sketches for possible application scenarios, which were projected onto the

Figure 3.12: Materials used in the design workshop.

ceiling. Participants discussed the sketches in the group and afterwards rated each application individually by attaching Post-it notes to the corresponding design sketch printed on a paper (figure 3.12). In the third part participants answered design questions and were encouraged to sketch design ideas for ceiling applications.

Functional Prototype

A functional prototype for visualizing sound and a set of design prototypes were used within the design workshop. All prototypes were displayed on the room's ceiling using a standard projector. The functional prototype further consisted of a microphone attached to a laptop, which was running a Processing program. The program produced rippled patterns based on live audio input (Hodgin, 2005).

Design Prototype

The design prototypes were static sketches to explore the visual appearance of the graphical representation of ambient sounds. Figure 3.13 shows the sketches, which ranged from very simple to rather complex approaches, both in terms of their visual execution and technical implementation. The first three sketches (sound ripples, patterns, and icons) ignored the location where the sound occurred and aimed at simply making people aware of its occurrence. The third sketch (icons) additionally suggested the identification of sounds and

Figure 3.13: Sketches used in the ambient sound study: sound ripples, patterns, icons, positional ripples, positional icons, sound ripples in a map, and icons in a map.

their iconic representation. The sketch only included two sample icons, a barking dog and a ringing doorbell. The fourth and fifth sketches (positional sound ripples and positional icons) included the representation of the location, where the ambient sound occurred. The remaining two sketches (sound ripples in a map and icons in a map) went beyond representing sounds within one room and instead displayed a map of the entire household, where the position of occurring sounds was highlighted using either ripples or icons respectively.

3.3.3 Results and Discussion

This section summarizes the results from the expert interviews, the online questionnaire, and the design workshop.

Expert Interviews

An important issue that was raised by the social worker was that deaf people suffer additional stress due to the fact that they cannot notice acoustic events. The possibility of using the ceiling as an ambient display was discussed with both interview partners. The technical assistant was concerned about the additional information overload, while the social worker was very interested in introducing such an application to her clients. An informal discussion after the interviews revealed that this ambivalence might come from the age difference between the two experts: the technical assistant was older and had deaf parents. Therefore he had been confronted with the problems of deaf and hearing impaired people all his life. He claimed that they knew how to cope with everyday challenges and that new information technologies would add to the stress they experience from their lack of hearing.

Questionnaire

From about 40 people that were subscribed to the mailing lists, eight (4 male, 4 female) filled out a questionnaire. The age ranged from 22 to 40 years, one participant was 54 years old. All of the respondents used a mobile phone and a PC. All but one used a fax machine, three of them had a mobile phone that supported video transmitting, and five of them used a web cam with their PC. All participants stated that they used a doorbell sensor and a special alarm clock (four with flash lights, two with vibration, and two with a combination of both). Four participants had children and three of them used a light-signal baby-monitoring device. The generally preferred notification method was flashlights (4), followed by light signals (2) and vibration (1).

Participants had to rate the sketches, shown in figure 3.11, on a scale from 1 to 5 with 5 being the best. The question was whether they would use an application similar to the one displayed in the sketch. The average acceptance rate of the first sketch (the desktop-based monitoring device) was 4 (SD=1). The second sketch (the ceiling-based monitoring display) was rated 3.3 (SD=1.8). One respondent stated that he would like to see a presence awareness monitor for people in his surrounding incorporated into the device from the first sketch. Opinions against the sketches were concerns about high electricity consumption (both sketches) and installation costs as well as aesthetic considerations (second sketch only).

Design Workshop

Ten participants (6 male, 4 female) aged between 22 and 30 years took part in the workshop. According to the analysis of the background questionnaires, all of them had experience with PCs and were interested in new technologies. Furthermore, other deaf people that attended the club evening continuously passed by the sessions and joined in the discussions. No background data from those people was collected. Figure 3.14 shows the setup of the design workshop.

The working prototype for visualizing live audio had a few limitations – it was lacking location detection of sound source and the projected area only covered a fractal of the ceiling – but it worked well to communicate the idea of visualizing sounds on the ceiling to the participants. They appreciated it with great interest and curiosity, and spontaneously started interacting with the prototype. They clapped their hands, screamed, and did all other sorts of things to produce noise and watched the corresponding patterns that were displayed on the ceiling.

Table 3.1 shows the results and comments for the design sketches. Post-it notes that were illegible were omitted. During the discussions it was revealed that icons were slightly preferred over sound ripples, although this trend is not reflected from the ratings. Location of

Figure 3.14: Participants and setting of the workshop at WITAF (left) and projector setup used for the ceiling display (right).

sounds was rated to be very important. Of the presented design sketches, participants liked the iconic representation of sounds within an overview map of the apartment or house best. During the presentations they also discussed other possible implementations of novel systems to provide sound awareness. The ideas ranged from floor projections (in shopping malls), over displays hanging at the wall, to augmented reality glasses that superimpose the real environment with virtual traces of sounds. In the final discussion of this part participants agreed that they would like to have a combination of an ambient ceiling projection and a display that hangs on the wall like a picture. The display should provide an overview of acoustic events in the entire apartment or house. One of the participants said that he would appreciate a multifunctional ceiling application to combine the functionality of all different devices he currently has to use in one system.

In the third and final part of the workshop participants had to form three groups. Each group was handed out a set of cards with design questions and tasks. The questions aimed to reveal their requirements for ceiling applications in general and for ambient sound visualization in detail. The design tasks encouraged them to sketch icons for sounds and possible arrangements of a ceiling display in their home. An interesting result was that people were not interested in ambient sounds emitted from the street, their neighbors' apartments or some

Table 3.1: Ratings of the design sketches and selected comments from the workshop participants.

	Bad	Fair	Good	Selected comments from the participants
Design sketch	3	1	4	Difficult to recognize, does not attract attention
Patterns	1	1	6	Good visual appearance, difficult to memorize
Icons	1	1	6	Too small
Positional sound ripples	0	2	7	Supports orientation and localization of sounds
Positional icons	1	1	5	Very practical
Sound ripples in map	0	0	9	Even better, great overview
Icons in map	0	0	10	Very clear due to icons

home appliances, such as the dishwasher. This contradicts some of the results found by Matthews et al. (2005). Other findings were confirmed, like the fact that deaf people sometimes forget to turn off their appliances, since they lack the acoustic information. Examples for this included cookers and water taps, another group mentioned the washing machine.

Two groups pointed out the following issues as important information, which they would like to be covered by a ceiling display: mobile phone, fax machine, and baby monitoring. Other (less important) issues were weather conditions, traffic conditions, and calendar data. One group said that they would also like to be able to call people, who are located in other rooms, via the ceiling.

We also asked the participants to point out where they would like to have ceiling displays inside their own apartments. However, we did not receive meaningful answers to this question. Instead they produced sketches to show how they thought a ceiling display should be arranged inside a room. They further told us that they would like to see similar displays in public places, like hospitals, train stations, airports, and subways.

Discussion

The results from the expert interviews suggested that especially deaf adolescents, who are already familiar with information technologies, would be interested in such an application. The questionnaire was designed to verify this assumption. However, a methodological problem was that the questionnaire could only be distributed over WITAF mailing lists. Therefore it addressed people, who were already

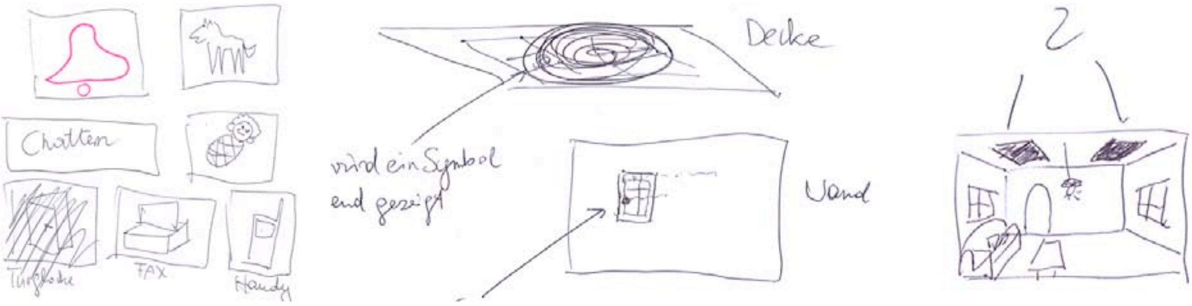


Figure 3.15: Selected sketches from the workshop participants.

familiar with PCs and the Internet. Nevertheless, we were able to strengthen our assumption later on during the design workshop. Some older WITAF members, who spontaneously joined in the discussions for a short time, explicitly stated that they did not need such an application. *My dog never barks and I don't care about the noise inside my room*, one participant stated. In contrast the workshop participants were very enthusiastic about the idea and presented concepts.

Results from the workshop session were probably biased due to the fact that all participants used their desktop computers on a regular basis. They therefore adhered to the metaphors and interaction paradigms known from desktop computer environments. This phenomenon was strongly supported by some of the results. For example two groups mentioned that they would like to have a screen saver view on their ceiling in case there is no other activity going on. The icons sketched by one group (figure 3.15) also featured a strong desktop-like character.

Design Guidelines

Matthews et al. (2005) already identified a number of general functional requirements for ambient sound applications: identify what sound occurred, view a history of displayed sounds, customize the information that is shown, and determine the accuracy of displayed information.

All requirements, except for the second one, were confirmed in the ambient sound study. Additionally the results from the study led to the formulation of the following design guidelines for visualizing ambient sounds through a ceiling-based information display:

1. Use either the entire ceiling or multiple areas as projection surface.

2. Provide a low-level awareness of sounds through the ceiling display.
3. Determine the location of occurring sounds.
4. Use aesthetic visualizations for the ceiling display.
5. Provide a second traditional display for higher-level sound awareness that features an overview of the entire living space (e.g. a desktop screen fixed on a wall).
6. Use icons for sound representation (especially on the additional display).
7. Show location of other people in the environment on the map.

The ceiling display for ambient sound visualization should therefore represent information about location and source of sounds in a peripheral, glanceable, and aesthetic way. The additional display acts as a primary display that provides the users with the same information in a higher resolution. This display is only consulted once the users were made aware of an event by the ceiling display.

The guidelines presented above are specifically for developing an ambient sound display based on the concept of interactive ceiling. They therefore supplement the general guidelines introduced in section 4.5.

3.4 Study IV: Sound Allocation

This study investigates the use of a low-resolution ceiling display for visualizing spatial data. The prototype that was implemented as part of the study represents the sound level distribution within an architectural environment.

3.4.1 Motivation and Goals

The motivation for this study is to explore ceiling-based visualization for a public everyday environment, such as a cafè. The study investigates ways to augment the ceiling of such an environment with information that would add to the quality of the space. The specific approach is based on the observation that cafès are often noisy places, where new arrivals might desire to find a quiet spot. According to the CeDis model (section 4.3), sound represents a spatial data source that can potentially be incorporated into a ceiling-based visualization providing contextual information. Thus, the prototype developed in this study visualizes the current distribution of the sound level in real-time through the changing of ambient light patterns. This allows

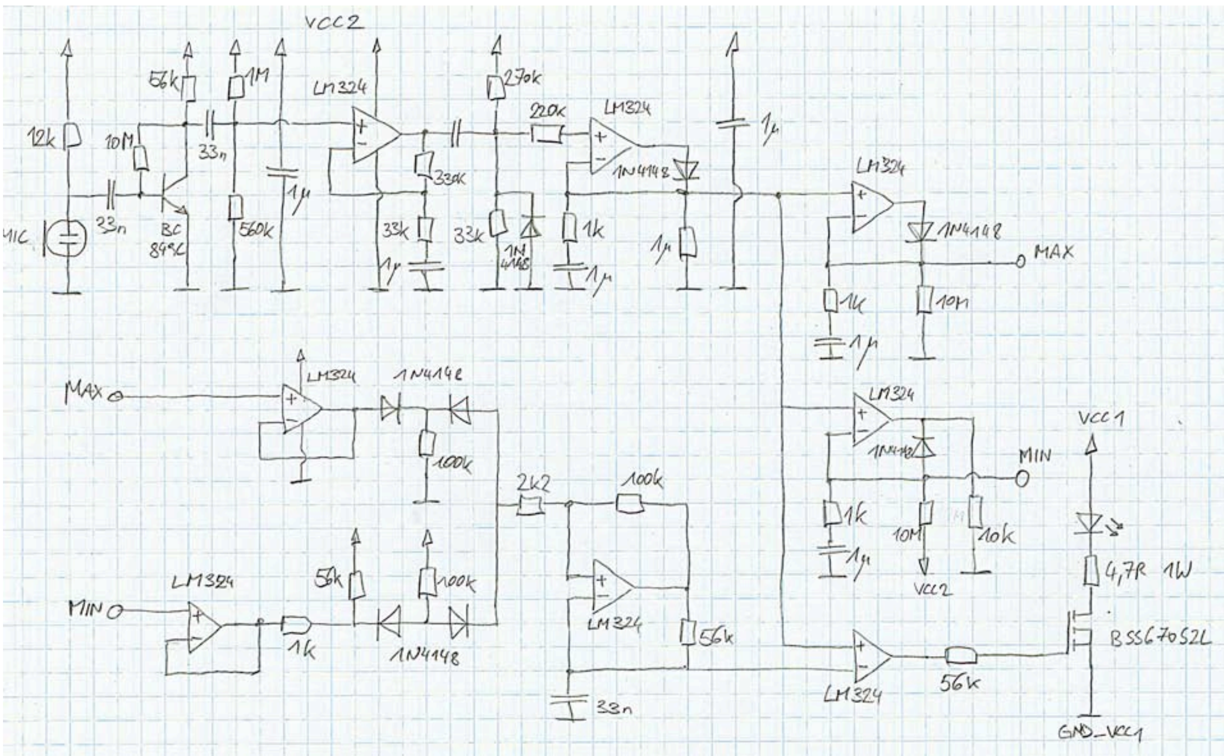


Figure 3.16: The circuit design for the sound allocation prototype.

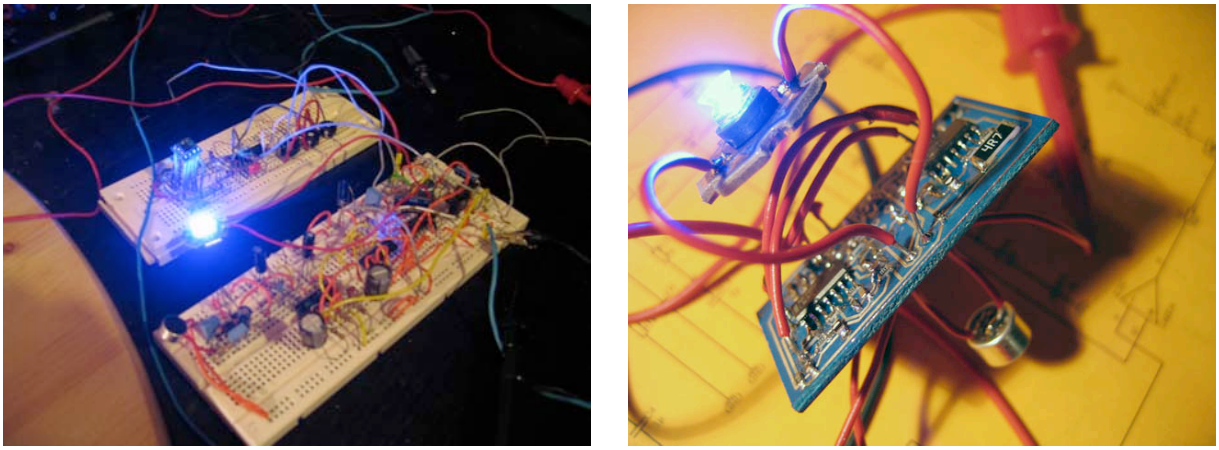


Figure 3.17: The first prototype assembly (left) and the final print design (right).

people, who are looking for a quiet spot, to choose their table in a cafè by simply glancing at the ceiling.

While the other studies presented in this chapter use one or multiple projectors to simulate ceiling displays, the goal of this study was to investigate the application of custom-made low-resolution and low-fidelity displays. The motivation for this approach was to develop a ceiling display that covers the entire ceiling of a room.

3.4.2 Method and Materials

The sound allocation prototype was implemented and tested following Verplank's spiral model. An electrical circuit that featured a microphone and an LED (light emitting diode) – representing one pixel – provided a first hack to try out the approach (figure 3.17, left). After iteratively refining this hack, a prototype of the display, consisting of 12 units was designed and built. Figure 3.16 shows the electrical circuit design of the final prototype. Figure 3.17 (right) shows one of the assembled prints. The prototype was tested by installing it in a room sized 2.6 x 5 meters.

Each of the 12 units features a microphone with a directional characteristic (i.e. it reacts more sensitive to sounds received directly beneath the microphone) and a blue LED. The microphone is directed towards the floor, while the LED is facing the ceiling. This creates a projection on the ceiling, which diffuses the emitted light. Other approaches, such as covering the LEDs with light-diffusive material were considered but discarded, since they would have increased both costs and complexity of the display.

Figure 3.18: Final sound allocation prototype reacting with light patterns to sounds within the room.

The units work independently to assure the scalability of the display system and are connected to each other for power supply and communication. Each unit puts the measured value representing the sound level on the network, which allows adapting the light intensity of each pixel to the overall sound inside the room.

3.4.3 Results and Discussion

Figures 3.18 and 3.19 show the installation of the sound allocation prototype. Mounting the LEDs so that they faced the ceiling worked fine and produced an appealing visual display. Sensing short acoustic impulses also worked well, however steady acoustic signals, such as the humming of a vacuum cleaner, were not visualized well. The current implementation of measuring the sound level is affected by acoustic signals reflected from the walls and other surfaces within the room. The prototype therefore only works well in large spaces, which feature less reflections.

Using a low-resolution light display for creating a ceiling display proved to be a good approach in case the objective is to cover the entire ceiling of an architectural space rather than having high resolution. However, this approach requires considerable skills in electrical engineering and is also costly in terms of time, since the system has to be designed and implemented from scratch. At the same time it is a fairly low-cost approach for building interactive ceilings. Both, costs and complexity depend on the desired resolution and intended purpose of the application. Other application scenarios that could be

Figure 3.19: Installation of the 12 units within the room.

built using a similar approach to the sound allocation prototype are: visualizing mobile network coverage, temperature distribution, or air quality (see also the open space project described in section 2.3.3).

3.5 Study V: Ceiling Interaction

There exists a large body of research on interaction techniques with distant large-scale displays (section 2.3.4). Techniques from this field can be adopted for ceiling-based information displays, but need to be designed specifically for this interaction space. The requirements for enabling ceiling interaction are fundamentally different to those of large-scale display interaction. People can approach large-scale displays, which means they can decrease or increase their distance to the display. In comparison, the ceiling has always a fixed distance to people interacting with it. Another difference is that people have to bend their head to interact with a ceiling-based information display. Interaction techniques that work well for large-scale displays, such as free-hand pointing, might therefore not be suitable for ceiling interaction. In this study three different techniques for interacting with a ceiling-based information display were investigated and evaluated: direct hand pointing, laser pointing, and ball activation. The first two techniques were adopted from related work on large-scale display interaction. The third technique, ball activation, was included to also investigate a more playful interaction. Using this technique people can select an item by throwing a ball at the ceiling.

3.5.1 Motivation and Goals

The studies presented in the previous sections included two applications, which were designed for direct user interaction. Firstly, the weather forecast application from study I (section 3.1) allowed users to change the time span of the forecast. The feature was implemented through keyboard shortcuts in the working prototype, but the design idea foresaw that users could change this through direct interaction with the ceiling-based information display. Secondly, one of the design scenarios from study II on emotional awareness allowed users to change light patterns through directly interacting with the ceiling display. None of the applications were further explored in terms of the suggested interaction techniques, which were direct hand pointing in the first and ball activation in the second case.

The problem of interacting with a ceiling-based information display has not yet been formally investigated. The goal of the study was to reveal user preferences and to gather qualitative feedback on the different interaction techniques.

Figure 3.20: One of the participants interacting with the wizard of oz prototype.

3.5.2 Method and Materials

Wizard of oz prototyping. The wizard of oz prototyping technique was initially developed to allow for empirical studies of natural language dialogue systems (Dahlbäck, Jönsson, & Ahrenberg, 1993). It provides users with a fully functional interface, where the functionality, such as speech recognition, is simulated by a researcher sitting at the other end of the system.

Direct hand pointing, laser pointing, and ball activation were evaluated in a controlled experiment. The task was to activate one specific panel within a grid of nine panels that was projected onto the ceiling (figure 3.20). Subjects had to repeat the task five times for each condition. The number of tasks was deliberately kept low, since looking at the ceiling can be fatiguing.

The method used for the experiment was wizard of oz prototyping, which was implemented in Processing. The grid of panels was projected onto the ceiling using a standard projector. The panels were square-shaped with a length of 32 centimeters. The distance between the panels was 14 centimeters. The ceiling had a height of 2.5 meters and the room measured 3.5 by 4.3 meters. Direct hand pointing was prototyped by attaching a small laser pointer to the participants' index finger using tape.

In post-test interviews participants had to rate the interaction techniques according to five dimensions (table 3.2).

Table 3.2: Means (and standard deviations) of the questionnaires.

Questions	Laser	Finger	Ball
I felt that selection speed was ... fast (1) - slow (5)	1.4 (0.89)	1.6 (0.89)	3.4 (1.14)
I felt that the selection method was ... precise (1) - imprecise (5)	1.4 (0.55)	2.6 (1.14)	4.2 (0.45)
The interaction was ... fun (1) - boring (5)	2.2 (1.30)	1.8 (0.84)	1.4 (0.55)
The interaction was ... facile (1) - exhausting (5)	1.4 (0.55)	1.8 (0.45)	4.2 (0.84)
I liked this interaction method ... very much (1) - not at all (5)	1.2 (0.45)	2.6 (0.55)	3.4 (0.89)

Five subjects (3 male, 2 female) aged between 20 and 30 years participated in the study. All of them had computer experience and interacted with computers on a daily basis. Each experiments took approximately 20 minutes.

3.5.3 Results and Discussion

Table 3.2 shows the results from the post-test interviews. Overall, laser pointing received the highest ratings. Participants favored this interaction technique, since it was *fast and efficient*. They also felt that they could control their actions best with the laser pointer. In contrast to direct hand pointing, they were able to turn the pointing device on or off. They further stated that laser pointing was less tiring, since they could hold the laser pointer at a lower height. Both laser and direct hand pointing were rated as being fast, but four of the participants thought that direct hand pointing was less precise. Ball activation was last in all categories except fun. Participants liked the playful interaction, but also said that it was far more exhausting than the other two interaction techniques. Only two of the participants complained that the tasks were tiring for their neck. An analysis of the experiment protocols showed that these two participants tended to stand close to the projection, while the others moved around the room.

The error rate was zero in the first two conditions. When using the ball for interaction, participants experienced about two to three void hits (i.e. they did not activate any panel) and one false hit (i.e. they activated a wrong panel) each. Performance was not measured since this would require actual working prototypes.

3.6 Conclusion

After a short summary of the presented studies, technological aspects in regard to prototyping and perspectives for further application scenarios of interactive ceilings are discussed in this section.

3.6.1 Summary of the Studies

This chapter introduced five studies on prototypes that were developed as probes into the design space of interactive ceiling applications. Two of the prototypes were implemented as design scenarios or prototypes (emotional awareness, section 3.2, and ambient sound, section 3.3), one of them was built using a projector mounted on the floor (weather forecast, section 3.1), and one of them was based on a custom-made low-resolution display (sound allocation, section 3.4). This mixed approach allowed for an investigation of interactive ceiling applications from different perspectives.

Study I, the weather forecast study, was inspired by the metaphor of the natural ceiling that provides visual cues about upcoming weather conditions. This prototype was developed as a ceiling-based visualization in a home's hallway, which translates the behavior of looking up for receiving information about the weather into an indoor environment. The prototype can be configured to display the current weather, the weather forecast for the current day, or the forecast for the following day. Weather conditions are represented through animated graphical images and temperature is color-encoded.

Study II, the emotional awareness study, spanned a number of design prototypes, to explore various approaches for employing the ceiling to support implicit communication between distant couples. The designs included spatial representation of sound or activity, as well as more engaging approaches, such as creating patterns of light through interacting with the ceiling.

Study III, the ambient sound study, was conceptually similar to to the sound allocation study, but was based on the same technical approach that was already used in the emotional awareness study. The goal here was to investigate ceiling-based concepts (rather than technological prototypes) for visualizing ambient sounds for deaf and hearing-impaired people in a home environment. The study involved various design prototypes in the form of sketches to explore different visual approaches.

The prototype for study IV, the sound allocation study, was developed using a custom-made 3x4 pixel display. It provided additional information within a space in terms of representing the spatial mapping of acoustic data onto the ceiling. The motivation for this prototype was to investigate the potential of the architectural ceiling as a useful surface for responsive display. The objective was to develop a system that would serve as an ambient display for environmental sound and also allow for interaction between passers-by and the environment. At the same time this prototype allowed me to investigate the technological approach of using LEDs for implementing an interactive ceiling.

Study V on ceiling interaction investigated three different techniques for interacting with interactive ceiling applications: direct hand pointing, laser pointing, and ball activation. A wizard-of-oz prototype was evaluated with five users, who had to rate the techniques according to qualitative criteria. Overall, they preferred laser pointing, since it was *less tiring*.

3.6.2 Technological Aspects

The aspects discussed in this section are based on experiences from the studies presented above, as well as the review of media architecture (section 2.2).

Large-scale Displays

Installing ceiling displays is still a considerable technological challenge. It is also often a matter of costs, since most interactive ceiling applications require turning the entire ceiling surface into a display. Contemporary media architecture applications typically use LED-based screens (cf. section 2.2.5), which are still quite expensive for large-scale display applications (including installation costs, etc.). For example, the total costs of the LED screen installed in a shopping mall in Beijing were 32 million dollars (Sparkes, 2007). With a total size of 7,500 square meters, this is more than 4,000 dollars per square meter.

Other commercially available display technologies exist that could be mounted onto the architectural ceiling, such as the SmartSlab™display. However they are also expensive and attaching them to the ceiling is a tremendous effort, given the weight they have. SmartSlab™units weigh 69 kilograms per square meter.

Thus, commercially available large-scale displays for adopting

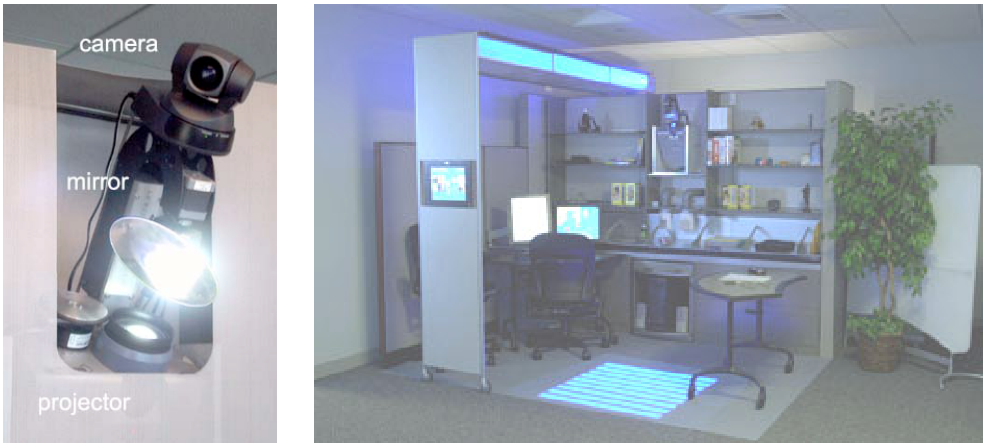


Figure 3.21: The Everywhere Display prototype allows projecting onto any surface within a room. (Pinhanez, 2001)

interactive ceilings beyond research exists, however, they are currently still too costly and therefore not affordable within a research context.

Laser Displays

Systems used for laser light shows represent another technology that might be suitable for implementing interactive ceilings. Such laser systems are still quite expensive and bring other disadvantages with them (e.g. low resolution, only limited number of colors available, etc.).

Projectors

Most of the prototypes used in the studies on interactive ceiling applications were based on simple data projectors. This represents a good approach in terms of affordability and availability, since projectors have become a pervasive device in recent years.

A disadvantage of using a projector is that it can only display a limited field of view, depending on the quality of the projector and the height of the respective room. For example a standard projector placed on the floor of a room with a height of 3 meters produces an image with a diagonal measurement of about 2.3 meters.

Another problem of using projectors is that people passing by cast their shadows onto the projected area. A solution to this would be the installation of the projector above the ground and using algorithms to compensate for the perspective distortion. The Everywhere Display (Pinhanez, 2001) developed by IBM Research represents a projector system that can project images onto any surface inside a room without distortion (figure 3.21). A disadvantage of this approach is that it further reduces the available size for the field of view.

The installation of mirrors or distortion lenses provide solutions to the problem of limited field of view. This approach is also an affordable solution, being roughly as expensive as a high-end projector.

Custom-built Displays

One of the prototypes presented in chapter 3 was built using LEDs. The advantage of this approach is that it can potentially cover the entire ceiling. However, this requires electrical engineering skills and might be costly in terms of hardware and expenditure of time, depending on the functionality of the system. This approach is further only suitable for very low-resolution displays. Costs also rise with higher resolutions and room size respectively.

In this regard, another approach is to use existing lighting systems within a room. For an example, consider the art installation by realities:united, described in section 2.2.7 (figure 2.30).

3.6.3 Perspectives

The initial approach to address the research problem of this thesis was the investigation of the ceiling as an information and notification system. The emphasize was on the usefulness of the application. The ambient sound study for instance was an attempt to turn the architectural ceiling into an assistive system that notifies deaf and hearing impaired people about sound happening in their environment.

However, the review of literature on ceilings in art and architecture as well as the results from the studies revealed that interactive ceilings should strive for other goals than purely functional ones. This is reflected by the outcome from the design workshop with deaf and hearing impaired people, who preferred an abstract representation over accurate positioning of icons on the ceiling. The reason for this is most likely that the ceiling, as a peripheral surface, is not built for displaying information that has to be consciously read by people.

In fact, it can be a frustrating experience for people if they have to look up regularly to receive information. This means I would have failed in reaching one of the major goals of this research work: to provide people with access to information in a way that is not frustrating but non-obtrusive, subtle, and engaging. The problem with the approach based on icons was that icons fail in providing a continuous awareness at the periphery of human perception. The choice for a user-centered design process was mainly driven by the goal to determine the functional requirements of the users. As it turned out, it was also really helpful for guiding the design in aesthetic respect, and eventually steered the application into the right direction.

The sound allocation study was a further step towards the vision of interactive ceiling display. The prototype implements a functional purpose – revealing the sound distribution within a room – but puts an emphasis on the aesthetic integration into the environment. Interactive ceilings augment the architectural environment, establishing a social skin to spark communication between people and the building. It is social in terms of enhancing the social character of a space, i.e. it affects how people perceive, experience, and interact with each other in this space.

A next step of this research would be to conduct longitudinal studies, with the goal to learn more about the acceptance of interactive ceilings and how people would use such applications. The impact of new technologies is often hard to predict and putting them into a user context can reveal surprising application scenarios. To discover new interpretations it is necessary to abandon the presumption that a specific interpretation of the built systems exists (Sengers & Gaver, 2006). By this interactive ceiling applications might reveal unexpected usages in a real context, which could guide and influence further research in this area.

For further design explorations of interactive ceiling display, it is necessary to consider the existing architectural environment, which has to become a substantial design parameter in the process. Experimenting with the ceiling attributes (section 2.1.2) and their impact on human perception of space (section 2.1.3) might also lead to new application scenarios. For instance, as stated above, a dark-colored ceiling creates an impression of top-heaviness, even leading to a claustrophobic experience of space. To exploit this as a design element, the color tone of the ceiling could be connected to the to-do list or the number of unread e-mails of a person. To escape the claustrophobic experience he/she would have to work on the to-do list or start replying to e-mails. Therefore the interactive ceiling acts as an awareness and persuasive display at the same time. The color (or rather the subconsciously experienced character of the space) constantly informs people about the state of their tasks, which might trigger an action at one point, when the information is consciously processed, in order to counteract negative impact on the experience.

This scenario shows that it is important to not only consider the ceiling as a surface for information display, but as part (and contributor to the experience) of an architectural space. In this respect interactive ceilings are fundamentally different to traditional computer screens (aside from other more obvious differences, such as size or location).

Another interesting direction, which has not been explored so far, is the implementation of physical interactive ceilings. For example, a large array of cords suspended from the ceiling can be used to visualize information in a physical or three-dimensional way. The length of the suspended cords can be mapped to spatial data, such as sound. This would therefore provide another, more whimsical, approach to the ambient sound study described in section 3.3: people would become aware of a sound in their environment by cords reaching down from the ceiling. The length of the suspended cord could be used to display historical information, e.g. the longer the cord, the longer ago the sound occurred.

Once again, these scenarios point out how large the design space of interactive ceilings is. While this thesis research creates a foundation to establish a common understanding of the field, there are still many directions left untouched, which gives opportunity for further explorations. The CIx framework, which is described in the following chapter, provides guidance for future work on interactive ceilings.

4

A DESIGN FRAMEWORK FOR CEILING INTERACTION

This chapter introduces a design framework derived from the literature review and studies presented in the previous chapters. The framework consists of three components: a model for architectural display, a model for ceiling display, and a model for ambient display. Each model contributes multiple design dimensions to the framework. The framework represents a design tool, but also allows for evaluation, classification, and categorization of interactive ceilings.

4.1 Framework Outline

The Ceiling Interaction (CIx) framework presented in this chapter represents a consolidation of the theoretical and practical research discussed in this thesis. It is constructed around three components, which reflect the theory and related work presented in chapter 2, and is informed by the experiences from the studies presented in chapter 3.

Ix for interaction. The abbreviation for the framework, CIx, is adopted from the abbreviation IxD, which is commonly used for interaction design.

The three components represent different perspectives on interactive ceilings, incorporated into distinctive models. The perspectives are: Architectural Display (ArDis model), Ceiling Display (CeDis model), and Ambient Display (AmDis model). The models are designed in a way, which also allows their application outside the framework. Figure 4.1 shows the composition of the CIx framework.

The objective for developing the models was to provide a design tool for interactive ceilings. The purpose of this design tool is to guide both design and research in the field of interactive ceilings. At the same

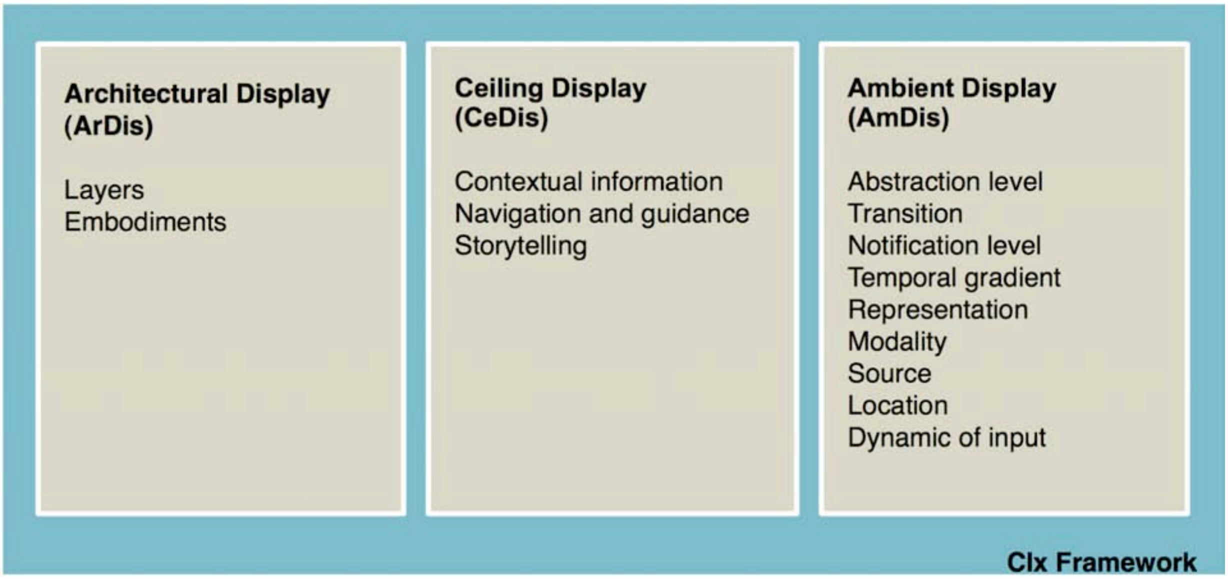


Figure 4.1: The three components of the CIx framework and their design dimensions.

time the models define the design space of interactive ceilings, i.e. they explore different directions, which are consolidated into the design dimensions of the models.

Each of the models helps designers answering on of the questions of *where* to place the information display in the architectural environment, *what* data the display conveys, and *how* to represent this data.

The models are further supplemented by a set of design guidelines that provide another view onto the findings from this research work.

4.2 The Architectural Display Model

The architectural display (ArDis) model is based on an investigation of applications that augment traditional architectural spaces with pervasive computing technologies. It introduces a classification based on two dimensions: layer and embodiment.

4.2.1 Layer

The layers that depict the components of architectural environments represent the first dimension for this model (figure 4.2, left). The instances for this dimension are derived from Brand's classification of buildings into *shearing layers of change* (Brand, 1994). They reflect how

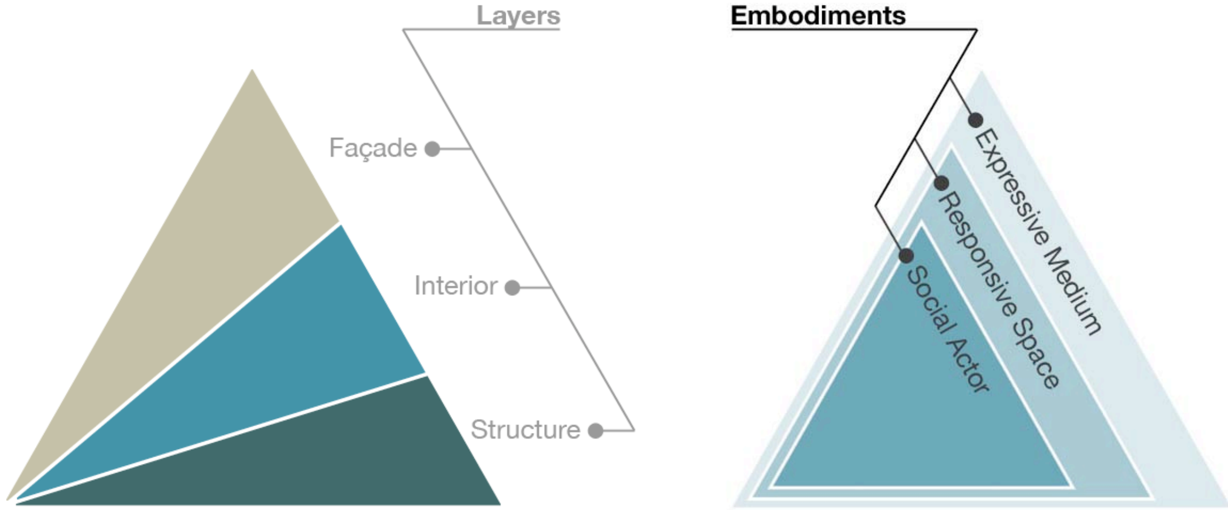


Figure 4.2: Layers (left) and embodiments (right) of the ArDis model. Embodiments are, opposed to layers, of cumulative character: e.g. a social actor is also responsive space and expressive medium.

buildings change over time. Each of the six layers of buildings (site, structure, skin, services, space plan, and stuff) changes in different paces according to the layers' longevity.

An investigation of the layers suggested by Brand for determining potential layers for architectural display resulted in the following attributes:

Façade

This is the exterior surface, i.e. the façade, of a building. Media architecture applications typically exploit this layer. This category is identical with the skin as described by Brand.

Interior

The interior layer spans all fixed surfaces that are inside a building, like the walls, floors, ceilings, etc., but not their structural arrangement. Objects that Brand classifies as stuff would be partly based on this layer, e.g. a picture could be placed on a wall. An example for an application from this layer is a wall within a building that is augmented with digital information.

Structure

The structure covers the foundation and load-bearing elements as well as what Brand calls space plan, which is the interior layout (i.e. the arrangement of walls, ceilings, floors, and doors). Applications on this layer have an impact on the segmentation of space. An example is a folding screen used for dividing a room.

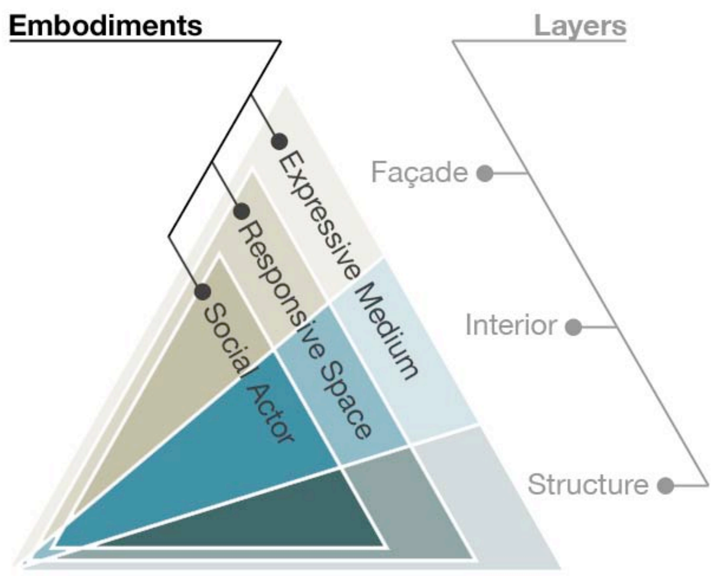


Figure 4.3: Visual representation of the architectural display model, showing the superstition of the design dimensions embodiment and layer. (Tomitsch et al., 2008)

4.2.2 Embodiment

The investigation of current trends in the field of architectural display led to the following embodiment attributes: expressive medium, responsive space, and social actor. These attributes are not mutually exclusive, but have a cumulative character. For example a responsive space always acts as an expressive medium as well. Figure 4.3 illustrates the relations between the attributes of this dimension.

Expressive Medium

Architecture as expressive medium describes the integration of digital media into the built environment with the goal to augment the physical experience with a virtual layer, adding to the individual experience (cf. 2.1.3) of space. Applications from this category affect the way passers-by perceive their surroundings and potentially engage them into dialogues with others sharing the space. However, they do not support interactions between passers-by and the architectural space. Thus, applications from this category are active according to the model for interaction by Giannetti (2004).

Ambient display is a good example for an application area within this category. Applications from this dimension apply the concept of ambient displays for visual representations of information within architectural environments. They should be calm, non-obtrusive and opportunistic, revealing information only for interested inhabitants or passers-by (Vande Moere, 2007), in order to avoid distraction for other people in their vicinity. Applications from this dimension therefore have to feature the following characteristics: (1) non-obtrusive, (2) informative, and (3) socially engaging.

Responsive Space

A responsive space is an environment that interacts with the people who pass through it (Bullivant, 2006). Thus, this category describes applications that allow for interaction between passers-by and their environment. Applications from this category convey both reactive and interactive systems according to the model for interaction by Giannetti (2004).

Pervasive computing environments are equipped with sensors, embedded displays, and networking technologies, allowing tracking of people, movement, and environmental conditions. Their aim is to create digitally enhanced social spaces, inviting people to interact with their environment as well as with each other. Once a user decided to interact with the system it should stimulate an engaging dialogue, maintaining the user's attraction and interest. In addition to the three characteristics of expressive medium, responsive spaces are therefore also (4) interactive and (5) enjoyable.

As an example for a reactive system that falls into this category consider the GroupCast display (Mccarthy et al., 2001; section 2.4). The display is integrated into the hallway of a building and does not require user interaction (non-obtrusive). It displays information about interest of people passing the display (informative, interactive), which might stimulate conversation between people sharing the same interests (socially engaging, enjoyable).

The iFloor application (section 2.3 represents an example for a reactive system: The items spread on the floor of a library (informative, non-obtrusive) are controlled through body movement (interactive), which turns into a playful challenge when more than one person interacts with the floor (socially engaging, enjoyable).

While those examples were chosen to illustrate the difference between reactive and interactive systems, this distinction is deliberately not emphasized by the ArDis model.

Social Actor
In the context of the ArDis model a social actor is a space equipped with technologies that mimic typical behavior of humans, animals, or plants, such as physical features or emotions. Environments embodying social actor can invoke social responses from users (Reeves & Nass, 1996). They are perceived as social characters and evoke the feeling that they need our attention to survive, that we have to take care of them. Systems from this category rely on sensors and other pervasive computing technologies to communicate with people in a non-verbal direct or indirect way. In addition to the characteristics of expressive medium and responsive spaces, applications within this category are (6) social and (7) adaptive.

For example the performative ecologies project (Glynn, 2007; section 2.2) features three autonomous robots suspended from the ceiling that try to engage passers-by in non-verbal communication by performing different gestural patterns (social). They further remember and teach each other about which performances were most successful (adaptive).

4.2.3 Discussion

The ArDis model depicts the first component of the CIx framework. It helps answering the questions, which architectural layer in combination with which embodiment is suitable for a given design problem. Outside of the framework's context it represents a classification scheme and a design tool for the field of architectural display. The two-dimensional nature of the framework (i.e. architectural layer and embodiment) allow for a classification of applications based on the pervasive computing paradigm that are situated in architectural environments. While the framework specifically aims at new applications, it can also potentially be applied for classifying historic examples of architectural art. For example, ceiling frescos (section 2.2, page 38) exploit the interior layer and represent an expressive medium. Such a classification of architectural display applications has the potential to point out current trends and interesting areas for future research.

4.3 The Ceiling Display Model

The ceiling display (CeDis) model introduces three categories for the classification of ceiling-based applications: contextual information, navigation and guidance, and storytelling.

The first two categories are grounded on the conceptual counterpart of the ceiling in a natural environment, the sky. In history the architectural ceiling has often been associated with the natural sky and has become decorated with elements resembling the natural sky, including stars, clouds or birds (section 2.2.3, Figure 2.18). In terms of representing information, the sky is richer than a typical indoor ceiling: it provides us with several clues about time, location, and environmental conditions. The CeDis model is therefore particularly based on the observation that looking up in a natural environments increases knowledge about situational awareness. Thus, the architectural ceiling represents a natural opportunity to provide contextual information and guidance in indoor environments based on the metaphor of the sky.

The third category, storytelling, is derived from the role of the natural sky in ancient tales, e.g. in ancient Native American storytelling stars often constructed the stage for tales about gods. The metaphor of using the space *up* for narrative representations is further supported by historic European ceiling art, where frescos often told about stories with historical or biblical origins (section 2.2.3).

This section defines the categories of the CeDis model and provides a discussion on possible application scenarios for each category. The scenarios are based on related work (section 2.2.5 and section 2.3) and personal experience from developing ceiling-based applications. Table 4.1 shows a summary of the three categories.

4.3.1 Contextual Information

This category is strongly based on ambient display (section 2.4). It suggests augmenting the ceiling with contextual information that users need to be aware of while focusing on other tasks. The fact that the ceiling is located at the periphery of human perception allows users to maintain a continuous awareness of the information displayed. Similar to ambient display, applications from this category should alert users, exploiting the notification levels available for ambient display (section 2.4.5).

Foundation. The underlying principle for this category is the behavior of looking up for receiving further information in the natural world. The sky constantly provides us with additional contextual and peripheral information, such as the current time and upcoming weather conditions through light conditions, clouds and the relative position of the sun.

Example. The Open Plan project (Meagher et al., 2007) uses the ceiling for a visual representation of environmental conditions, such as humidity or temperature (section 2.3.3).

Data. Any data can be represented that features characteristics defined by the concept of ambient display, such as non-vital, dynamic, context-related, etc. Particularly, the visualization of spatial data denotes a promising application area, since it allows a direct mapping of the physical location onto the ceiling. Examples of spatial data are environmental conditions (see example above), sound level, or network coverage (e.g. Wi-Fi reception) within a closed space.

4.3.2 Navigation and Guidance

The second category suggests the application of the ceiling for navigation and guidance within architectural environments. The advantage of the ceiling as a representation platform for navigational cues is that it is not already occupied by other kinds of information displays. This also suggests the application of the ceiling for displaying information in emergency cases, such as indicating dangerous areas and directions towards the closest exit.

Applications within this category provide relevant information about directions or places. They either show general information that changes depending on parameters like the time of the day or user-specific information. The latter presumes that the environment is aware about both the presence and the intentions (i.e. where the person wants to go to) of people passing through that space. There is a broad body of research in context recognition available that addresses these issues.

Foundation. This category exploits the natural behavior of looking up for receiving a sense of orientation. In case the immediate environment is lacking specific cues, people are still able to derive knowledge about directions and their location from looking at the sky, based on the position of the sun or the stars.

Example. The original design concept for the Seattle library featured real-time navigational cues on the floor, exploiting the spatial nature of a library to support visitors in their orientation (section 2.2.5). In a similar way the architectural ceiling offers the opportunity for providing navigational cues in public or semi-public buildings. In an ubiquitous computing scenario this might even involve knowing the users' intentions and displaying personalized cues.

Data. Any data that helps people orient themselves within an architectural space falls into this category. This can be either a visualization that points the user towards a certain direction (e.g. a sign) or a representation that maps spatial information (e.g. the location of a specific spot within a large room) onto the ceiling.

4.3.3 Storytelling

Storytelling makes an important part in the life of humans. While the importance of physical objects for storytelling has been acknowledged (Whittaker, 2003), there is also scientific evidence that digital representations possess similar potential (Viegas, Boyd, Nguyen, Potter, & Donath, 2004). In line with this research, this category proposes using the architectural ceiling for the display of digital information that evokes storytelling. The narrative aspect can further arise from the information itself, informing people about historical events or conversations that happened in that space. Due to the spatial location of the ceiling, applications from this category should not aim at involving users in long interactions that require constant awareness. Instead, applications should take advantage of the peripheral character of the ceiling and engage users in short dialogues.

Foundation. The category of storytelling is based on the observation that throughout human history people used the space above them (both the sky and the architectural ceiling) as a framework for storytelling. Ceiling paintings typically featured a story, but also inspired people to tell stories to each other about historical events and personal experiences.

Example. Inspired by the visual concept of ceiling frescos from the Renaissance time and related research on informative art (section 2.4), the ceiling could be exploited for visualizing e-mail conversations, based on the metaphor of storytelling (cf. Viegas et al., 2004).

Table 4.1: The three categories of the CeDis model.

	Foundation	Example	Data
Contextual information	Natural sky	Ceiling-based visualization of air quality (2.3.3)	Generally: non-vital, dynamic, context-related; specifically: spatial data (environmental conditions, sound level, network coverage (e.g. Wi-Fi reception), etc.)
Navigation and guidance	Natural sky	Ceiling-based navigational cues (2.2.5)	Pointing out directions (e.g. a sign) or representations that map spatial information (e.g. the location of a specific spot within a large room)
Storytelling	Ancient storytelling and ceiling art	Renaissance ceiling frescos (2.2.3)	Ambient data (e.g. noise level or amount of movement), remote data (e.g. presence patterns of distant people), and digital/virtual data (e.g. e-mail conversations)

Data. Most time-varying data can be used for creating stories. Examples are ambient data (e.g. noise level or amount of movement), remote data (e.g. presence patterns of distant people), and digital/virtual data (e.g. e-mail conversations).

4.3.4 Discussion

The categories of the CeDis model represent a classification scheme for interactive ceiling applications. At the same time the model also serves as inspiration for potential application areas. The first two categories, contextual information and navigation and guidance, describe application scenarios of very practical nature: they add to the quality of the architectural space by augmenting it with context- or user-related digital information and can potentially improve the problem of visual noise overload by porting information into the periphery of human perception. From my experience, the most promising category is contextual information, which suggests that most applications will fall into this category. Applications within the third category, storytelling, primarily aim at creating an ambience, similar to Renaissance ceiling frescos, but based on dynamic visualizations and enhancing social interactions between passers-by.

4.4 The Ambient Display Model

The ambient display (AmDis) model is based on an analysis of previous work in the field of ambient display. The objective for developing this model was to reveal current trends and potential areas for future research. At the same time the model serves as a design tool for ambient display. This characteristic is also its contribution to the CIx framework.

4.4.1 Approach

The initial basis for the AmDis model was a detailed analysis of 51 research projects (Lehner, 2006; Tomitsch, Kappel, Lehner, & Grechenig, 2007). The projects were collected in a literature review and represented the state of the art at that time (the review was conducted in the beginning of 2006). The analysis revealed more than 20 distinctive characteristics comprising different dimensions, such as input, output, and location (Lehner, 2006). According to Fishkin (2004) it is important to balance the number of dimensions. Whereas more dimensions increase the descriptive power, few dimensions may provide simplicity and clarity. Therefore only the most significant characteristics were incorporated into the model. The significance of the characteristics was determined through ratings by three researchers (two colleagues, working in this field, and myself), under the perspective that they had to be applicable for the entire list of 51 projects. The final set of dimensions was determined by applying the dimensions from the previous step on the list of 51 projects. This led to the reconsideration of some of the dimensions in an iterative process.

4.4.2 Design Dimensions

The analysis process revealed nine significant characteristics serving as design dimensions for the AmDis model. The dimensions are as follows: abstraction level, transition, notification level, temporal gradient, representation, modality, source, location, and dynamic of input. The dimensions and their attributes are described below.

Abstraction Level

As ambient displays sit at the periphery of users' attention, data has to be represented in a way that users can read the information *at a glance* (Arroyo & Selker, 2003). Abstraction supports this requirement, since it reduces the amount of displayed elements. It encodes data in a way that allows easy and comfortable monitoring of data. Almost every previous work on ambient display mentions the importance of this characteristic (e.g. Ames & Dey, 2002 and van Mensvoort). The attributes for this dimension are adopted from Blattner, Sumikawa, and Greenberg (1989) and defined as *representational*, *abstract*, and *semi-abstract*.

Ambient displays that use a representational level of abstraction map the source data to the displayed information in a direct or slightly abstracted way. They display data in a one-to-one relation to the real world. An example of this is Wattson (DIY Kyoto), an electricity meter that displays energy consumption. A semi-abstract representation enables easy comprehension of the encoded data. This level provides a good balance between degree of abstraction and comprehension. An example for this level is the Short Term Weather Forecast Window (Rodenstein, 1999), which uses on-screen projections, such as frost patterns, to inform about upcoming weather conditions. Systems that use an abstract representation apply a strong encoding of data. There is no obvious relation to the real world. It depicts information as symbolic design items.

Transition

In accordance to changes within the data source, the displayed information has to switch from background to foreground awareness to attract users' attention. This may be accomplished by different means, for example by smooth changes in colors or a sudden increase of audio frequency. Arroyo and Selker (2003) investigated the use of ambient displays as interruptions. The disruptive effect varies for different modalities, e.g. heat presents a greater disruptive effect than light. Depending on the speed of transition in consideration with the modality, the according attributes are *slow*, *medium*, and *fast*.

Ambient displays that incorporate the first attribute feature a very slow transition from one state to another. This implies that users only recognize global changes in the data realm. Systems that use medium transitions change the state of display information more abruptly. This makes it easier to recognize changes than in the case of slow transitions. Fast transitions immediately lead to changes in the display whenever the source data changes.

Notification Level

The notification level depicts the degree at which an application alerts users or even forces them to interrupt their primary task. For many applications, there is a tight relation between the dimension of transition and the dimension of notification level. An application that is defined to have a high notification level should use abrupt and fast transitions from one state to another (e.g. flashing, beeping, etc.). In case of low notification levels transitions should be subtle and calm. Depending on the source, high notification levels should be used for critical data, whereas a lower notification level does not interrupt and therefore can only display non-critical data.

The attributes for this dimension are adopted from Matthews et al. (2004), who defined different levels of notification based on literature about cognitive psychology and human attention. Accordingly the attributes are *ignore*, *change blind*, *make aware*, *interrupt*, and *demand action*.

Ignore represents information that does not demand any attention and probably should not be displayed. Change blind does not require attention from users. However, changes can be recognized when in focus. The attribute make aware represents information in a way that evokes more attention. Changes are noticeable in peripheral vision. This is the most common notification level for ambient display, as changes can be perceived without shifting the focus. Interrupt distracts users temporarily to inform them about important information. Demand action distracts users permanently and requires immediate action. This last notification level does not fulfill the requirement for ambient display to sit in the periphery, but is still included for critical information.

Temporal Gradient

Most ambient displays present continuous information that changes its state over time. There are only a few systems that also visualize the history of temporal changes. The vast majority just depicts a discrete value and presents one state at a time. Temporal gradient defines, whether a system features a history view of the displayed data or not. The according attributes are *history* and *current*.

Representation

Representation describes the output device used for ambient display. Many systems rely on a screen for output, e.g. (Miller & Stasko, 2001) and (Redström et al., 2000). Others are integrated in existing physical objects, e.g. (Materious, 2005), or introduce a new object that serves as ambient display, e.g. (Violet). Accordingly the three main categories of output devices to represent data, which represent the attributes for this dimension are: *physical*, *integrated*, and *screen-based*.

Physical representation describes devices that are developed solely for the purpose of being an ambient display. Applications that use integrated representations are objects that previously existed. They have some initial purpose or functionality and are augmented with technology to additionally provide ambient information. Such ambient displays are often integrated into everyday objects. Screen-based representation depicts applications that display information by means of traditional screen technology, such as LCDs.

Modality

Ambient displays are not limited to visual information design. Information can also be embodied by other modalities, such as audio or movements of objects. To reflect this the attributes for this dimension are: *visual*, *tactile*, *olfactory*, *auditory*, and *movement*. Movement and visual are two distinctive attributes due to the fact that separate visual subsystems exist for processing motion, such as the perception of brightness, form, or color (Ehrenstein, 2003).

Source

This dimension refers to the location of the information that is conveyed in an ambient display. The source can be divided into three categories, which serve as attributes: *local*, *distant*, and *virtual*.

For ambient displays that have a local source the application itself and the source of information are located in the same environment. An example is the Power Aware Cord (Gustafsson & Gyllenswärd, 2005), which visualizes the consumption of power in a home environment. The display (the power cord) and the data source (consumed power) are located in the same environment. A distant source relates to a geographically large distance between the location of the display and the data source. Nimio (Brewer, Williams, & Dourish, 2005), an application that visualizes distributed activities, represents an example for an ambient display that relies on a distant source. The attribute virtual describes systems that retrieve the data from the virtual world (e.g. the Internet).

Location

This dimension refers to the location or context of the output device (i.e. the ambient display). The attributes are adopted from Ames and Dey (2002) and are: *private*, *semi-public*, and *public*.

Dynamic of Input

The dynamic of the input (i.e. the velocity of data changes) has an important impact on the design of ambient displays. Depending on the nature of the source, incoming data can change quickly or slowly. This dynamic has to be considered when choosing the data source (Mankoff & Dey, 2003) as it has relevant influence on design issues. The attributes are: *slow*, *medium*, and *fast*.

A slow dynamic of input stands for a rare change of the data coming from the input source and results in rare updates in the display. A medium dynamic of input means a regular change in the input source. A fast dynamic of input relates to fast changes in the input source. As the changes are very fast, the display has to be designed by means of appropriate transitions and notification levels. It is also possible to design an ambient display that uses a high-dynamic input, which is mapped to slow changes in output, and vice versa.

4.4.3 Discussion

To demonstrate the utility of the AmDis model 33 ambient displays were chosen from the entire collection of 51 projects in order to provide a representative cross-section of previous work in this field, and classified along the design dimensions described above (Tomitsch, Kappel, et al., 2007). Figure 4.4 shows the resulting table of projects and their attributes according to the AmDis model.

The AmDis model represents the third component of the CIx framework, but it was initially developed as an independent model that functioned as a taxonomy tool for ambient display. Defining a taxonomy and its design dimensions is a difficult task, especially for relatively new fields. There are different approaches for developing the design dimensions, depending on the requirements and expectations. Therefore different models might be helpful or appropriate in different contexts. Two other taxonomies for ambient display are presented in section 2.4.5.

The main difference between the AmDis model and the taxonomy developed by Pousman and Stasko (2006) is the number of design dimensions. As stated earlier a low number of dimensions assures simplicity and clarity. This is clearly an advantage of their taxonomy. The drawback of including only few dimensions is a lack of descriptive power by neglecting important design dimensions, such as

	Transition			Notification Level			Temporal Gradient		Abstraction Level			Representation			Modality					Source			Location			Dynamic of Input		
	Slow	Medium	Fast	Change Blind	Make Aware	Interrupt	History	Current	Representational	Semi-Abstract	Abstract	Physical	Integrated	2D	Visual	Tactile	Olfactory	Auditory	Movement	Local	Distant	Virtual	Private	Semi-Public	Public	Low	Medium	High
Progress Bar	■			■			■			■		■			■							■	■			■		
History Tablecloth	■			■			■				■		■		■					■			■				■	
bench	■			■			■				■		■			■					■				■		■	
Breakaway	■			■				■			■	■			■					■				■		■		
Weather Patterns	■			■				■			■			■	■					■					■	■		
Forecast	■			■				■			■		■		■							■	■				■	
Dollars & Scents	■			■				■			■	■					■					■			■		■	
Informative Art	■			■				■			■			■	■						■	■	■			■	■	
Bus Mobile		■		■				■			■	■			■						■			■			■	
DataFountain		■		■				■			■		■						■			■			■			■
CareNet		■			■		■		■				■		■						■		■				■	
nimio		■			■			■			■	■			■						■		■				■	
InfoCanvas		■			■			■		■				■	■						■	■	■			■	■	■
flashbag		■			■			■		■			■		■							■	■				■	
Weather Display		■			■			■	■					■	■					■			■				■	
Power Point		■			■			■		■			■		■					■			■				■	
Ambient Orb		■			■			■		■	■	■			■							■			■	■	■	■
Pinwheels		■			■			■			■	■							■		■	■			■		■	
Oxygen Flute		■			■			■			■							■		■					■		■	
LaughingLily		■			■			■			■	■			■				■	■				■				■
AuraOrb			■		■			■	■			■			■							■	■				■	
Wattson			■		■			■	■			■			■					■			■				■	
IN-Visible (exterior)			■		■			■		■			■		■					■					■			■
Power Aware Cord			■		■			■		■			■						■	■			■				■	
Ladybag			■		■			■		■			■		■					■				■			■	
Dangling String			■		■			■			■	■						■	■			■		■				■
Inform. Percolator			■		■			■			■	■							■	■				■				■
Hello.Wall			■		■			■			■			■	■					■				■			■	
Interact. waterfall			■		■			■			■			■	■					■					■		■	
Nabaztag			■			■		■		■		■			■			■	■		■	■	■				■	
LumiTouch			■			■		■			■		■		■						■		■				■	
Shaker			■			■		■			■	■				■					■		■				■	
AudioAura			■			■		■			■							■			■		■				■	

Figure 4.4: Classification of 33 ambient displays along the dimensions of the AmDis model. The first six columns represent dimensions that are determined by the designer, whereas the last three dimensions are predetermined by the system's nature. (Tomitsch, Kappel, et al., 2007)

modality. This decreases its value as a design or evaluation tool. The motivation that guided the design process of the AmDis model was to balance simplicity and descriptive power. This led to the decision to keep all nine dimensions that resulted from the analysis process. Another difference to Pousman and Stasko's taxonomy are the attributes used for the design dimensions. They propose the same attributes across all design dimensions, whereas the AmDis model features specific attributes for each dimension. One set of attributes allows the visualization of application classification in the form of a diagram (figure 2.53), however, a larger set of attributes further contributes to the descriptive power of the model.

The taxonomy developed by Rohrbach and Forlizzi (2005) features a large number of design dimensions. This is extremely valuable for the design process, but may not be suitable for pointing out current trends and potential areas for further research, since an attempt of classifying existing projects along those dimensions would lead to a high number of clusters. The design dimensions, which Rohrbach and Forlizzi call design variables, further relate to the information that ought to be communicated through the ambient display, while the AmDis model emphasizes the ambient display as a whole.

As demonstrated in figure 4.4 the AmDis model has the potential to point out current trends and areas for future research. For example, most applications only display current data. The classification of 33 applications showed only two applications that also provided a history of displayed data. An immanent observation was that almost all applications were based on visual embodiment as modality. There were only few applications that used movement and hardly any applications that featured tactile, olfactory, or auditory characteristics.

Moreover the ranking showed that all applications featured change blind, make aware, and interrupt characteristics for the dimension of notification level. This is due to the requirement that ambient displays should not distract users from their primary tasks. Some applications showed multiple characteristics within one design dimension, because of their multiple purpose nature (e.g. Nabaztag and Informative Art).

In case the AmDis model is used as design tool, it is important to notice that three of the nine dimensions (dynamic of input, location, source) represent fixed specifications that serve as input for the design problem. They restrict the design possibilities of the other dimensions, e.g. a high dynamic of input requires a medium or fast transition, as the transition cannot take longer than the change of input data. Furthermore the location can determine the necessary abstraction level. These dependencies have to be considered when designing ambient displays and are therefore also relevant for interactive ceiling applications that communicate at the periphery of human perception.

4.5 Design Guidelines

Guidelines. The application of guidelines provides a *systematic approach to (1) take advantage of practical experience, (2) disseminate and incorporate applicable experimental findings, (3) incorporate rules of thumb, and (4) promote consistency among designers responsible for different parts of the system's user interface* (Brown, 1998).

This section conveys answers to the question of how to design interactive ceiling applications into a set of design guidelines. Ten guidelines are presented, which are clustered into four categories: data, physical experience, visual design, interaction, and evaluation. They are specifically defined for the design of interactive ceiling applications, extending other guidelines from related fields (such as ambient display, see section 2.4.5). The guidelines are based on (1) literature on ceilings in architecture, (2) review of related research work, and (3) results from the studies presented in chapter 3.

Data

The first and foremost question is which data to convey with the interactive ceiling display. This influences other design issues, such as context or dimensions of the ceiling display. Therefore it should be the first thing to be determined.

The CIx framework was a valuable design tool for reflecting on the data that was incorporated by the prototypes used for the studies on interactive ceilings. It helps application designers in deciding whether the ceiling represents an appropriate surface for the data they want to visualize. In this respect it is important to consider the peripheral character of architectural ceilings: they are visible from various viewing angles within a room and – depending on height and size – are perceived at the periphery of our perception.

The following guidelines refer to the data displayed by the interactive ceiling and give high-level advise on their characteristics.

#1 Convey only data that users can perceive at the periphery of their vision (most of the time). The ceiling sits at the periphery of users' perception. Therefore it is well-suited for displaying data that users have to be aware of, but which does not require constant attention.

#2 Only display non-critical data. Due to the peripheral character of ceiling displays, they should not be used to inform users about critical events that need their immediate attention.

The CIx framework covers further suggestions about the type of data that can be conveyed in ceiling displays. For instance, spatial data (such as sound or air quality) is well-suited for providing contextual information, since its position in space can be directly mapped onto the ceiling.

Physical Experience

The desktop computer, which can be seen as a standard human-computer interface, is an external device, which is usually not designed for a specific context. Therefore applications for desktop computers only incorporate general design guidelines, which do not consider the design of the environment, where the computer will be used. Desktop computer applications provide the same experience independent of the locality of use, which can be the living room, an office, in a train, etc.

In contrast, ubiquitous computing applications are typically developed for a specific application context. For instance, the GroupCast display (section 2.4.4) was developed to be used within a corridor in an office building (Mccarthy et al., 2001). Its design takes into consideration that people are passing by, but not necessarily stopping in front of the display. Therefore it can be used in any environment, where there is a traffic of people.

Using the architectural ceiling as information display requires even further consideration of the context. The ceiling is part of an architectural space, which provides a very unique experience. The physical experience of architectural spaces is influenced by various factors, such as size of the room, decoration, furniture, type of floor, and to a large extend by the character of the ceiling. It is therefore important to reflect how people currently experience the architectural space and how turning the ceiling into an information display might affect this experience. For instance, as described in section 2.1.2, the overall color impression of both the floor and the ceiling have a large impact on the character of a room. An ascending color scale from the dark tone of the floor to the faint color of the ceiling lightens the room and apparently raises the height of the ceiling (Wharton & Ogden, 1898). Changing this color scale by installing a ceiling display that mainly features dark colors therefore lowers the room height and produces an impression of top-heaviness.

Physical experience here describes how people, who are physically present in an architectural space, experience that space. The following guidelines aid in designing the physical experience.

#3 Specifically design the interactive ceiling display for the architectural space where it will be used. Since each architectural space is unique in its physical appearance, interactive ceiling applications have to be customized for the actual environment.

#4 Consider the attributes of ceilings and reflect on how the design alters the perceived quality of those attributes. The relevant attributes are size and height, color and patterns, and shape. See section 2.1.2 for further information.

Visual Design

The studies on interactive ceiling applications have shown that users prefer abstract over literal representations. For instance, participants in the ambient sound study preferred sound ripples over icons (for ceiling-based display) to determine the location of sounds within an architectural space. Applying desktop computer design practices for the design of interactive ceilings is the wrong approach. A better advise is to look into historical examples of ceiling art for inspirations (cf. section 2.2.3).

As discussed in chapter 2 the ceiling is usually free of information, in contrast to most of the other surfaces in everyday environments. This provides a potential for using the ceiling to display information, but at the same time it is important to avoid a visual "pollution" of this surface. Figure 4.5 shows an advertisement that has been recently installed at the airport in Vienna, which serves as a negative example. Designers of interactive ceiling applications should consider the following guidelines to strive for visually pleasing and unobtrusive information display.

#5 Use abstract representations. Since users perceive the ceiling at the periphery of their perception, abstract representations work better than literal ones. For instance, it is difficult to read text or numbers that are displayed on the ceiling, since users might approach it from different directions.

Figure 4.5: Advertisement installed in the ceiling at the airport of Vienna: the image adds to the quality of the space and is also context-related, but the fact that it represents an advertisement degrades the perceived value of the installation and increases visual “pollution”.

#6 Emphasize the aesthetics of the visual design. The aesthetic design of interactive ceilings is crucial for their acceptance, since they are constantly perceived by people within the space. This guideline is also in line with the definition of ambient display (cf. section 2.4).

It is also important to note that the design of interactive ceiling applications is not limited to the use of two-dimensional screens: suspended objects (section 2.2.4) might also be suitable to convey information for people within a space. For instance, consider the Pinwheels installation, described in section 2.4.2 (figure 2.46). In this case it is especially important to consider guideline #4, since objects hanging from the ceiling change the perceived size and height of ceilings.

Interaction

According to their definition, interactive ceilings are used for ambient visualization of information and are therefore based on the concept of ambient display. Similar to ambient displays, interactive ceilings can also support user interaction. This means that users can interact with the application to change its state or configuration.

The most promising interaction technique is pointing, since it is a gesture that we use when communicating (Vogel & Balakrishnan, 2005). The study on ceiling interaction (section 3.5) showed that users preferred laser pointing over direct hand pointing. They felt that they had better control over the pointing and selection process and stated that it was also less tiring. Ball activation represents another technique for direct interaction, which involves physical activity and is suitable for playful application scenarios. Other techniques include interaction through an interface on the wall or floor. They are less direct and their applicability depends on the specific application scenario.

The following guidelines are derived from the study on ceiling interaction. The actual implementation of an interaction technique depends on further context-specific parameters, such as the ceiling height or whether users can be provided with an interaction device (e.g. a laser pointer) at all.

#7 Keep the amount of user interaction low. The application should only require sporadic interaction, i.e. the interaction should not require several tasks in a row. Interactions over a longer time can be tiring for users since they have to look up while interacting with an interactive ceiling application.

#8 Design the interactive area in accordance with interaction technique and ceiling height. For instance, laser pointing requires only a small interactive area, while the interactive area in an application based on ball activation should be of considerably larger size.

#9 Use a circular design for interactive areas (e.g. icons). If the application features an interactive area, it should be designed in a circular way, since users might approach the application from different directions.

As already pointed out above, it is important to stress that the guidelines only concern user interaction to change the state or configuration of an interactive ceiling application. The reactive character of the application is not covered by those guidelines. See section 4.2 for a discussion on the differences between active, reactive, and interactive applications.

Evaluation

User-centered design and evaluation have a long tradition in HCI (Preece, Rogers, & Sharp, 2002). The application of user-centered design methods in the studies on interactive ceilings showed that this is a big challenge, since people tend to adhere to traditional interaction concepts known from desktop computers. Confronting them with simple prototypes that demonstrate the possibilities of new technologies helps, but it is sometimes difficult or impossible to prototype such applications with out-of-the-box hardware, such as projectors. For instance, one of the application scenarios was designed to run on a display that spans the entire ceiling, however, the projector that was used for the prototype only covered a fraction of the room's ceiling.

Another problem was the fact that people tended to comment on technological issues, such as costs or noise produced by the projector, rather than on conceptual aspects.

Despite those challenges, trying out a prototype of an interactive ceiling application is important, since it gives a feeling for the application's appearance within the architectural space. This does not necessarily have to include users. A first and valuable step is trying out the prototype in a research environment. Therefore the following guideline is introduced to reflect the importance of prototyping and evaluations early in the design process.

#10 Create quick and basic prototypes that allow for preliminary evaluation. This includes both expert evaluation and evaluation through user testing.

This guideline is not interactive ceiling-specific, like the others, but has been included here to emphasize the importance of prototyping and evaluating as part of the design process.

4.6 Conclusion

The contribution introduced in this chapter is a framework to guide design and research of interactive ceilings as well as a set of design guidelines. Figure 4.6 shows an extended view on the framework, including the attributes for all design dimensions of the ArDis and AmDis models. No attributes are given for the CeDis model, since the nature of its design dimensions does not require further specification through attributes.

The modular composition of the framework allows for different applications of the respective models:

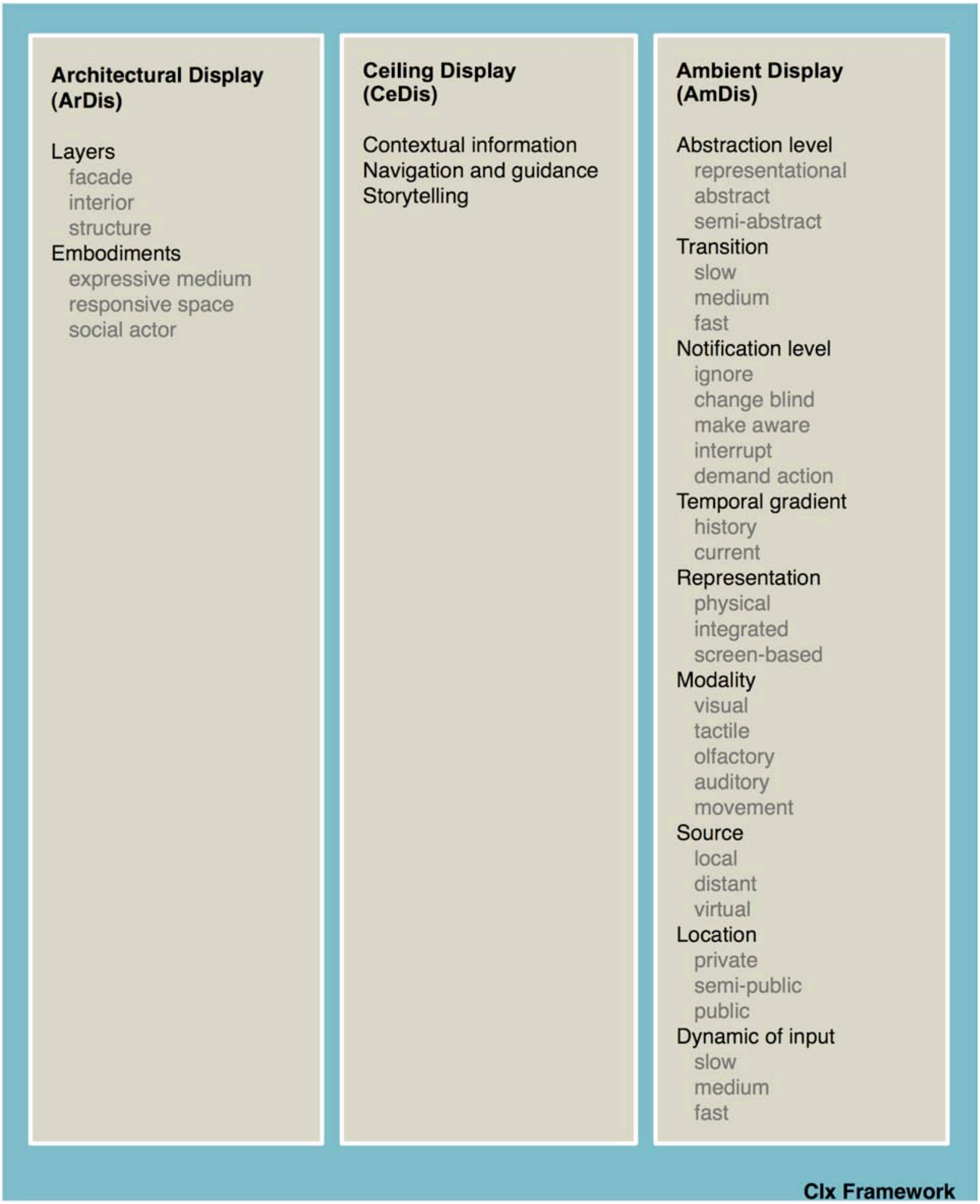


Figure 4.6: The three components of the CIx framework and their design dimensions, including the attributes that were defined for the respective models.

Design guidance. The framework is designed to inspire and loosely guide the design of interactive ceiling applications. Depending on the application context a different selection of components should be considered. The last component, the AmDis model, can also be used independently for guiding the design of ambient displays in general.

Evaluation tool. The design dimensions introduced by the framework allow for an evaluation of interactive ceiling applications. Specifically the dimension of embodiment from the ArDis model as well as six out of the nine dimensions from the AmDis model (abstraction level, transition, notification level, temporal gradient, representation, and modality) are well-suited for evaluations.

For example, applying the ArDis model (section 4.2) for evaluating the sound allocation prototype from study IV (section 3.4) reveals the insight that the application represents a responsive space that utilizes the interior layer for representation. Therefore it should comply with characteristics (1) to (5) defined by the design dimension of embodiment: non-obtrusive, informative, engaging, interactive, enjoyable.

The application is non-obtrusive (1) since the ceiling sits at the periphery of human perception. It provides passers-by with additional information, which is of informative (2) nature. The represented information relates to individuals as well as groups sharing a space, potentially evoking dialogues between them, which means that it is socially engaging (3). It is interactive (4), since passers-by influence the visual appearance indirectly as well as directly. Finally, the ambient blue light patterns produced in real-time based on environmental sound create an enjoyable (5) experience.

Classification. Conveying the design dimensions of all models into one graph allows for a classification of interactive ceiling applications. Figure 4.7 shows the corresponding graph that represents the three models. Figures 4.8 and 4.9 show the classification of four interactive ceiling applications described in chapter 3: the weather forecast application, the sound allocation application, the ball interaction application from the study on emotional communication, and the final application from the ambient sound study.

Categorization. Each component allows independently for a categorization – similar to a taxonomy – of applications within the respective field (architectural display, ceiling display, and ambient display) based on the dimensions/categories. The utilization of the components for categorization was demonstrated within the AmDis model, where 33 applications were categorized according to the design dimensions of this model (cf. figure 4.4).

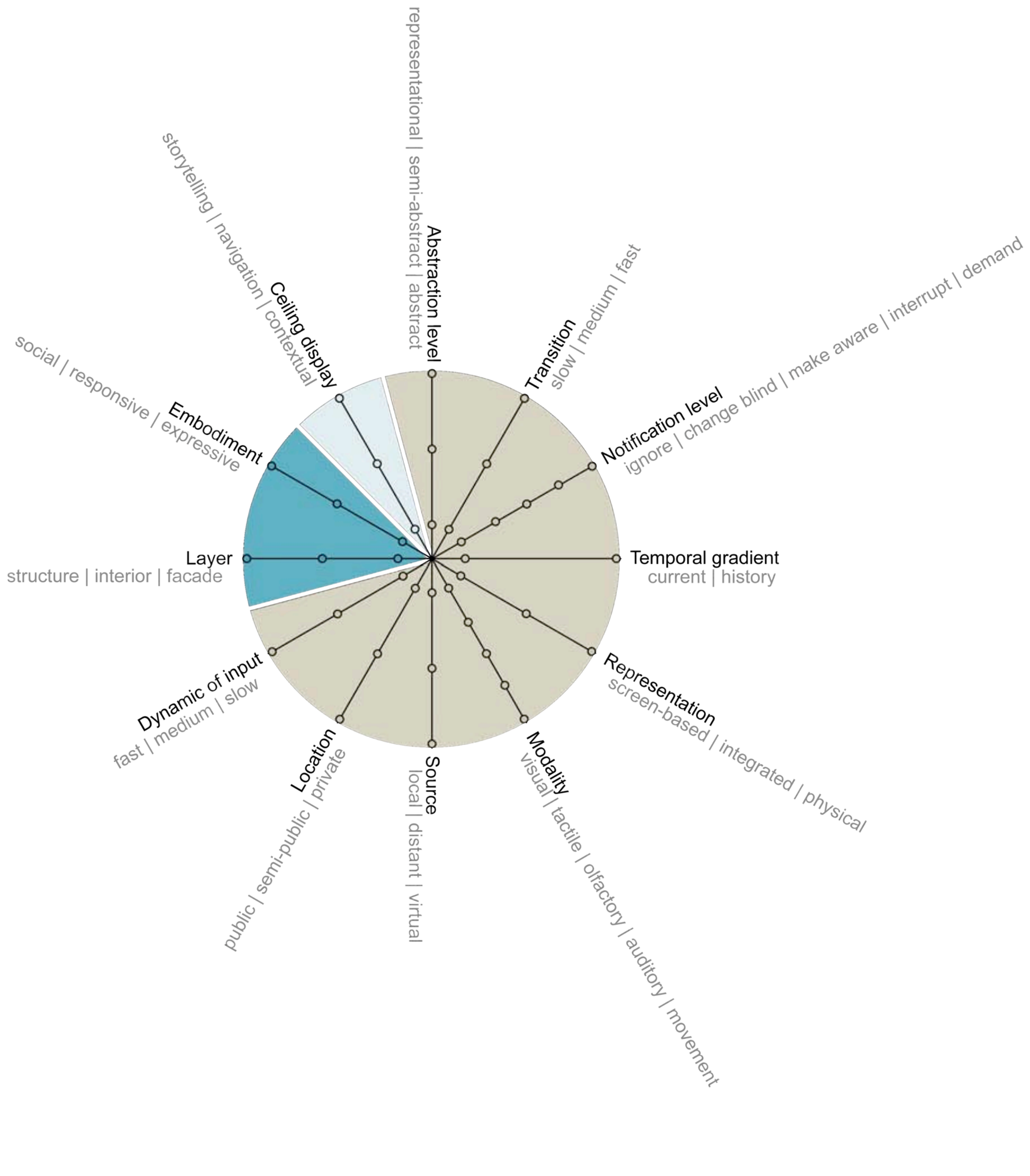


Figure 4.7: The design dimensions of the three proposed models conveyed into a holistic graph representation. The models (ArDis, CeDis, and AmDis) are represented by color. The dots relate to the respective attributes for each design dimensions.

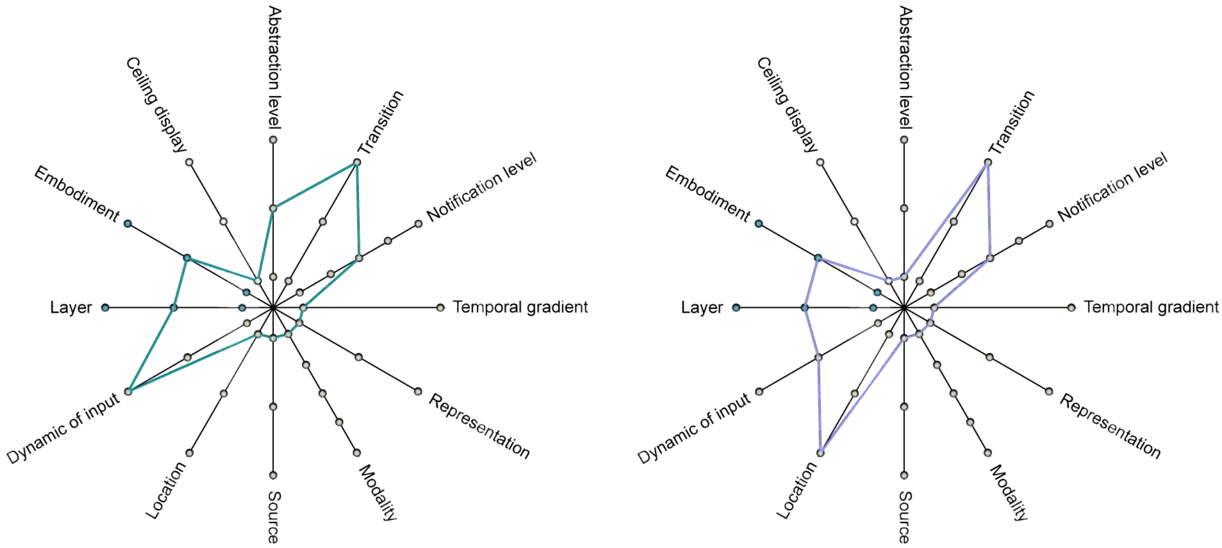


Figure 4.8: Graph representation for the weather forecast and the sound allocation applications.

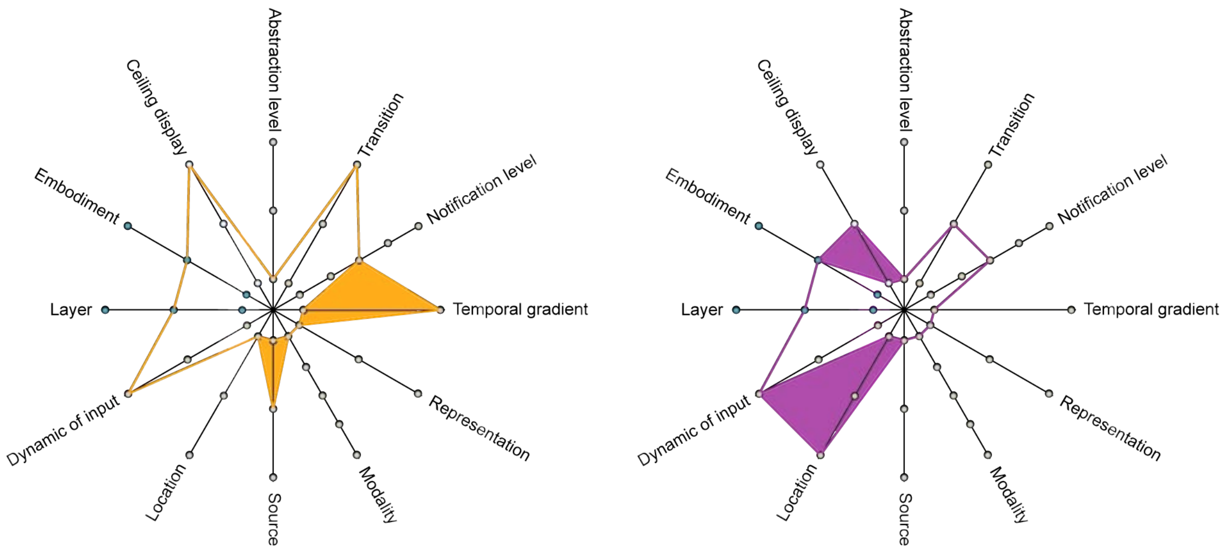


Figure 4.9: Graph representation for two applications from the emotional communication (left) and the ambient sound (right) studies. Filled areas represent multiple attributes that are applicable for the respective application.

5 CONCLUSIONS

This chapter starts with a critical discussion of the questions and research aim posed in the introduction of this thesis. This is followed by some general conclusions regarding the design and implementation of interactive ceiling applications.

The research aim of this thesis was *to investigate the architectural ceiling as information display in everyday environments that conveys information at the periphery of human perception*. The investigation of ceiling attributes and characteristics in section 2.1 revealed two insights. Firstly, it proved that the ceiling is perceived at the periphery of human perception depending on different attributes, such as height, size, and shape. Thus, the ceiling is suitable as peripheral display, where its quality is determined by those attributes. Secondly, the investigation led to the insight that the ceiling has a large impact on how people experience a space. Attributes that constitute this experience are ceiling height, size, shape, and color. This observation emphasizes the importance of a suitable integration of interactive ceilings into the specific architectural environment. The character of the interactive ceiling will inevitably influence the experience of the space they cover.

The literature review of ceilings in architecture and art showed that artists of ceiling frescos were well aware of their impact on the experience of space. For instance, in Renaissance ceiling frescos the ceiling was often painted as a virtual sky (an opening in the ceiling) prolonging the architectural space. Andrea Pozzo, whose work is introduced in section 2.2.3 was a master in this respect. He created ceiling frescos that visually extended the space in a perfect perspective illusion, when viewed from a specific point of view. This allowed people to explore the visual experience of the fresco by physically moving through the space. Pozzo's frescos from the 17th century therefore already supported basic user interaction by giving them control of the perceived representation.

Another contribution of the discussion of ceilings in architecture and art was the insight that objects suspended from the ceiling can also provide both information display and interface for interactive ceilings. Suspended objects that were discussed in this context are lights, ceiling fans, and hanging signs. An art installation by realities:united demonstrated how lights can be used to communicate information through the ceiling (figure 2.30). The section on media architecture mainly summarized the use of ceiling displays in contemporary architecture, which revealed that most existing applications represent active systems, according to the model of interaction by Giannetti (2004). Thus, passers-by have no influence on the content displayed on the ceiling. In contrast, the field of interactive architecture emphasizes the interaction between people and the architectural environment. The interaction loop can be either of reactive or interactive character. Applications from this field are mainly of inspirational value for the research on interactive ceilings.

Ubiquitous computing and ambient display provide a scientific foundation for interactive ceilings. The review of interactive surfaces in ubiquitous computing showed that there are many projects that employ walls or tables, to some extent also floors. Only few projects use the ceiling as interactive surface. The concept of ambient display provides the theory for presenting information at the periphery of human perception, which constitutes an important part of the research question.

While the literature review in chapter 2 sets the stage for an investigation of the ceiling according to the research question, the studies described in chapter 3 provide a more specific discussion and insights for the use of the architectural ceiling as information display. The studies and their contribution to this thesis are outlined in the context of the research questions below.

For which tasks can the ceiling be used to visualize information? In HCI tasks are defined as means to achieve work, which should lead to reaching desired goals (Diaper & Stanton, 2003). The concept of interactive ceiling supports users in achieving goals in everyday life.

For example, in the ambient sound study, described in section 3.3, the goal is to develop a constant awareness of sounds happening in the environment for deaf and hearing impaired people, which eventually leads to an awareness of events through interpretation. In the weather forecast study, described in section 3.1, the goal is to remind people of bringing their umbrella when leaving the house, in the likelihood of rain. Both tasks are of unconscious nature, i.e. users are not consciously working on the task to reach their goal. In fact, the applications from the studies support the execution of tasks at a peripheral level, while focusing on another primary task. This is one of the requirements of the concept of interactive ceiling and also in line with the concept of ambient display. On a higher level the tasks in the studies can be described as awareness tasks, which might trigger an action, i.e. another task, in the case of notification, such as taking an umbrella before leaving the house.

The emotional communication study, described in section 3.2, provides people with an awareness about their distant partner's activities, presence, or emotional state. This again might trigger an action, for instance a phone call, in case the partner is experiencing an unhappy mood. Therefore one of the tasks supported by interactive ceilings is constant monitoring of a state or activity of people, the environment, or a system.

Another type of task is proposed by the CeDis model, which is part of the CIx framework, described in chapter 4: the task of way finding in an unknown environment. Interactive ceilings are well-suited to display navigational cues, either personalized or generic, to support the execution of this task.

What kind of information can be displayed on ceilings? The CIx framework conveys data classified into three categories – contextual information, navigation and guidance, and storytelling – which is suitable for information display incorporated into the architectural ceiling. Of the data that was used in the studies (e.g. sound, location, activity, mood, weather, etc.), spatial data (e.g. ambient sound) and information, which can be found in the space *up* in natural environments (e.g. weather conditions) was most promising. The first type, spatial data, is well-suited for interactive ceiling display since its location can be spatially mapped onto the ceiling surface. The second type is intuitive for people to understand, since they can draw on their knowledge and experience of natural environments for interpreting the information. This type of data is therefore motivated by the metaphor it is based on.

Another example is the display of information to support way finding (cf. section 4.3). A good approach for information display is demonstrated in the sound allocation study, where the data represented through the ceiling is influenced by people sharing the space as well as the space itself, therefore creating a communication loop between people and the architectural environment. Further, the information displayed on ceilings can have different characteristics. For instance, the data can be local or remote, in case of the weather forecast showing the local weather forecast or the weather conditions in another part of the world to create an emotional connection between the distant spaces. Those characteristics are described by the AmDis model (section 4.4), which is part of the CIx framework.

Which interaction techniques can be applied for interactive ceiling applications? The review of interaction techniques for interactive surfaces in ubiquitous computing environments presented in section 2.3.3 revealed the following techniques: hand-held indirect pointing, laser pointer-style devices, body and hand tracking, direct hand pointing, and eye tracking. Apart from the last one, they are all suitable candidates to enable interaction with interactive ceiling applications. Eye tracking is not well-suited since it would require extensive bending of the users' head upwards. The type of interaction technique eventually depends on the context and type of application. For instance, an application in a public environment should rather support device-free interaction, since people might drop in and out of interactions on a frequent basis. Devices might further get stolen or lost in public contexts. The interaction study, described in section 3.5, revealed that users preferred laser pointing for selection tasks in terms of performance, precision, degree of difficulty, and general preference. Finger pointing was less liked. Participants stated that it was more tiring than laser pointing and that they felt they had less control of the selection process. Ball activation was explored as a more playful way of interacting with interactive ceiling applications. It was last in all categories but fun. From the techniques investigated in the study, laser pointing is therefore best-suited for efficient interaction. Ball activation is suggested for engaging interactions in playful applications or ceiling-based games.

What are the design constraints for interactive ceiling applications? The last question is difficult to answer, since there are hardly any design constraints for interactive ceiling applications as discussed in section 3.6.3. Interactive ceilings can convey information in visual two-dimensional or physical three-dimensional ways. The visualization can span the entire ceiling surface or only part of it. As stated before this is also the reason why the design space for interactive ceilings is so large. Design constraints therefore rather stem from the specific application that is incorporated by the interactive ceiling. Some additional design constraints can be derived from the characteristics of ceilings (section 2.1.1). For instance it is difficult to directly interact with the ceiling. Further, the ceiling represents a fixed non-mobile surface. A good starting point for defining design constraints are the CIx framework and the guidelines described in chapter 4.

An important outcome is that aesthetics really matter for interactive ceilings. This fact is not being reflected by the research question of this thesis. In this thesis work the emphasis was put on a user-centered design process within the framework of HCI research, rather than approaching the topic purely from a design perspective, which inevitably would have included the importance of aesthetics. This not only covers the visual appearance of the application but also how well it is integrated into the existing architectural space. The aesthetic aspect is important to reach user acceptance. If the interactive ceiling fails in this, it is at danger of either reminding users of desktop computers and their frustrating experience with them or being perceived as just another form of visual "pollution" (cf. figure 4.5). It is especially crucial to avoid the latter case since the ceiling currently represents the only surface in our everyday environment that is free of information and empty.

The research work presented in this thesis does not suggest to turn the ceiling into yet another information display. The vision of interactive ceiling is rather to enhance the recreational character of the ceiling and add to the experience of space. Who has not been sitting in an office chair, leaning backwards and starring at the ceiling, while mentally reflecting on thoughts?

Augmenting the ceiling with images, even static ones, such as a painted sky featuring clouds (figure 5.1), already has a great impact on the experience of space. Whether it is a positive one has to be

Figure 5.1: Painted ceiling in a hotel room in Taipei, which changes its representation according to light conditions inside the room, since it also features fluorescent stars that light up in the dark.

evaluated in a real context. This is why HCI has an important role in designing interactive ceilings, despite the emphasis on the aesthetics. Applying user-centered design methods proved to work well, but this should not be done on the costs of creativity. It is a good approach to use Verplank's spiral (Davenport et al., 1998) to achieve a balance in this respect.

There are still many problems that remain. Most of them are of technological nature though and will most likely be obsolete in the near future due to advances in information technologies. But despite the technological aspects, this thesis raises many issues about ceiling interaction and experience of space that provide the stage for further research, from an HCI, architectural, and art perspective.

To summarize, designers of interactive ceilings should strive for simple aesthetic visualizations that create an engaging experience rather than for complex ceiling-based applications that translate the concept of desktop computing into the built environment. Advances in information technologies will soon enable a paradigm shift from simple points of interactions scattered within architectural spaces towards fully adaptive, environmentally aware, and socially reflective environments that involve inhabitants and passers-by in constant unobtrusive, subtle, and informative conversations.

Imagine how Andrea Pozzo, who was not only a great painter but also a brilliant thinker and architect, would use information technologies available today for creating interactive ceiling experiences.

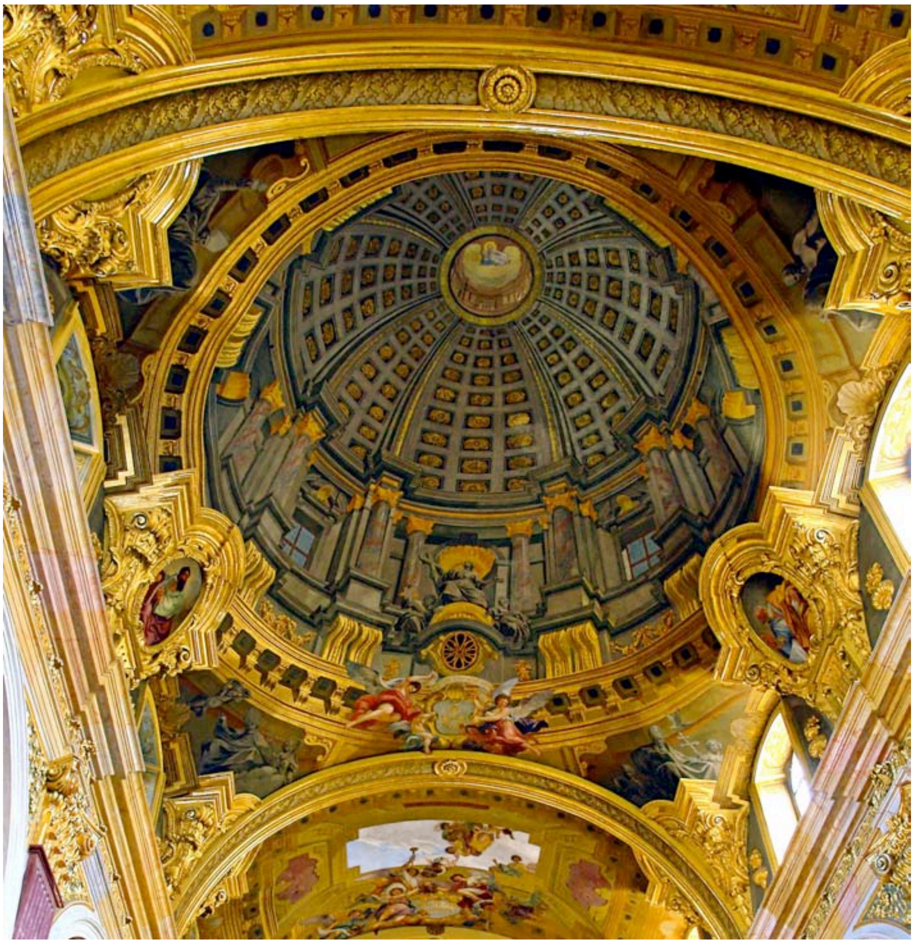


Figure 5.2: Trompe l'œil at the Jesuit Church in Vienna, fresco by Andrea Pozzo (1703).

List of Figures

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Thesis Publications

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Tomitsch, M., & Grechenig, T. (2007a). Design implications for a ubiquitous ambient sound display for the deaf. In *CVHI'07: Proceedings of the conference and workshop on assistive technology for people with vision and hearing impairments.*

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Formal Education

2004 to 2008	*Ph.D. student in Informatics with special focus on Human-Computer Interaction*, Vienna University of Technology; supervisor: Professor Thomas Grechenig.
2005 to 2006	*Magister in Computer Management*, with a special focus on pedagogical methodologies, Vienna University of Technology.
2005 to 2006	*Selected courses from the "Product and Industrial Design" Module M17,* Vienna University of Technology.
Sept 2004	*Convivio Summer School on Interaction Design*, Split, Croatia: 2 weeks of lectures held by international experts in the field, accompanied by an atelier project on sustainable tourism in the context of Split.
1997 to 2004	*Master in Informatics (M.Sc.)*, Vienna University of Technology; title of research thesis: *"Trends and Evolution of Window Interfaces"*; supervisor: Professor Thomas Grechenig.
1992 to 1997	*College of Engineering (HTL)*, St.Pölten, Austria; 3 years of electrical engineering and 2 years of computer science; completed with a general examination for university entrance.

Research and Professional Experience

since March 2004	Research and project assistant at INSO (Research Group for Industrial Software), Vienna University of Technology, Austria
since March 2004	Lecturer at Vienna University of Technology, Austria
1998 to 2007	Institut 2F Informatik GmbH, Vienna, Austria: web application and database development.
1997 to 2002	Coaching Institute I.E.L.L., St.Pölten, Austria: teaching summer courses for high school students in mathematics, physics, and programming languages.
Summer 2001	DML Publish Marketing GmbH, Vienna, Austria, project management and web design.
July 2000	Trainee at the weather station in Reykjavik, Iceland.
Summer 2000	Pedagogic Institute of Lower Austria: lecturing computer courses for high school teachers.
July 1999	Pedagogic Institute of Lower Austria, co-lecturing computer courses for high school teachers.
Feb to June 1999	Siemens Austria, practical training: collaborative implementation of a management software system used by salesmen.
Summer 1996/1997	PGV Computer, St.Pölten, Austria: personal computer assembling and service

International Experience

Dec to June 2008 *Visiting scholar at the Faculty of Architecture, Design & Planning, The University of Sydney:* activities included research on architectural ambient displays (leading to two peer-reviewed publications), research on the use of large-scale public displays for information visualization, and tutoring a design studio on information visualization.

March 2004 *Research visit at Université Paris Sud, InSitu Research Lab, Paris, France* for the purpose of publishing a collaborative journal paper on window management techniques.

June to Nov 2003 *Visitor at Université Paris Sud, InSitu Research Lab, Paris, France:* pursuing research for my master thesis in collaboration with researchers from the renowned InSitu group.

Jan to June 2002 *Exchange student at KTH Stockholm, Sweden:* elective courses on computer science and human-computer interaction.

Other Experience

Program committee The Ambient Information Systems Workshop at the International Conference on Ubiquitous Computing 2008

Session chair Conference and Workshop on Assistive Technology for People with Vision and Hearing Impairments (CVHI07)

Session co-chair International Conference on Pervasive Computing and Applications (ICPA07)