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DISSERTATION

The ColorTable: an interdisciplinary design process

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Abstract

The step of moving from Graphical User Interfaces (GUIs) toward Tangible User Interfaces (TUIs) creates a rich set of manipulation possibilities and redefines requirements for interaction design, that can hardly be described within a detailed framework. This thesis seeks to analyze complex tangible technology and describes the development of a tangible user interface, the *ColorTable*, which is the result of an iterative process of design-evaluation-feedback-redesign within a period of 4 years. Several prototypes have been evaluated within the scope of participatory workshops in the context of real urban planning projects. Each workshop includes preparations of scenarios and content, the translation of these into interactive functions, the design and development of physical components for their manipulation, and the assembling of all those elements to present a tangible user interface being used in a specific context, as response to a specific need.

We provide a separate analysis of each domain being involved in the design process and focus on its relation to other domains. We identify the main questions to be addressed while developing a *tracking technology*, implementing *application functions*, designing the *interaction space* and preparing *real use* of the technologies. Different prototypes are compared to provide a rich set of examples illustrating how different solutions influence design possibilities for other aspects of the interface. It further proposes two frameworks abstracting facets of tangible interaction design in order to understand possibilities, limitations and complexities of the design process.

Zusammenfassung

Der Gedankensprung von grafischen Benutzerschnittstellen (engl. Graphical User Interfaces - GUIs) zu greifbaren Benutzerschnittstellen (engl. Tangible User Interfaces - TUIs) schafft neue Möglichkeiten der Verwendung und definiert neue Bedingungen des Interaktionsdesigns, welche nur schwer in einem detaillierten Framework beschrieben werden können. Diese Dissertationsarbeit untersucht eine komplexe, greifbare Technologie, den *ColorTable*, und beschreibt dessen Entwicklung anhand eines iterativen Prozesses bestehend aus Design-Evaluierung-Feedback-Redesign in einem Zeitraum von 4 Jahren. Im Rahmen von partizipativen Workshops über reale Stadtplanungsprojekten wurden mehrere Prototypen getestet und evaluiert. Für jeden der Workshops wurden Szenarien und Inhalte vorbereitet, diese in interaktive Funktionen umgeleitet, physische Komponenten für deren Steuerung entwickelt und gestaltet, und alle diese Elemente zu einer greifbaren Benutzerschnittstelle zusammengeführt.

Jeder an diesem Prozess beteiligter Bereich wird individuell untersucht und die jeweilige Relation zu anderen Bereichen beschrieben. Die Hauptfragen bezüglich der Entwicklung eines Trackingverfahrens, der Implementierung von Anwendungsfunktionen, der Gestaltung eines Interaktionsraumes sowie der Vorbereitung der realen Verwendung werden identifiziert. Unterschiedliche Prototypen werden verglichen, um so eine reiche Sammlung an Beispielen zu liefern, die veranschaulichen, wie einzelne Lösungen andere Aspekte des Systems beeinflussen. Zusätzlich werden 2 Frameworks vorgeschlagen, die die Facetten der greifbaren Interaktion abstrahieren, um so die Möglichkeiten, Grenzen und Komplexitäten des Gestaltunsprozesses zu verstehen.

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Related Publications

This thesis is based on the following publications:

- Wagner I., Basile M., Ehrenstrasser L., Maquil V., Terrin J., Wagner M. **Supporting community engagement in the city: urban planning in the MR-tent** In *Proceedings of Communities and Technologies, June 25 - 27, University Park, PA, USA, 2009.*

- Boerner A., Maquil V. **Enhancing synergies between computer science and urban disciplines: Semi-automated applications for tangible user interfaces, a case study** In *Proceedings of CAAD Futures 2009, June 17 - 19, Montreal, Canada, 2009*

- Ehrenstrasser L., Maquil V. **Supporting complex tangible interactions: a long-term iterative study of the ColorTable** (Draft version), 2010

- Maquil V., Sareika M., Schmalstieg D., Wagner I. **MR Tent: a place for co-constructing mixed realities in urban planning** In *Proceedings of Graphics Interface 2009, May 25-27, Kelowna, British Columbia, Canada, 2009*

- Maquil V., Psik T., Wagner I. **The ColorTable - A Design Story** In *Proceedings of TEI 2008, Feb 18-21, Bonn, Germany, 2008*

- Maquil V., Psik T., Wagner I., Wagner M. **Expressive Interactions Supporting Collaboration in Urban Design** In *Proceedings of GROUP 2007, Nov 4-7, Sanibel Island, Florida, USA, 2007*

It is further based on the following reports:

- Basile M., Boerner A., Ehrenstrasser L., Idziorek M., Maquil V., Sareika M., Terrin J., Wagner I., Wagner M. Integrated Project on Interaction and Presence in Urban Environments. **D6.2. First Prototype of Urban Renewal Applications**. Report, (February 2008).
- Boerner A., Ehrenstrasser L., Idziorek M., Maquil V., Sareika M., Terrin J., Wagner I. Integrated Project on Interaction and Presence in Urban Environments. **D6.3. Second Prototype of Urban Renewal Applications**. Report, (February 2009).
- Maquil V., Wagner I., Basile M., Ehrenstrasser L., Idziorek M., Ozdirlik B., Sareika M., Terrin J., Wagner M. Integrated Project on Interaction and Presence in Urban Environments. **D6.4. Final prototype of Urban Renewal Applications**. Report, (March 2010).

Contents

CHAPTER 1

Introduction

Ever since the invention of Durell Bishops *Marble Answering Machine* in 1992 [Smi95], an increasing number of researchers adopted the idea of tangible user interfaces (TUIs). A high number of TUIs to be used in a variety of contexts have been developed. Examples reach from a tabletop system for planning disaster measures [KKN+07] over cubes for creating and exploring sound [SV08] to a 'magic carpet' for storytelling [SBN+01].

While the well known Graphical User Interfaces (GUIs) can be designed using the common principle of WIMP interaction (windows, icons, menus, pointing devices), comparable frameworks or design principles for TUIs hardly exist. In literature, we find concepts describing definitions [Fit96][UI00], frameworks used for classification (e.g. [Fis04]) or specification (e.g. [SLCGJ04]) of tangible user interfaces. These concepts however just consider a subset of the tangible interactions or provide a very generic concept not going into details. The step of moving from GUIs toward TUIs makes interaction design much more versatile and complex, and can hardly be precisely explained within a clear framework.

This thesis describes the development of a complex tangible user interface, the *ColorTable*, which is the result of an iterative process of design-evaluation-feedback-redesign within a period of 4 years. Several prototypes have been evaluated within the scope of participatory workshops in the context of real urban planning projects.

Each workshop includes preparations of scenarios and content, the translation of these into interactive functions, the design and development of physical components for their manipulation, and the assembling of all those elements to present a tangible user interface being used in a specific context, as response to a specific need.

Due to the complexity of urban projects, the *ColorTable* was required to support a high range of different features and therefore ended up in a complex tool with several components. To simultaneously respond to interaction design issues, the development of the *ColorTable* affords combining and comparing requirements and solutions from different disciplines.

This work provides a separate analysis of each involved domain as well as its connection to other domains. It identifies the main questions to be addressed while developing a complex tangible user interface to be used within a specific context. The comparison of different prototypes provides indications how different solutions influence design possibilities for other aspects of the interface. An in-depth analysis of the main interconnections enables a systematic discussion about possibilities and limitations of tangible interaction.

1.1. The ColorTable: a tangible user interface

The idea of the *ColorTable* was to create a tangible user interface in support of urban planners and diverse stakeholders to collaboratively envision urban change. Throughout the early beginnings, we considered three main components that best pursue the goals of this novel interface (Figure 7.1):

- The **table** is typically a place where people meet to discuss and exchange ideas. It supports a circular configuration of the participants, where each of them plays an equal part in the negotiation process. Its surface is used to plan and perform interventions.
- The perspective **MR view** rendering the composed scene against a background shows a collective view of the participants' vision. It shows the result of their work on a commonly visible screen. The real background is familiar to participants and provides a reference point for the urban intervention.
- The **colored tokens** provide a simple and familiar access to the technologies. They are easy to understand and invite participation for a diversity of stakeholders.

After four years of development, the *ColorTable* became an interactive, round table providing a collaborative planning and discussion space. It is set up in a tent, on the

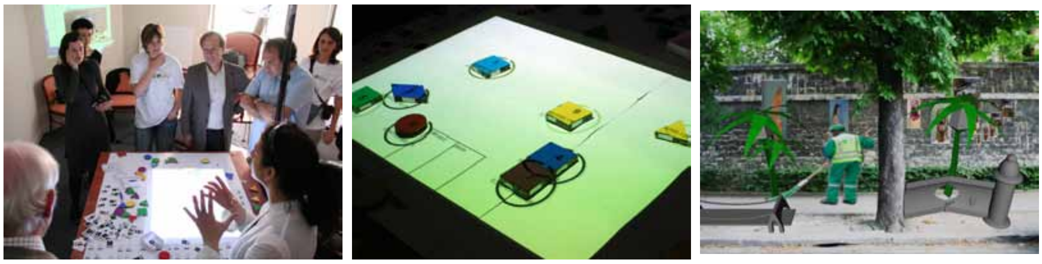


Figure 1.1.: The main components of the ColorTable as very first prototype: a table (left), tangible objects (center) and a perspective view (right).

site of the urban project. To express their visions, users can arrange and position tokens of different shapes and colors on a physical map. The tokens enable users to set urban elements such as buildings, streets, pedestrian flows or ground textures. The table view is augmented with digital information to provide a top-down view onto the project site. A vertical projection renders the scene against a background, which is produced by either a video stream, a panorama image of a view onto the site or a see-through installation and creates a perspective mixed reality view.

In addition to this simple positioning tool, we provide a configuration board where users can place content or command cards onto one of the color areas to associate and manipulate objects to be positioned into the scene. Furthermore, the *ColorTable* allows simple navigation methods; users can select different points of view to be shown on the vertical projection and change their orientation using a rotating wheel. Barcodes, presented on trays and on the physical maps enable switching the views and scales of the map, and provide possibilities for saving and loading.

Figure 1.2 shows the final version of the *ColorTable* with all its components.

1.2. Our approach: participatory design

The *ColorTable* was developed in a participatory design process undergoing several cycles of development-evaluation-redesign, each connected to a participatory workshop in the context of an urban planning project. It involves a multi-disciplinary team of computer scientists, designers, artists and social scientists working together with experienced urban planners. The urban specialists in the team suggested a set of 'urban themes' they considered as particularly relevant for urban projects and illustrated these by providing a number of visual examples: scale, temporality, borders and layers, fuzziness, ambience, and mobility. These themes guided technology development, as well as scenario and content creation for the participatory workshops with users.

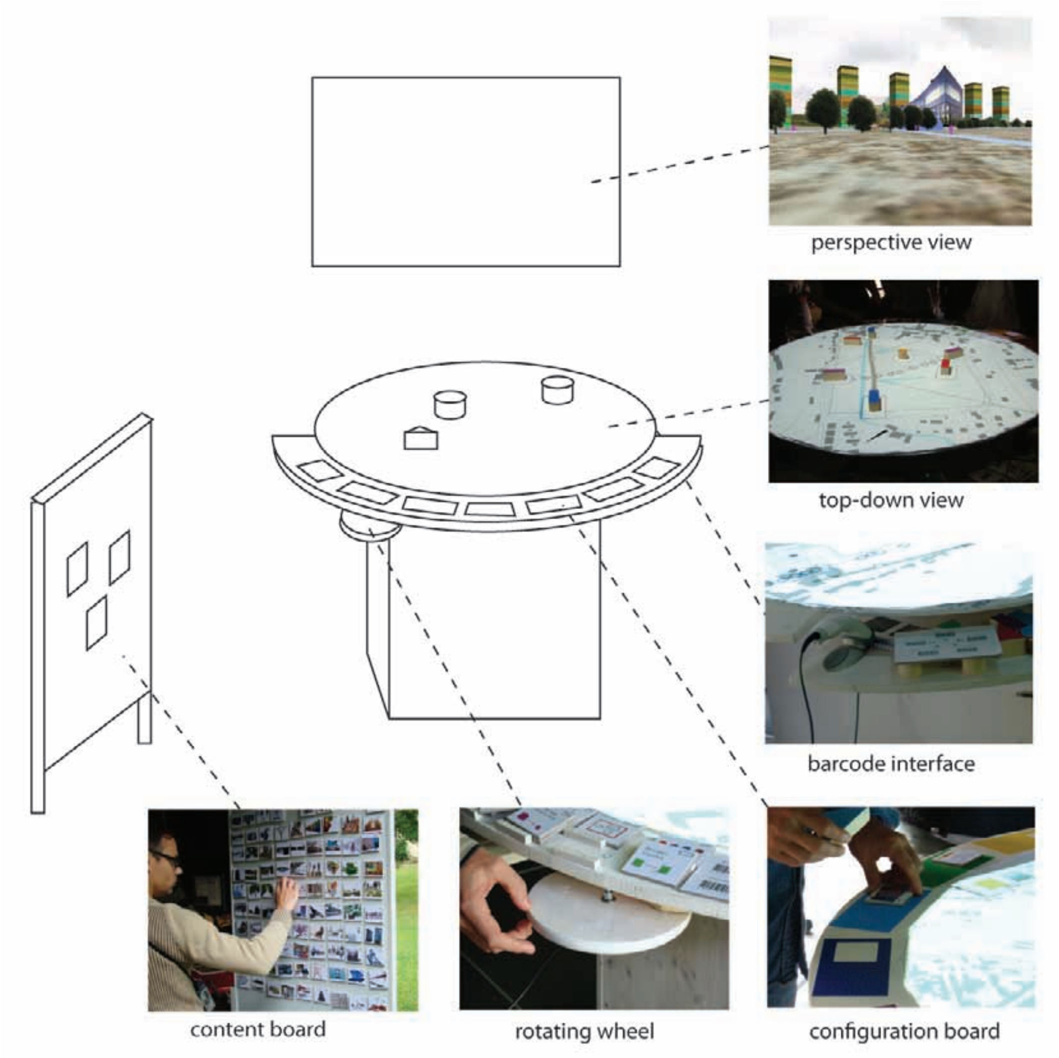


Figure 1.2.: The latest version of the ColorTable with all its components.

Each of the *ColorTable* prototypes was presented to users in a participatory workshop, connected to an ongoing urban planning project. Aim was to learn from users' engagement with the tools and their evolving functionalities. The workshops dealt with a different set of urban issues on different locations. In this work we use the prototypes and applications of the following workshops as basis for descriptions and evaluations:

- **1st and 2nd Workshop** (June 2006, March 2007): in Paris opening up to public use of the psychiatric hospital of Sainte-Anne
- **3rd Workshop** (September 2007): implementation of a new Paris courthouse (*Tribunal de Grande Instance de Paris*) and the surrounding area
- **4th Workshop** (December 2007): revitalisation of a former airfield Aspern in Vienna with a focus on *Urban Density*
- **5th and 6th Workshop** (June 2008, September 2008): revitalisation of a former military site (*Quartier Bossut*) in Cergy-Pontoise (F) and its integration within an urban context
- **7th Workshop** (June 2009): constitution of a greenway in the city of Pontoise (F) and the future role of the public gardens of Lavandières in such a scheme

For each workshop we studied the site and its urban issues, selected participants, prepared scenarios a well as content: panoramas from different viewpoints, architectural models, isolated images created from photographs, textures and sound. We developed a *ColorTable* prototype supporting the context related requirements and an 'experimentation protocol' leading through the participatory sessions. The workshop sessions were video-recorded, and transcripts of significant episodes were produced. In addition, we used several digital cameras to capture interesting situations. Screenshots of both projections were generated every minute. Data analysis was carried out collaboratively in the team, with attention to the details of participants' interactions (as revealed in selected video clips) and to the intense discussions that took place during the workshop sessions, where participants addressed questions of the project - which interventions to carry out - but also commented on features of the tools and on their potential role in urban planning.

1.3. Thesis contributions

This work deals with the development of a complex tangible user interface within the context of real life scenarios. It seeks to analyze how requirements and possibilities of multiple disciplines can be balanced in order to enrich real life tangible user interfaces. In particular, it provides solutions and answers to the following research questions:

- How to develop a tracking framework supporting a multiplicity of interaction possibilities? (Chapter 6)
- How to develop application functions dealing with complex urban issues while being controlled with a simple set of manipulations? (Chapter 7)
- How to design objects and space to support consistent, understandable and collaborative interactions while ensuring a high amount of manipulations? (Chapter 8)
- How to prepare real use in order to provide a basis for technology development and, at the same time, respond to technology related requirements? (Chapter 9)

To address these questions, we break down the complexity of the development process into 4 themes, each dealing with a different facet of the design process. The themes being considered focus on the development of the technology as well as directly related issues of the design of the interaction space and of the context. Figure 1.3 shows the 4 themes described in the thesis and the respective facets they deal with.

Crucial is that the themes do not represent any stages of the design process and cannot be treated in a specific order. They are closely related, and decisions being taken in one theme affect the situation within another theme. We therefore claim that their respective design issues should be addressed iteratively or even simultaneously, by collaborating in a multi-disciplinary team.

This thesis seeks to make computer scientists aware of the extent of decisions that have to be taken while developing tangible user interfaces and to provide a basic knowledge needed to cooperate with experts of the related disciplines.

The contributions are as follows:

- The thesis points out which design decisions related to which disciplines have a large impact onto the overall design of the TUI. It clarifies this impact by showing problems and conflicts related to such decisions and proposes solutions for solving them.
- The thesis provides a rich set of examples, collected over four years of development, which illustrate the myriad of possibilities for changing the design of a TUI. The examples serve as inspiration for addressing complexities, improving interactions or enriching applications.

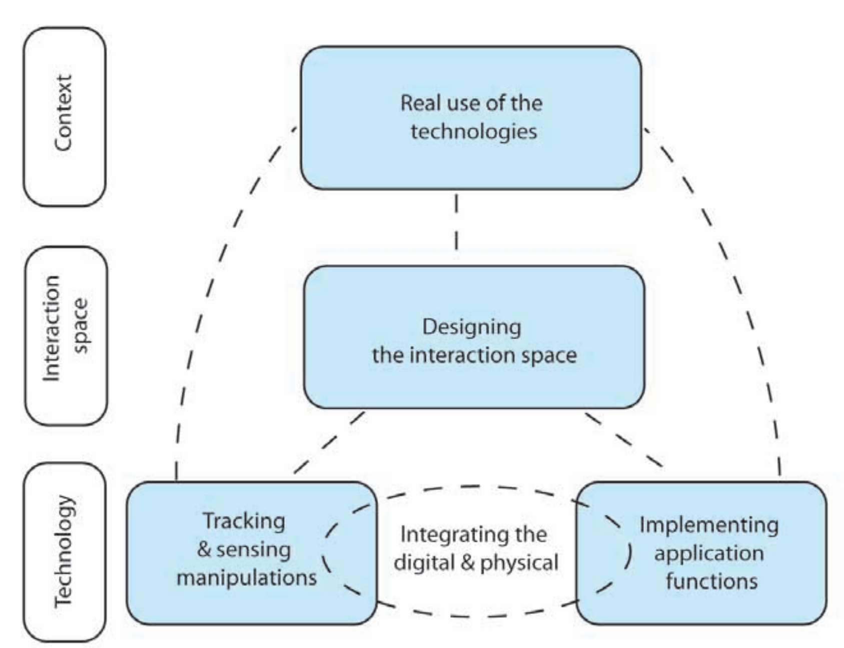


Figure 1.3.: Concept map showing the four themes being addressed in this thesis, the facets of the design process they deal with, as well as their relations in-between.

- The thesis proposes two simple design models which enable abstracting facets of tangible interaction design in order to understand possibilities, limitations and complexities of the design process.

1.4. Thesis overview

The thesis starts in chapter 3 with an overview of the different participatory workshops by describing the related urban projects, the setup of the technologies and the way participants used them during the individual sessions. This is the context of urban planning in which the *ColorTable* was developed and which was the basis for the design decisions and implementations.

The work continues with a description of two frameworks, enabling the analysis and comparison of interdisciplinary design decisions. While chapter 4 describes the relation between tracked data and application functions, we address in chapter 5 the connection of the interaction space to aspects of technology and context.

The implementation and evaluation of the four domains of tracking technology, application functions, interaction space and real use are described and analyzed in chapter 6, 7, 8 and 9.

The thesis uses different prototypes to describe and compare the issues related to the individual domains. Table 1.1 lists the chapters as well as the different prototypes which they are based upon.

	Tracking technology	Application functions	Interaction space	Real use
1: Ste Anne			X	
2: Ste Anne			X	
3: TGI			X	
4: Aspern		X	X	
5: Caserne Bossut			X	X
6: Caserne Bossut			X	X
7: Pontoise	X	X	X	

Table 1.1.: Different prototypes are used to describe and compare issues related to the individual chapters.

1.5. Related project

This thesis is based on research done within the project IPCity (FP6-2004-IST-4-27571) funded by the European Commission. The IPCity project aims to develop analytical and technological approaches to presence in real life settings by developing portable environments and light-weight, mobile mixed reality interfaces.

The field of urban renewal is one of several application scenarios being in the IPCity project. It provides groups of stakeholders with a set of technologies enabling the collaborative discussion and debate of different ideas and concepts. Architects, specialists, investors, politicians and ordinary citizens are able to use the system collaboratively in order to express their intentions, concerns and visions and discuss different issues related to the preliminary stages of urban planning projects.

1.6. Related thesis

A thesis dealing with a related subject is provided by Lisa Ehrenstrasser in *Materiality and Design: Exploring two essential areas in the development of novel interfaces.* It deals with the development of the physical interaction space of the *ColorTable* including a comparison of the different stages and an analysis of use based on the different workshops. While Ehrenstrasser's thesis describes the design process of the *ColorTable* from a designers perspective and focuses upon issues related to materiality, space and design, this work addresses the topic from the perspective of a computer scientist, seeking to point out the complexity of developing tangible technology and to clarify the relations to connected disciplines.

CHAPTER 2

Related work

2.1. Tangible interaction

Tangible user interfaces are designed, implemented and evaluated by different research groups all over the world. Although 'tangible user interface', as well as 'tangible interaction', 'graspable interface', 'physical computing', 'IT product design' or 'interactive spaces' are widely used to describe a same type of novel interfaces, various definitions of their meaning co-exist. This section presents definitions, concepts and frameworks, as well es diverse examples of tangible interaction in current literature.

2.1.1. Definition

The first steps for establishing a definition were taken by Fitzmaurice, Ishii and Ullmer in two different approaches called *Graspable User Interfaces* and *Tangible User Interfaces*. Both approaches provide their definition by comparing the tangible idea to the idea of graphical user interfaces.

The core aspect of Fitzmaurice's [Fit96] definition of Graspable User Interfaces lies in the conceptual shift in thinking about physical input devices not as graspable *devices* but as graspable *functions*. Such a graspable function consists of a specialized physical input device which is bound to a virtual function and can serve as a functional manipulator.

The more generic and elaborate approach of Ullmer and Ishii [UI00] [UIJ05] is build upon the relationship of representation and control of digital data in a user interface. In their proposed interaction model (MCRit model), the view component is split up in two different components: the tangible, physical representation of the digital information, and the intangible representation of the digital data (e.g. video, projection and audio). The key characteristics of the MCRit model are defined as follows:

> 1. *Physical representations (rep-t) are computationally coupled to underlying digital information (model).*
> 2. *Physical representations embody mechanisms for interactive control (control).*
> 3. *Physical representations are perceptually coupled to actively mediated digital representations (rep-i).*
> 4. *Physical state of tangibles embodies key aspects of the digital state of a system.*
>
> [UI00]

Although this definition is widely mentioned in publications, several researchers criticize it as being to narrow and excluding several aspects of tangible interaction. Arising from the field of HCI, it focuses on the representation of data as physical containers.

To provide a broader view upon tangible interaction and include research from related areas such as interactive spaces, Hornecker and Buur [HB06] propose a framework around the four themes of *Tangible Manipulation*, *Spatial Interaction*, *Embodied Facilitation* and *Expressive Interaction*. The themes provide concepts addressing design issues from a specific and a generic point of view, such as *Haptic Direct Manipulation*, defining if users can 'grab, feel and move the important elements' or *Multiple Access Points* to provide users with the possibility to see what is going on and reach the central objects of interest.

2.1.2. Concepts and frameworks

Besides the frameworks provided by Ullmer and Hornecker, a number of frameworks have been proposed, each with a slightly different focus. Holmquist et al. [HRL99]

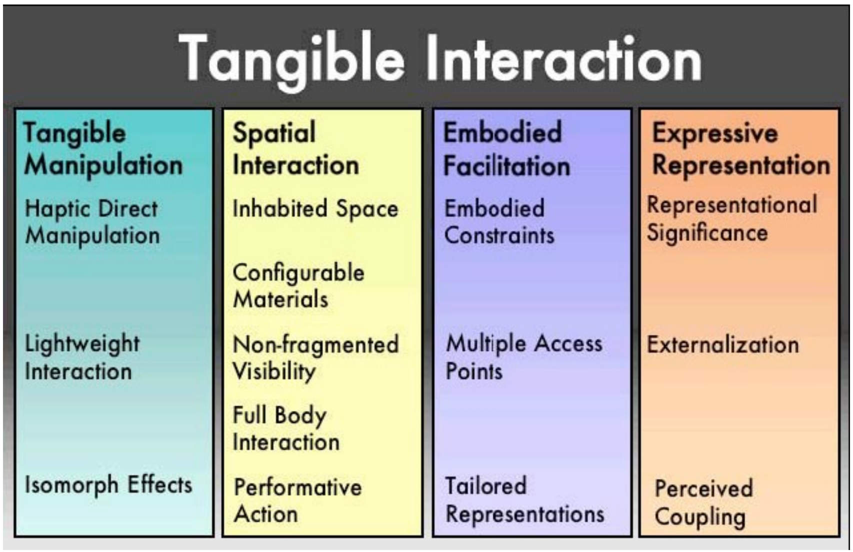


Figure 2.1.: Tangible interaction framework by Hornecker and Buur [HB06]

laid the foundation of the token-based taxonomy by suggesting that physical objects can be linked with digital information. The three classes of containers, tools and tokens each represent a different object: *containers* refer to a generic object that can be associated with any type of digital information, *tokens* have their associated digital information reflected in the physical properties of the object and *tools* are used to actively manipulate digital information.

Ullmer [Ull02] introduced in his dissertation the concept of token+constraint systems, where tokens are considered as physical artifacts representing elements or aggregates of digital information. This digital information gets confined by constraints, which physically channel how tokens can be manipulated. The relationship of the token to one or more constraints is then mapped to a computational interpretation. The two modes of interaction in this concept are association and manipulation, the most common relationships are presence, position, sequence and proximity.

The Token and Constraints (TAC) paradigm by Shaer et al. [SLCGJ04] is based on the token+constraint approach by Ullmer. It identifies components and properties to specify a wide range of TUI systems. The notions of tokens and constraints are taken from the definition of Ullmer, and completed by two additional terms. A *pyfo* describes a physical object that takes part in a TUI, and a *variable* is the digital information or a computational function in an application. These four terms allow to define the TAC as relationship between a token, its variable and one or more constraints. The designer specifies the relationship, the instantiation is done by either the designer or the user. A physical manipulation of a TAC is a manipulation of a token with respect to its constraints, and has computational implications.

Koleva et al. [KBNR03] analyze the different ways in which physical and digital objects can be coupled. They propose a coherence continuum, categorizing the extent to which linked physical and digital objects might be perceived as being the same thing. In addition, Koleva et al. analyze the underlying properties of this link, such as transformation, lifetime of link, autonomy, etc.

A taxonomy based on two dimensions is proposed by Fishkin [Fis04]. He distinguishes the axes of embodiment, describing how close the input focus and the output focus are tied, and metaphor, saying whether the system effect is analogous to the real world effect. With this taxonomy a more elaborate range of tangible user interfaces can be analyzed and classified by giving it a certain range of both axes.

An analysis of 'Action' and 'Function' in tangible interaction is given in [DWFO04]. The framework describes practical characteristics for coupling users' actions with information such as time, location, dynamics or expression [WDO04].

A good overview and classification of the myriad of proposed tangible interaction frameworks is provided by Mazalek and Van den Hoven [MVdH09]. They analyze facets of frameworks by differentiating between experiences, domains, physicality, interactions and technologies. A second classification is done via type, describing whether the frameworks are for abstracting, designing or building tangible interaction. The work indicates which areas on the framework map remain empty, and which ones are most populated.

2.1.3. Example systems

A very first example system described in literature is the *Marble Answering Machine* [Smi95], designed by Durell Bishop. Its idea is to use marbles for representing and playing back messages on a telephone answering machine. Users can play back a message by placing it on the dedicated area, or to clear it by putting it on a different spot.

A second early example is the *Media Block* system, which was described by Ullmer et al. [UIJ05] as token+constraint system. This TUI uses small wooden blocks to capture, retrieve and manipulate images and video files. The blocks may be put into different slots to send them to different media input and output devices, such as a printer or a whiteboard.

Recent approaches are often based on tabletop interfaces where interaction takes place on and around a table which is augmented by a projection. A quite popular example is the *reacTable* [JGAK07], a musical interface for collaborative control of sound synthesis processes. The system allows users to place and arrange specialized blocks on a translucent surface. Each block represents a type of sound generator, filter, or controllers that can be modified through finger tips.

Other examples for tangible user interfaces use the whole room as interface. *I/O Brush* [RMI04] is a drawing tool to explore colors, textures, and movements found in everyday materials by 'picking up' and drawing with them. *I/O Brush* looks like a regular physical paintbrush but has a small video camera with lights and touch sensors embedded inside. Outside of the drawing canvas, the brush can pick up color, texture, and movement of a brushed surface anywhere within the room. On the canvas, artists can draw with the special 'ink' they just picked up from their immediate environment.

A tangible interface based on movements on the floor is the *magic carpet* [SBN+01], which uses pressure mats physical props to navigate a story. While children's drawings can be selected and viewed on a screen via barcode, they can be moved and zoomed using 12 different sensor mats on the floor.

While a majority of the TUIs use blocks or cubes as physical objects, others explore other materials and forms that are suitable for manipulating digital information. *WebStickers* [LRH00] is based on paper stickers that can be attached to physical objects making them act as bookmarks to the worldwide web. A barcode allows the user to save or load the respective web pages. Topobo [RPI04] uses parts of different forms to build robotic creatures. The movement of special joints can be programmed individually through demonstration. Illuminating clay [PRI02b] allows users to analyze and alter the topography of a clay landscape model. A ceiling-mounted laser scanner captures in real-time the changing geometry of the clay. Results are back projected as color gradients onto the workspace.

2.1.4. Sensing technologies

Detecting positions and orientations of several physical objects on a table or within a specified area is a common issue for researchers. A simple and cheap possibility to implement this is to use computer vision algorithms and fiducial markers. These types of frameworks focus on calculating the positions of each of the markers and/or the camera in 3d space. Each of the tangible objects is labeled with such an optical marker to be detected by the camera. The ARToolKit library [KB99], developed at the University of Washington, is used in many augmented reality applications like Handheld Augmented Reality [WS03] or the Magic Book [GDSB07]. It uses rectangular size-known fiducials with a wide black border to calculate their position and orientation in 3d space while an inner pattern allows the identification of the fiducial. Another system: TRIP [DLdIMH02], uses a combination of circular barcode tags, so called ringcodes and cheap CCD cameras to achieve a similar goal. Cho and Neumann [CLN98] proposed a multi-ring, multi-size fiducials system where markers, consisting of concentric circles in different colors are used to solve registration problems in large-scale environments.

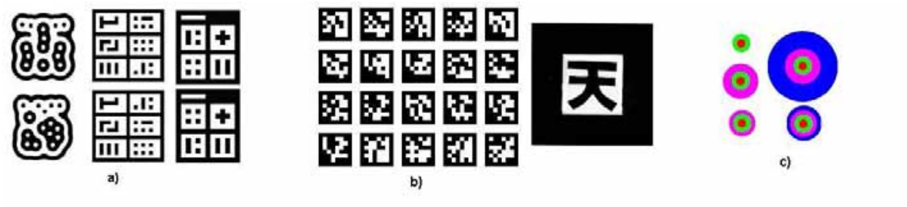


Figure 2.2.: Examples of fiducials in different existing visual tracking systems a) reacTIVision, b)ARToolKit, c) Multi-ring Color Fiducial Systems

Fiducials, claimed to be quite aesthetical and allowing smaller sizes then the ARToolKit markers or the reacTables initial D-Touch engine [CSR03] , are used by reacTIVision [KB07] for the reacTable music interface. They are attached to the bottom of physical objects and tracked through a semitransparent surface. ReacTIVision is concepted for 2d tracking purposes. Tangible Notes [SWA$^+$06], a music-toy for preschool children, employs plain circles in different colors, that represent several note-lengths, and can be placed on a table in different positions to compose a tune.

A different type of tracking frameworks is based on RF tags, small circuits consisting of a coil of wire and a capacitor. The circuit resonates when entering an electro magnetic field and can be tracked using antennas. Typically, two RF tags are attached onto an object to detect positions and orientations. Example systems being based on this technology are Audiopad [PRI02a], an interface for musical performes or Sensetable [PIHP01], a platform for tangible interfaces.

Further technologies use the commercial RFID, such as the PitA-board [Ede02]. This interface, developed within the context of the Envisionment and Discovery Collaboratory, uses a DGT Electronic Chessboard creating an interactive grid of 8x8 fields. In contrast to optical markers, RFID tags can be integrated more easily within the design of the tangible objects. A disadvantange of this tracking technique is that positions are not detected continuously, but only on the specified 64 areas.

A newer development, called SurfaceFusion [OW08], combines RFID and computer vision to create a simple and reliable solution for tracking a high number of different objects.

The tracking framework of the *ColorTable* is based on computer vision and uses color and shape information for detecting and tracking objects. These can then be numerously variated in size, shape, color and material, to be seamlessly integrated into the design of the physical objects.

2.1.5. Tangible interaction urban planning

Within the field of tangible interaction we find different examples of interfaces used in urban planning. Arias et al. [AEF+00] have proposed a conceptual framework that stresses the fluidity of real-world problems, such as urban planning, and the fact that 'the very process of collaboration among stakeholders further increases the ever-changing problem context' (p. 90). One of their applications is the *Envisionment and Discovery Collaboratory* (EDC) [ESH02], a tabletop application where participants work around a table, interacting with computer simulations through manipulating physical tokens, representing elements of the domain. They have, for example, in this way simulated the dynamics of a bus route, with participants engaging in 'what-if' games and being able to anticipate and discuss the consequences.

Another tabletop example is *Urp*, a physically based workbench developed by the MIT Laboratory that allows users to study light properties and flows of an architectural scene [UI99]. When physical models are placed on a table surface, the resulting shadows, reflections, and pedestrian-level wind flow are digitally visualized on the surface. A second tabletop application developed by the Media Lab is the *Illuminating Clay* [PRI02b]. Users of this system may alter the topography of a clay model in order to design and analyze landscapes. The results of a modification are constantly projected back into the workspace. The *Luminous Table* [IBJU+02] is an augmented reality workbench integrating multiple forms of physical and digital representations, such as 2D drawings, 3D physical models and digital simulations. All of these elements are overlaid on the same table surface.

Caretta [SHH04] focuses on the integration of personal and shared spaces by using a tabletop tangible user interface for group collaboration and personal digital assistants (PDA's) for each user. Within a shared space, participants manipulate scale models of houses, stores, or office buildings to redesign a town. Within their personal space, users can test a plan in private by redesigning one on the PDA.

BenchWorks [SS05] was developed within an experiment and explores simple possibilities of positioning virtual models in an augmented environment. *ARTHUR* [BLO+04] further investigates this idea and uses an elaborate set of interaction possibilities to integrate functionalities of CAD systems into a collaborative environment.

2.1.6. The ColorTable as tangible user interface

To analyze the *ColorTable* as system based upon tangible interaction, we refer to the framework proposed by Hornecker and Buur [HB06] and describe its characteristics related to each of the themes and concepts.

Tangible manipulation: To support *haptic direct manipulation*, we provide colored tokens, as well as content cards and barcode trays that users can grab, feel and move. Also the physical maps and the rotating wheel can be physically manipulated to perform interactions. Placing and rotating objects is directly mapped with respective movements of the colored tokens (*Isomorph Effects*). The use of command cards or barcodes for manipulating the objects' appearance or the scene however requires some explanation.

Spatial interaction: Due to the arrangement of table, screen and content board within a common space, the *ColorTable* supports *full-body interaction*, as well as *performative actions* while gesturing and pointing towards the different components. We use large paper maps, as well as clearly presented areas for selecting and assigning content (*non-fragmented visibility*).

Embodied facilitation: Embodied constraints are provided by the large table, and the tangible objects and devices being distributed all around. Users reach the objects around and help each other. The colored tokens and the content cards are accessible for all users (*multiple access points*), most devices or components however are located at one specific position and therefore only accessible for the users standing right next to them. The round table, the physical maps and the wooden tokens are familiar for users and invite participation (*tailored representation*).

Expressive representation: Users hold the colored tokens and the content cards while thinking or discussing (*externalization*). The coupling of physical and digital representations however is more complicated to follow. Users can read this information on the info area when placing a command card onto the configuration board, or check them by looking at the positions of the projected objects on the top-down view or perspective view.

This reflection shows that the *ColorTable* features most of the characteristics as required by the proposed tangible interaction framework. Concepts that are less represented, such as expressive representation, are mostly explained by the complexity of the application, or the limitations of the technology.

2.2. Augmented and mixed reality

The concept of mixed and augmented reality arose in the nineties: instead of concentrating on purely virtual environments hiding all elements from the real world, the real world is deliberately taken into account and mixed with virtual elements in order to produce an enriched version of the existing world.

The original definition was expressed by Milgram et al. [MK94] [MTUK94] to show the relationship between Augmented Reality and Virtual Reality. The key component of their definition is the *Reality-Virtuality Continuum*, considering a generic mixed reality environment as one which lies anywhere between the two extrema of a purely virtual and a purely real environment. One possible configuration is an *Augmented Reality* environment, where the real world is enriched by a limited number of virtual objects or information.

According to Milgram et al., a *Mixed Reality Application* therefore defines any application that

- serves for visualization, animation, generation or modification of scenarios of real or abstract character
- presents real world and virtual world elements together within a single visual display

An alternative approach to the notion of Mixed Reality is provided by Benford et al. [BGR+98]. Departing from a classification of CSCW technologies, they propose the concept of *mixed reality boundaries*, joining multiple physical and synthetic spaces. An important aspect of their work is that they explicitly deal with non-Cartesian coordinates to connect the different locations.

2.2.1. The ColorTable as mixed reality tool

The *ColorTable* uses different types of mixed realities to visualize the scene users are creating.

The see-through view To provide a see-through view, we use a special projection screen which is fixed on a window showing on the landscape to be augmented. As screen we use a type of grid reflecting the projection, and simultaneously providing a view onto the real environment. The virtual objects, positioned in an empty space and seen from the same viewpoint as the viewer, are projected on the white cloth in order to overlay it on the real scene.

This optical see-through solution provides a most direct and natural view onto the real site, the experience of looking at, feeling and sensing the environment is preserved. A well known problem of this type of mixed reality is the alignment of the virtual objects with the real environment. Each user sees the scene directly from his point of view. As there is only one screen visualizing the virtual, overlaid objects, their alignment can only fit for one user; the rest of the group will perceive a displacement of the virtual objects relative to the real environment.

Another problem, see-through systems have to deal with is contrast. The high illuminated real landscape needs to be cross-faded by an electronic projection. It is possible to narrow the illumination of the outdoor by using a darkening plastic film and a grid, however, contrast suffers from this procedure.

The video augmented view The video view captures the view onto the real environment with a video camera. The scene is thus not viewed directly, but through an electronic synthesis process. Users see the scene from the point of view of the camera, which can be perfectly aligned with the virtual objects. This augmented view can then be contemplated by a high number of users.

To navigate in the video augmented view, the camera needs to be manipulated in order to change the point of view. We use a pan-tilt unit that can be controlled with a custom input device from the distance. It enables rotating, tilting and zooming of the viewpoint with an external controller.

The panorama view The panorama view provides a most processed view onto the urban site. To show a view into a specific direction, we use the corresponding section of a cylindrical panorama and augment it with the virtual objects. As this view is static, we can store additional knowledge about the scene. We use a depth map to define distances of individual objects and experimented with a height map as shape information of the floor. This background is therefore the scene which is most modeled and which handles occlusion and alignments most precisely.

The top-down view Although the top-down view does not provide any realistic view onto the urban site, it is a composition of real and virtual elements. The real parts are the paper maps and colored tokens providing an amount of detail, graspability and natural manipulation that virtual scenes hardly present. These elements are augmented with the digital lines, dots and thumbnails representing contents of the colored tokens, viewing direction and feedback of the detected tokens.

The top-down view is a two dimensional, illustrative MR view of the urban site providing a good overview to discuss and perform different interventions.

Part I.

Requirements and concepts for design

CHAPTER 3

The context of urban planning

The idea of the *ColorTable* was to provide possibilities for diverse stakeholders to address urban space in different ways, and to modify its meaning by creating a new space and a new language showing a common vision of the involved parties. As explained in [MWB^{+}10], the three main tasks to be supported are:

- *Understanding space: identifying urban issues (centralities, flows, landmarks, etc.), relating to places, occupying.*
- *Manipulating space: define objectives, confronting ideas, annotating, negotiating.*
- *Augmenting space: putting together, creating urban scenes, presenting, and communicating.*

To guide technology development within this context, a number of workshops have been organized dealing with specific urban issues of ongoing urban projects. The objective was to bring together stakeholders who are involved or are concerned by the project to discuss on the project site. The workshops have been organized on different sites and in collaboration with the public authorities in charge of the project.

Participants have been chosen to constitute a representative group of existing stakeholders: representatives of public authorities, urban specialists, private stakeholders and citizens involved in the ongoing project have been invited for their professional as well as their personal competence and knowledge of the site.

This chapter provides an overview of the different urban planning projects, the setup of the technologies and how participants used them during the individual sessions. Parts of this chapter are based on the papers *Expressive Interactions - Supporting Collaboration in Urban Design* [MPWW07] and *Supporting Community Engagement in the City: Urban Planning in the MR-Tent* [WBE+09].

3.1. Sainte Anne

The first and second workshop were carried out on the premises of the psychiatric hospital Sainte Anne in March 2007, which is undergoing a ten-year renewal process. The scenario we developed for the workshop focused on the wall enclosing the hospital. The wall evokes issues such as closure/openness, intimacy/exposure, safety/security. For patients, the experience of the wall is ambivalent. While feeling protected in a unified and quiet space, they also are locked in. For the medical staff, the wall helps structure the inside space and keep it under surveillance. For the neighborhood, Sainte Anne looks like a fortress, like the La Santé prison located in the same street, a few blocks away. The wall protects them, shielding them from 'delicate' encounters. But the inhabitants of the district also have a feeling of curiosity and mystery about what happens behind the wall (Figure 3.1).

Figure 3.1.: The wall from inside and outside.

The wall has architectural quality; it requires dealing with materials, transparency, diversity, and rhythm. Openings in the wall facilitate the crossing of sound and gazes from both sides. The wall can also be considered as a screen, as an information support, a landmark, an icon for the urban situation. Knowing that there is a tradition in Sainte Anne to encourage patients to express themselves through graphic means, an exhibition of the art brut collection of the hospital could be an interesting way to express a link between the world of therapy and the outside world. People passing by could also be involved by being able to give and modify information, leave and remove messages, etc.

3.1.1. The technologies

At Sainte Anne we experimented with an early version of our mixed reality tools. In the first workshop, we demonstrated our idea of the *ColorTable* as collaborative space using a table and colored objects for positioning virtual objects onto a real background. The early technology probe was appreciated by the participants and suggestions for improvement were provided.

In the second workshop, the *ColorTable* was set up in a hired tent, on a parking lot at the site (Figure 3.2). It provided users with the possibility to arrange and position tokens on a surface, representing a 3d scene. The tokens in combination with a barcode interface, were used for associating multimedia content and for manipulating this content, varying positions, scales, transparencies, and colors. Two projections visualized the composed scene. The tabletop projection displayed a map on the surface of the table, which provided a bird's eye view of the site. A vertical projection rendered the scene as seen by a pedestrian standing in the center of the working area. A customized infrastructure of the table enabled rotating the surface of the *ColorTable* in order to move the scene around the user.

Figure 3.2.: The setup of the ColorTable in Ste Anne.

3.1.2. The sessions

In the second Sainte Anne workshop, we worked with two different user groups. The first group included the chief architect for Sainte Anne, the director and a manager of the hospital, as well as a representative of the urban heritage institution of the city of Paris (ABF). The second group consisted of two participants from Sainte Anne, several architects involved in an urban planning institute ('Ville en mouvement'), a journalist with a focus on urban issues, an urban sociologist, and a sound specialist.

Participants in the two workshop sessions had a quite different approach to work with the mixed reality tools. The chief architect (R.) led the small group of participants through the first session, with the long and still unresolved debate on how to transform the wall surrounding Sainte-Anne in the back of her mind. She had already been part of our first workshop in Sainte Anne and her approach was explorative, taking the scenario as an opportunity for exploring the potential and limitations of the mixed reality tools.

> *When moving to the ColorTable, R. was immediately captured by the panorama. She turned the table, looking at the moving view. She grabbed some of the color objects, searching for suitable objects in the printed-out material. At each move, R. looked for agreement with young heritage architect (Ch.), who contributed to the selection of images, also placing her own objects. But it was R. who clearly was in charge, while Ch. contributed in a silent way. They started by creating a park in the parking lot, placing bushes, some trees (to hide the hideous residential buildings on the street behind), and flowers. They also tried to place two of the towers (the ones with water textures) (Figure 3.3). R. asked for a texture (pebbles) to cover the ground. She would like to tilt the tower, which is not possible in this application, and she added people to the scene. R. was also excited by the see-through installation, probing to place trees and a person, while trying to focus so as to capture the mixture between real and virtual scene. [MPWW07]*

> *The second group had a much more cooperative approach. They first rotated the table to have a good view onto the wall - 'this is something to see from both sides'. They played with the idea of a 'mur vegetal' - 'does this have to be a parking lot'? - changed the floor to a mosaïque pattern, placed bushes, two benches, several lamp posts and populated the space with silhouettes of people. Their emphasis with these moves was on creating a story of changing the parking lot and their main focus on playing with atmospheres. [MPWW07]*

Figure 3.3.: 'Furnishing' the panorama.

Figure 3.4.: Cooperative imagining.

The way of cooperating within this second group was rather different from the first group. While the first group concentrated onto the urban planning specialists, the second group was more inclusive and also one of the hospital doctors participated (Figure 3.4). The group started by discussing their interventions and selected objects together by looking through the printouts of thumbnails and barcodes. They studied the projected map on the *ColorTable* and then took the first color tokens and placed them onto the projected map. We experienced a high level of concentration while participants selected objects, placed them, looked at how they appeared on the panorama view, carefully rotated the table to change perspective, and all this in a highly cooperative way, commenting on each move.

3.2. Courthouse (TGI)

The third participatory workshop took place in September 2007 in Paris. It deals with the implementation of a new courthouse (Tribunal de Grande Instance) close to the Seine and the Bibliothèque Nationale de France (BNF) (Figure 3.5). The French Ministry of Justice launched an international architects competition for the master plan of the new Paris courthouse. In October 2006, a first ideas competition has been undertaken, and the administration of Justice has negotiated with the City of Paris about the opportunity of building the courthouse on this site. Issues to be discussed deal with the impact on the urban fabric, the symbolic of the location, public transportation and accessibility and the compatibility with a housing program.

Figure 3.5.: The site is located near the Seine river, the new Library and a railway line.

The program includes three main issues:

- Creation of a large esplanade which will be covering the existing railways between the future TGI and the BNF (Library). The housing blocks will be built on the esplanade
- Use or destruction of an existing industrial building (la halle Freyssinet) from the beginning of the 20th century and of great historic importance
- Accessibility of the site: progress from the main public transportation (especially from the metro stations), entrances to the TGI, differentiation of the different users, etc.

3.2.1. The technologies

The workshop took place in a multiplex cinema (MK2) in a large room with a glass front reaching down to the floor, with a view onto the site (Figure 3.6). The *ColorTable* prototype we used for this scenario was an improved prototype of Sainte Anne. Basic features were unchanged, such as the positioning of elements, the modification of elements and the use of different realities. In addition, the prototype supported navigation in the scene using different panoramas, direction of flows and the addition of paper sketches on an separate interface. Several interaction modules had been redesigned.

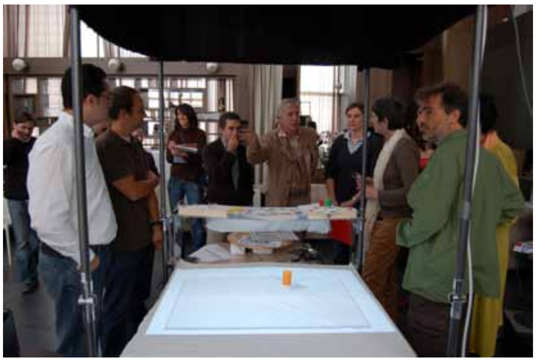


Figure 3.6.: The ColorTable prototype was setup indoors in a large room.

Prior to the workshop, students from the School of architecture at Versailles have been working on this project, on the basis of the past competition. Three projects were selected to be used with the *ColorTable*. Beyond typical design documents, these projects included physical models, digital models, and images of different textures for façades. In addition, three photographic panoramas from different viewpoints were prepared and one night panorama.

3.2.2. The sessions

Two different user groups worked with the IPCity technologies on two consecutive afternoons. Participants were a representative from the Ministry of Justice, architects, sound specialists, as well a few selected residents.

When participants worked with the *ColorTable*, they usually started with a panorama showing a view from the multiplex cinema. The basic interaction was to place objects - the TGI models developed by students and/or quite neutral building blocks representing housing - and size them up or down, change color and transparency. Participants used both tangible selectors for assigning content to the colored objects and they used the command poster for changing size, color and transparency of the objects. As soon as a scene was composed, the panorama view could be changed using the small paper map in order to look at the mixed reality scene of site and architectural interventions from different viewpoints. They also experimented with the sketching function and with inserting and directing flows of people through the terrain.

3.3. Caserne Bossut

In year three (September 2008) we organized a more elaborate workshop within the context of the urban planning project of the Caserne Bossut in the city of Pontoise. The site was chosen in relation with the urban issues addressed by the Agglomeration Community of Cergy-Pontoise and the Planning and Urban Design Summer Workshops organized by the Ateliers with Cergy-Pontoise University.

An important issue concerned the identity and the future uses of the site to reflect local needs.

> *The barracks of the Caserne Bossut (1914-1916) are nowadays a wasteland situated at the borders of highway A15 that crosses Cergy-Pontoise, a town 40km away from Paris (Figure 3.7).* [...] *Since 2005 the area is hosting a police department and is used as a training field by the fire brigade.* [...] *As the casern was not open to public life, it is perceived as a sort of huge hole in the urban texture. It is nowadays one of the last large land reserves in the city of Pontoise.* [WBE+09]

A communal development plan anticipates the development of a vivid future district for the site, which is surrounded by residential areas, a private school and a university. 90% of the existing buildings will be replaced by new constructions, but the streets will be conserved. The Place d'Armes, the central open space, will become a major public place with lively community interaction.

The main urban stakes deal with different scales and the point of view of several stakeholders. The City of Pontoise, for instance, is interested in how the revitalisation could affect the nearby residents or the relation of a historic town to the modern center of Cergy. The Agglomeration Community is concerned about the identity and the uses of the site and thinks about using it for vivid activities or to rest and leisure. Therefore connections and public transportation are very important elements. As the site is at equal distance from the two main train stations of Cergy-Préfecture and Pontoise, it could represent a new centrality (Figure 3.7). While the

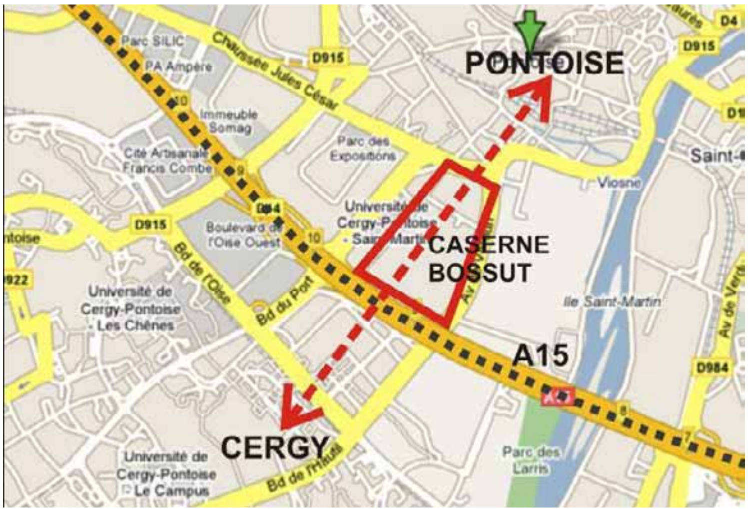


Figure 3.7.: The Caserne Bossut is situated between Cergy and Pontoise, 40 km away from Paris.

highway A15 acts as a border for the moment, a subject of discussion could be how it will be crossed.

As preparation of this elaborate workshop, an additional smaller workshop was organized in June 2008 (see Section 3.5.2).

3.3.1. The technologies

The workshop took place outdoors on the site of the Caserne Bossut. We used the MR Tent to provide shelter for workshop participants and equipment. The *ColorTable* prototype was set up in the center of the tent, while two projection screens simultaneously provided different MR views of the urban scene. Several aspects of the prototype had been improved such as the design of a physical table providing space for all tools and tangible objects. We also implemented a series of new features: the positioning of connections, rows of objects and land use areas. Wooden tokens in different shapes provided the handles to manipulate these urban elements. Along with the barcode interface, tangible selector and info screen to associate and manipulate content, this prototype provides an elaborate set of tools to create complex mixed reality scenes. The compositions can be viewed against 4 different panorama backgrounds, a live video stream or the see-through screen (Figure 3.8).

Further, the *ColorTable* prototype was connected to an application called *Urban Sketcher* [SS07]. It uses a pen allowing participants to sketch onto virtual objects or

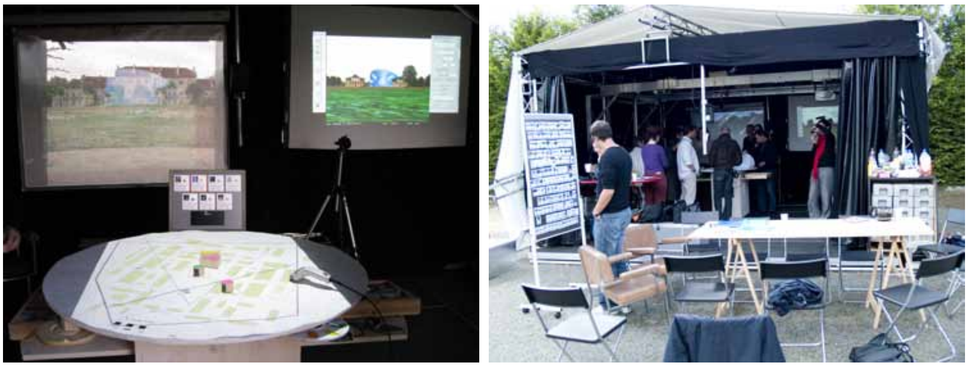


Figure 3.8.: The setup of the technologies for the workshop in the Caserne Bossut.

the composed scene.

3.3.2. The sessions

Aim of the workshop was to put all participants on 'equal footing', irrespective of their competencies and to create an atmosphere where each of them brings his/her own vision of the future site, based on what he/she had elaborated before. Participants were asked to settle on 2-3 questions they would like to address together and then convened around the *ColorTable*. Members of the research team occupied different observer roles without interfering in the negotiation process. To give a flavor of participants' interactions we here describe one session with six participants (architect, specialist for water and environmental risk, policeman, student, representative of commerce).

> *During the morning tutorial the group had quickly appropriated the MR technologies. After that they decided on the questions they wanted to focus on: how to connect the site with the two towns, the university and the river Oise; how the centrality of the site should be defined; and what kinds of housing and activities to envision. [WBE+09]*

> *As soon as participants had assembled around the table, they started explaining the site and its environment to each other, with the policeman (P), who is stationed on site, describing his view. There was an animated discussion and the group decided to start setting paths, beginning with the*

Figure 3.9.: Setting flows (left); Flows and family houses as seen against video stream of site (right).

'transversal' ones (Figure 3.9). They first checked all the tokens they needed and placed them on the edge of the table. Road setting was done in a cooperative way, first on the map 1:500, and embedded in an intense discussion of the territory, issues of access, and the central axis. Each step was checked if everybody agreed. Participants tried to exactly position three parallel roads (50km type). The next step was to set 'flows', step by step, looking at them from 'the blue tower' panorama. This involved a debate about the kinds of traffic to invite and how this would affect the site. They also set a path for pedestrians and cyclists along the main axis. E (the responsible for commerce) suggested placing a bridge across the highway (large enough to also allow a small bus to cross) and a bus stop nearby. A blue arch appeared in the panorama taken from the roof of the nearby university. After that participants examined the area close to the Oise, with again P explaining, and E engaging in a long conversation about this area, the traveling people who live there, and they finally decided to set a pedestrian path from the site to the Oise. [WBE+09]

The next scenes are to do with participants selecting and placing buildings. They first looked at different types of residential buildings placed on the whiteboard, later they also added images representing ambiances (e.g. streetscapes, facades) and scenes (e.g. children playing). They discussed all the time, taking an image, placing it back, sometimes all together, sometimes two of them. At one point, JM (from the municipality) took over and placed the cards in front of him on the table. He started by presenting an idea and all the others joined. There was a moment of vivid

> *simultaneous pointing and explaining. They created a row of 3D buildings close to the viewpoint of the panorama - the blocks looked gigantic and the participants rearranged them and placed another row symmetrically. E lifted up a card as a reminder - these are one-family houses, which they arranged in the corner left to the entrance. They also added a texture to cover the ground. You could see the houses along a 'real' path (in the panorama). You could also see the pedestrian path crossing. Participants now really started 'filling' the scene (Figure 3.10). They also worked more on details, like G and E, who discussed the corner left of the entrance, with G mentioning that there should be more housing and he also pointed out paths and vistas from this point into the central place. [WBE+09]*

Figure 3.10.: Placing 3D buildings, green spaces and a texture on the ground.

3.4. Pontoise

The participatory workshop in year four was organized in cooperation with the City of Pontoise, the Agglomeration Community of Cergy-Pontoise and the University of Cergy-Pontoise. The urban project that has been chosen has been defined as the future use of the Chamber of Commerce of Versailles (CCI) with the help of these institutions.

The CCI building is located near the city center of Pontoise, 40km to the west of Paris. It houses the direction of the Chamber of Commerce of Versailles, which will be dislocated soon. The urban issues around this site deal with different scales of interrogation. Next to the future use of the existing building, public authorities negotiate its relation with the garden of Lavandières and the city center. Furthermore, the immediate surroundings, namely the park and chateau de Marcouville and small creek next to the parking lot are important elements near the project site. Their future use is being discussed by the CCI and the local government.

Further questions at city scale deal with the different centralities composing the city of Pontoise, such as the river Oise, the center of the new town of Cergy-Pontoise, the social housing neighbourhood of Marcouville, the military barracks of Caserne Bossut, as well as the St.Martin exhibition centre. An important matter is how to valorize the different existing centralities and how to address issues of connectivity (Figure 3.11). The project site can therefore be questioned as one of the elements of an urban pathway that would pass through the city and the different sites that compose it.

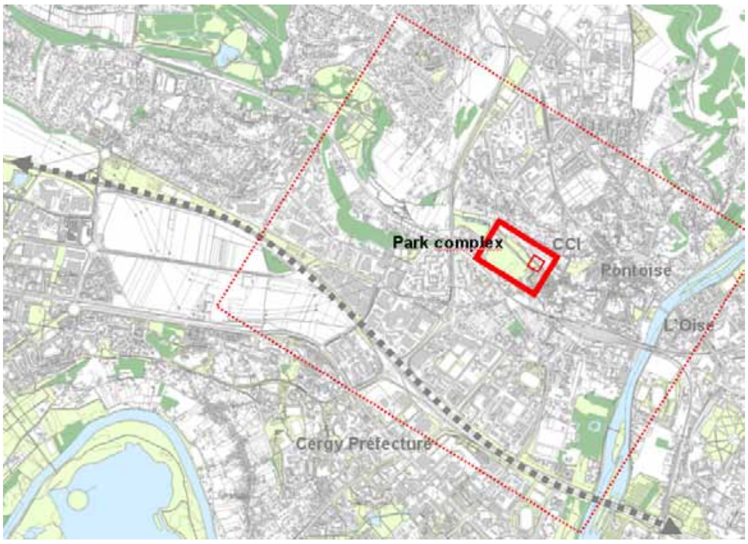


Figure 3.11.: The urban issues around the CCI deal with different scales of interrogation.

A preparatory urban workshop using the method of cultural probes had been organized to help participants formulate their vision and researchers to refine the different scales of interrogation, the questions to be addressed and the content material to be prepared. It took place in a building close to the site about a month before the participatory workshop.

3.4.1. The technologies

As in the Caserne Bossut, the workshop took place outdoors in the MR Tent. Based on observations and feedback provided from the previous workshop, we redesigned the *ColorTable* prototype and the space around. 5 different types of views could be used to visualize the composed scene on one projection screen: a panorama view, a live video stream, a see-through view, a mobile camera view and a virtual view controlled by a color token. Furthermore, a few features and interaction modules have been improved to simplify the workflow while preserving the complex set of urban manipulations. Tangible selector and content barcodes have been substituted by the configuration board and info area. Connections, flows and land use areas have been improved. As before, the prototype provides a connection to the *UrbanSketcher* to enable participants sketching, annotating and painting onto objects and scene.

Figure 3.12.: The ColorTable is set up in the center of the MR Tent.

3.4.2. The sessions

Two different user groups worked in separate workshop days with the *ColorTable*. In each group the main stakeholders of the site, as well as different competences - urban planners and designers, technical staff and elected counselors from the city of Pontoise, as well as residents as experts of everyday life of the site - were represented. We focus here on the second day, including an urban planner, an associate of the CCI, an inhabitant of Pontoise, the head of the green spaces service, an artist and a member of the local association.

The sessions started with a discussion without the *ColorTable*. Participants talked about the different centralities and their connections, what to do with the CCI building and the question of use. The group then gathered around the *ColorTable* and started with a view onto the viaduct. One participant started to paint onto the viaduct to create a 'mur végétal' with roses. Next they switched to the central panorama and made an effort to place two pedestrian paths exactly where they wanted them to be, leading through the park to the castle. They placed a bridge, football players, and a row of grass chairs (Figure 3.13). They also added stairs, symbolizing easy access for old and disabled people. Further, they focused on sound and heard football players, children playing, people talking and birds singing.

Figure 3.13.: Placing pedestrian paths (left), football players, a row of grass fauteuils and stairs (right).

The participants continued working with the detailed map. They concentrated onto the round parking and discussed how to redesign it. They recreated the CCI building with the *UrbanSketcher* and painted it in 'bleu Klein'. They defineed the limits of the parking area and attributed a texture of grey gravel. Next started a discussion about how to connect the castle with the town. Should it be accessible to pedestrians or to cars? They switched to the aerial view and placed a high traffic road to add cars onto the existing roads. They also added one parking for cars and a bus stop. Due to a misunderstanding how the scaling is interpreted by the system, they made the objects very huge. Back on the central panorama, the giant parkings rose behind the trees and they decreased their size again. They continued working on the park, placed two ponds with water lilies on the location of the old ponds. They activated the see-through view and controlled the positions of the different objects.

Participants switched again the panorama and concentrated onto the parking lot. They wanted to make it smaller and placed some green space. Although it required some effort, they modified the existing zone, colored it green and added some 'cabanes'. They decreased the spacing and colored them purple (Figure 3.14). Next they placed a row of green arches. E. looked for a symbol to add but did not find any.

A noisy car lead the discussion onto sound aspects. They decided to use some of the sound cards and associated them to the objects: people walking and talking, a small shopping area, birds singing. They switched to the video view and used the joystick to navigate through it. They also tried the mobile camera view to verify the position of the building and the cabanes.

Figure 3.14.: Creating a green zone and purple cabanes.

3.5. Further workshops

Additional smaller workshops had been organized in cooperation with two consecutive classes of the postgraduate program Urban Strategies at University of applied Arts Vienna in conjunction with the particular course programs 'density' and 'networks'. Together with the students, we exploited the potentials of urban rules within the given environment of the *ColorTable*.

Three steps served as conceptual guidelines within the design process. After getting familiar with the tangible user interface, each student group was asked to explore potential elements to conceptualize the city according to the given site. Within several sessions, these factors of influence were translated into simple parameters and precise numbers to build a system that reflects their mutual relationship. Designating variables and invariants of the model and exploiting possible representation methods cross-linked to the tangibility of the interface. The students then had the chance to test the implemented prototypes and explore interaction possibilities and feedback design with the *ColorTable*.

3.5.1. Urban Density: Airfield Aspern

Urban density is commonly measured by the relation of building land to the actual distribution of building mass on the site, which is expressed by the F.A.R. index, Floor Area Ratio. Other parameters, such as the minimum allowed distances between buildings in relation to their height predefine the general physical character of built environment. These kinds of quantifications summarized in an 'urban code', partly reflect restrictions, interdependencies and regularities within the underlying complexities of urban planning processes.

According to the course program, the subject of investigation was the former airfield 'Flugfeld Aspern' north of Vienna. Enclosed by opposing rows of single-family houses on two sides of the 240ha territory and an adjacent motor-plant opposite to agricultural land, the field should be transformed into a mixed-use area with different types of dwelling, social and cultural infrastructures, commercial uses, a university campus as well as public and green spaces.

We adapted the former *ColorTable* prototype to serve as a platform for a rule based urban planning tool. It uses 5 different colors to create blocks of predefined volumes, 2 colors to be used as force fields and one type of special token to create a territory. The amount of available barcodes was reduced heavily to improve the handling and encourage interaction. The prototype uses one top projection including a digital map, one perspective projection and one aerial view, while a wheel can be used to rotate the viewpoint. The *ColorTable* was set up in our institute in Vienna.

The workshop started with an introduction by the members of the organization team. The students were explained the goal of the workshop and the different steps and tasks they should work on. It followed an introduction of the *ColorTable*, which theoretically explained how the students can use tokens, barcodes and projections to experiment with different urban numbers.

The students gathered around the table, grabbed the territory tokens and experimented with it. As it was very unstable they froze it. They set a building inside the territory and turned the wheel to see it on the panorama. The students then continued with increasing the territory and setting several valid buildings (Figure 3.15). They experimented with the different parameters shown on the info screen and discussed how to increase the height of the buildings. They changed the building coverage, which increased height a little.

Figure 3.15.: Placing valid buildings (left); invalid buildings are displayed as red wireframe (right).

In the next step, students were told to change scale and work with a type of typology where one dimension of the buildings is fixed to a certain number. The students, again, put buildings inside the territory and experimented with different positions. They used the force fields and tried to understand how it works. As the buildings were again very low, the students tried again to understand how the height is related to the other parameters. It followed a discussion whether the different constraints and rules of the application were useful for urban planners.

The last step of the workshop dealt with the multi-objects. It raised questions about the distance between the different blocks. The workshop ended with a discussion about the student's impressions and suggestions for improvements.

3.5.2. Time and Connectivity: Caserne Bossut

The students were asked to choose individual topics in relation to future users of the application and their specific points of view. The students' projects varied from abstract approaches, specific local issues up to complex conditions in larger contexts, such as the general questions of spatial distance and actual reachability, the influence of noise or the relation of public and private properties. They particularly addressed individual patterns of daily life, responsible parties and decision makers regarding reciprocal relationships between economic values of territories, different uses and spatial organization.

We set up the technologies in our institute in Vienna. We used a round surface and a physical map. Tokens of 8 different colors as well as 3 two-colored tokens were provided to create programs, connections and trips. A perspective view showed the MR scene on four different panoramas that can be switched by barcodes. The viewpoint is rotated with a small wheel. To assign programs we used the tangible selector and small content cards being provided on a magnetic content board.

The workshop started with an explanation of the different tasks the students were confronted with. These were to discuss topics of time, distance and reachability in the city by negotiating a) the connectivity of the site; b) the distribution of programs and c) individual visions for the public and communal space. We continued then with the introduction of a role play and the students were adapting to the roles of elderly, businesspersons, family members, youth, urban planners/architects and persons from city council representing the typical stakeholders of the *ColorTable* prototype.

In a first step the students assembled around the contend board and started to discuss and select the programs (Figure 3.16 left). They first arranged the cards on the board and then put their selection onto the content tray: people drinking (orange), place du marche (pink), swimming pool (green), wood houses (light blue), cinema (purple) towers (red), airtree madrid (yellow), row-houses (dark blue).

We then continued with an explanation of the different functionalities of the *ColorTable*. The students immediately started to define several streets (Figure 3.17

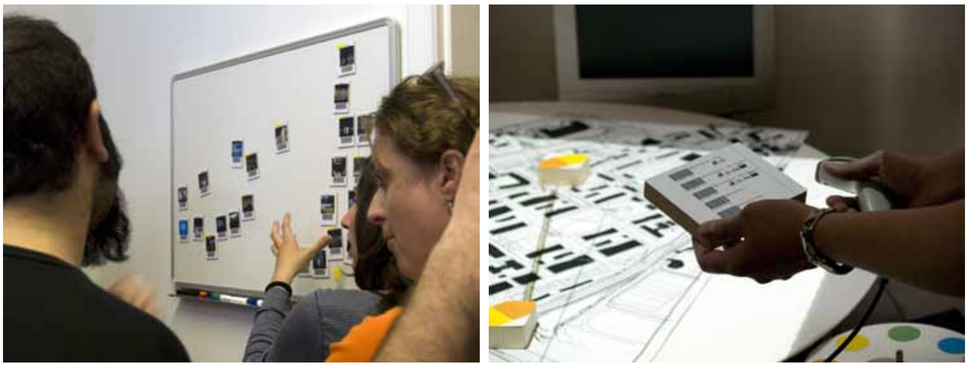


Figure 3.16.: Discussing and selecting content (left); setting a connection between Cergy and Pontoise (right).

right). As the map was too small to show the surroundings of the site, they did not manage to connect Cergy and Pontoise.

In a next step the group switched to the programs and discussed their location in relation to the surroundings and the streets. To visualize their ideas, they put the content cards directly onto the table and moved them until they agreed on the distribution. One of the students adopted then the role of assigning the programs to the colored tokens. He selected stepwise each color, assigned one of the programs, and placed the card onto the content tray to remember the representations. Some other students prepared the tokens, they placed the wooden objects on the side of the table and equipped them with colored plates. When finished, the group positioned the tokens onto the map and observed the footprints and the visualizations on the panorama (Figure 3.17). A lot of time is dedicated to the positioning of the towers and the pool. As the tower seemed to small, the participants changed the size. They added and removed constantly some tokens, observed the modifications on the panorama and on the info screen, changed the viewpoint, rotated the panorama, modified streets and added flows.

The workshop ended with a debriefing sessions around the table where participants commented on their experience and ideas for redesign.

3.6. Summary and conclusion

The workshops' themes started with relatively simple scenarios, such as filling a relatively empty real space with many small urban objects to work on an enclosing wall in the psychiatric hospital of Sainte Anne. They then continuously shifted toward more complex issues, such as the comparison of different architectural proposals for

Figure 3.17.: Discussing and selecting content (left); setting a connection between Cergy and Pontoise (right).

the court house in Paris, to finally address a scenario very close to a real urban situation: In Pontoise, stakeholders were debating on the future of a sensible site and were very concerned by its eventual transformation.

Within this context of urban planning, some aspects were considered being most important while developing the technologies.

- **Precision**: Architect users from the very beginning stressed the importance of scale and of the exact positioning of virtual objects. Therefore, it is necessary to provide solutions for supporting a certain accuracy between the physical and the digital and to support a most realistic mixed reality view onto the site. Further, most of the manipulations should be supported in a very precise way.
- **Complexity**: The technology needs to support a complex set of different functionalities, reaching from navigation methods, over quick compositions of MR scenes, to small modifications of specific attributes.
- **Familiarity**: Since a mixed group of stakeholders is using the technologies it is necessary to enable simple interaction possibilities which are not favoring a certain type of users.
- **Collaboration**: To best support communication and negotiation between the different participants, the tools are required to support a collaborative setup including multiple access points. Each of the participants should be able to enter the conversation and to perform interventions at any moment to support a natural way of discussion and collaboration.

CHAPTER 4

Integrating the physical and the digital

While designing and developing the *ColorTable* and its applications, we experienced the need for comparing different possibilities in order to be able to best relate the physical and the digital and to create tangible manipulations. In our research team consisting of designers, computer scientists and representative users, we argued about advantages and disadvantages of technical and design aspects in each phase of the development. This provided us with the information we needed to take decisions describing the best compromise for an interaction. These discussions needed a detailed level of understanding, where each aspect and component can be considered and which includes computational interpretations, physical objects, respective actions and how these are connected to each other.

In our opinion, the design and implementation of the technology of a TUI includes the design of physical objects (tokens, containers) supporting physical actions, *and* the design of digital objects (classes, software components) supporting digital actions. These two are closely related, and changing aspects or requirements of the physical design has consequences for the digital design and vice-versa. When a TUI is developed, the idea often originates from a set of physical objects and corresponding actions, where an adequate application is developed. But also the opposite procedure is quite common: A user interface of an existing application ought to be improved and convenient physical objects and actions are designed. In an iterative design process, such as participatory design, it is necessary to adapt digital and physical aspects throughout the design process in order to develop optimal design solutions.

To support this communication intensive process, we propose a framework creating terms to describe the detailed relationship between physical actions and digital actions in a tangible user interface. We believe that this framework provides the means to allow engineers, designers and users to more specifically discuss ideas and make decisions for future developments.

Although a high number of frameworks can be found in literature, none of them addresses the relation of the digital and the physical at this layer of the design process. Referring to the proposed map and overview of Malezek and Van den Hoven [MVdH09], our framework provides hints for abstracting and designing technological aspects of tangible interaction.

4.1. The A-Token framework

To understand how physical actions and digital actions are related in a TUI, it is necessary to take a closer look at how physical actions are detected by the system. The core component, responsible for detecting actions, is the tracking technology. It captures events, such as a trigger, or current states of the tokens that are changing over time. Examples of TUIs use different approaches to detect manipulations. The *reacTable* [JGAK07], for instance, uses fiducial markers that are captured by a video camera. The information that this tracking technology provides are the positions and orientations of each *reacTable* object on the interactive surface. An example for an alternate tracking technology is given by *Posey* [WDG08], using LED-sensor pairs to detect yaw, pitch and roll angles made by two connected objects.

In both examples, it is the values of these captured attributes that is used as input for the application and not the tokens themselves. We therefore propose to rethink the notion of tokens as smallest components and create a new framework where attributes of a token (A-Tokens) are used as key notions. As manipulations of a physical object do always modify one or more attributes of this object, it makes sense to refer to specific attributes instead of whole objects.

This shift in thinking provides us with a high range of interaction possibilities as attributes of a same object can control different functions. Also the values of several tokens can be combined to enable certain manipulations. For instance the relative position of two tokens can be used to compute a distance function, as it is the case in the *reacTable* [JGAK07].

We will now present the new framework based on A-Tokens, variables and their relations. Figure 4.1 gives an overview of the main notions of the framework. The concepts will be illustrated by the different interactive elements that were used throughout the development process of the *ColorTable*.

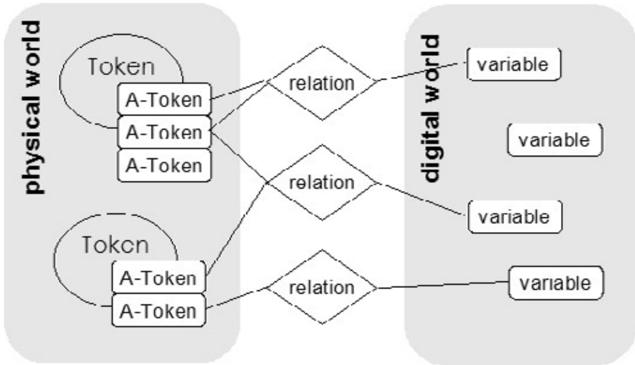


Figure 4.1.: The different elements of the A-Token framework.

4.1.1. A-Tokens

According to Holmquist et al. [HRL99], a token of a TUI is defined as a 'small thing representing the whole', in which properties of the digital information are reflected, and which should have some characteristics of the information it is linked to. The definition of tokens as physical artifacts associated with digital data was adopted by several researchers and became widely-used in descriptions of TUI applications [Ull02] [UIJ05] [SLCGJ04].

We use this same notion of token and refine it further by introducing *A-Token* as a new term. The A-Token as *A*ttribute of a *Token* is the key component in our new framework. It refers to any physical attribute or property within the tangible user interface that can be measured by the associated technology.

This property of being 'sensable' was described by Benford et al. [BSK+00]. An interface's sensable movements describe the ones that can be measured by the *"particular combination of sensing technologies that are used with the interface"* [BSK+00].

An **A-Token** can therefore be defined as an attribute of a token, that is:

- sensable,
- related to a variable, and

- limited by one or more constraints

Hence, the A-Tokens of the *ColorTable* are provided by the colored objects used for interaction. The sensing technology captures the x position, the y position, the color, the shape and the size of each object. These five attributes of each object are thus the A-Tokens of our system. Figure 4.2 shows the image that the camera captures as well as the information the software extracts from it.

Figure 4.2.: A-Tokens of the ColorTable that the sensing technology captures: 2D positions, sizes, shapes and colors

In contrast to fiducial marker based tracking systems, the color tracking does not identify each object on the table, but detects where a colored object is, and which size, shape and color it has. Therefore it is not possible to connect object IDs to certain functions, and it is necessary to consider the individual A-Tokens.

Further A-Tokens provided by the *ColorTable* are the ID codes related to barcodes and RFID tags.

4.1.2. Variables

The term *variable* is used in the same sense as in the TAC paradigm [SLCGJ04]. We use it for any input value that the application software needs in order to run its functions and compute the output data. A variable in our framework does not depend upon the value of other variables, and none of the variables of a specific system is redundant. Each variable may be of different nature, but is always one-dimensional. A position in space is thus defined by three independent variables: x, y and z.

Depending on the software design, the developer chooses a different set of variables as input for the application. This means that a different set of input values is needed to achieve a certain result, what again influences the requirements for interaction design. Additionally, it may be necessary to adapt software design and the corresponding variables in order to support a specific manipulation in the TUI.

4.1.3. Constraints

Constraints as notion in TUIs were first introduced by Ullmer [Ull02] as part of token+constraint systems to map structured compositions of tokens into a variety of computational interpretations. They are confining regions, where tokens can be placed into.

The shift in thinking from physical objects to attributes of objects affords an adaptation of this concept. A-Tokens as attributes of a physical object are limited by different types of constraints, all narrowing the set of possible values. One limitation is due to the nature of the A-Tokens: the values of a size must be positive, while the values of a color need to be within color spectrum.

Another set of constraints is provided by the sensing technology that only senses attribute values lying within a certain range. It influences the accuracy, as well as minimal and maximal values. An optical tracking system senses visual patterns, an RFID system senses the identity, and GPS tracking senses the position of a specific object. In each case, the system is able to provide different kinds of information about the physical objects. The tracking technology of the *ColorTable* tracks the positions within the camera view, a discriminative set of colors and shapes, and sizes lying within a minimum and maximum range.

Furthermore, the design of tokens defines an interval for the A-Token values as they are constructed in a way that only restricted values are possible. The *ColorTable* provides users with objects of several selected colors and shapes, and therefore limits them in their choice. Similarly, the size of objects is limited to a few values. When analyzing the different generations of our colored shapes, we notice how small modifications in design affect constraints.

The objects a) in Figure 4.3 are shaped as circles, squares and triangles. Magnets are embedded on the sides and encourage users to attach shapes to each other. Users may modify the size of one colored region by attaching several objects of the same color and therefore manipulating the *size-A-Token*. Alternatively, they can choose to create a combination of two different colors which can be interpreted by the system as a new type of object.

The objects b) each have a white border around them. This constraint imposes a minimum distance between two colored regions. It is not possible to place two

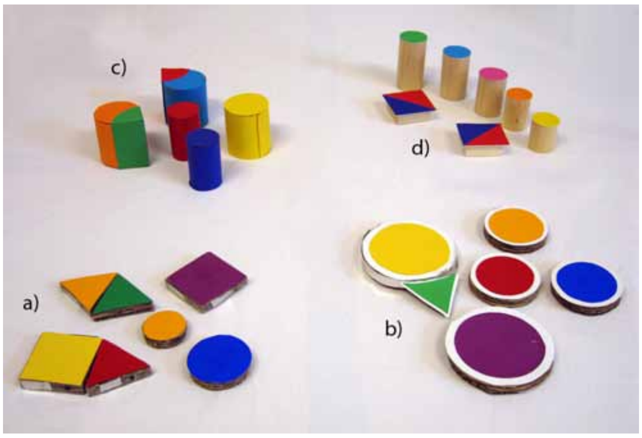


Figure 4.3.: Four different designs of colored shapes for the ColorTable

adjacent color regions and to modify their sizes as it is the case for the objects a). A colored object of this type has thus a predefined size that can only be modified when replaced with another colored object of the same color, but different size.

In Figure 4.3 the colored shapes c) are designed as cylinders. It is possible to place several objects adjoining, the round shape however does not encourage users to do so. This set of colored shapes also includes some composed of two different colors, that cannot be separated as the objects a). This helps users to understand that this combination of two colors represents a new object that is different from the objects represented by a single color.

The design d) shows a set of colored shapes with two types of shapes. Simple cylinders of different colors represent entire objects, two-colored squarish tokens represent a vertex of a polygon. The constraints of this set of objects are the same as the ones in c).

The area shown in Figure 4.4 demonstrates a constraint provided by the sensing technology. The region that the camera is able to capture is highlighted. Users can place objects outside of this area, the corresponding attribute values however will not be sensed.

The set of attribute values that are possible due to the design of tokens is however independent of the set of attribute values the sensing technology is able to measure. Benford et al. describe such thoughts of independent, overlapping sets of movements in [BSK+00] and distinguish *sensable*, *sensible* and *desirable* movements to better reveal potential problems with an interface and also inspire new features. This idea of overlapping sets can also be translated to our framework and we can distinguish attribute values that are *sensable* and values that are *adoptable* according to the

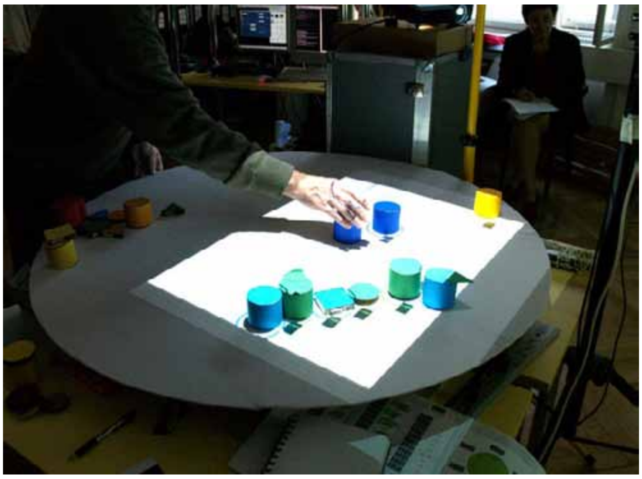


Figure 4.4.: Highlighting the positions that the camera is able to capture.

restrictions of the design of the TUI. A third set of attribute values are the *conceivable* ones, including the two other subsets. Figure 4.5 illustrates the different sets of attribute values and shows how they are overlapping. In contrast to [BSK+00], we are not considering manipulations themselves, but attribute values resulting from manipulations. Moreover, Benford et al. further divide the adoptable manipulations into desirable and sensible ones. Figure 4.5 shows the different cases of how values of A-Tokens are restricted in a TUI design.

Input for an application is provided by the subset defined by the overlapping part. These are the attribute values that can be adopted by TUI elements, and that can also be captured by the sensing technology. Attribute values which are sensable, but not adoptable, are the ones that the the sensing technology can measure, but no manipulation of the TUI's elements can provide such a value. In our example these are the colors, shapes and sizes that do not exist in the provided sets of tokens. In contrast, attribute values which are adoptable but not sensable represent the ones that are out of range of the sensing technology. A typical example for this is the position of tokens that can be placed anywhere, but can only be detected inside the tracking area, as shown in Figure 4.4. Another example for this subset are equal positions of tokens. When users superpose two objects, these have the same x and y position. The sensing technology however cannot recognize the bottom one, as it is covered by the other one. Also the accuracy of attribute values that can be adopted is often different from the accuracy that the technology offers, and very small movements that can be done with colored objects cannot be recognized by the camera. As users are not aware of what a system is able to sense, appropriate feedback [BBE+02] has to be provided for the sensed attribute values. Figure 4.6

shows these examples of attribute values for the different cases.

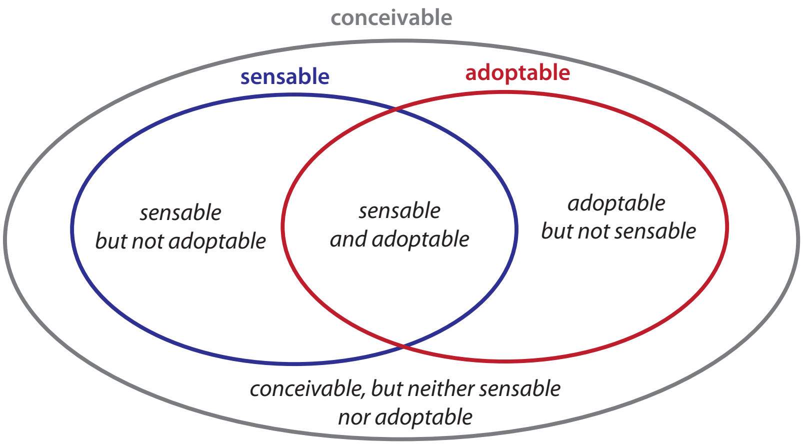


Figure 4.5.: The different constraints that are defined for an A-Token.

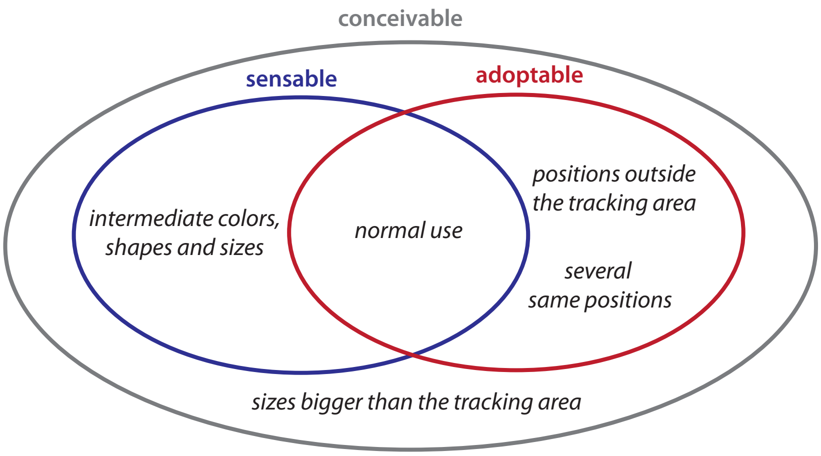


Figure 4.6.: Conceivable, sensable and adoptable attribute values of the ColorTable.

4.1.4. Relationship to variables

As illustrated in Figure 4.1, A-Tokens do not have to be mapped directly to variables but may be combined with other A-Tokens within a relation. The value of a variable thus depends upon the state of all A-Tokens being part of the relation.

Several A-Tokens may be combined with any mathematical operation, such as an arithmetic, relational or binary operation. Good interaction design affords the users to be able to relate the manipulations of an A-Token in the physical world to changes in the digital world [BBE+02].

The different ways in which physical and digital objects can be coupled are analyzed by Koleva et al. [KBNR03]. The underlying properties of this link can partly be adapted to our framework. The relationship of an A-Token with a specific variable can feature a certain amount of coherence between the two elements. This degree of coherence between physical and digital objects can be analyzed in terms of configurability of a transformation, lifetime of link and autonomy. The configurability of transformation describes whether the link of an A-Token to a variable remains fix or is configurable over time. Lifetime of link specifies for how long the A-Token and its variable remain connected. The extent to what the existence of the variable is dependent upon the existence of the A-Token is described as autonomy. Finally, the cardinality of link defines whether an A-Token is linked to one or more variables and vice versa.

The relationship of A-Tokens to variables establishes the actual connection between the physical actions made by users and the digital actions as reaction of the computer. It specifies which kind of manipulation controls which feature of the application. As the A-Tokens and constraints of the system are known, the development team is aware of the properties of a certain manipulation and can easier decide if it provides the best set of input for a specific function in the application.

The relations of the *ColorTable* implement its main idea. We wanted to use the surface of the table, including the colored objects, as representation of a virtual scene. The positions of the colored shapes are therefore related to the positions of their representations in the virtual scene and the colors of the objects are related to the geometry of the virtual objects. At a later point, we included the shape information to distinguish between different types of functions. While a triangular object produces a single object of a certain geometry, a whole line of same objects can be created by two square objects of that same color (see Figure 4.7 left). When the geometry of that color is exchanged, both the triangular objects and the square objects represent the new geometry.

In addition to these simple relations, the values provided by the A-Tokens can be used in more complex manners in order to provide input data for an application. When attaching two objects of different color of the type shown in Figure 4.3a or using a two-colored object as in Figure 4.3c or 4.3d, the values of their A-Tokens can be used differently in relations. One possibility is to use both positions of each color shape in order to calculate an orientation (see Figure 4.7 center). Alternatively, we can consider the colors of both the objects and handle this mixture of two colors as a new color value. In Figure 4.7 (right) the two-colored objects represent the vertices of a territory.

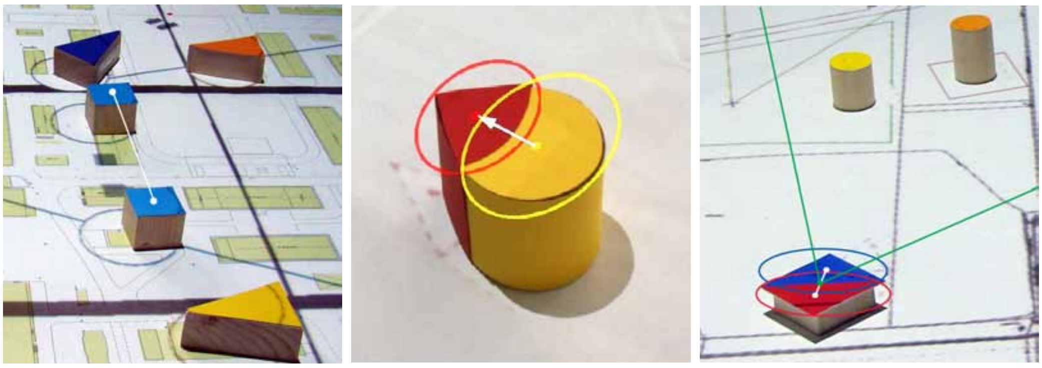


Figure 4.7.: Relating A-Tokens into a line of objects (left), an orientation (center) or different object (right).

When taking a closer look at the positioning of the colored shapes, we found another example for complex relations. By introducing maps of different scales, the positions of the colored shapes actually ceased to be directly related to their digital representations. We additionally considered position, orientation and scale of the map within a same relation. Depending on these coordinate systems, the position of the colored objects were interpreted differently (see chapter 6).

4.2. Consequences for the TUI design

4.2.1. Interaction

Interacting with a TUI system is performed by interacting with A-Tokens, and through them changing the variables. Physical attributes are modified by manipulating physical objects, and result therefore in a modification of the related variables.

Of course, there are several possibilities to achieve a certain modification of an A-Token. The users need to choose a new value for the A-Token, and the action to do this depends upon the design of the tangible objects and the constraints of the system. This action can for instance be based on everyday life actions to do similar manipulations. Such interaction issues are discussed in [Fis04] and [KBNR03]. Fishkin distinguishes the axes of *embodiment*, describing how close the input focus and the output focus are tied, and *metaphor*, saying whether the system effect is analogous to the real world effect. Koleva et al. propose a *coherence continuum*, categorizing the extent to which linked physical and digital objects might be perceived as being the same thing.

The different sets of colored shapes for the *ColorTable* show how differing concepts for modifications influence the interaction possibilities and their features. When comparing the two-colored objects of type 4.3a and 4.3c, we notice that the action of producing such an object is different in the two cases. When the users want to modify a red object into a red-green object, they will simply attach a green object to the red one in case 4.3a. So the green object represents an additional parameter that was added to the red one. In case 4.3c however, the users need to completely exchange one object against another one. This type of interaction suggests that the two objects are two different things that are not related to each other. Depending on how these A-Tokens are mapped to variables, the users will produce a different result by this modification and the coherence and metaphor will change.

When considering the *ColorTable* as common space of all A-Tokens, these can be embedded and distributed within the physical components using various approaches. Several A-Tokens can be integrated in one object and therefore be manipulated by interacting with this same object. The decision, by which A-Tokens are integrated in one object, and by which ones are distributed along several objects has a strong influence how people use space around the TUI. An example illustrating this issue deals with the switching of panorama views. In an early prototype, we provided users with a small paper map with barcodes to switch between viewpoints (see chapter 8). For the prototype of Caserne Bossut, we integrated this type of A-Token directly into the physical map. Barcodes were attached onto the positions of the viewpoints (Figure 4.8 left).

Figure 4.8.: Integrating several A-Tokens in a same physical object: further to the map position and scale, the map area includes barcode IDs for switching viewpoints (left) and rotating mechanism for rotating the viewpoint (right).

Integrating A-Tokens into common objects reduces the number of objects which may be useful for workspace organization. However, it may complicate manipulation of single A-Tokens without modifying the other ones. A physical separation of A-Tokens may be useful to guide users through different interaction steps, to support collaboration, or to increase interaction possibilities. This issue can be illustrated by the rotating wheel. In a former prototype, the rotating mechanism was integrated into the map area of the *ColorTable*. Rotating the viewpoint therefore additionally rotated the map, the colored objects that were currently in the scene, but also the physical objects that had been disposed at the border (Figure 4.8 left). Separating the rotating-A-Token from the map space into the rotating wheel therefore increased possibilities for map and viewpoint manipulations.

4.2.2. Software development

The A-Token framework can be used to support developers in abstracting and designing a software framework for tangible interaction. When considering A-Tokens, variables as well as their relations in the center of design, we are able to specify the nature of input values as well as the variables to which they are bound. Depending on this information, we can select an appropriate technology for network communication, a database format for storage or define requirements for further extensions. Figure 4.9 shows a simplified diagram of the *ColorTable* software framework, which is based on the A-Token concept.

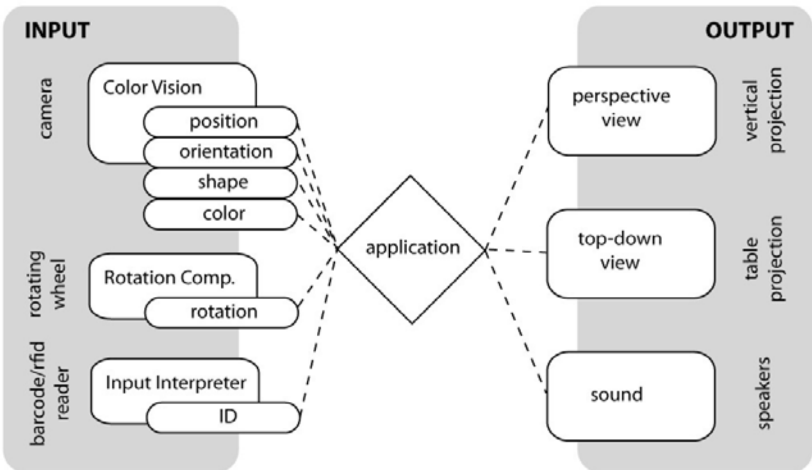


Figure 4.9.: A simplified diagram of the ColorTable software framework.

The **color vision component** processes the individual images of the USB stream of the digital camera capturing the top view of the table. After correcting the white balance, the different color regions are detected and the corresponding *positions*, *orientations*, *colors* and *shapes* are extracted (see Chapter 6). The **rotation component** detects users' manipulations of the rotating wheel. A conventional computer mouse is attached right under it to provide relative values of its *rotation*. The **input interpreter** detects signals provided by barcode and RFID readers and senses the respective *ID* values to transform them into application specific commands. Using these A-Tokens provided by the input components, the *ColorTable* application performs different types of computations to produce visual and auditory feedback on 2 projections and 8 speakers.

Note that the A-Token values as well as conversions of them can perfectly be used for communicating between distributed software components. A separation of the application's functionality in several components supports rapid prototyping, which is a necessity in participatory design. To exchanging data between each other, the *ColorTable* uses OpenTracker [RS01] for values changing continuously, Muddleware [WS07] for values changing from time to time and a Hypermedia Database [BDMG+04] for values being changed only once a while.

4.3. Consequences for the design process

In the following we show, using the urban rules application as example, how the A-Token framework can be used as basis for discussions in a collaborative design process. We explain how the different aspects help to understand possibilities and limitations, what is an important prerequisite to take design decisions.

4.3.1. Prototype density

To develop the density application, we decided to consider a set of buildings (cubes) that can be manipulated in their 2d *position* on the floor, their *volume* - 5 different sizes described in cubic meters, and their *typology* including quadratic and rectangular footprints.

Depending on those parameters and some global settings, the system should show a reaction and adapt the sizes and positions of the buildings. As only a certain percentage of the territory is allowed to be covered by buildings, the *area of the footprints* gets smaller the more objects are placed within the territory (see Figure 4.10). This means at the same time that the *height* of the buildings increases to preserve the volume. As extreme example, the territory is filled with skyscrapers and has a maximum of density. To show the consequences of the distance rules in urban planning, we planned to adapt the *positions* of the different buildings to prevent them being too close to each other. When other urban planning regulations are broken, (e.g. building outside the territory, or too many buildings inside the territory), the cube(s) are displayed as *red wireframe*.

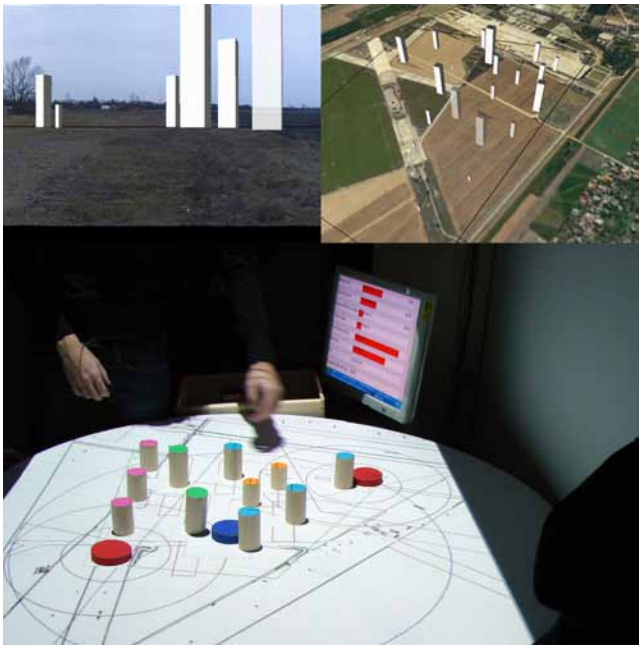


Figure 4.10.: Exploring urban rules with the *ColorTable*.

In addition to the *ColorTable*, we decided to use the barcode interface as complementary input possibility. This interface translates barcodes into a specific value or command. Although such an interaction can barely be considered tangible, it is a handy way to add an unlimited amount of input possibilities that can be combined with those of the *ColorTable*.

The tracking technology used for that prototype was able to detect positions and colors. To control positions of buildings, we connected each color object to a cube where the position on the table is related to the position on the site. Interaction design for controlling volume and typology turned out to be more tricky. Both of the variables could either be mapped to color or be controlled by barcodes. Furthermore, such a barcode could modify the variable of all colors, or of one selected color. There are thus 9 different solutions to this problem, and each of the solutions provides a different set of interaction possibilities. Table 4.1 shows the different cases and their consequences for the application.

Interaction using color is the fastest way to modify such a parameter, as users only need to choose an appropriate object. A global barcode requires participants to

Table 4.1.: Possibilities for the interaction design of the urban rules application

Volume controlled by	**Typology controlled by**	**Consequences**
color-A-Tokens	color-A-Tokens	each cube has a predefined volume and typology that cannot be modified
color-A-Tokens	barcode for all	each cube has a different volume, all of them with a same typology
color-A-Tokens	barcode for one color	each cube has a different volume and can have a different typology; it is not possible to define two same volumes with a different typology
barcode for all	color-A-Tokens	each cube has a different typology, all of them with the same volume
barcode for all	barcode for all	all the cubes have the same typology and the same volume
barcode for all	barcode for one color	each cube can have a different typology, all of them with a same volume
barcode for one color	color-A-Tokens	each color represents a different typology and can have a different volume it is not possible to define two same typologies with a different volume
barcode for one color	barcode for all	each cube can have a different volume, all of them with a same typology
barcode for one color	barcode for one color	everything is possible

make use of the reader, a barcode per color even asks for two steps. First users have to select a color, and as second step, read the barcode. This method is, however, the only possibility to allow all combinations of volume and typology. It us thus necessary to discuss which settings are really needed and which interactions can be simplified. This problem was discussed in detail in our team, and we finally decided to map the color-A-Token to the volume and use a global barcode to change typology.

Once agreed how to design interaction for the input parameters, we discussed and tried detail the actual rules. It was necessary to isolate each reaction and define how the related variables are influenced by an A-Token. In this step we noticed that the dimensions of a cube are not the same for each *color*, but have to be specified for each *building*. Depending on the size of the territory, the position, the volume and the typology of the colored object, each cube has different dimensions. The same applies for its color and drawing style. So it is not only the color-A-Token that causes a rule to be broken, but it is the position that is most relevant.

During this design process, we noticed that the repositioning of cubes, depending on their distance to other cubes, rises some questions. Can a position (variable) of a cube depend on the position (A-Token) of its color object as well as on the position (variable) of the neighbor cubes? If yes, is there a maximum distance that is allowed between the center of the virtual cube and the center of the color object? Is it the center of a cube that is repositioned to meet the distance rule, or do we consider its corner points? As we discovered that a solution to this problem would require heuristic approaches, we decided to not adjust the positions of cubes and only give feedback when the distance rule is broken. So each time two cubes are too close to each other, they are displayed as red wireframe.

4.3.2. Prototype time and connectivity

A second design process describes the development of the prototype for the participatory workshop in Caserne Bossut. In cooperation with an international group of students of the University of Applied Arts Vienna's postgraduate program, a large variety of conceptual approaches of possible negotiation scenarios for the site was developed. We combined the student's projects and identified three main elements to work with: connectivity, points of interests relating to required uses and measurements of reachability. Variables we decided to consider were therefore a more complex set dealing with the types, positions and sizes of programs, the types and courses of connections and the types and speeds of the flows.

A first question to answer was how to define the respective parameters and the formation of a set of rules. We discussed if placing a program should automatically affect nearby streets and vice versa. Figure 4.11 shows two possibilities for handling this issue. One approach is to adapt the sizes and boundaries of the programs according to the positions of the nearby streets. Another approach could be to give specific sizes to programs that are then intersected by the streets. To allow individual visions we decided to not correlate them and provide users with most freedom in allocating uses and connecting the area to its surrounding.

A second dependency to discuss dealt with reachability and spatial distances. Our idea was to enable a definition of a trip by selecting a sequence of programs. The system then calculates the closest path in-between. Within a sketching session, we discussed the exploration of movements and various kinds of locomotion (by foot, bike, car) between two allocated programs. As tokens will most certainly not be

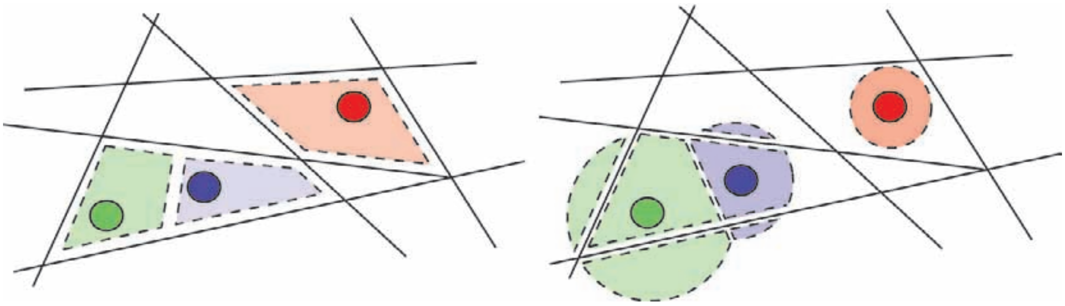


Figure 4.11.: Two possibilities how the position of programs and streets could affect each other.

placed directly onto an intersection or path, we need a rule defining how to connect the program to the nearby street (Figure 4.12). The definition of how programs are attached to the street-network affects the way distances are calculated. Although we aimed at working with approximations, this choice strongly modified the overall distance. Since it is important to define a most suitable approximation we decided to use the closest perpendicular connection between the represented use and the nearest street as basis for calculations.

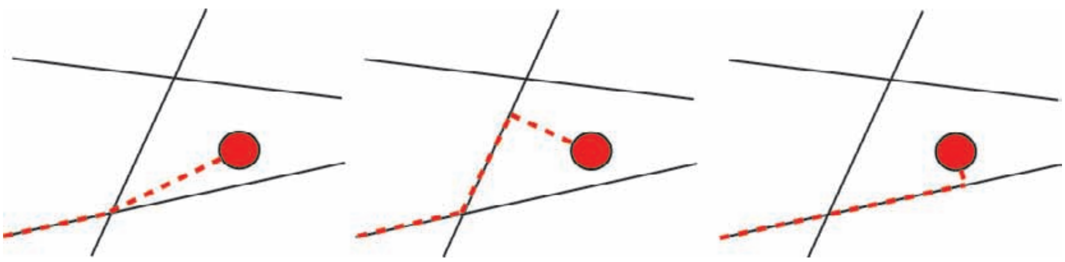


Figure 4.12.: Three possibilities to connect a program to the street network.

To couple the elements with the input possibilities of the tangible tabletop, we had to decide how these could be manipulated with the A-Tokens of the *ColorTable*: an obvious solution for defining and positioning programs is the use of the tokens, since a color can be selected with the tangible selector to associate a chosen program with the barcode interface. The *color* is therefore related to the type and size of program while its position is directly related to the position of the program.

Defining the different paths and streets however required a more complex solution. To achieve the most possible variety of different programs, we discussed several possibilities of how to increase the manipulation variability of the 8 different colors.

One solution is to introduce two modes of manipulation that can be activated separately: in a first step, connections can be created using two tokens of the same color. Different colors could then represent different types of connections. In a second step those connections can be saved to reuse the tokens to assign and position uses. This workflow however requires users to handle the tasks separately as they cannot position connections and programs at the same time. A second possibility is to introduce combined, two-colored tokens for defining connections. This approach uses color and relative positions of tokens in a relationship to calculate the variables of programs and streets. To prevent the tabletop of being too crowded, we decided to use one type of combined tokens for defining connections, and use barcodes for saving them. This possibility enables users to define streets and allocate uses at the same time. Specifying a whole network of streets however requires a stepwise placing and saving of each single connection.

The third interaction to be supported by the *ColorTable* is the exploration of different distances between sequences of programs. We introduced two further combined tokens to mark the start and the end of the trip. The times for different transport possibilities (pedestrian, bike, car) can be observed on the information screen and by animated flow objects moving along the path.

4.4. Summary and conclusion

A-Tokens (attributes of physical objects) are manipulated by manipulating the respective objects. Constraints of this manipulation arise from the combination of the sensing technology and the design of the TUI. This notion of constraints referring to attribute values rather than to objects further clarifies limitations of the sensing technology and possibilities for the interaction design, which is one of the major issues in developing technology for tangible user interfaces. The relations between A-Tokens and variables describes how the physical manipulations are related to digital manipulations.

In contrast to other frameworks, the A-Token framework distinguishes between the different actions and manipulations that are performed with one tangible object. This enables a more complex view on tangible interaction, as it is required for abstracting and designing technology. We have more possibilities to describe interactions in this framework and more possibilities to design them in order to respond to the requirements of the application.

The design of an interaction itself is also more powerful and flexible as it can be composed of any relation between A-Tokens and variables. The combination of attributes across tokens provides new possibilities for design and implementation that have rarely been considered in existing models and frameworks. This flexibility also increases possibilities when there is a need for considering redesign decisions. The A-Token framework supports rethinkings, as required in iterative design processes, and clarifies the understanding in each phase of the development.

The categorization of constraints into *conceivable*, *sensable* and *adoptable* focuses on actions by defining limitations for a set of attribute values. It provides us with the means to analyze constraints on a different level where users' manipulations, as well as technical aspects are considered. An understanding of those limitations and how they can be adapted is crucial for a more specific definition of requirements for the design of physical objects, software components and sensing technology. As those requirements are often discussed in a team of interaction designers and computer scientists, a language for communication is needed to exchange requirements, restrictions and solutions.

The examples describing the two design processes show that the A-Token framework is suited to discuss and compare different design decisions together with users of the system. It helped us as developers to understand the full potential of the system by identifying the different A-Tokens and how they can be used in combination with each other. In fact the A-Token framework helped us to focus on the attributes of the tokens and not only at the tokens themselves, which resulted in a much more detailed understanding of the interaction possibilities.

To design technology for interaction, it is necessary to define how the manipulation of these attributes influences the application. So a main task for the developer and all participating parties in the development process is to decide which manipulations are mapped to which changes in the application. While this process is often guided by standard design guidelines, a common language and understanding for the possibilities and limitations is essential for a discussion. We believe that the different parties involved in a TUI design project can better articulate and understand the problems and find solutions through the use of the framework of A-Tokens.

CHAPTER 5

Designing with constraints

To deeply analyze the connection of the interaction space to aspects of technology and context, we suggest to take a closer look upon single design decisions, as well as their implications for the related fields. While designing and developing the *ColorTable*, we experimented with different types of tangible interactions. To be able to take single design decisions, we analyzed their range of possibilities and limitations as well as their impact onto the type and variety of users' activities. Constraints dealing with such ranges can be provided and specified for all elements and components that are part of a tangible user interface. Throughout the design process, we noticed that a high number of constraints in different areas and levels exist, and correlate with each other.

This chapter provides insight into the different types of constraints that exist in tangible interaction. Focused on the design and development of the interface and the various physical objects including their usage and handling, we consider constraints as an important aspect in TUI's. Constraints provide limitations and can be used to guide users in their interactions.

Parts of this chapter had been developed in cooperation with Lisa Ehrenstrasser.

5.1. A model of constraints

Throughout the development process of the *ColorTable*, we experimented with different types and arrangements of interactions. We therefore took a high number of design decisions, and modified them again in each iteration. An important aspect was that each design decision we took implicated a high number of consequences related to other design decisions.

An example for such a decision is the size of the colored tokens. When designing objects of a certain size, we need to think about implications for the tracking algorithm, the position of the camera overhead, the size of the tabletop, the place of deposit for the tokens, the way users can hold them in their hands and position them onto the table, what size they represent in the application and so forth.

A second example for such a decision is the size of the tabletop. By choosing a large surface, more people can stand and work around it and collaboration is improved. This decision however influences the tracking technology as a bigger area needs to be tracked and the projector needs to be further away to be able to lighten the whole table. On the other hand, users may have problems to reach the whole area on the map and a bigger table means that we need more space to set it up, so the environment around us is affected by this decision.

5.1.1. Constraints and dependencies

In the field of tangible interaction we come across constraints in different manners. A quite common use of the notion of constraints is the token + constraints framework [UIJ05]. This concept defines constraints as confining regions limiting the manipulation of tokens in order to invoke and control a variety of computational interpretations. Hornecker and Buur [HB06] use constraints as part of their framework on tangible interaction. They mention embodied constraints and refer to the physical set-up of space and objects that can be used to encourage certain behavior of the group. The implementation of constraints within a tangible tabletop interface is described in [PI07]. *Pico* is based on mechanical constraints that can be manipulated to interact with the underlying software process. An important aspect is their relationship to the movement of objects over time and how they provide a variety of novel interaction techniques. Further, Coughlan et al. [CJ07] analyze how constraints being developed by users can support creative tasks. They propose a model of constraint development for creative processes with 4 categories: tangible constraints, conceptual constraints, internal constraints and static underlying constraint structures.

We adopt this notion of constraints, generalize it, and consider the different levels and relations at the same time. Each design decisions specifies a type of constraints and depends upon a certain number of other constraints. Expressing a design decision as constraint, helps us to understand the ranges for modifying them. In contrast to other definitions, we conceive constraints as a dynamic situation that either can be modified and set during the design process (e.g. size of the tokens) or is provided by external circumstances (e.g.: a blind user of the tangible interface).

When analyzing the different types of constraints, we can group them into three classes. Constraints considering the way users work with the tangible user interface, how they stand around the table, touch and hold the colored tokens deal with the *user*. This aspect provides guidelines for designing objects, manipulations and workspace in a way which is comfortable to use. Hence it specifies a range for the height of the table, distances between devices, understandable feedback, and so forth.

In contrast, each constraint provides consequences for the software and hardware we are using, as well as resources (time, money, persons...) that are needed to implement a certain design. These aspects, such as types of shapes that can be tracked or the connection of devices to electricity, are related to the *technology*.

A third type of constraints deals with the space and circumstances around the tangible user interface, as such an interactive system cannot be considered by itself and is influenced by lighting conditions, the size of the room it is standing in or ambient sound. These types of dependencies we refer to deal with the *context*.

Each constraint that is specified provides dependencies in all three of these domains, and, on the other hand, the circumstances of each domain provides a certain tolerance for the constraint, as for instance we have to adapt the *ColorTable* to the conditions and limitations of the space around. We therefore have a certain interplay between the different components of our model. Figure 5.1 illustrates these different domains in a model of constraints.

Freezing the structure in this present snapshot of dependencies facilitates evolving from the right angle. It helps us to focus on one aspect of this huge network of relations and to solve problems step by step. Therefore it is necessary to position a single constraint in the center of the model.

5.1.2. Examples

To illustrate this model of constraints, we come back to our constraint defining the size of the colored tokens. We can analyze all of its consequences using our model of constraints (Figure 5.2). When increasing the size of the tokens we need to think about the technology and adapt the algorithm of the tracking software, the place to store the tokens and allocate resources for the re-design. The modification also influences aspects related to the users as these grasp, hold and position them

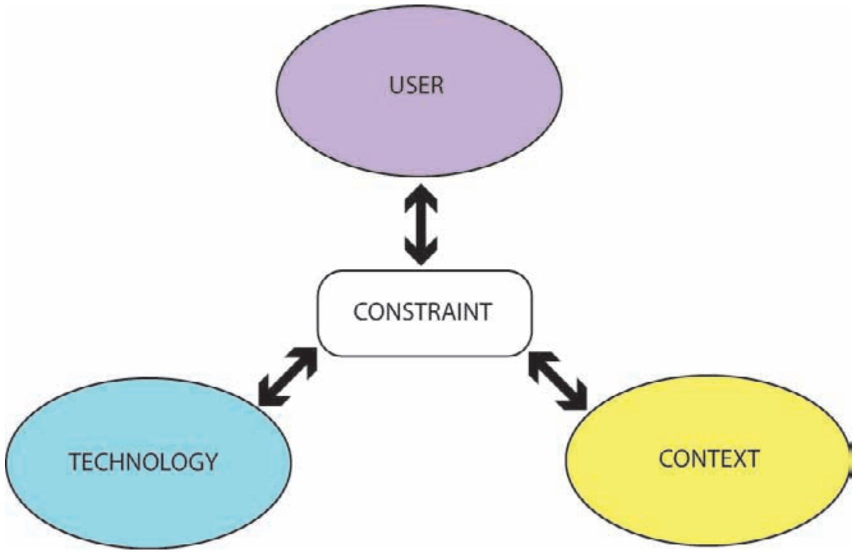


Figure 5.1.: The model of constraints.

differently. Further, aspects of cognitive perceptions and emotional impacts can be affected. The context is influenced by our decision as the space around may be used to deposit tokens and higher tokens may be tipped over by the wind. Some dependencies are also related to the context of the application as their physical representation on the map should fit with the size of the contents. When changing the size of tokens, we therefore need to adapt the scale of the map and the size of assigned contents.

To be able to take a best design decision, it is important to discuss advantages and disadvantages of each of the implications. Most of them provide a certain tolerance for setting the constraint, so we can consider which of the dependencies can themselves be constrained differently, and what consequences the modification of this new constraint implies. In our example we could now decide to increase the size of the tabletop in order adapt it to the increased size of the tokens. In this case we can, again, consider what consequences result from this (Figure 5.3).

Regarding the technology, we need to adjust the height of the camera and the projector, the size of the table, find a solution for transport and plan resources for development, transport and setup. In addition, a larger table changes its use as it affects collaboration and the number of active users that can stand and work simultaneously around the table. It has an impact onto the type of gestures and performative actions users are expressing, as well as the visibility of the worktop. Next to the cognitive perception and emotional impacts it also influences the way of positioning as users can work with a higher range of different positions. Some

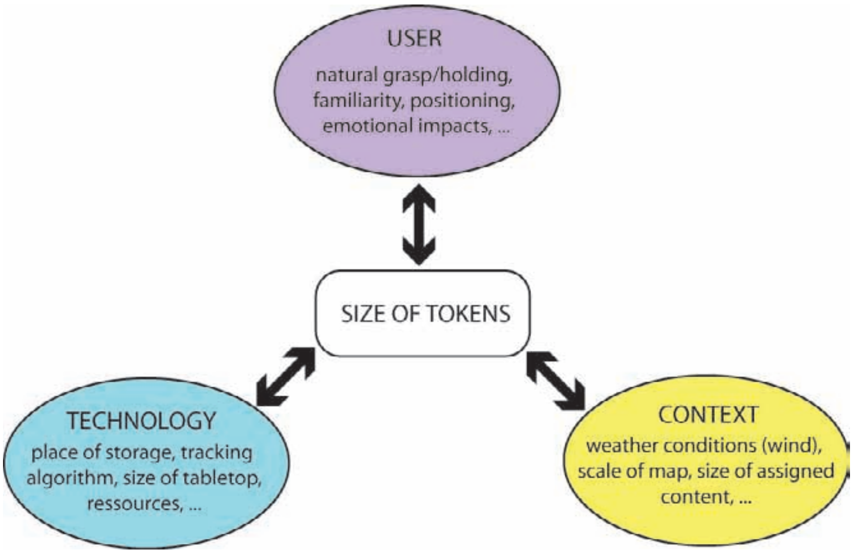


Figure 5.2.: The model of constraints with size of tokens.

consequences are also related to the context as we may need to adapt the size of the room, the scale of the map or the number of participants to allow for simultaneous use.

5.1.3. Properties of constraints

The simple example of the size of tokens shows the complexity of small design decisions. Each decision has a large number of dependencies, so none of them can be considered independently.

Some dependencies are in conflict with each other, as it is the case for the tracking technology and the context that both have to manage the size of the tokens and the tabletop. The tracking technology best handles big sized tokens and a small sized tracking area, to ensure that the different colored areas are best recognized. In contrast, the site and the urban issues we are dealing with usually work better with smaller tokens and a large tracking area. These two elements allow us to use a bigger scale of the map as the tokens can represent smaller contents in a larger area. It is therefore important to find some kind of compromise and define these constraints in a way which is best for the overall result.

By comparing the different constraints of an interactive system, it quickly becomes evident that not each constraint can be modified equally. We may have a large number of possibilities to decide for a size of tokens and tabletop, we however have

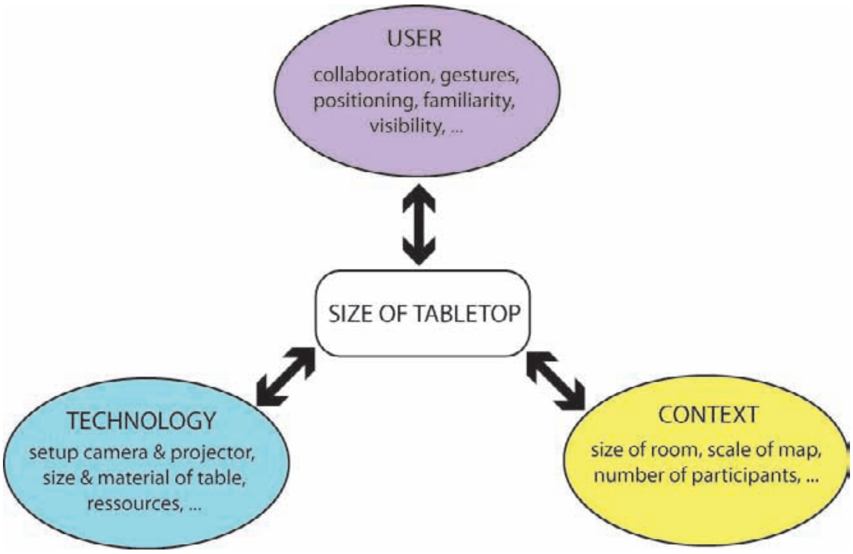


Figure 5.3.: The model of constraints with size of tabletop.

no possibilities to constrain the size of the user's hands to enable them to well grasp and hold the different tokens. In the design process of a tangible user interface it is hence necessary to identify those constraints that allow a certain range for modification. These are then the elements we can manipulate in order to experiment with different interaction configurations.

But also the dependencies we cannot constrain differently are worthwhile to be analyzed in the constrain model. Giving the fact that we work with a user group that is blind, we can analyze what consequences and re-designs are needed to support these users in an equal way.

Note that ranges for constraints are rarely available in exact numbers. Some values are better suited to support a specific aspect of the interface, others may just provide some slight disadvantages. It is important to picture advantages and disadvantages of all aspects simultaneously to be able to find the best compromise. This affords a close cooperation between computer scientists, designers and representative stakeholders to develop a common understanding of these aspects and their dependencies as well as their ranges of tolerance.

5.2. Summary and conclusion

To support cooperation between computer scientists, designers and representative stakeholders throughout the design process of the *ColorTable*, we suggest considering constraints in the center of interaction design and think about its relation with other constraints. When analyzing potential re-design decisions and their consequences step by step, we are able to extract the best compromise. To understand all implications of an individual constraint, we propose a simple model of constraints, based on the domains *user*, *technology* and *context*. Each constraint is dependent upon a high number of other constraints, that need to be balanced to improve or enrich interactions. We do not see constraints as cumbersome limitations, and rather point onto the range of options we have at our disposal while experimenting with them. The model of constraints enables to simultaneously consider issues related to the interaction space, to the technology and to the real use.

Part II.

Implementation and evaluation

CHAPTER 6

The tracking framework

Although a tracking technology is usually expected to stay in the background and to be invisible to users, it is an important component of a tangible user interface. It detects the manipulations of objects on the table to provide values for the application and therefore makes a connection between the physical and the digital in a tangible user interface. Depending on how objects and movements are detected, a different set of object manipulations and interaction possibilities can be supported. Hence, the choice and implementation of a tracking framework influences manipulations and therefore also the design of the TUI.

As part of a design process of a TUI, it is essential to select and develop a tracking framework which is best adapted to the type of manipulations to be supported. It should detect these using a fast and reliable algorithm while providing space for re-design activities.

This chapter describes the tracking framework of the *ColorTable*. It analyzes the requirements and solutions for developing a reliable detection, while responding to challenges provided by the domains of interaction design and urban planning.

6.1. Challenges

The setup of a collaborative user interface poses a certain number of challenges that are often not considered by tracking technologies. To encourage collaboration, size and arrangement of the table and objects need to be carefully designed as these are important factors in a team work. For instance, when preventing all components of an interface to be accessible by one person at one position, users are forced to collaborate in order to distribute tasks efficiently, as described in [HB06]. This is the main reason why the tracking technology needs to detect a high number of objects on a relatively big area.

Being a tangible user interface, the *ColorTable* is based on different forms of physical manipulations of the colored objects. This means that users can touch and move objects in a multitude of different manners. They may occlude objects when touching them, place objects adjacent or even stack them. Depending on the situation, there are several hands being on the table manipulating several objects instantaneously. Users may wear colored sleeves and produce different types of shadows. Figure 6.1 shows typical situations arising while interacting with the *ColorTable*.

Figure 6.1.: Typical situations of the ColorTable: colored objects along with projection and map (left); user moving an object (center); several hands gesturing (right).

In addition to these interaction issues, the urban renewal scenarios provide some further requirements to the system. As the *ColorTable* is used outdoors on site, in a mixed reality tent with openings to the outside, lighting conditions are difficult to control and change constantly.

Moreover, urban renewal projects often involve a high number of aspects related to space, time, distance, density, and so forth, hence, a combination of several layers of information enriches the understanding of the project. In this way, additional physical artifacts such as maps, diagrams or barcodes as well as a digital projection based on an illustrative feedback are needed to create a top-down view on the table. These elements should not interfere with the tracking of the colored objects.

As the different colored objects represent urban planning elements, such as buildings, plants or people that are placed on a map, their physical size is a reference for the scale of this top-down view of the scene. To make it easier to understand the relations between the different elements of the mixed reality space it is important that the scale suggested by the colored objects is similar to the one of the map. While smaller objects can be surrounded by a larger illustration of their digital representation, a similar augmentation for large tokens representing small urban elements is hardly possible.

6.2. The color tracking framework

To meet the rather strong requirements explained above, we propose a tracking technique including several steps.

6.2.1. Calibration

This first step involves the calibration of the different colors and the calibration of the coordinates of the tokens' positions. While shapes of objects - currently circles, rectangles, triangles and squares - are predetermined by the system, different colors can be appointed during the calibration step. A sample token of each color is placed onto the table. The developers manually specify by mouse click the different color regions to get a color sample of each object. The system uses information from a series of subsequent frames and a threshold to group objects into different color clusters; the larger the threshold the smaller the number of clusters.

Figure 6.2.: Selecting the different color regions to calibrate colors

To define transitions between different coordinate systems, we use a set of five calibration matrices (as shown in Figure 6.3). First of all, we obtain the table coordinates, which is the real space coordinates of the table surface, by putting a rectangle configuration grid on the table and use its vertices for the assignment of the calibration matrices. The camera and projector matrices convert the pixel coordinates of these devices into table space and vice versa. We use 4x4 matrices to allow perspective correction, so the camera and projector do not have to be perpendicular to the table surface. An additional matrix adapts the coordinates of the table space into map coordinates, depending on the different scales of physical maps. Finally, since many system components rely on real-world coordinates, a 3x3 matrix describes the mapping from map coordinates to global coordinates.

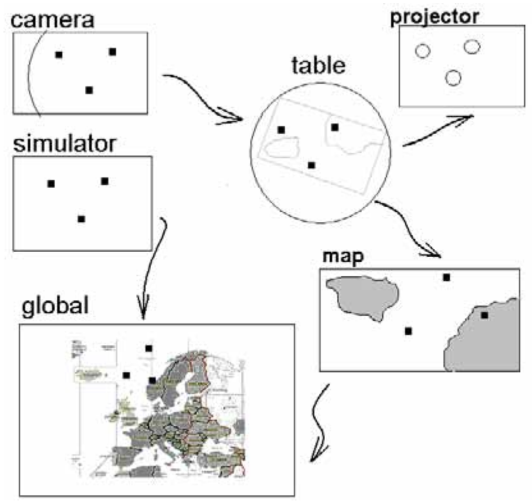
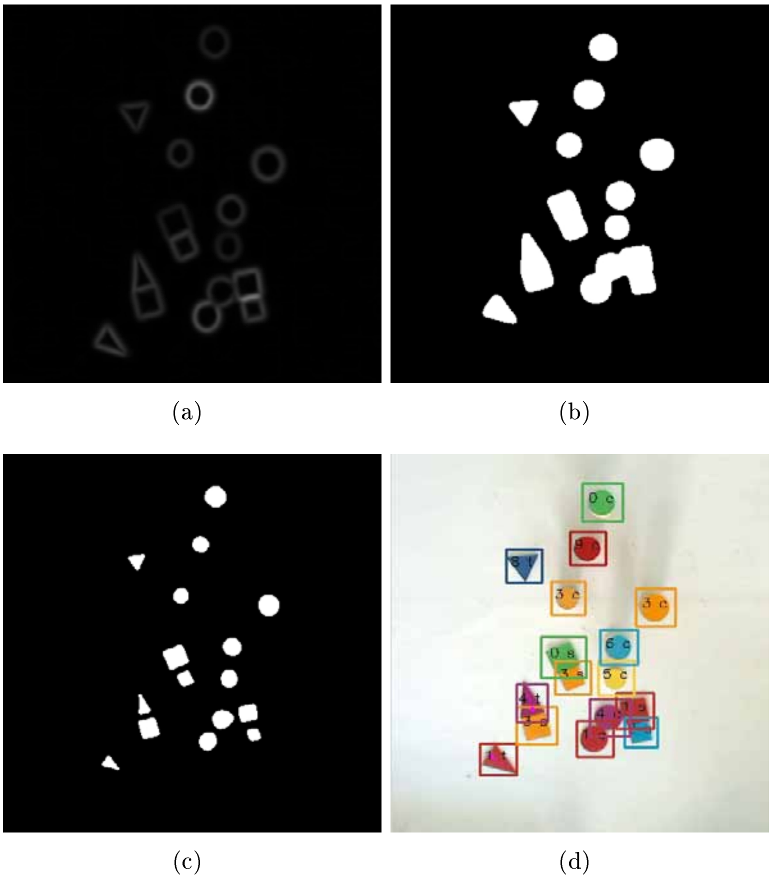


Figure 6.3.: Relation between calibration matrices.

6.2.2. Object detection

The object tracking process consists of four main steps as shown in figure 6.4. For each input video frame, edges of objects are detected as a first step. To account for different illumination conditions, we implemented the illumination invariant color segmentation method introduced in [GdWS06; GvdBSG01].

In a second step, objects are segmented into separate regions. As the *ColorTable* is based on physical manipulation of a selection of objects, these may be positioned close to each other or touched by hands and therefore share a part of their boundaries. As the system should detect them as separated objects, we use a simple but very



(a) (b) (c) (d)

Figure 6.4.: An example of edge segmentation using Cw. (a) chromatic edge detection (the brightness indicates edge strength). (b) first segmented image (c) final segmentation (d) original image embedded with segmented regions and their tagged features (color, shape, position and orientation).

effective way to deal with this problem. First, the edge image is eroded to get thinner edges. The system then fills out all the boundaries found in the edge image. After that, the filled image is subtracted with the edge image to get an segmented image. With this step, all boundaries are removed and all areas are based on one color (Figure 6.4(d)).

After object segmentation, shape, color, position and orientation information are extracted. To detect color detection, we sample a number of pixels in an area of 3×3 around the center of gravity. The region is signed with the respective average color.

Regarding the shape detection, in our system four different shapes are considered namely circle, square, rectangle and non-regular triangle. We use special properties of these objects to classify them. Circles and squares need to satisfy given roundness and squareness criteria. For the triangle, we extract the extreme points (i.e. corner points); an object which has three extrema will be signed as a triangle. Finally, objects which do not have three extrema points and do not satisfy the squareness and roundness criteria, will be tagged as rectangles.

To find the orientation of the non-regular triangles, sizes of the three sides are computed, the one with shortest length is assumed to be the bottom of the triangle. Based on that, the orientation of that triangle is found. For the orientation of rectangles, we commute the rotation of its longest side to get a value between 0 and 180 degrees.

In a final step, extracted information is assigned to an object and interpolated with the results of the previous frames. Our data filter compares the tracking-data of multiple successive video frames, and considers the differences. It assigns data to a certain object when its distance lies within a certain threshold. An object needs to be reported several times in a row to be accepted while must not be reported several times to be removed. The objects positions are interpolated over time based on a smoothing parameter. The different parameters can be adjusted during runtime to balance the stability of the resulting data versus its reactivity to user interaction.

6.3. Evaluation

The tracking framework as important component of the *ColorTable* has been tested and re-designed throughout the participatory design process. We started with a first version of the tracking framework supporting a simple detection of specific colored regions and extracting their sizes and positions. After several cycles of development, evaluation and re-design the tracking framework ended up in a more complex tool detecting additionally shapes and their orientation and providing possibilities for calibration of colors and positions.

The different sessions of the workshops showed the importance of the reliability of the tracking framework. Interactions and workflow strongly depend upon how well objects are recognized. Although participants are in general very patient and willingly wait for the tracking framework to correctly detect the tokens, they adapted their behavior with respect to the tracking framework. We could observe how they chose color tokens that 'work well', displace objects with one finger and remove their hands from the table as soon as the objects are well positioned. Participants are frequently interrupted in an activity to displace tokens slightly and wait until they are correctly detected

Throughout the different workshop sessions, we identified several issues influencing the stability of the tracking technology.

Material issues

We experimented with different forms and materials to provide good prerequisites for creating clusters. Best results could be achieved when using 7-8 different colors with a high saturation. As the saturation is a main criteria for thresholding the color areas from the background, it is important to select a similar saturation for all colors. Material found useful is paper based, which can be stuck onto plane objects to prevent glossy reflections.

As set of shapes we decided for triangles, rectangles and circles. Squares turned out to be less reliably detected as they were too similar to circles (same aspect ratio).

Light issues

The well known problem of changing lighting conditions turned out to be much more complex as assumed before. After using our system during a whole day, with a varying number of users, the conditions considerably changed compared to other tests at our lab at the institute. In addition to the modifications due to the weather and daytime, lighting conditions were influenced by the participants themselves and by the angle or distance of their surface to the projector.

To respond to these problems, we adopted several approaches, that each can be improved in the future:

- The use of black cloth for the tent construction created a less varied lighting condition inside the tent, as the beams were not reflected by white surfaces, and the overall light was not intensified.

- Drawback of this circumstance is that the ambient light is reduced and most of the light arises from the back opening and the projector above the table (Figure 6.5). We therefore experienced dropouts when participants occluded the light from the back opening. A possible approach for future trials could be to experiment with multiple, smaller openings all around the tent, creating a more regular, ambient light inside the tent.

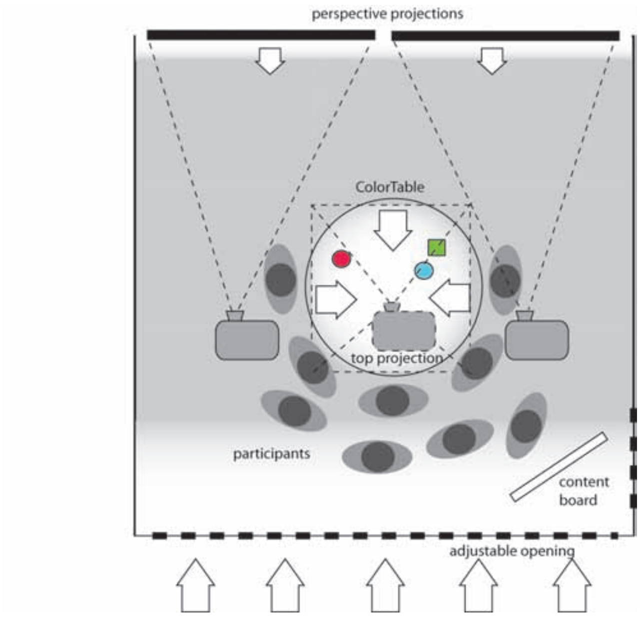


Figure 6.5.: Most of the light arises from the back opening and the projector above the table.

- We calibrate the different colors of the tokens on the same day of the workshop, and recalibrate them when weather conditions are changing. In our trials we experienced that a same color token is not equally well recognized on each position of the table. This observation is due to the fact that most of the light arises from two different directions, as explained above. In addition to a more regular distribution of light inside the tent, we suggest experimenting with a calibration method based upon several positions of a same color token or a looser classification of colors.

Interaction issues

Another issue influencing the stability of the system deals with the type of interactions and gestures that users are performing with the *ColorTable*. Being used as a discussion and planning space, in combination with the physical maps, participants frequently gesture and point to positions and regions on the map. During such discussions, tokens are repeatedly occluded and lead to a dropout of the detection.

In contrast to these movements during discussions, the design of the physical interaction space influences the way users touched and grasped the objects. Higher objects facilitate a grasp from the side, to avoid occlusion of the colored top. Angled shapes (rectangles, triangles) invite participants to position two tokens close-fitting, which represents an additional complexity for the tracking framework. In addition, the height and size of the table motivate users to bend over the table or reach objects to each other. As we track and project from above the table, hands and objects create shadows that can be misinterpreted by the tracking software.

Approaches that address these circumstances are:

- The installation of camera and projector has impacts on the quality of the camera image, the size of the projection and also the sizes of shadows and occlusions by participants. To minimize the latter, camera and projector should capture and project from a central position above the table. It is not possible to align them completely as one of the devices would occlude the image of the other device. The use of a mirror to reflect to the projectors beam creates a larger projection onto the table, but complicates the geometric problem. As the camera should be installed close to the table to increase the quality of the video stream, it may create shadows in the projector image (Figure 6.6). Both devices should therefore be as close as possible to each other.
- Dropouts during discussions mostly remained unnoticed by participants as they were concentrated onto the table view and not onto the perspective view where the objects ceased to be displayed.
- It is necessary to teach participants how to touch and move colored tokens, this is in general rapidly understood and put into practice.

6.4. Summary and conclusion

In this chapter, we have described a tracking framework based on color and shape. It introduces a novel method to pursue the different manipulations and interventions

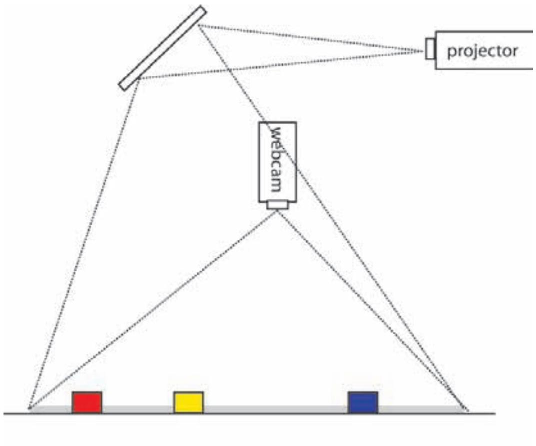


Figure 6.6.: The current setup of camera and projector, creating shadows.

on the table. The interaction tokens are distinguished by color and shape, providing good identifiers for both the users and the tracking technology.

The proposed framework provides high flexibility in developing a tabletop interface with a large variety of possible interactions, which is an excellent starting point for an iterative design approach. Color tokens can be made of diverse materials and simple prototypes can be used to try out several designs. The differentiation into attributes rather than a single identifier enables development of more complex applications with a more variated set of interactions.

Our experimentations in a series of participatory workshops provided us with useful findings concerning the development of a tracking framework for TUIs. A complex and influential issue is the control and distribution of light inside the tent. The use of black cloth helps controlling the intensity of light, it is however necessary to ensure a regular distribution of light sources inside the tent. Dropouts of detecting during discussions and gesturing turned out to be no problem, in contrast tokens need to be well recognized when positioning them on the table. To assure a reliable detection of colors and shapes, the tokens need to be designed in a way that users quickly understand how they are allowed to use them.

The development of an efficient tracking framework for tangible tabletops requires consideration of a multitude of aspects including discriminative features, efficient segmentation and recognition, design of tokens, calibration of colors and positions, filtering of results, light conditions, context and training of users. By coordinating all these aspects, an environment can be created as reliable basis for complex tangible tabletop interfaces, such as the *ColorTable*.

CHAPTER 7

The application functions

Implementing functions for an application means giving meaning to the various parts and elements of the *ColorTable*. The application is the tool for solving problems and answering questions given by the (urban) context. These answers are provided as visual or audible feedback as direct result of participants' manipulations.

To be able to respond to this need, we have to deeply engage with the questions and create potential answers. Based on these information we can formalize contextual issues as well as manipulations and create concepts for functions. Crucial within this process is to develop functions that can be easily manipulated by the users and that create feedback complying with their demands for performing interventions.

This chapter describes and analyzes the applications of two prototypes, each of them pursuing a different goal and implementing a different type of application functions. The first application was implemented and improved along the four years design process of the *ColorTable*. It focuses on enhancing the dialogue among different stakeholders and was last used within the participatory workshop in Pontoise. Aim of the second application, dealing with the revitalization of Airfield Aspern, was to experiment with urban planning regulations to show consequences of different configurations on a territory.

Parts of this chapter are based on the papers *MR Tent: a place for co-constructing* *mixed realities in urban planning* [MSSW09] and *Enhancing synergies between computer science and urban disciplines: Semi-automated applications for tangible user interfaces, a case study* [BM09].

7.1. Application Pontoise

This application is the result of a long-term design process using a series of workshops for evaluation. Each of the workshops took place on a different site, but all dealing with a similar set of urban topics. For every workshop, the set functionalities have been extended and improved in an iterative process of design-feedback-evaluation-redesign.

As described in [BOT09], the urban concepts initially proposed by the urban planners dealt with physical characteristics of urban space, such as dimension, scale or depth. Further issues to be addressed by the tools are temporal aspects of a site, such as its past or its future. Mobility is a concern dominating and transforming the city and related aspects of accessibility, modes of transport or density should be considered. Additional proposed themes deal with use and ambiance.

Based on these concepts we developed an application that allows to modify a mixed reality scene by adding different types of virtual elements. The very early prototype supported the positioning of 2d and 3d objects and to explore the ambiance of the scene on one perspective view. A later prototype improved this functionality by providing a more detailed amount of modifications and allowing participants to change scale, transparency and color of the objects. To support urban issues related to mobility and use, we extended the application of the 5th prototype with a possibility to set streets, flows and ground areas.

This section presents the final application as it was used in the last participatory workshop in Pontoise. While the early field trials were based on projects at a late stage of the conception phase, the workshop in Pontoise addresses the preliminary stages of an urban development scheme. The idea of this application was therefore to not focus on design issues, but rather deal with uses, ambiances, problems of daily use, connectivity and accessibility. Participants decide on a number of general principals concerning the site with the outcome to eventually guide the urban design process and the urban design team. The issues to be addressed are interdependent and participants can restructure the scenario as they seem fit.

7.1.1. Application functions

The application supports a quite complex set of features, allowing participants to compose and modify MR scenes using several urban elements, such as buildings, roads, people or ground areas. In the following the different functions of our application will be presented.

Placing and modifying objects

To decide on the type and location of future elements of the project site, participants can add objects into scene. The mixed reality views help them to address issues related to ambiance and problems of daily use. To add an object, participants place colored tokens on the map. For example, a triangular token produces a single virtual object, shown as 3d model or as photograph billboard that is always aligned to the current viewing axis. In case of 3d objects, users can also decide about their orientation by rotating the triangle. Each object being placed onto the table is added to the scene shown in the perspective view, its position on the map corresponds to its position in the 3d view.

Users can change object properties and associate tokens with new objects selected from the hypermedia database. We support modification of scale, offset (from the ground), spacing, color, transparency and sound. This property management is performed with the configuration board, a dedicated interface consisting of 7 different color areas, each corresponding to a different color object (Figure 7.1 left). Individual contents of the hypermedia database, as well as menu objects are available as small cards and can be activated by placing them onto the color areas. The application offers the possibility to override default values and change size, transparency, offset from the ground, color, sound as well as brightness and contrast of objects. During modification of these properties, the values are displayed next to the object in the vertical projection (Figure 7.1 right). In addition, the current status of each color can be monitored on an rectangular info area, projected next to the colored areas on the top-down view. This area displays detailed information for an activated token color.

To facilitate the construction of rows of identical objects, e.g. to build a residential area of a certain housing type, we offer the possibility to define a line by setting its both end points. Two triangular objects of a color previously loaded define the end points of such a line and are filled up with identical objects, spaced at adjustable distances. The value of this distance can be modified with the configuration board.

Adding roads and flows

When thinking about an urban area, its connectivity and transportation to existing locations in the environment play a major role in the discussion. To decide on the types of transport, speed and concurrency, we let users define different types of roads and flows of animated objects moving on a given path.

Figure 7.1.: Changing object properties by placing small cards onto colored areas. The status is displayed on the vertical projection and on a info area.

In an earlier prototype, flows could be generated in a specific direction using a directional token. Individual flow objects then move along this line and can be redirected in another direction or absorbed with other dedicated color tokens. In order to animate the moving objects in the perspective view, we store view dependent cyclic flip-frame animations (Figure 7.2).

Figure 7.2.: A moving pedestrian stored as view dependent cyclic flip-frame animation.

To allow flows to follow more complex paths, we improved this feature and combined them with a network of roads that can be defined by participants. We introduced rectangular objects that have to be positioned at both endpoints of a straight road. Each color represents a different type of road (e.g. highway, normal road, footpath). Both top and perspective views show a colored stripe of variable width to visualize the respective road. Flows are then generated using two dedicated tokens defining start and end of the flow. They follow the shortest way between both points using the street network.

In our last version, the function has been improved once more to create curved roads and to simplify generation of flow objects. Depending on the orientation of the rectangles, a Bézier curve is created between both points. Instead of defining start and endpoint of a trip, the network of streets and paths is immediately populated with different types of flows. Animated objects advance on the roads in both directions. Figure 7.3 shows the 3 versions for defining roads and flows.

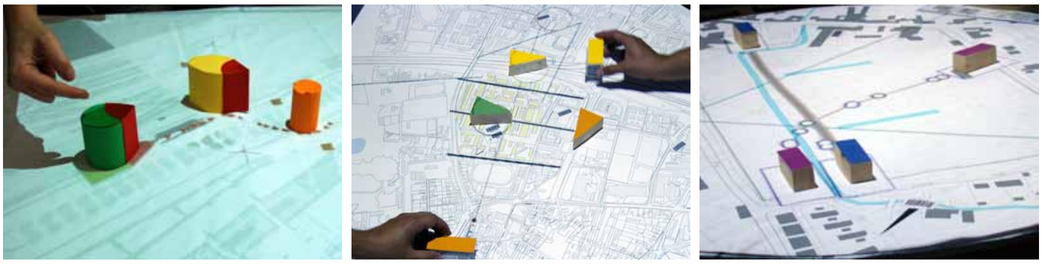


Figure 7.3.: Creating and populating roads with moving objects: 3 different versions.

Defining land use

To define and discuss specific uses of land, we created the possibility to create polygonal areas that can be filled with a color or a texture representing a specific land use. Our first approach was to use an automatically computed Voronoi decomposition using circular tokens put by the users as anchor points. Each color of the circular tokens provides a different texture filling the Voronoi cell (Figure 7.4 left).

To allow for more specific definition of borders we provided in a later prototype the possibility to define each border separately by creating several overlapping connections as borders. The area can then be filled with a color or a texture representing a specific land use by placing a circular token inside (see Figure 7.4 center and 7.4 right). The 7 different colors can be assigned with a texture using the configuration board.

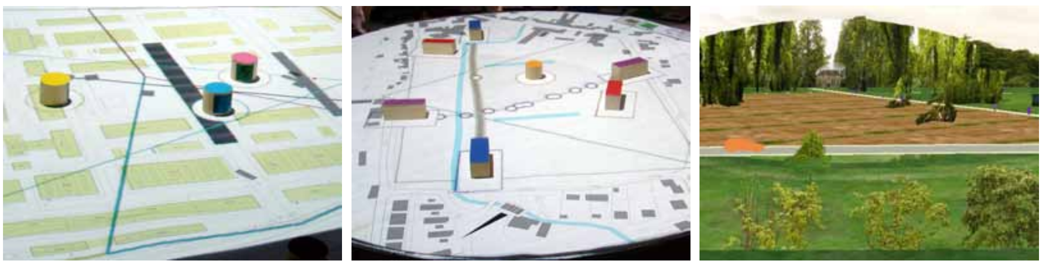


Figure 7.4.: Creating and texturing polygonal areas.

Navigating using different views

The composed scene is constantly shown on a vertical projection. By activating dedicated barcodes, users can switch between several panorama views, an aerial view, a live-video feed from a camera outside the tent, a mobile camera or a optical see-through screen. The panorama views are created by stitching a set of pictures taken from interesting spots within or outside the site. They are stored with a depth map and therefore handle occlusions properly. The video feed is captured by a controllable camera that is placed close to the *ColorTable* or by a mobile camera that can be walked around. The see-through screen is a half-transparent canvas, providing both a reflective surface for virtual elements and a degree of transparency that enables a view onto the real scene. It creates the MR scene by combining the virtual scene composed by the users with a direct view onto the real site outside. The three types of views are shown in Figure 7.5.

Figure 7.5.: Exploring the scene using three different types of backgrounds: panorama, see-through and mobile live-video feed.

When the panorama mode is activated, users can change the orientation and zoom of the actual view by manipulating a rotating disk. In case of reorientation, the panorama background including all virtual objects is then adjusted into the corresponding direction. When zooming, participants first switch to zooming mode by barcode, and then manipulate the same disk to increase or decrease the viewing angle.

Two types of live video feeds are provided by a connected application called *UrbanSketcher* [SS07]. A camera placed outside the tent can be controlled by a joystick to explore the scene. Further, we provide a mobile camera being moved by a person. Participants can give instructions to this person how to move around in close proximity to the tent.

Change map and scale

A top-down view is constantly provided by the surface of the *ColorTable*. It is composed of real, physical elements, as well as digital information being projected from the top. Physical maps of the site in different scales are available and can be placed onto the *ColorTable* surface. Each of these maps provides barcodes at specific positions, to switch between the scales and different viewpoints in the perspective view. The map is augmented with virtual information, like outlines of defined land uses, courses of connections, limits of the viewing cone, positions and contents of the individual objects and flows (Figure 7.6 left). In addition the top view shows feedback from the tracking system and projects the detected shape and color onto each colored token (Figure 7.6 right).

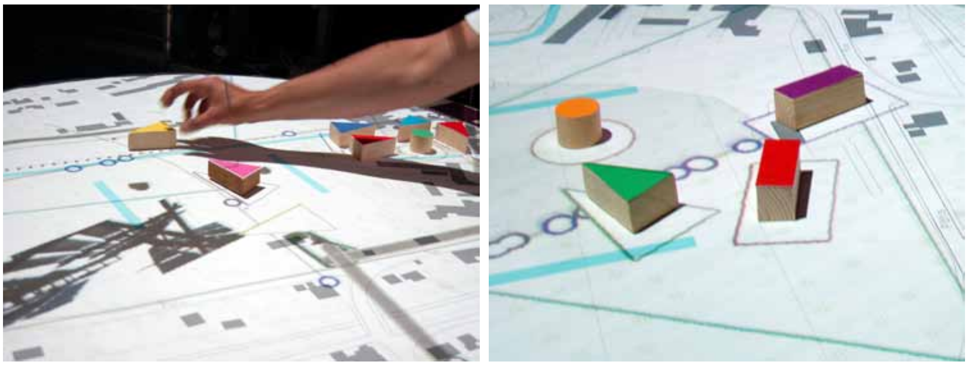


Figure 7.6.: System feedback shown on the *ColorTable*: outlines of land use areas, connections, flows, limits of the viewing cone, positions and contents of (saved) objects and detected shapes and colors.

Exploring soundscapes

The *ColorTable* supports the exploration and manipulation of soundscapes. Each object can be associated with a sound additionally to its visual representation. The resulting soundscape can then be explored in two different manners by activating a different mode. Users can select the camera position as hearing position and listen to the sound which corresponds to the panorama or video feed. Another possibility is to set the hearing position by placing a special triangular token, defining the virtual listener's position and orientation. When switching to this mode, the perspective projection shows a purely virtual view of the listener's position.

Working with persistency

The composed scene can be stored anytime by invoking the 'freeze' barcode. All color tokens currently placed on the table are permanently added to the scene and saved as a new instance in the history application. After saving, all the corresponding tokens are freed and available for arbitrary use. A once frozen object can only be removed with the eraser token. Users place this special token on the respective thumbnail on the top projection and wait until an audible feedback is provided as confirmation. Barcodes allow users to step through the design process and examine or even change all frozen states. The history function does not only allow to go back in time to a previously obtained interesting state, but also allows to use temporality as part of the inspirational process by looking at the evolving scene over time. Freezing a scene is also necessary before changing physical maps, because once frozen, objects are scaled properly and remain at their absolute spatial positions.

Printing

Users can take snapshots of their compositions at any time. The current top and perspective views are then saved as images and automatically printed for later reference.

7.1.2. Evaluation

The application was evaluated in the 3 days participatory workshop in the City of Pontoise. The workshop took place in the MR Tent in the Lavandières garden and involved different types of stakeholders.

Understanding the 3D space

As tool for urban planning, the *ColorTable* is based on a three dimensional space which participants explore, modify and discuss. As our applications are based on mixed reality, they align purely virtual and real elements to compose a new space combining both realities. Although a high number of factors are known for both types of realities, some are still uncertain and it is therefore not possible to create a scene where all elements are correctly positioned, occluded and aligned. The circumstances are even more demanding as our tool aims to support an ad-hoc creation of mixed reality scenes using images and objects expressing the ideas of participants. Contents are therefore rather approximations being prepared for each urban project and site where the *ColorTable* is used. The background panorama is based on a series of photographs that are stitched; billboards show a photograph of an object from a specific perspective. The combination of these approximative elements creates images that challenge human perception and can be interpreted in different manners. Figure 7.7 shows two examples of such images. The bridge on the left image appears like a small bridge positioned before the trees. It is however a huge bridge standing far behind the trees. As it is not occluded by these foreground objects, the viewers easily misinterpret the configuration. The playground on the right image is created with a flat canvas showing a specific perspective. As this perspective does not correspond to the background's perspective, it seems floating above the ground. A main issue is therefore to optimize the compositions in order to support users in understanding the 3d scene they are creating.

Figure 7.7.: Two examples of images being easily misinterpreted.

In the different participatory workshops we experimented with visual cues that help users to understand position and size of the elements in the MR scene. An important step forward was the use of a *depth map* in combination with the panorama image. It gives additional 3d information to the background image to allow for occlusion of virtual objects by real objects .

The integration of *moving people, cars and bikes* is another visual cue providing a reference for participants. The flows moving along the viewing direction give a good impression of where the ground floor is and at what distance the different objects are positioned. In addition, the size of these objects can be directly compared to the size of people which helps to understand the different dimensions. Figure 7.8 shows how a depth map and flows increase the understanding of the 3d scene.

Figure 7.8.: Occlusion and moving people as visual cue to understand position and size of objects in a 3d scene.

Moreover, the modification of the viewing point supports users to conceive their MR scene. Although we only support simple navigation methods such as switching to a fixed point of view or rotating the camera, the scene can be perceived from a different point of view to better see all elements.

Despite the different visual hints we provided, users still experienced problems in understanding where the virtual floor is and how it is related to the optical floor they perceive in the panorama image. Added objects, especially billboard objects, are often conceived as 'floating' above the ground. This can partly be explained by the mismatching perspectives, but also by the unusual appearance properties. To understand a 3d space, the human visual perception not only considers position and perspective of objects, but also its shading, color and shadow.

Exact positions of all elements within the scene are provided by the top-down view on the *ColorTable* surface. To support users in understanding this representation, it is necessary to show best illustrations of all objects. The physical map provides a good resolution and a familiar way of studying a site. The height of tokens underlines the three dimensions of urban elements, however their scale cannot be controlled and can cause confusions about the respective representations. By using thumbnails for saved objects, the comprehensibility of the top-down view could be increased.

Performing urban interventions

Participants intensively interact with the *ColorTable* to express their visions. While the table and the physical maps are mainly used to plan interventions, the tangible objects in combination with the perspective view are the common elements to be used for performing them. Participants are building a scene and need to know how their interventions translate into an MR scene and different backgrounds. Table 7.1 lists the different reasons why participants made use of the application functions:

Placing objects - To mark further properties of a connection (e.g. stairs, passerelle, parking) - To add activities to be done on site (e.g. tai-chi) - To add urban furniture along a connection (e.g. benches)
Modifying scale - Increase size to see / identify an object in the perspective view - To put an object in the correct scale
Modifying color - To have a better contrast with the background - For aesthetic reasons (e.g. cabanes)
Modifying offset - To adapt perspectives of a billboard on the panorama
Modifying spacing - To add more objects in a row - To create a tunnel (galerie)

Adding sound
- To add additional information to an object (children noise to football players)
- To create a specific sound atmosphere (birds)
Adding roads and flows
- To mark how to traverse an area / the site
- To mark a specific connection between two places
- To add flows to an existing road
- To use it as a border of a zone
Defining ground textures
- Define a zone on the ground (e.g. parking)
Repositioning elements
- To have them exactly aligned with the panorama or the map
- To align the perspective of the image with the perspective of the panorama
- To find the elements in the panorama
- To find out which object is connected to which color
- To optimize tracking (objects too close; outside tracking area)
Change map and scale
- To place objects that have a similar scale as the map
- To place objects on a place only visible on a bigger map
Navigating
- To have a view onto a place where they want to add objects
- To find an object that had been placed
- Zoom: To see 'more' at the same time
- Virtual view: to navigate with the sound token
- Camera (mobile/fixed) view: to explore what they have created
- Aerial view: when no panorama shows the place where they work on
Save scene
- When finished with an entire part of their project
- To have more space on the table and a better view onto the map
- Before changing scale
- To better see the end points of a road
- Before making a break to make sure nothing changes
Erase
- To redo a frozen object
- To delete objects that were created due to tracking errors

Table 7.1.: The different reasons why participants performed manipulations in Pontoise workshop 2009.

Objects were added to the scene as marker for activities to be done or to add further characteristics to a previously placed object. For instance, participants placed an image of stairs next to a pedestrian path to specify an elevated section of the path. It symbolized easy access to the park for old and disabled people. The possibility to add rows helped participants to rapidly define repeating objects along a road. Participants used it, for example, to create a series of benches along a pedestrian path.

Moving objects - pedestrians, cyclists, cars, and boats - connected to the different types of paths not only introduced an additional, human scale in the scene and provided depth information, but also animated it. Participants' gaze drifted between the table view, where the flow was represented as moving dots, and the animated mixed reality scene. They examined the spatial arrangements of 2d and 3d objects they had created in relations to these flows, eventually changing the position of a road and/or of an object that turned out to be too close to it.

Participants added ground textures to specify a specific zone, such as a parking space or a green area. Although the textures were appreciated and represented well the type of zone, they were quite imposing as they were hiding much of the underlying background. A possibility for changing the transparency of textures was requested.

When positioning objects, participants usually first put an object onto a specific place on the map. To verify the position, they look at the perspective view. Then follows a certain amount of time to find the object within the panorama, by rotating the point of view, moving the token or increasing its size (Table 7.2).

As soon as objects have been found in the panorama, participants adjusted their position in relation to the background by repositioning the color token or changing offset or size (Table 7.3).

Interestingly, the real size of both, 2d and 3d objects, something the urban planners had deemed crucial in an urban composition, did not matter so much to non-expert participants. They often made an object bigger to emphasize an intervention, and they arranged the object optically in relation with other objects and the panorama view, without necessarily focusing on the real size. To accommodate both types of stakeholders we feedback the scale number above the object image in the perspective view, which turned out to be a good solution.

Also the possibility of changing offset seems a good solution for adapting mismatching perspectives. Depending on the situation, it however may appear as being repositioned horizontally rather than vertically, and therefore creates a mismatch of positions on the map and on the screen.

Navigation possibilities were widely used to explore and verify the scene that has been created. Participants switch viewpoint or rotate mainly to find and verify the appearance of the objects that were just placed. They also plan in advance and

Ch and EV have left for a short period of time and M, J and E continue. M explains CT and previous actions to J, who has just arrived - E takes the role of technology support - they look at the screen trying to identify objects that have already been placed. 15:17:35 J: *Where on this map (screen) are the ponds (douve), we can't see the ponds?* 15:17:45 E pushes the yellow token a bit 15:17:53 J: *This we can put here* - traces a line along the Viosne with his finger - *et là* - tracing again 15:18:33 J: *This is a path* - M: *No, this is the cone of vision* - points out on map 15:18:08 J: *This path here is this path over there* - points first on map and then on screen 15:19:40 I turns wheels - rotates 15:19:59 E shifts blue token 15:20:06 The other pond appears - all are staring on the screen 15:20:35 E deactivates the zooming function and starts rotating FC15:21:55 M and MI touch blue token looking at the screen FC15:22:10 *And where is the other pond? - It is behind the trees. - It was not behind the trees in the beginning - Has it disappeared? - We have lost a pond.* - FC15:22:20 V moves yellow token - FC15:22:29 *Ah, here it is!*

Table 7.2.: Searching for objects in the scene.

The group has placed a series of chairs and they are looking for them in the panorama - G points with both hands 12.53:15 *We cannot see them since we have placed them closer to here and they are very small* - V points them out on the screen - they start increasing the size 12:53:27 *Not too much, stop, we have to decrease again* - they look intently at the screen 12:54:09 EV: *They are not really well positioned; we may have to push them to the other side?* - E and EV push the chairs to the other side of the path while the others look and direct, Ch also helps 12:54:45 M: *They are between the Viosne and the ... Well, are you satisfied?*

Table 7.3.: Repositioning and manipulating a row of chairs.

select an appropriate point of view giving overview onto the relevant space before they position an object. Although zooming increased distortion and therefore mismatched perspectives at the borders of the screen, it was appreciated by participants as they were able to have a wider field of view.

While most of the functions of the application had been used to perform meaningful interactions, several had been misused to solve a technical problem. For instance, color tokens were often repositioned to improve its detection by the tracking technology. Other interactions were accomplished as prerequisite do do other manipulations. For example, participants saved the scene because they needed more space on the table or because they wanted to switch to another physical map. It is important to spot those interactions as these indicate a workflow that can be simplified in a further prototype.

7.2. Application Airfield Aspern

Although rather small, the application that was developed for the scenario in airfield Aspern is worthwhile reporting as it implements a quite different set of urban issues and pursues another goal.

The application deals with issues of urban density, which is commonly measured by the relation of building land to the actual distribution of building mass on the site. This value is expressed by the index F.A.R., Floor Area Ratio. Other parameters, such as the minimum allowed distances between buildings in relation to their height, predefine the general physical character of the built environment. These kinds of quantifications are summarized in an 'urban code' and partly reflect restrictions, interdependencies and regularities within the underlying complexities of urban planning processes.

In contrast to the Pontoise application, which allows diverse subjective interpretations of the projected images, the Aspern application operates with quantified figures that are provided by the system.

The development of this prototype was integrated in a class of the postgraduate program Urban Strategies at University of applied Arts Vienna in conjunction with the particular course programs 'density'. Together with the students, we exploited the potentials of urban rules within the given environment of the *ColorTable*.

In order to designate single parameters of the complex urban environment, the elements of the *ColorTable* served as an abstract model with two different entities: the tabletop itself is interpreted as a two dimensional territory whereas the tokens signified static or mobile objects (uses, buildings, individuals, abstract values and flows) that have impact on the territory or influence each other. After getting familiar with the tangible user interface, each student group was asked to explore potential elements, direct or indirect forces to conceptualize the city according to the brief and the given site. Within several sessions, these factors of influence were translated into simple parameters and precise numbers to build a system that reflects their mutual relationship. Designating variables and invariants of the model and exploiting possible representation methods cross-linked to the tangibility of the interface. The students then had the chance to test the implemented prototypes and explore interaction possibilities and feedback design with the *ColorTable*.

7.2.1. Application functions

Defining territory

Users can define the outlines of a territory by placing up to 5 dedicated color tokens. The convex hull of the specified points is used to create a polygon defining the territory. The system calculates the area of the territory and verifies if any volumes exceed its boundaries. To avoid jitter the outlines can be frozen, via a barcode, to stay perfectly stable.

Adding volumes

Tokens, representing different types of buildings, can be placed on the user-defined territory (see Figure 7.9). 5 different colors can refer to buildings (cubes) of 5 predefined volumes. When a volume is added to the territory, the system adjusts the dimensions of the footprints of all volumes, to cover the maximum allowed area. This value is derived from the parameters for *Net Building Land* and *Building Coverage*. To preserve the volume of the building, their height is adjusted in a same step.

Adding force fields

Additionally, two different types of force fields with variable ranges can be positioned. The force fields either increase the density, by multiplying all affected volumes by a given factor or generate empty space by transferring volumes from the force fields inner to its outer radius (Figure 7.10). This functionality can be used to model for instance subway stations (densification) or public parks (empty spaces).

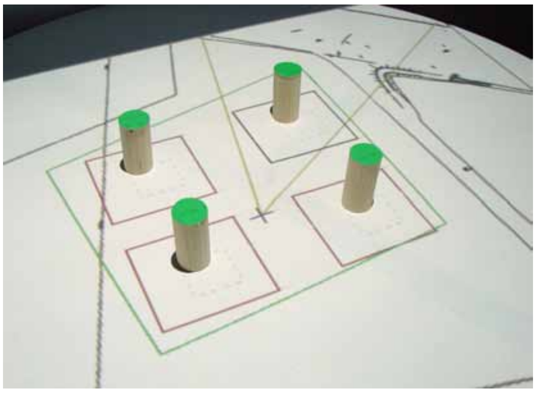


Figure 7.9.: Four volumes placed on a relatively small territory. Three of the volumes are invalid thus displayed in red. They are outside of the territory or do not fulfill the minimal distance rule.

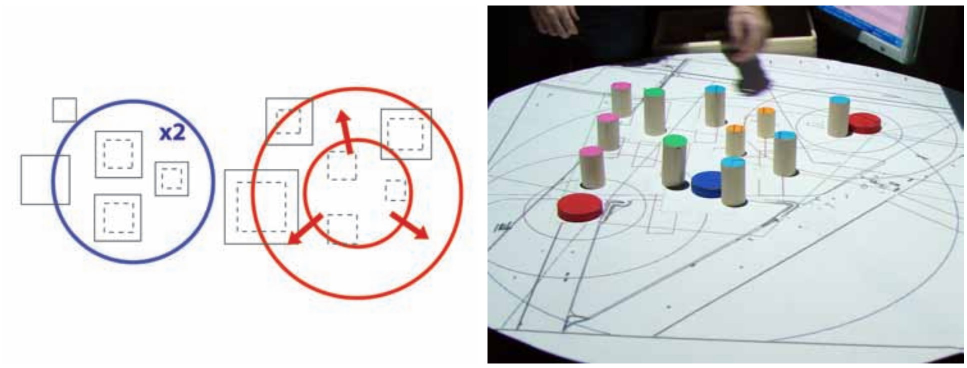


Figure 7.10.: Two types of force fields for densification (blue token) or empty spaces (red token).

Experimenting with parameters

Users can choose from some predefined realistic values for *Net Building Land*, *Building Coverage* and *FAR (Floor Area Ratio)*. The footprints of the volumes can be selected from a collection of predefined typologies, including quadratic footprints and footprints with one dimension fixed. Multi-objects allow the volume, represented by one token to be segmented into a cluster of smaller structures: 3x3 and 5x5 clusters are available. These global parameters can be controlled with the barcode interface.

An information screen (see Figure 7.11) allows monitoring the crucial numbers and parameters. These include the building coverage, resulting living area and approximated number of inhabitants. Values indicating areas are additionally expressed by bars to visualize the proportions.

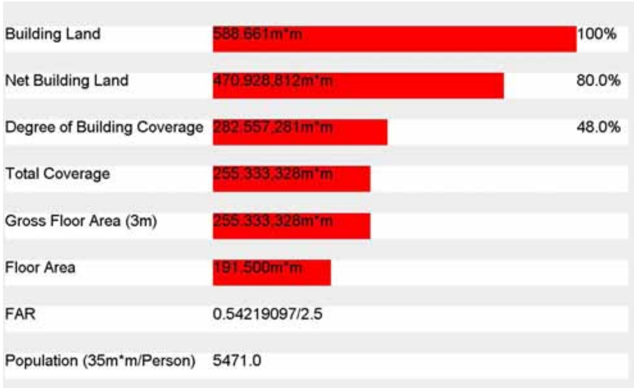


Figure 7.11.: The information screen with relevant values.

Navigating using various views

The composed scene is visualized on the surface of the table itself as well as on two projections showing different perspectives. Next to a panorama showing a pedestrians view, an additional projection shows an aerial photograph with the represented objects (see Figure 7.12). The top-down view feedbacks on the positions and dimensions of the volumes, the outlines of the defined territory and the positions and ranges of force fields. Volumes exceeding the territory or not maintaining the minimal distance are painted in red and displayed in wire-frame mode.

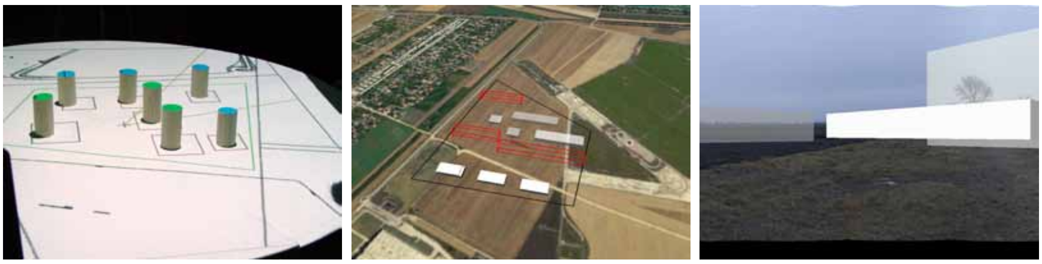


Figure 7.12.: The composed scene is presented from three different viewpoints.

The perspective views on both projections can be rotated synchronously by rotating a wooden plate. The field of view for the panorama projection is displayed on the table as a cone for better orientation. The displays of the cone as well as of the map have been simplified, to achieve better tracking results.

7.2.2. Evaluation

The rather simple application was tested in a 5 hours workshop at our institute. Aim for the students was to create and negotiate an urban master plan for the airfield. After a short training for the main functionalities, the students commonly defined a territory and threshold limit values (F.A.R, building coverage), placed, negotiated and adjusted building masses while observing the augmented scene and the changing figures at the information screen, which shows various numbers of the building code and the calculation of an average population density.

Understanding urban rules

Although the feedback on distances between volumes was shown on the table (size of footprints for each object) and in the projections (wireframe objects), the adjustment of proper distances between the objects seemed to be difficult in the beginning. The students developed a successful technique by placing all volumes in the center of the territory to then move them systematically apart, until none of the volume was represented by a wireframe bounding box.

The rules we had implemented turned out to present some undesired side effects. The ground coverage of an area is predefined according to a rule (e.g. 80%). Before growing in height, the footprints of the volumes need to cover this entire amount of 'Net building land' while simultaneously following the distance rule. As the current concept makes it difficult to optimize distances by manually positioning each building with a color token, it is hardly possible to create high rise buildings. Not until the ground area is perfectly filled with buildings, further volume tokens can be added and the system increases the building height - a situation which is impossible to reach.

In a second scenario, students used different typologies as well as the force fields. Here a problematic side effect was that when limiting the maximum depth of the volumes in one axis to the smallest size, the resulting curvature of larger volumes stretched out of the defined building area. To be able to evaluate the created configuration with respect to the numbers that were set before, the buildings must stay within the building area.

Operating with force-field objects seemed to be practically and conceptually clear. After positioning the objects and observing the impact on the scene, the distances between the surrounding volumes were adjusted. The students immediately reacted to the object that represented the impact radius of an underground station, because it raises different questions that reach beyond the restrictions in mass distribution. Increasing the complexity of the rules by integrating parameters, which include economic values and addresses questions of mobility (e.g. public transport), seems to be relevant for the further development of the application.

Changing scale for a third scenario was easy to handle for the students. After introducing the multi-object, the concept of solving the problem of a crowded table by simply representing a series of volumes in the scene with a single object on the table, first seemed to be successful. The division of the total volume into a number of smaller ones was principally clear, but in relation to the former scenarios, the fact of fixed distances between them was questioned. Because of the static shape, the students had difficulties to imagine a meaningful scene.

Working with representations of urban elements

An interesting observation was how the students collected the needed information from the different modes of representation and how these were connected. The axonometric view was important to understand the overall scene. Switching between top-down view and axonometric view gave information about the positioning of objects (volumes) and for adjusting their distances. Looking at the axonometric view and the info screen helped understand the relations between the numbers on the screen and their actual representation by masses in relation to the defined building area.

For orientation and the spatial composition, the panorama was compared with the top-down view. The perspective view especially supported users in understanding the heights of volumes. While discussing issues of representation, the students made some remarkable comments. Concerning the projected map on the table and the aerial photograph in the axonometric view the need for a clearer focus was addressed. One of the students stated that within the axonometric view, the whole scene is 'translated into reality'. In the discussion, the students suggested to reduce the architectural map to an amount of lines that enables an orientation in space but still provides certain background information about the context (e.g. land register). Due to their immediate visualization, the statistical figures became somehow graspable within the panorama scene.

Another important issue was the perception of scale. To understand the actual size of the volumes, placing a person into the panorama would be helpful. In the axonometric view, a soccer field could give an idea of the extension of the whole territory. Furthermore, a measurement could be included in the top-down view and serve as a permanent reminder for the dimension of the volume's footprints and the surrounding.

7.3. Implementing application functions for tangible user interfaces

From the above descriptions of two different *ColorTable* applications, we can extract a number of aspects that need to be considered while implementing new applications for a tangible tabletop system. While a formal analysis and description for coupling physical manipulations with digital ones are provided in chapter 4, we provide here a set of more practical issues to be considered when creating concepts for application functions.

7.3.1. Dealing with possibilities and limitations of tangible interaction

The core interaction of a tangible tabletop is the positioning and rotating of tokens onto its surface. Most important interventions should be directly manipulated through this type of interaction. Within the field of urban planning, it is rather obvious to use the table as representation of a 3d scene, while virtual objects can be placed and rotated with the tokens.

To develop further application functions beyond the simple positioning of individual objects, we can make use of a combination of several tokens belonging together. Within the case of our example applications, such functions were implemented for setting streets (with two tokens), rows (with two tokens) or a territory (with up to 5 tokens).

Further possibilities are to define specific areas on the table that activate a state as soon as an object was placed into them. We used this approach at the very beginning for the configuration area (see chapter 8). Note that such areas may remove valuable space of the tracking area to be used for other functions.

Besides these interaction possibilities with tokens onto the tabletop, manipulations can be easily created using barcodes or RFID. Barcodes can trigger a function, and are therefore best suited for processes like saving or the confirmation of choices being done elsewhere. This justifies the fact that barcodes were a good choice for selecting content from the database. Participants discussed and selected content in front of the whiteboard and just confirmed their selection by reading its barcode. In contrast, changing a size per barcode was experienced as cumbersome as users would like to select the correct scale by experimenting with different sizes.

RFID based interaction provides similar possibilities for developing application functions. Placing a transponder next to a reader triggers the identification code of the transponder. While a barcode is triggered at the moment a user pushes the button of the reader, RFID codes are triggered through proximity. This allows RFID technology to be entirely embedded within the physical objects and better support direct haptic manipulations. However, as users can not exactly control the moment of trigger, it is impossible to detect how often in a row a function was supposed to be executed. When working with absolute values, such as setting a predefined size or content, multiple executions of a same function have no effect and therefore are best suited for this type of technology. When however working with relative values, such as increasing size with incremental steps or saving, barcode technology is a more obvious solution. In the last prototype of the application Pontoise, we triggered increasing of size, offset, transparency, color and spacing, at equal intervals of time. This was a solution for the problem as participants could control triggering moments through time: when satisfied with the value, they took the transponder off the reader.

7.3.2. Creating sensible application functions

Within the scope of urban planning, a common requirement of applications is to show or illustrate urban interventions as well as consequences of them. The different functions and manipulations of an application need to reflect the issues of the urban project. For the proposed urban projects, important interventions deal with the positioning and arrangement of urban elements onto a realistic background. Participants positioned individual objects as well as rows of them, created curved roads and streets, populated them with different types of animated objects and defined borders and zones. Objects were manipulated to improve the optical appearance of the MR scene; participants adjusted their size, color and offset according to the background.

The numerous participatory workshops showed that users wish to express themselves in a precise manner. Each time a function for working on a different urban issue was introduced, participants requested to control related aspects precisely. Individual objects were required to be adjusted in their size, color, transparency and offset. They wished to modify the curved shapes of streets and indicate type and density of the corresponding flows. Further the idea of defining ground textures through a Voronoi decomposition had to be refined and we implemented their creation by specifying the individual borders.

To increase precision, we can decide for functions and the respective manipulations to be controlled with a certain number of physical handles, each related to a different parameter. The position of one individual object in the Pontoise application is based upon the position of one color token. Streets are set using two color tokens. When using several tokens for controlling an urban element, the possibilities for manipulation are considerably increased. Streets can be modified in their position, shape and exact course with the two tokens, while an individual object can only be positioned and rotated with its physical handle.

An increased set of possibilities for manipulating urban elements invites participation and helps users to express themselves correctly and precisely. It however may complicate and elongate the interaction as soon as too many tokens need to be positioned and manipulated for achieving a result. The concept of zoning provides an example for this situation. The former version was based on a Voronoi composition, where cells could be defined using a small number of tokens. In the later version, such zones could be defined by setting all borders individually with two tokens. To define a rectangular zone, users need to place 8 tokens, which resulted in a long process with a high number of interaction steps. It did however enable them to create zones of all conceivable sizes and shapes.

The request of precise and complex manipulations can be explained by the common work practices of architects and urban planners. Software supporting urban planning is usually provided to visualize designs at a late stage of a negotiation process. At this stage, main subject of discussion are decisions concerning precise values of sizes, colors, materials or distances. When providing more approximate manipulations, the type of decisions which participants take on the *ColorTable* rather correspond to early stages of an urban planning project. The degree of precision or approximation therefore influences the types of discussion to be conducted around the *ColorTable*.

To visualize the interventions, we experimented with abstract representations, shown on the tabletop, and expressive elements on the perspective view. Abstract representations, such as curved lines for streets, or footprints for buildings provide precise characteristics of the intervention, such as their exact course or dimensions. Expressive elements, such as photographs or textures show the ambiance of the intervention. We further added feedback on the actual values in numbers; a request by the urban planners.

Depending on the goal of the application, it is necessary to integrate all three types of them. Numerous feedback locations however may present a problem for the design of the interaction space. As described in chapter 8, places for gaze have a strong impact on the distribution of participants around the workspace. In our last version of the Pontoise application we integrated the quantified numbers of the currently modified object in the map area and on the perspective view. This approach decreased the locations for feedback as the former info screen could be removed. The new visualization was then limited to the values of one object at a time, which participants handled well.

The selection of meaningful kinds of additional information the system provides has a strong impact on user guidance and freedom of thought in the decision making process of the later use. The application Airfield Aspern, which operates with quantified figures, could easily provide data, such as an average number of inhabitants or simplified cost models that in turn correlate to the representation of the building masses. In contrast, the application Pontoise allows subjective interpretations of the projected images, without being directly linked to the actual layout on the table. The designation of qualities and quantities therefore lies within the ability of the users to evaluate the visible situation.

Feedback and visualizations generated by the application can represent a different degree of automation. This choice is an essential factor for specifying the level of the discussions being made around the tabletop. We mainly distinguish between an automated reaction, modifying another value, and visual feedback, highlighting certain aspects. The first possibility, as in the Aspern application, lets the software take the decision and skips long experimentations to find a valid solution. Such rules defined the footprints and heights of building. A problem of this approach is that the decisions may not be satisfying for the user. When leaving the degree of automation to a mere highlighting of specific aspects, the decisions are entirely taken by the users, as in the application Pontoise. Drawback of this approach is that the composition of a valid solution may require a lot of time including several interaction steps, or may even not be provided due to a lack of knowledge of the users. Depending on the amount and complexity of urban issues to be dealt with, it is important to decide for a compromise of the two types of automation.

When working with a three dimensional space, possibilities for navigation are crucial in order to explore and understand the scene. A continuous modification of the viewpoint helps participants to estimate distances, locations and sizes of objects. When working with real backgrounds, navigation cannot be easily implemented. Our solution with several locations for viewpoints that can be rotated or zoomed was a good compromise. To additionally support users in understanding the MR scene, we worked with several visual cues such as the a depth map and moving elements.

An important aspect, enabling the composition of more complex scenes, is the saving and loading of previous work. Being used to be able to 'undo' at any moment, users wish to have a similar possibility for tangible interactions. When working with lightweight, direct manipulations, individual modifications however can hardly be identified, which makes them difficult to undo. Saving and loading can more easily be supported, as this process is explicitly triggered by the users. Tricky however is how to include the configuration of the physical tokens. While their positions can be easily stored, it is not clear how these physical objects can be 'loaded' to continue working with them. In one of the earlier versions of the application Pontoise, we experimented with a possibility to project the locations where users need to reposition the objects. As this approach highly complicated the workflow for saving and loading, we implemented a different procedure for a later prototype. Instead of conventional saving, participants could 'freeze' the current configuration of objects, which meant that their digital representations are stored into the scene. The relation to their physical is lost and a current snapshot of all positions, contents as well as their attributes is written in a file. These types of snapshots can be loaded at a later point of time. To enable simple modifications of this configuration, we provided the possibility to erase single objects that can then again be added and manipulated.

7.4. Summary and conclusion

In this chapter two applications of the *ColorTable* have been described and analyzed. While the first application focuses on enhancing the dialogue among different stakeholders, the second one deals with urban issues of Airfield Aspern and experiments with planning regulations to show consequences of different configurations on a territory.

To illustrate urban interventions and related consequences with the *ColorTable*, the applications use representations of urban elements that can be positioned and arranged onto a realistic background. Participants may position individual objects as well as rows of them, create curved roads and streets, populate them with different types of animated objects and define borders and zones.

Several types of visual and sound feedback can be used to highlight the consequences of different interventions. We experimented with numerical data to show sizes and transparencies of objects, illustrations on the top-down view and realistic representations on the perspective view.

To deal with the complexity of urban interventions, corresponding manipulations have to be developed. One of our approaches is to combine multiple colored tokens and barcodes or RFID in one application function. This possibility was used to be able to change the content of one color token by reading the ID of one of the numerous content cards. The use of two objects for defining a street, further highly increased the possibility for changing its course.

A second approach to support complexity is to provide a possibility for saving and loading. This functionality allowed users to stepwise compose a complex scene using a small amount of colored tokens.

CHAPTER 8

The interaction space

Designing an interaction space of a tangible user interface means to take a large amount of decisions concerning size, form, amount and arrangement of physical objects for controlling a set of application functions within a common space. We agree with Hornecker and Buur [HB06] that tangibility and materiality, physical embodiment of data, embodied interaction and bodily movement are an essential part of interaction and embeddedness in real space. Such design decisions therefore influence collaboration, expression, communication and discussions between participants.

Due to the long-term iterative design process enriched by the numerous design ideas of participants, the *ColorTable* became a complex tool with a high amount of tangible interactions. To support this complexity, numerous components had been developed which increased the amount of physical objects as well as their distribution all around the workspace. Step by step, the complexity of interactions could be reduced while at the same time functionalities of the application had been expanded.

This chapter describes the different prototypes of the *ColorTable*, with a focus on the various types of manipulations and the physical design. It provides a set of more general design issues related to the design of tangible interactions, in particular the design of physical objects and their arrangement within a common workspace. It analyzes its impact onto users' way of working using different workflows and collaborating.

As support for collaborative design in a multidisciplinary team, a model of constraints is provided, helping to balance requirements and possibilities of related disciplines within a common interaction space.

Parts of this chapter are based on the papers *The ColorTable: A Design Story* [MPW08] and *Supporting Complex Tangible Interaction: A long-term iterative study of the ColorTable* [EM10].

8.1. The different prototypes

While designing and developing of the interaction space of the *ColorTable* as part of a participatory design process, we collected a high number of observations on how participants interacted with its different components. In the following, we will describe the different prototypes each of which was developed as an improvement of a previous prototype.

8.1.1. The first prototype

The very first prototype was presented in Ste Anne (Paris) to show a simple set of possibilities to manipulate space.

Introducing the basic interaction

The *ColorTable* approach is based on a worlds in miniature (WIM) paradigm [SCP95], where the table and the color objects serve as representations of different elements of a mixed-reality world. The 'world' is represented by the table and the color objects refer to virtual objects. By manipulating the color objects, users directly manipulate their representations in the WIM. The relative positions of the shapes on the table are used as relative positions of the virtual objects in the scene. The part of the table where objects are tracked is highlighted by a projector. The first prototype of the *ColorTable* is modeled on this approach. It consisted of a white surface (the table) with two configuration areas, a series of color objects, and a barcode interface. The basic interaction consisted in picking up one of the colored objects (squares and triangles), placing it in a small squared region on the table, and assign an image or sound file using the barcode interface. Users of this first prototype quickly learned to create visual scenes, with a background image and virtual objects, which can be manipulated (turned, sized up and down) by moving the color objects as their physical representations.

The color objects, in the beginning flat geometric shapes, may represent all kinds of contents, each with a color defining a different virtual object. In Figure 8.1 (left) we can see how objects of the same color can be joined to scale up an object. To give objects a direction, green triangles could be attached to a color object. In the first prototype we also used a combination of two specific colors (blue and violet) for changing the projected background.

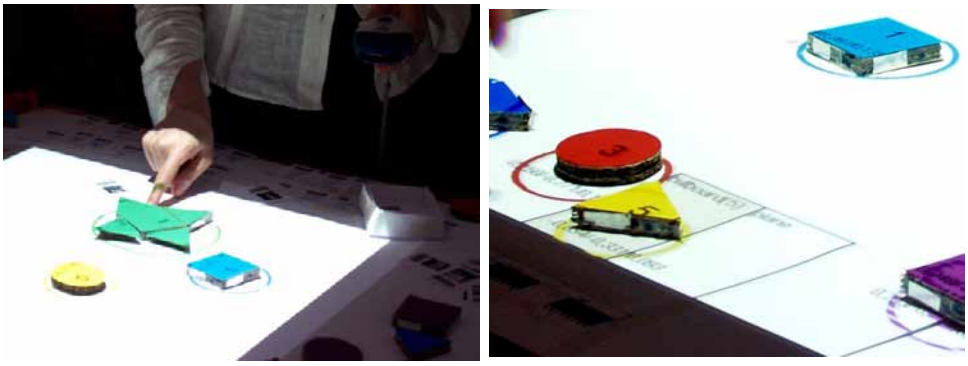


Figure 8.1.: Enlarging a virtual object (left); selecting an object by placing it on the configuration area (right).

The first *ColorTable* prototype had a specific area - the configuration area - for activating a color object which was marked on the table by a squared projection. Users had to place a color object on this configuration area (Figure 8.1 right) in order to select the color. Visual feedback was given through the outline of the area changing to the color of the selected object. A subdivision of the configuration area was used for activating a shape, either as 'billboard' (which rotates itself in direction of the viewpoint) or 'plane' (which can be rotated manually). The idea was to allow users to create 3D scenes (and not only collages of 2D images). The barcode interface was and is still used to access elements of a media database by reading in dedicated barcodes (Figure 8.2 left).

Observations

A major topic of discussion was how to change perspective. Participants wanted to be able to see an object from different points of view or to have the impression of moving around, to be able to turn the head and get another perspective. This discussion sparked the idea of building a rotating table and to experiment with a static and/or a video panorama.

Positioning objects was experienced as difficult. There was a lack of depth and exact sizing and placement were near to impossible. The idea took shape to project the map of the area onto the table to facilitate the positioning of objects in the scene relative to each other.

Figure 8.2.: Reading in barcodes representing content (left); table littered with barcodes (right).

Workshop participants had difficulties to understand all the possibilities to perform interactions. For example, the distinction between 'billboard' and 'plane' remained unexplored. Another problem was that users were not able to recognize immediately, which content the objects they were manipulating represented and they sometimes disagreed about what color was linked to what content.

Controlling the size of virtual objects by combining several shapes also produced some problems. As the tracking system was not sufficiently precise, the virtual objects seemed to 'jump' because the 'noise' of tracking made them change their size. Another issue connected to tracking was that users partly overlapped the shapes when touching them with their hands. This called for a different design of the color objects that invites users to grasp them from the side instead of touching them from above.

Finally, content organization was a problem from the start. In the first workshops, all barcodes were arranged separately on small sheets of paper and placed in small boxes. As more than one user was working with the *ColorTable* and picking out barcodes, it was impossible to keep them in order (Figure 8.2 right).

8.1.2. The second prototype

Based on the feedback provided in the first workshop, the *ColorTable* was significantly improved and used for a second workshop in Ste Anne.

Rotating the table One of the main design decisions after the first workshop was to construct a rotating table. It is used with a panorama as background. The panorama, which emulates a representational practice with a strong tradition in architecture, enables users to stand in one or several particular positions within a space built either with photographic images or with a video image.

The rotating table consists of a turn-tilt plate which is fastened in the center of the table board (Figure 8.3). An optical computer mouse is placed upside down under this plate in order to track the relative angle of rotation. A foldable, circular disk, covered with white, opaque cloth is placed upon the turn-tilt plate. The viewpoint is positioned in the center of the disk and oriented into the direction of the vertical projection. To change the orientation of the viewpoint, the user rotates the disk, and provokes the rotation of the whole scene around the viewpoint. The fact that the color objects rotate with the disk and are tracked ensures that the virtual objects move with the scene. The panorama needs to be adapted depending on the current rotation.

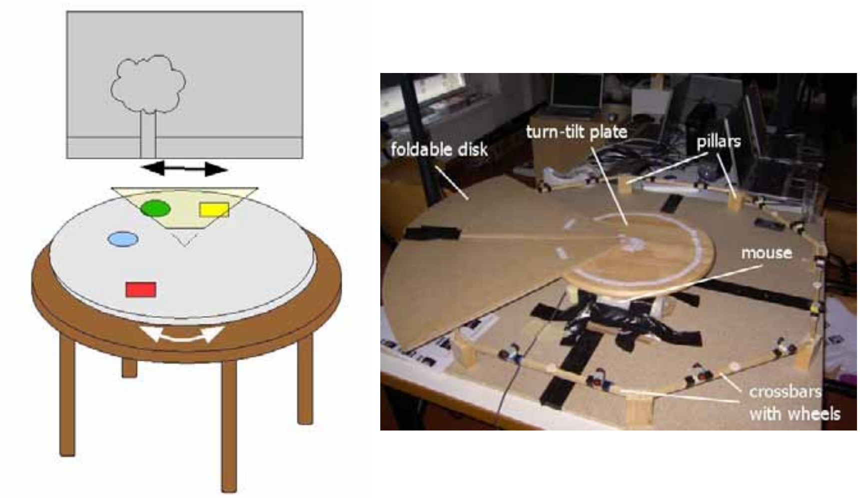


Figure 8.3.: The rotating table.

This decision had several consequences. Before this change to rotating, the viewpoint was located outside the table (about the position of the users) and therefore nearly the whole surface of the table could be used to position objects in the scene. With the rotating mechanism in place the viewpoint needs to be located in the center of the disk. This led to a significant reduction of the space for manipulating the mixed reality scene (about one sixth of the previously usable area), as can be seen in Figure 8.3. It is still possible to place (and track) all objects on the table, however only those objects currently within the viewing frustum are also augmented in the virtual scene. We provided users with feedback to help them understand this limitation by projecting the viewing frustum on the table. Another drawback connected to rotating was that because of the smaller physical space the precision of the tracking was reduced.

Despite these limitations, users considered as significant progress the possibility to change the viewing angle and to look at different parts of the mixed reality scene by rotating the table. For users the rotating mechanism also has the advantage of strengthening the spatial effect, helping them to perceive the 3Dness of the mixed reality scene. Furthermore, they can influence the velocity of the rotation. We observed how in exploring a scene they wished to travel faster, while in building or changing a scene they traveled slower.

Projecting a map onto the table A map as a way finding cue was easy to add to the rotating *ColorTable* by projecting a map of the site represented by the panorama on the working area as shown in Figure 8.4 (left). The positions of the colored objects are shown directly on the map. When rotating the table, the projection of the map follows the rotation and is therefore always aligned with the mixed reality scene.

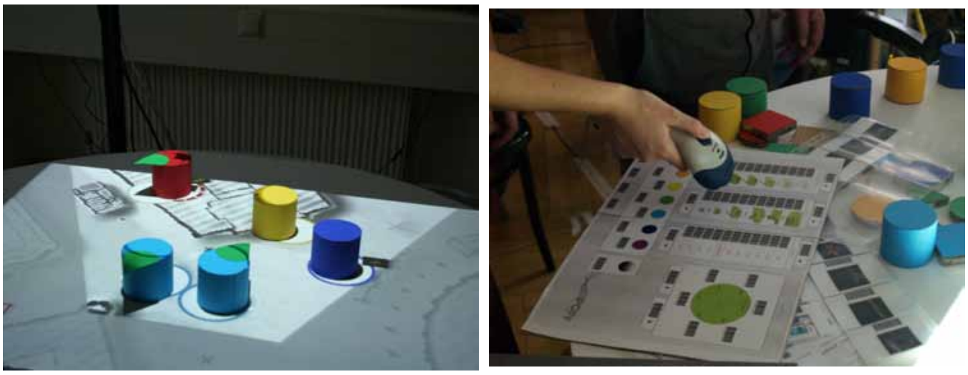


Figure 8.4.: Placing objects on the projected map (left); working with command posters (right).

Introducing command posters We also had to find another solution for changing the attributes of virtual objects, in particular their size. Barcodes are a fast and easy method to make commands available to users. This is why we decided to use barcodes for manipulating object attributes, at this point scale, transparency, and color (Figure 8.4 right). This solution offers users more possibilities to manipulate objects, in particular to scale them more precisely. It also solved the problem of virtual objects 'jumping' (changing scale all the time).

The barcode itself provides no direct feedback about whether it has been used or is active. This is why we introduced the projection of information about the objects' current attributes directly on the surface of the table. This also offers a solution to the problem for users forgetting what object each color represents.

Observations With this new version of the *ColorTable* we could observe how different groups of participants - stakeholders in an urban planning project - through gesturing, selecting content, placing color objects, and rotating the table for the first time, 'performed' a mixed-reality configuration, emphasizing particular interventions, and bringing an expressive element into a scene [MPWW07].

The size and materiality (haptic quality) of the color objects clearly influenced the way participants interacted with them and how they actively engaged in building a mixed reality scene. The new shape of the color objects - cylinders that users can grasp and firmly hold in their hands - supports this.

We observed several problems participants experienced with the configuration area. It took some time to learn not to just pick up a color object and associate content with it but to first place it on the configuration area, and to repeat this step each time they wanted to change an object attribute. Rotating the table moved the currently selected object out of the configuration area, which frequently was overlooked by the participants, so further attempts at changing object attributes did not succeed until participants became aware that the object had moved out of the configuration area. Also, only one person could make changes at a time.

Workshop participants had no problems to understand the relationship between the rotation of the table, the map, and the mixed reality scene. The map, however, did not provide much way finding aid, as only a small extract was visible on the table. Moreover, the calibration of the map with the table and the mixed reality scene turned out to be tricky.

We also observed that the table gets quickly cluttered with color objects, while the projected visual scene may still be quite empty. Making the objects much smaller so as to be able to see many of them not only poses challenges to the tracking system but also may make it difficult for participants to keep an overview of the virtual objects they introduce and changes made to them.

8.1.3. The third prototype

A more complex prototype was developed within the context of the implementation of a new courthouse in Paris.

Introducing a tangible selector and info screen We resolved users' problems with the configuration areas by introducing a separate workplace for selecting objects. The tangible selector consists of several disks, on which all the available color objects are represented as flat illustrations. When users want to select an object, they take the corresponding disk, put it onto a small rod, next to which a barcode reader has been mounted, and turn the disk until the right object is selected (Figure 8.5 left). RFID transponders are used to tag the different positions of the illustrations on the disk. When a certain object is selected, the RFID is captured by the reader and used as input for the application. The selected object can now be modified using the barcode interface. To encourage collaboration, two tangible selectors are provided (each of which has been assigned a different color) and users may split up into two groups working simultaneously.

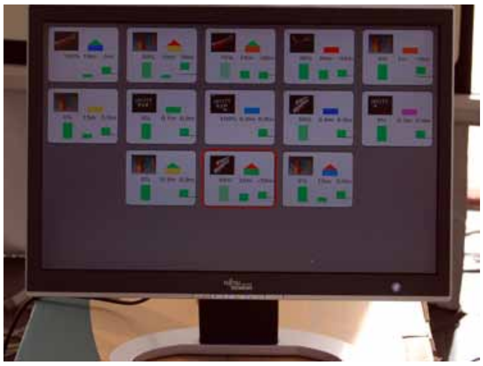


Figure 8.5.: Selecting an object with the tangible selector (left); monitoring feedback on the info screen (right).

We also decided to no longer project object attributes onto the table surface but to use a separate monitor as an info screen, on which users can see the content of selected objects (Figure 8.5 right). The info screen also gives feedback on the object which currently is selected by the two tangible selectors (through color coding) and on the content it is associated to. The monitor can be viewed from either tangible selector workplace.

Tangible selector and info screen are important steps in improving the workspace organization of the *ColorTable*. Now the activity of selecting objects is separated from moving them on the table and changing attributes. On the table surface itself users can have a clearer view of the map, unobstructed by additional projections. Information about each object appears on the separate space of the info screen, where the attributes of all color objects in use (not only those placed on the table) can be perceived in one compact space.

Enlarging the interaction area Another important step forward was to enlarge the interaction area. The rotating mechanism requires the viewing point always to be in the center of the table, so that the objects can turn with the projection. As implication, only one sixth of the table surface can be used to position objects inside the current field of view (Figure 8.6 left). To enlarge this interactive area, we introduced a second mode, in which rotation is suspended. Users can decide to use the whole table for placing objects in the scene as the viewpoint no longer needs to be in the center of the table. Instead of rotating the whole table, users now can change the viewing direction and look around by turning a separate rotating disk between the two tangible selectors.

Decoupling the map projection and mixed reality scene made it possible to add commands that allow users to change the scale of the map (zoom in and out) and also to move the map freely, for example when switching the viewpoint. They still see the viewing frustum on the map, which helps them to orient themselves and they get feedback on which objects are currently visible in the mixed reality scene. Zooming into the map allows for a more precise placing of objects, since the movements of the objects are relative to the scale of the map (while the tracking precision remains the same). We introduced a small paper map with barcodes indicating the different viewpoints, from which the panoramas have been produced. It supports users in switching between these panoramas, hence to be able to look at a mixed reality scene from different viewpoints (Figure 8.6 right).

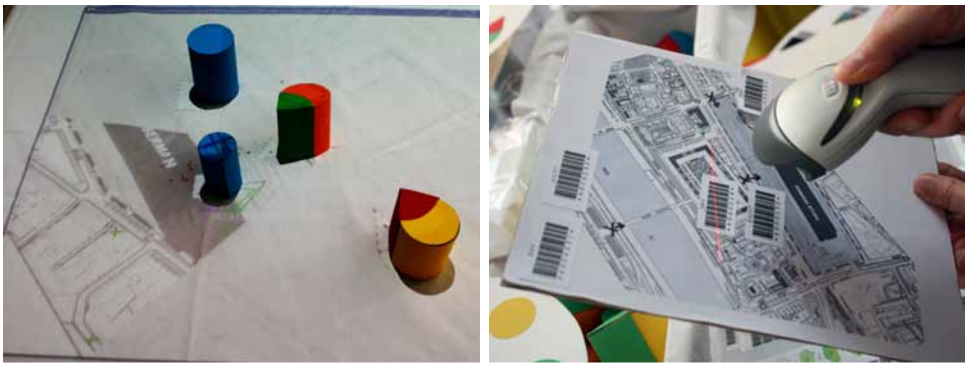


Figure 8.6.: Field of view being projected onto the table (left); paper map for changing viewpoint (right).

In addition to the different viewpoints, the paper map provides the possibility to switch between different map sections being projected onto the table. As a consequence of this additional possibility of zooming in and out, some intermediate steps become necessary. After each zooming or change of viewpoint users have to manually reposition the color objects. The system can load all necessary information from the database, but users must still place the physical objects in the positions they had before, and we support them by projecting the position and shape of the objects onto the table. We use the same mechanism when restoring previous settings, to allow users to continue their work.

Re-designing the color objects We also redesigned the color objects (Figure 8.6 left). They are smaller so that users can use more of them and also put them closer together, thereby increasing the density of virtual objects, hence create more complex mixed reality scenes. We made them somewhat heavier so as to increase their hapticity, ameliorating the feeling users have when they pick them up and hold them in their hands. Instead of tagging those objects that should be rotated, we now work with two types of color objects - round shapes with one color and pointed shapes with two colors which are used for rotating objects.

Additional workspace The high number of new interaction modules of the *ColorTable* stress the importance of organizing the workspace. All the material and devices needed should be within reach but not in the way. The size and shape of the table are important aspects to enforce or encourage collaboration. For this purpose, an additional workspace has been developed, assembling two tangible selectors, two barcode readers, a rotating viewpoint, space for putting the colored tokens and the barcode sheets. The two tangible selectors can each be used simultaneously along with one of the barcode readers. Input from the barcode application is assigned to the object currently selected by the respective tangible selector.

Observations The tangible selector in combination with the info screen facilitated the manipulation of individual objects. Participants easily managed to select a specific color and to modify it using the provided barcodes. The info screen provided useful information to the users. It turned out to be a reliable source of information to control which settings are currently active.

Users liked the new possibilities of navigating in the scene. They often changed the panorama and viewpoint to see their compositions from different points of view. They also used the whole surface of the table to place objects, and manipulated the rotating disk and the barcodes to see the objects in the panorama. While increasing navigation possibilities, it became clear that a precise map, showing the site in an appropriate scale is an important element for participants. We observed that our projected map did not provide enough information to allow for a deep discussion. This is due to the limited resolution of the projector, but also because of the conflicts with our tracking technology, that becomes unstable when the projection is rich in contrast (Figure 8.6 left).

The possibility of modifying the current map section being projected onto the table mainly remained unexplored. The different steps that are needed to do this interaction (save, remove objects, change map, replace objects, reactivate tracking) turned out to be too complicated to be done by a lay user. We concluded that a different workflow is necessary to support this manipulation.

By introducing the new components and tangible objects, the *ColorTable* became a complex TUI. To interact with the table, numerous physical objects are needed and put down on each possible spot (Figure 8.7 left). The additional workspace being part of this prototype partly provided space for these objects, but completely changed the positions where people were standing and discussing around the table. It created a sort of barrier between participants and table and restrained discussions to be hold around the table (Figure 8.7 right). It became clear that the workspace needs to be redesigned by including these collaboration issues. It needs to provide space for all objects, but also for participants and their discussions.

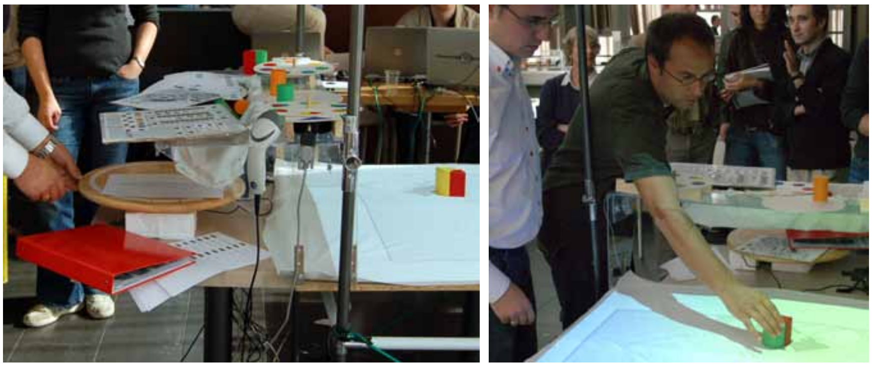


Figure 8.7.: Different tangible objects are put down on each possible spot (left); additional workspace represented a sort of barrier (right).

8.1.4. The fourth and fifth prototype

Within the context of two smaller workshops, we developed a special *ColorTable* prototype for exploring the possibilities of implementing rules. In cooperation with an international group of students of the University of Applied Arts Vienna's postgraduate program, we experimented with novel interaction possibilities to develop a more reactive system, providing solutions and consequences in an automated manner.

Increasing use of tokens To allow for a higher amount of input possibilities, we introduced new, special tokens, that can be used for a different type of interactions. As the tracking technology is limited to the detection of 8 different colors, we use a combination of two colors to create additional tokens. In contrast to the conventional tokens, the special tokens do not represent a single object that can be positioned and oriented into space. They are used in combination with other special tokens to create a more complex geometry, such as a territory or a street (Figure 8.8). To confirm the position of such a geometry, users read a barcode freezing the position. They then remove the tokens to use them for defining further geometries.

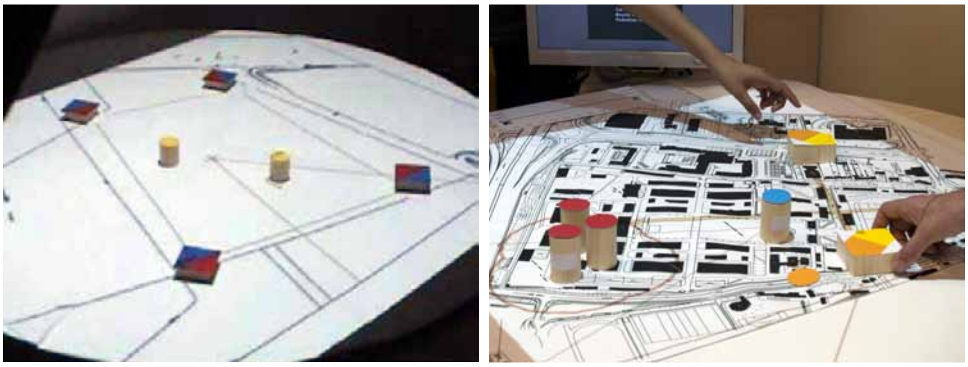


Figure 8.8.: Using multiple special tokens to create a territory (left) and a street (right).

The new tokens are presented in a different design with a lower height to visually distinguish them from the conventional tokens. As the tracking technology affords color regions to be of a certain size, we increased the size of the special tokens to be reliably detected and recognized.

Introducing the physical map In this prototype we introduced a physical paper map to be placed onto the tabletop (Figure 8.8 right). It significantly increased the size of the map area and provided a much higher resolution as the digital, projected map. When several maps of different scales are needed to discuss specific aspects of the site, the physical map can be changed by removing all tokens and putting a different map on top of the other one. Although removing the tokens is an additional step in the workflow, it reminds users that the tokens need to be repositioned to ensure them being aligned with the new scale.

Introducing content cards, board and tray To resolve users' problems with the multiple tangible objects lying around and blocking the interaction areas, we introduced a new workplace and workflow to discuss and select content. We created small magnetic cards, each showing a thumbnail of one media object along with a barcode. We arranged a collection of content cards on a whiteboard next to the *ColorTable*. This allows participants to discuss, order and select the objects they want to work with in a separate step (Figure 8.9 left). To conclude this selection process, we introduced a content tray, providing space for 8 media objects - one for each color (Figure

8.9 right). The users can therefore decide in advance which objects to add to the scene and collect their selection onto the tray.

Figure 8.9.: Discussing content on the content board (left) and deciding for a selection on the content tray (right).

Observations The use of special tokens to perform a different set of interactions increased the complexity of the application. More manipulations and interventions can be performed with the colored tokens, the most natural, haptic and direct form of interaction of the *ColorTable*. The users quickly understood which tokens could be used for what interaction and positioned them onto the map. We became aware that the use of two colored tokens hinders the stability of the tracking results as it gets easily confused with two unicolored tokens being positioned close to each other. Further, the limitation of 2-3 of such special tokens created a cumbersome workflow including the positioning of the endpoints and their confirmation via barcode several times.

Participants used the magnetic content cards to point, move around, arrange, and rearrange their collection of media content. They offer a certain haptic quality and users liked it to take them into their hands and arrange them onto the content board or content tray. In contrast to the former booklet, it provided a much better facility for discussing content as a high number of people are able to observe and contribute to this selection step. The whiteboard as an additional workspace turned out to be an important improvement in the organization of space and objects around the *ColorTable*.

Although the content tray did not provide a perfect amount of space for 8 content cards, it was well accepted by participants. They used it to store their selection of content and looked at it from time to time to check which colored token is assigned to which media object. However, in the later process of the workshop the tray was blocking the access to the basic tokens.

The participants experienced some problems with the handling of the multiple components giving feedback about and controlling the different objects in use. They suggested integrating content tray, tangible selector and info screen in one touch screen. We identified the need to simplify this working environment and to look for different solutions.

The use of a physical map was an important step forward in the design process of the *ColorTable*. It improved the table in its role as planning and discussion space, offering participants a familiar tool for pointing and gesturing.

8.1.5. The sixth prototype

This more complex prototype was developed within the context of the urban planning project of the Caserne Bossut in Cergy-Pontoise. Main re-design activities included a new physical *ColorTable* with dedicated spaces for all objects.

Re-designing the color tokens To increase the possibilities for using colored tokens as input parameters, we extended the tracking framework to detect shape information of tokens (see chapter 6). It is now able to track circles, squares, triangles and rectangles, along with the orientations. This modification enables the system to differentiate between 4 shapes and 8 colors, i.e. 32 objects, that can be used to create and manipulate different urban elements.

We therefore re-designed the color tokens to reflect the new interaction possibilities. The new tokens are generally reduced in size and designed in different materials (wood, Plexiglass, cork) and shapes (Figure 8.10 left). We used them as replacement for the former special tokens that had to be quite large and could only be used for a quite limited set of interactions. The different shapes enable direct composition and manipulation of single objects, streets or ground textures as each shape can be linked to a different type of urban elements. To set a few streets simultaneously, several pairs of objects of a same shape and different color can be used. The confirmation via barcode is no longer necessary.

Re-designing the physical ColorTable To resolve users' problems with the multiple devices and physical objects, we decided to design a new physical *ColorTable* providing an adequate space for each of these elements. Our idea was to support participants with a clear structured workspace where tools and objects are easily accessible.

Our design provides a round table surface (diameter 120cm) to be used as interactive map space. The worktop is mounted at a height of 120cm to be comfortably accessible for pointing and positioning. Rotating disk and tangible selector are attached directly under the table surface as second working layer. A third layer is provided as storage place for the remaining physical objects; colored tokens, barcode trays and barcode readers can be disposed on two retractable frames mounted at a lower height. The inside of the table is used for placing hardware and cables needed for the devices. As we did not yet find a suitable place for the info screen, we placed it behind the table to be viewed by the most frequently adopted positions around the table (Figure 8.10 right).

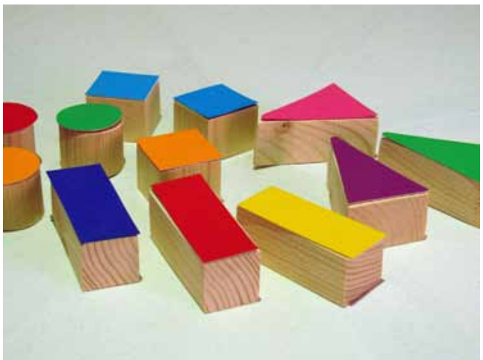



Figure 8.10.: Re-designed color tokens (left); physical ColorTable including rotating disk, tangible selector and retractable side frames (right).

Introducing saving and loading The sixth prototype further provided possibilities for saving and loading. Via barcode, users can 'freeze' the positions and orientations of the colored tokens and the corresponding digital representations are decoupled from their physical handles and added to the MR scene. The different saved scenes can be loaded at a later time, however, as the relation to the colored tokens is lost, they cannot be manipulated any further. To enable users to modify the saved scene, we introduced the eraser, a special token deleting objects within the scene.

Introducing maps of different scales Along with the possibility for saving and loading, we introduced maps of different scales. To change such a map, users freeze the tokens, remove them from the table, place a new physical map and read a barcode to adapt the scale of the projected top-down view.

Observations The re-designed physical *ColorTable*, along with the new color tokens were an important step forward in the organization of the workspace. It separates the different areas using multiple levels, and presents them as one common, round planning and discussion table. Participants quickly understood how the different shapes could be used for different interventions. They liked the table, arranged themselves around it and used the map and color tokens to discuss, point and gesture. The increased height of the worktop helped them to better reach and position the objects.

Participants used the maps of different scales depending on the interventions to be discussed and performed. A limitation occurred when participants wanted to change the map in the middle of an intervention. Although the configuration was not entirely decided at such a moment, participants triggered the saving process in order to be able to change the map. They then needed to perform the more complicated manipulation of erasing and re-creating in order to manipulate the objects on the new map. We observed how participants became aware of this limitation and checked the current configuration before saving.

The retractable side frames provided enough space for all objects and devices. We however observed that participants did not use them all the time, but preferably put the most needed objects directly onto the surface of the table. We can explain this way of working by the fact that the objects lying on the side frames were hidden for most of the participants. To reach specific objects, users need to bend down and look through all the objects on each side. To facilitate the access to the most needed objects, they put the ones being needed for the next step into unprojected areas of the table (Figure 8.11 left).

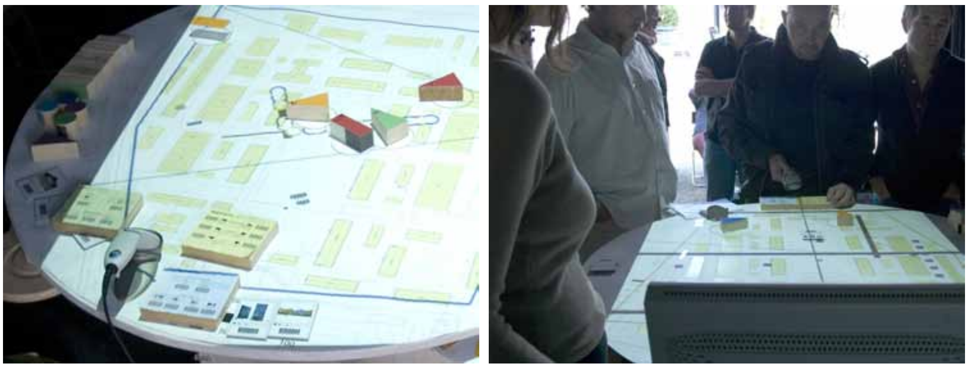


Figure 8.11.: Placed objects on unprojected areas of the table (left); one participant being in charge for reading barcodes (right).

Another observation dealt with the organization of tasks within the group of participants. Users usually selected a place at the beginning and then learned the tasks that can best be done from that position. During the rest of the session, they felt responsible for that task to be done and kept the respective tools within their reach (see Figure 8.11 right).

Although the new table provided a much better space for all objects and devices, the workflow for some tasks turned out to be still very complicated. An example for such a task is the association of content to a color token. It requires manipulation of the tangible selector and the barcode interface using objects from the content board and the side frames. Feedback is provided on the info screen, being positioned at the other side of the table. We concluded that it is necessary to further integrate these components and simplify the number of steps needed to accomplish the task.

8.1.6. The seventh prototype

In a final workshop, we presented a slightly improved prototype with a re-designed physical table offering more simplified interactions. It was developed within the scope of an urban planning project in Pontoise (France).

Introducing the configuration board and info area To simplify the workflow for placing content into scene, we developed a special board with rectangular areas for each of the available colors. To assign a specific content to a colored object, users place the content card onto the respective colored area. Underneath the colored areas of the board, 7 RFID readers are mounted to capture the RFID code of the physical cards.

In addition to content creation, the board can be used to manipulate it; we developed command cards, triggering for instance automatic, incremental scaling or modification of the transparency. Users place the command card onto the colored area, which triggers a modification of the value each second. When satisfied with the value, they take the card off the area at the right moment.

The board is attached at the front side of the *ColorTable*, at a same height as the map area. Each color area provides space for placing the card, as well as space to put previously used cards (Figure 8.12 right).

Further to the configuration board, we introduced the info area, providing feedback about the current manipulations. It is a rectangular area at the front side of the table, where we project a thumbnail showing content as well as values for size, transparency, etc. To display the contents of one color, we provided a command card 'Information Request' to be placed onto the configuration board. The info area thus only shows current information of one color at the time. Along with the physical cards upon the configuration board, the info area replaced the info screen. Information about the current scale, transparency or spacing values were additionally shown on the perspective view.

Figure 8.12.: The configuration board and the info area are used to assign content (left); a half-round extension at the back of the ColorTable to store all physical objects (right).

Re-designing the physical ColorTable Along with the configuration board, we improved the design of the physical *ColorTable* to provide space for tokens and devices. Underneath the table are prefixed frames for the rotating wheel (i.e. mouse and plate) and the 7 RFID readers detecting the content cards being placed on the color areas. A second wooden half-round extension mounted 15cm lower at the back of the *ColorTable* for all the physical objects needed to perform manipulations. Inside the table, metal sticks and frames provide place for laptops, hubs and cables.

Observations The modified interaction for assigning content with the configuration board was quickly understood and used. Participants placed the content and command cards on the adequate color zones and used the space in between for piling used ones. After freezing the current configuration of objects, they removed all content cards from the configuration board and put them back onto the content board. To check the settings of individual objects, participants made use of the information request card and read the numbers on the info area. Although this combination of configuration board and info area did not provide the same amount of information as the former info screen, it turned out to sufficient for the participants' way of working.

By introducing the info area into the map area and showing feedback on the perspective view, the numbers of places for visual feedback were reduced. We observed how users checked the results of manipulation in the perspective view, by simultaneously watching optical appearance and the value in numbers.

Participants occupied the limited environment depending on the communication and interaction. Ehrenstrasser describes in [MWB+10] how the use of space in and around the MR tent showed various forms of body positions and configurations.

We could distinguish three basic formations, all three varying in the distance and accuracy (close or open configurations):

- *Row/line formation e.g. lining up to watch somebody drawing with the UrbanSketcher (Figure 8.13 left).*
- *Circle/curve formation e.g. to collaborate at the ColorTable and manipulate tokens (Figure 8.13 right).*
- *Triangle formation e.g. to discuss a specific issue in detail in a close group.*

The round table of the ColorTable specified the curve and circle formation when used by three people or more. Participants divided their roles for space according to their main interaction e.g. assigning content by standing in front of the configuration board, grabbing and passing tokens by standing next to it on both sides to reach the lower side bars or working with the wheel and barcode reader by standing on the left side of the configuration board.

Figure 8.13.: Forming a row to watch the projection (right); forming a close circle around the ColorTable (left).

8.2. Evaluation

The story of the *ColorTable* design highlights some general issues concerning interaction design for tangible user interfaces. Our observations from the various participatory workshops provided useful information on how users interacted, what manipulations they used, which physical design influenced this action, and how these helped to guide the users.

In our discussion, we analyze how tangible objects, manipulations, and workspace can support complex interactions. We summarize our main observations by comparing aspects of the different prototypes and their influence on participants' workflow and collaboration.

8.2.1. Working with the tangible objects

The *ColorTable* and the content board provide a huge number of physical objects in various designs. As described by Ehrenstrasser in [MWB+10], they vary in form, size, material and color.

> *The tokens and cards (content cards, command cards and barcode cards), which have undergone several cycles of re-design, are central to participants' interactions. They awake haptic engagement and support playful interactions. The basic geometric forms and materials are familiar to participants. The topside is always covered with a color or a print out. People know how to hold and use them. We made use of different materials (wood, Plexiglas, cork) to distinguish the different types of tokens (in addition to color and shape) and cards. People can feel and see the difference. The sizes invite to grab and hold in one hand. People were discussing or interacting and simultaneously holding tokens and cards to play or to have them when needed. The different objects were combined as needed: People worked with more objects of different materials and surfaces simultaneously.*

Participants liked working with the small content cards representing content. At the beginning they sometimes positioned them directly on the table. After having understood the need to link them with a token, the cards they had selected remained on the edge of the table, signaling 'this is a pile of our images'. Our strongest evidence in favor of the color objects is our observation of how individual participants used them in search of meaningful interventions, holding an object while observing from a peripheral position and thinking.

Essential in the design of the objects is to define in the requirements if the objects have to reflect their assigned multimedia content in form, size and color. Being physical objects, they do not change in their appearance to reflect the size of their assigned content. In our case this provided some conflicts for the context of urban renewal. Depending on the available contents and the chosen scale of the map, a token could represent a bench in the perspective view, but blocking an area on the map in the size of a river. The users confirmed this problem and gave feedback that the tokens were hiding too much of the underlying site map.

Increasing the interaction area for positioning tokens downsized the problem. The introduction of several viewpoints and maps in different scales provided users with more possibilities to position objects by changing map scale or switching to a closer viewpoint.

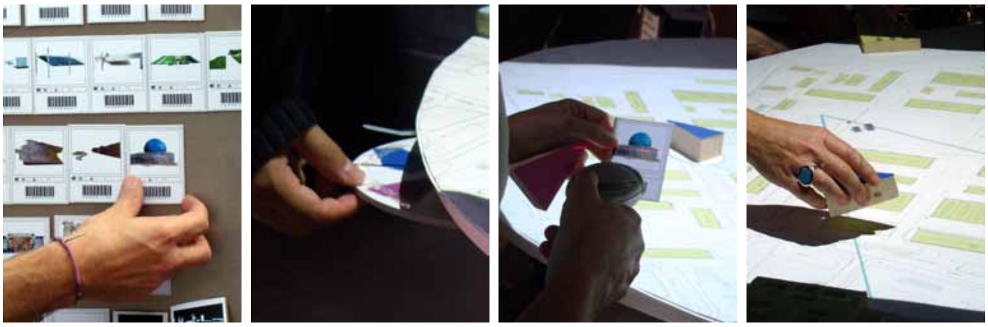
To support the high number of diverse manipulations in the MR Tent, we designed them to be controlled with different combinations of physical objects. Our observations showed that participants performed the manipulations with several hands collaborating. We can distinguish between one-hand manipulations, like placing a content card onto the configuration board, two-hands manipulations, like reading a barcode from a barcode tray and more hands manipulations, like changing the physical map.

8.2.2. Managing the workflow

The workflow depends upon the chains of actions users have to carry out to do the different interactions of the *ColorTable*. Each workflow uses a set of devices or objects, which can each be found on specific locations. In our development process we experimented with different components and combinations of components to provide the tools for doing complex urban planning modifications. Each of our prototypes therefore required a different workflow that users had to learn and carry out.

An example for such a workflow is the placement of content into the scene. In the former prototypes this interaction required a long chain of actions for the user. The single steps were: Selecting content at the content board, selecting an unused token, selecting the color on the tangible selector, assigning the content to the token color by reading the barcode and placing the token on the tabletop (Figure 8.14). The system provides feedback concerning the success of the different steps, in most cases on the info screen. Users thus have to manage 5 different steps, whereas each needs to be carried out on a different location, and feedback is provided on even an additional place. Our observations have shown that the users are helping each other out along the steps, sometimes alternating at each step. Nevertheless, users happened to forget individual steps (e.g. select the color with the tangible selector) and therefore performed an unmeant interaction.

In our latest prototype, we re-designed these different components and introduced the configuration board to associate and modify content. This transformation modified the chain of actions, which are now: Selecting content at the content board, selecting an unused token, assigning the content to the token color by placing the card on the RFID spot, placing the token on the tabletop and optional changing the content attributes (Figure 8.15). The info area is now shown directly on the surface of the table, next to the configuration board. This modification shortened the chains of actions, decreased the number of objects/devices needed for interaction and integrated some of the elements in one common space.



(a) (b) (c) (d)

Figure 8.14.: Chain of actions to add an object to the scene: Selecting content (a), selecting a token, selecting the color (b), assigning the content (c) and placing the token (d).

(a) (b) (c)

Figure 8.15.: Chain of actions to add an object to the scene: Selecting content (a), selecting a token, assigning the content (b) and placing the token (c).

8.2.3. Appropriating the workspace

Due to the high number of physical objects and interaction modules of the *ColorTable* it became a necessity to find solutions for organizing the workspace. All the material and devices needed should be within reach but not in the way. Our observations in multiple workshops showed that users often had troubles to organize the placement of the diverse objects. They were disposed at every possible spot around the tabletop and blocking tracking and free interaction. We therefore experimented with different possibilities to guide users in this spatial organization.

The first attempt to solve this problem was to create additional workspaces providing dedicated space for the objects. In the third prototype, we introduced an additional working layer, attached above the map area of the *ColorTable*. Although this workspace provided enough space for placing all objects, it blocked the access to the map area and therefore disturbed people in interacting and discussing around the top view of the site (see Figure 8.7).

The physical *ColorTable* of the sixth prototype had two retractable side frames for placing tokens and barcode trays. It also integrated the rotating disk and the tangible selector directly into the surface of the table. It ensured good access and view onto the map, and had specific positions for the other tangible objects. It however turned out that all objects on the side tables were not visible to the users standing in front of the table. The table itself was blocking the view onto these objects and users had to bend down to find the needed objects. To make these objects more accessible, participants placed the inactive tokens or barcode trays into the unprojected area of the table.

Our last design of the *ColorTable* provided a slightly displaced side frame, enabling users to better find and reach the colored tokens and barcode frames.

Throughout the different re-designs of the workspace it became a necessity to clearly distinguish between the individual interactions and create a place for each of them. This means that we have to think about where objects are when a corresponding interaction is performed and where they are while not in use. Main issues to be considered while creating and designing of such places are visibility and accessibility. Content cards need to be clearly arranged and in eyesight to allow for all participants to discuss them on equal footing. The same applies to the map being positioned onto the table. All users should be able to analyze it and reach it for pointing or placing objects. In contrast, unused tokens only need to be visible for 1-2 users as those can hand them to the other ones. Figure 8.16 shows how participants accessed the map area during workshops with the third and the sixth prototype.

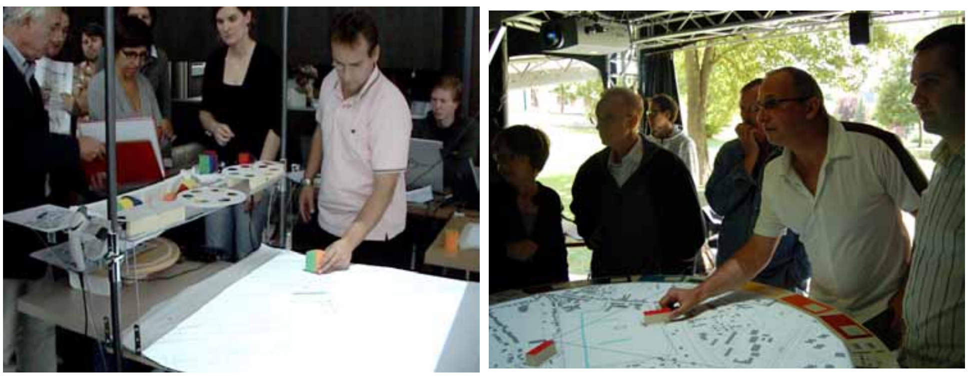


Figure 8.16.: Accessibility of the map area in the third prototype (left) and in the sixth prototype (right).

An additional issue connected to workspace deals with the distribution of visual feedback. While planning, performing and evaluating interventions, participants directed gaze onto the feedback provided on the table, the screen, the hands action or the other participants. While positioning objects, for instance, participants' hands actions are at the tokens, while their gaze is at the screen. In contrast, associating content has hands action at the configuration board and gaze directed onto the map. Both actions are superimposed when organizing workspace or select content cards when hands action and gaze have the same direction.

These directions providing feedback are important aspects for the arrangement of participants within the MR tent. The sixth prototype included an info screen (flat screen) situated at the back of the *ColorTable* to show basic information about object configurations. Although it ensured good visibility of these data, the screen increased the locations for visual feedack in addition to the map area and the projection of the panorama. Participants had to adjust their head movement and gaze every time depending on the visual feedback they needed, which complicated their workflow and influenced their configurations within the tent. To preserve the lines of sight and allow free gaze onto places for visual feedback, participants arranged around half of the table and round table configurations were disrupted.

In the sixth prototype we reduced the number of screens and projections and used only one vertical projection where users can switch between the different views. In addition we integrated the information shown on the info screen into the info area as part of the top projection. These modifications enabled participants' free movement in the tent and around the table and clarified the directions for getting feedback all along the workflow.

8.2.4. Collaborating

Multiple observations of our re-design activities show that the *ColorTable* supports collaborative activities and that we have set several steps to strengthen the collaborative aspect of the application. Users were arranging themselves in different ways around the *ColorTable* and started to work. Sometimes just one person carried out the interaction steps with fellow participants in the background just instructing. Others organized themselves in a team and interacted and created a scene collaboratively.

Users' interactions with the **color objects** illustrate the advantages of haptic directness as allowing users to watch the effects of their activities while performing them and as enabling simultaneous interaction. A quite common observation was that some participants work collaboratively with the tokens on the tabletop, while others wait for their turn with token and content cards in the hand. Moreover, interacting through the color objects produces a feeling of familiarity in the user groups we observed, as well as sensitivity towards each other's perspectives. This presents an aspect of social coordination, which we seek to strengthen.

The **design of manipulations** and their place within the workspace had an impact on the collaboration of users. Two-hands manipulations, such as setting streets or reading a barcode from a tray, were often done by two participants. Also changing the physical map was mainly performed collaboratively (Figure 8.17). The tokens and other mobile physical objects needed for interaction have been passed around excessively. As they did not have a dedicated position, people felt free to place them anywhere around the table. In our latest prototype we provided space for each of the objects and distributed the spaces all around the table. We could observe how participants distributed around the table and manipulated or passed the objects and interaction components being within their reach.

Figure 8.17.: Collaborating while setting streets (left) and changing the physical map (right).

We could see how the **size and shape of the table** are relevant. As Patten and Ishii [PI00] and Stanton et al. [SBN+01] observed, a large working space encourages or even enforces collaboration since there is no way for a single person to efficiently manipulate all objects. We observed how the round shape of the table was highly conducive to people gathering around and interacting. The increased surface we used for the latest version of the *ColorTable* along with the reduced number of places for visual feedback, provided space for more people and therefore encouraged more participants to actively contribute to discussions.

Also the **spatial arrangement** of the physical objects is crucial for collaboration to happen in a smooth way. In general, all the material and devices needed should be within reach but not in the way. Important steps in this direction were to present content cards on a large whiteboard or to use a large paper map as basis for discussion. The relevant information is accessible and visible for all workshop participants.

8.3. Summary and conclusions

One of the biggest challenges of the *ColorTable* is to design complex technologies supporting collaboration on an equal footing while evoking open discussions with all participants. The complexity of the urban projects increased the amount of manipulations based on a high number of physical objects distributed all around the MR Tent. To deal with this high complexity as well as the collaboration issues, it became a necessity to provide a clear workspace with the high amount of objects and to support a clear workflow along complex interactions.

In this chapter we have reported our main observations and findings regarding the development and re-design of the tangible interactions of the *ColorTable*. The different cycles of development-evaluation-redesign in a participatory design process provided us with rich explorations and creative results influencing participants' way of working with the physical objects, managing the workflow, appropriating the workspace and collaborating.

While designing the various manipulations, it is a necessity to consider the workflows participants need to deal with for accomplishing a task. Important is the number of intermediate steps, as well as their locations among the space. Further needs to be considered where visual feedback is provided. A more explicit distribution of these factors increases the complexity, but may support collaboration as users can help each other through the chains of action.

An essential part of making the interaction and the interface usable is the organization of the workspace. The design of the tabletop is a design of the table and the space around it. The spatial arrangement of the table, whiteboard, projection and the numerous objects and devices are crucial for the users workflow and collaboration. To support usage within a workspace, participants need a place where they interact with objects and devices, and where they store them. Accessibility, visibility and flexibility of this place highly influences the way users are planning and performing interventions.

CHAPTER 9

The real use

When designing and developing technologies to be used within a real context, part of the design decisions deal with how to show and embed the interaction tools within that context. In our case of the *ColorTable*, we needed to decide for a place on the site where it is set up, a set of viewpoints where panoramas are taken, a sequence of activities that can be performed by the tools, a certain amount of content to be at the users' disposal, an so forth. In addition to the materials themselves, the way of explaining and showing the technologies influences the users' way of working with them.

This chapter describes the questions and issues to be solved when preparing real use of a complex tangible user interface. We address this problem with a case study upon two participatory workshops organized within the context of a same urban planning project: the Caserne Bossut in the city of Pontoise.

The first workshop was carried out in Vienna, June 19, 2008, with a student group from the University of Applied Arts as participants. We installed a small setup of urban technologies and experimented with use-cases dealing with urban topics such as time, connectivity and distance. The results of this analysis were used to prepare a second workshop on site in Cergy-Pontoise in September 2008 in a more elaborate setup of urban renewal technologies, all assembled in the MR Tent. As participants, we invited different types of stakeholders - urban planners and specialists, members of the municipality and representatives of the local community.

9.1. Workshop Caserne Bossut 1

The aim of this workshop was to enable people to show their own interests and encourage discussions about modifications of the site. The prototype should give inspiration by providing possibilities and constraints, it should show problems and consequences, but not automatically solve them. As output, it should give ideas and preferences that urban planners can use for their project.

9.1.1. Activities

As part of the design process, we prepared a list of activities that best enable working on urban issues. This list had been developed in cooperation with the urban planners and was adjusted throughout the development process of the prototype.

Preparation step The first activity in the workshop plan was to choose programs from the content board. We anticipated that participants will want to think alone or in small groups, what types of programs correspond to their wishes and take them off the board. Later on, the content will be discussed in the whole group to select 8 of them and stick them onto the selection board next to a specific color.

Discussion steps We prepared three different issues to be discussed and explored on the *ColorTable*. To facilitate the learning of the different interaction possibilities, we planned to sequentially introduce the different discussion steps, just before participants are working on the respective issues. Users may however move to another step and come back at any time.

The three discussions address the issues of setting connections, positioning programs and exploring distances of trips (Table 9.1 and Figure 9.1).

9.1.2. Content

Most of the activities being supported by the *ColorTable* need to be 'filled' with content. To decide for the selection of programs that need to be available, we first set up a list, as shown in Table 9.2. We identified the need to distinguish between programs centered around a *point* (defined by a color token) and some that are defined as an *area* (using two color tokens).

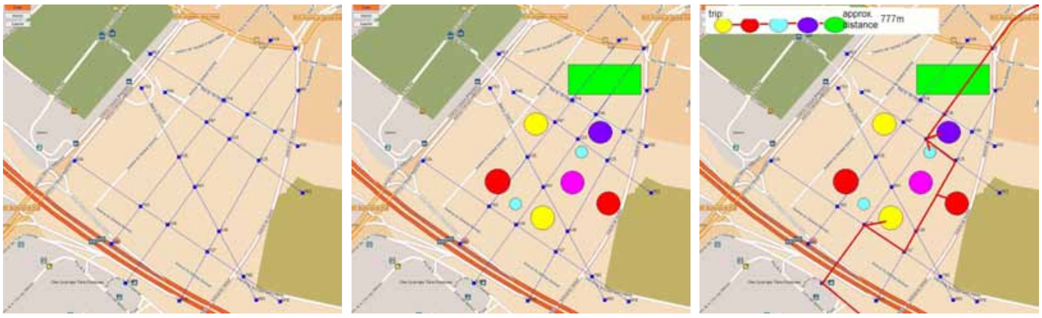


Figure 9.1.: Conceptual illustrations showing the three different issues to be discussed on the ColorTable.

To represent the programs in the perspective view, we decided to use images showing a typical activity related to the program. For instance, to represent a restaurant, we selected an image of people sitting around tables and eating. A sample of the prepared content is shown in Figure 9.2. Each of the punctual content objects is assigned with a default size, which provides a scale value for as well its representative billboard in the perspective view and the circular illustration on the top view.

Figure 9.2.: A selection of the content representing the different programs: towers, basket ball players, cinema, terrace and market place

As types of streets we decided to use pedestrian paths, slow streets (30 km/h) and fast streets (50 km/h). Flow objects are available as pedestrian, bike and car, that move along suitable streets of the network in an appropriate speed.

To explore the scene from different viewpoints, we prepared four photographic panoramas of the site from different elevations (Figure 9.3). The panoramas were edited and part of the buildings had been removed to provide an empty space.

Set connections - set or modify connections between main anchor points: each connection can be set as pedestrian way, slow street (30km/h) or fast street (50km/h).
Position program as points or areas - assign programs to color objects: each program is available in 2-3 different sizes. - position programs on the map as point or area. - see the programs as expressive billboards on the perspective view; the sizes of the programs are reflected in the size of the billboard.
Distances of trips - set a sequence of the programs according to the own interest. - as option set a start point and an end point anywhere within the site. - study distance to accomplish in meter and in time for 3 types of transport (pedestrian, bike, car). - see the flows walking onto that trip, each one having a different speed; the cars may go a different way, as they are not allowed on pedestrian ways. - change the speed of the time passing.

Table 9.1.: The three discussion steps of the first participatory workshop.

9.1.3. Moderation

In the workshop we used role playing as method to imitate real use and make discussions and interactions more alive. The idea was to define a set of roles which correspond to typical stakeholders of the *ColorTable*. Each student selects one of the roles and creates the character with a specific style, interests, argumentations and background. We planned different roles for elderly, businesspersons, family members, youth, urban planners/architects and persons from city council to represent the typical stakeholders from our *ColorTable*. Throughout the discussions and negotiations around the *ColorTable*, the students adopt their roles and hold the corresponding views.

To make participants familiar with the *ColorTable* we planned a stepwise introduction of the different functionalities. Each time a new discussion step is introduced, we explained the interaction possibilities corresponding to that use. After these instructions, we passed the tools over to the students and stayed in the background to allow them to become active while using the *ColorTable*.

Category	Point	Area
Public open spaces	Playground (children); Playground (youth); Look-Out; Restaurant; Café; Pub; Hotel; Youth hotel	Parc; Square; Market; Camping
Commercial	Shopping center; Discotheque	
Culture	Museum; Theatre; Library; Concert hall; Cinema; Exhibition centre	
Sports	Fitness centre	Swimming pool

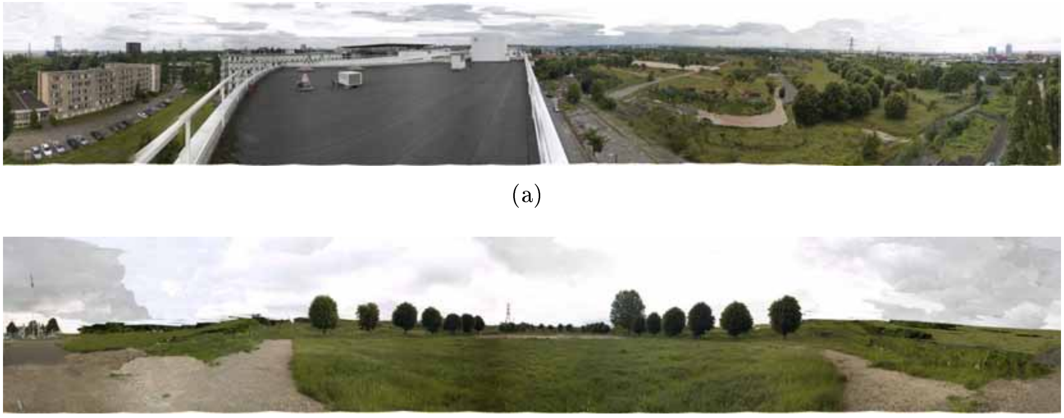
Table 9.2.: We prepared different types of programs.

9.1.4. Evaluation

After a short description of the workshop's aim and an explanation of the role-play, the students were able to enter into a discussion about choosing the programs and positioning them within the site. The *ColorTable* served as medium for communication - we observed intense discussions including placing, removing and exchanging of objects. An important part of the discussion was dedicated to the amount of towers to be placed onto the site, as well as the position of a swimming pool. We identified differences how the students adopted their given roles. While some of them seemed to be shy about arguing in terms of their role, others tried to convince the others with rhetorical means and focused upon winning the discussions rather than to respond to the needs of their persona.

In general our decision to split the workshop into a sequence of tasks which was explained forehand seemed to be very successful, since the participants were able to concentrate on the recent task. The temporal distribution of learning activities and actual working activities however turned out to be problematic. To explain the interaction possibilities of each task, we had to interrupt the discussions in order to get full attention. It therefore hindered participants' own workflow and their negotiations between different stakeholders. To limit the interruptions, not all functionalities have been explained and some of them have not been used, such as the definition of trips. Hence, we identified the need of clearly separating learning activities with working activities and of planning a separate learning session in a workshop.

Throughout the preparation sessions of the workshop, we became aware of the importance of discussing and working out a list of supported activities as well as



(a)

(b)

Figure 9.3.: Two of the panoramas showing different viewpoints of the site.

related questions dealing with content. In our design process, this list served as basis for computer scientists to explain the current status of the implementation and to take corresponding design decisions in collaboration with the urban planners and designers. At each of the numerous meetings, the list was refined and adapted to cover some unresolved issues. For instance, while implementing the placement of programs into the site, a related design decision dealt with their affect onto nearby streets (see Chapter 4). While several approaches could easily be implemented and supported by the system, not each of them supported a sensible way of dealing with urban issues. A discussion and exchange of possibilities and requirements could best be done by collaboratively discussing and re-discussing each activity as part of the iterative design process.

The combination of different types of representations turned out to be a good solution for discussing different types of issues. The top-down view along with the illustrations (projected circles, lines and animated dots, representing the flows) was used to discuss the compatibility or conflicts between adjacent programs as well as the adoption of paths and streets. In contrast, the perspective view supported users in adjusting the sizes of towers or other vertical elements that strongly affect the spatial representation of the scene.

9.2. Workshop Caserne Bossut 2

The idea of this workshop was to address the preliminary stages of an urban development scheme. It does not focus on design issues, but rather deals with uses, ambiances, problems of daily use, connectivity and accessibility. Participants decided on a number of general principals concerning the site with the outcome to eventually guide the urban design process and the urban design team. The issues to be addressed are interdependent and participants can restructure the scenario as they seem fit.

In contrast to the first workshop, the organization of the second one was partly based on a preparatory session with the participants. These were invited to join the research team at the Caserne Bossut so as to meet, distribute the cultural probes packages and explain their use as well as the workshop's objectives. This session was followed up by a visit of the abandoned military barracks that are not usually accessible to the public that gave the participants the occasion to discover the place.

We used the cultural probes method in combination with a narrative interview technique for stimulating participants' imagination and to help them prepare for the urban planning workshop. The cultures probes consisted of two maps of the site (and surrounding area) of different scale, three panorama pictures, and a CD with 99 sound files to select from. Participants were asked to think about connectivity, about the central public space, and also about housing types and activities they would like to see at Caserne Bossut; as well as collect and bring objects with which to represent their ideas.

9.2.1. Activities

The scenarios corresponding to the two sessions had to be conceived so as to allow participants to exchange ideas over issues prior to the urban project launch, questions related to the uses, the ambiances, the accessibility, etc. The activities should allow them to indicate collectively options and principles for the development of the future district Bossut by using the MR Tent and the *ColorTable*. They also had to reflect and make space for the visions participants had developed in the 'cultural probe interviews'. In this way, they would be able to outline strategies that could possibly lend new points of view to the urban planning team elaborating the development plan.

As for the earlier workshop, we prepared a list of activities in cooperation with the urban planners.

9.2.2. Content

From the visions participants created in the 'participatory interview', we extracted visual and sound content. The 2d images, 3d models, textures and sound files were

Work with issues of connectivity - Discuss the site in relation to its surroundings, using the large paper map as well as the aerial view (sketch, annotate) - Create connections - Define streets of different types and flows - Define a 'sound trip' (connected with a flow) - Save and print out important constellations
Work on connection across the highway into the central space - Place 'passerelle' - Define its qualities by sketching and painting, as well as working with billboards
Discuss allocation of spaces for different uses - Define areas for different uses (with special respect to housing) - Save and print out agreed upon solution
Work with housing typologies - Select and place different housing units on the site (taking account of already defined streets and flows) - 'Customize' appearance of some housing objects by painting - Place Congress Center (and other relevant 3D objects) - Discuss choice by looking at it from different panoramas - Discuss choice by annotating, sketching - Save and print out relevant solutions
Activities and ambiances - Select and place different activities - Take into account and eventually modify sound connected with activity - Switch views (panoramas)
Discuss options - Annotate with UrbanSketcher - Change your hearing position and evaluate choices from the point of view of the resulting soundscape - Save and print out important steps in decision-making process and/or alternative solutions

Table 9.3.: The different tasks dealing with questions related to uses, ambiances, accessibility and housing types.

chosen in relation to the different urban issues to be discussed: circulations, activities, housing types and centrality.

Circulations Connections with flows represent circulations and can be added to animate the scene and give a clear understanding of the dynamics of the infrastructure. We prepared 4 types of connections, each supporting different types of flows : Path (for pedestrians and bikes), slow road 30 km/h (for bikes and cars), fast road 60 km/h (for bikes and cars) and rivers (for boats).

In addition, we prepared simple images to be placed close to the connections to explain further characteristics. For example, the image of the bus stop explains what kind of traffic is invited onto the site. Sound is connected with the flows to heighten participants' sensitivity towards the difficulties of protecting green spaces, living spaces, children and their activities, when opening the Caserne Bossut and making it more accessible.

Activities Participants may express their ideas about activities to invite onto the site mainly by using 2d images. These show for instance school kids, chess players, street artists, different types of theaters or a library.

Housing types Different housing types are mainly represented by highly abstract 3d objects of different shapes and volumes. We provided houses of different stories and textures. To better consider and express the ambiance of these buildings we additionally provide 2d images of housing types.

Centrality To show specific interventions we provide images of fountains, playgrounds, or green spaces. Participants can also create textured ground areas to specify use of a place.

The 2d object content we provided is based on photographic images, sketches, architectural renderings, and paintings. To lend them a spatial dimension these images had to be cut out and 'abstracted' so that they no longer appear as flat canvasses. A selection of the object contents we prepared is shown in Table 9.4.

In addition, we used the same four photographic panoramas of the site as in the previous workshop as well as two maps in different scales (1:500 and 1:2000).

9.2.3. Moderating the sessions

In this workshop, we prepared a learning session where participants playful learn how to use the urban renewal prototypes. The learning session was explicitly separated

Figure 9.4.: A selection of the content to work with the urban issues.

from the working sessions and planned during the morning. We prepared 6 different tasks explaining the main components and dimensions of the *ColorTable*, as well as the respective interaction possibilities. Table 9.4 lists the 6 tasks that were explained to the users.

As the workshop was organized on site within the context of a real urban planning project and real stakeholders had been invited, a situation of real use could be created.

Although all decisions concerning the different interventions to be performed with the *ColorTable* had been left over to the participants, two members of our team supported them in using the tools. They showed and reminded the users how the different interaction possibilities could be done and provided solutions when technological problems occurred.

9.2.4. Evaluation

3d objects are important elements of the constructed mixed reality scenes. Some content, such as for example buildings, has to be 3d so as to maintain the sense of volume and orientation within space. On the other hand, 2d objects are needed for conveying 'telling detail' and creating ambience. Preparing the content requires special expertise, including artistic skills. The main challenge here is to select and edit content that allows to represent urban issues in ways not only professionals but also lay people can relate to.

We observed that participants selected content images based on an idea being discussed just before. In case no suitable image was found, they selected a different image and changed the interpretation. For instance, participants selected a painting of a garden to symbolize a green area. Although the inspiring effect of the visual material supports participation, it provides an additional problem of scale. How

1. Creating a scene: - Each participant selects one object and assigns it to a token - He/she takes the token and places it on the ColorTable surface (with map) - He/she modifies parameters (size, color, transparency, position) - He/she changes sound (on/off; next/previous; volume)
2. Sketching and painting: - Participants produce a sketch on the whole scene - They change one token into a painting object and paint on it.
3. Streets and flows: - Participants construct a street (selecting also the type of the street) - They introduce a flow
4. Land use: - Participants use circular objects to create a textured ground
5. Sound: - Participants move the hearing position and listen to resulting soundscape
6. History application: - Participants save the scene - They erase something with the eraser - They undo it again - They print the scene

Table 9.4.: The tutorial consists of 6 different tasks.

to define a default size for content material if its representation is interpreted individually by participants? This circumstance highlights the importance of being able to change scale manually. During the workshop participants adjusted size, color and offset depending on the background, but also to reflect the importance of the intervention.

While our first approach to scale objects was a relative manipulation, we switched to absolute values in one of the later prototypes and provided the possibility to select a number for the objects' height. The large amount of diverse content images however showed that the height is not always the obvious reference for scaling an object. For some objects, such as bridges, participants would rather scale its width or length. Other images, showing a composition of several elements, can hardly be expressed in numbers. Therefore, it is important to be able to adjust the size of objects in relation to the background and other objects.

9.3. Summary and conclusions

Questions to be solved while preparing real use deal with the type and number of activities to be supported, the learning of the different technologies, the type and number of content objects to be at disposal and how the different sessions are moderated. In this chapter two examples of such preparations related to two different workshops are provided. The two workshops deal with a same urban project about Caserne Bossut, each of them conducted on a different location with a different type of users.

To enrich opportunities for realizing interventions, a sufficient number of viewpoints and panoramas is necessary. When a same area or spot can be seen from different viewpoints, participants have more possibilities for 'navigating' within the scene, and therefore exploring it.

A viewpoint needs to provide some empty space for placing new objects. When working with a depth map, objects being in the foreground increase the three dimensionality of the scene. We experimented with edited panoramas, where real objects were removed in order to provide space for new objects. When working with such an approach, it however is necessary to preserve the characteristics of the real place.

It is important to separate learning activities from working activities to allow participants to concentrate on the urban interventions to be performed instead of experimenting to understand how the technologies work. During the workshop, one or two persons are needed to support participants with the technologies, however these should stay in the background to motivate participants in working independently.

A list of activities is one of the most important elements of an interdisciplinary development process. It serves as basis for discussions between urban planners and computer scientists, supporting them to transform an idea into a functionality and to take individual design decisions for the purpose of the urban themes to be dealt with.

CHAPTER 10

Summary and conclusions

This work describes the design process of a complex tangible user interfaces within the context of real life scenarios. Such a process requires the expertise of several disciplines in order to consider a multitude of aspects, that each have an impact onto how the system can and will be used. In this work, we consider the 4 domains of the *tracking framework*, the *application functions*, the *interaction space* and the *real use* as most important components to be designed and developed as part of a complex tangible user interface.

Crucial on this approach is that the domains do not represent any stages of the design process and cannot be treated in a specific order. They are closely related, and decisions being taken in one domain affect the situation within another domain. Design issues therefore need to simultaneously consider respective aspects in all four domains to find solutions which are best for the overall design. Requirements and possibilities need to be balanced to find solutions which are a best compromise for all four of the domains

Based on the comparison of different prototypes and applications, several relations between the domains could be identified, which strongly influence the overall design. In the following, the most important decisions, dealing with the design of a tangible user interface for urban planning, will be described.

The type of sensing technology

The choice of a sensing technology to be used for a tangible user interface has a large impact onto the possibilities for designing manipulations or the interaction space. Computer vision based tracking is commonly used for tabletop interfaces as it tracks positions and orientations of several objects on a table. This type of sensing technology detects continuous manipulations of these objects which can be used for precise interventions. However, these manipulations can only be detected within this precise area being overlooked by the camera. Although this limitation seems to be suitable for tabletop tangible interaction, it represents a problem when considering the workspace and the space around as part of the TUI.

ID based technologies like barcodes or RFID can more easily be integrated in objects all around the interaction space. The types of manipulations they can detect are however very limited. Barcodes can trigger a function by pushing the button of a reader, and are therefore best suited for processes like saving or the confirmation of choices being done elsewhere. RFID based interaction can be entirely embedded within the physical objects and provide most possibilities for designing the interaction space. However, as users can not exactly control the moment of trigger, it is impossible to detect how often in a row a function was supposed to be executed.

The number physical handles

To support complex interventions, multiple colored tokens, barcodes and RFID can be used and combined in one application function. This approach enables a more detailed and precise manipulation of urban elements, but may result in a complex and long workflow including a high number of objects and devices. A clear workspace and similar interaction steps serve as guideline to support users in this process.

The type and amount of feedback

The type of representations of urban interventions has a large impact onto the topics of discussion. During the workshops, participants referred to results shown as numerical data (e.g. while scaling according to the own knowledge), illustrations (e.g. while setting streets) or the perspective view (e.g. while adjusting the position of objects). To support these diverse types of feedback, a certain amount of screens and projections is necessary. However, the different lines of sight may disturb participants' free movement around the *ColorTable*, and therefore parallel feedback possibilities should be reduced and integrated onto common places.

The degree of automation

Feedback and visualizations generated by the application can represent a different degree of automation. This choice is an essential factor for specifying the level of the discussions being made around the tabletop. We mainly distinguish between an automated reaction modifying another value and an automated feedback highlighting certain aspects. Further, functions can trigger a whole series of reactions, based on specific configurations made by the users. The level of discussions is based on the input being specified by the participants; they discuss what input to perform and the different alternatives. The reactions being produced by the system, are mostly explored in a silent way, sometimes leading to a reconsideration of the input.

The degree of precision or approximation

The degree of precision or approximation influences the types of discussion to be conducted around the *ColorTable*. An increased set of possibilities for manipulating urban elements invites participation and helps users to express themselves correctly and precisely. In contrast, when providing more approximate manipulations, the type of decisions which participants take on the *ColorTable* rather correspond to early stages of an urban planning project.

To support a certain precision in urban interventions, corresponding manipulations have to be developed. One of the possible approaches is to combine multiple physical handles in one application function, which can be manipulated sequently or simultaneously. This possibility was, for instance, implemented for changing the content of one color token by reading the ID of one of the numerous content cards. The use of two objects for defining a street, is another example for increasing the possibility for changing its shape. Complex manipulations are further supported through saving and loading possibilities. These allow users to work in steps and assure them a certain persistency.

The accessibility and visibility of places for interaction

Due to the high number of physical objects and devices, it is essential to provide and create a place for each of them. Such places can show different amounts of accessibility and visibility, depending on their frequency of use and importance in the discussion. These aspects have a strong impact on participants' spatial interaction and therefore influence how the urban issues are addressed.

The integration or separation of A-Tokens into physical objects

When designing the physical objects used for interaction, we decide where and how to embed the A-Tokens being sensed by the technologies. Integrating several A-Tokens into a same physical object reduces the overall amount of tokens needed for interaction. A physical separation of A-Tokens however may be useful to guide users through different interaction possibilities and steps. In addition, separated A-Tokens can be manipulated with two hands and therefore support collaboration and increase interaction possibilities.

The type and number of supported activities

The first, but also final step in the design process deals with its real use within a given context. These preparations guide technology development by providing, in our case, an urban project on a specific site and related urban issues. At the same time, the preparations for real use are based upon the possibilities of the technologies. To support these interdisciplinary design decisions, the future activities need to be defined. Their type and number specify the type of urban interventions and the complexity of manipulations. They serve as basis for discussions between urban planners and computer scientists, supporting them to transform an idea into a functionality and to take individual design decisions for the purpose of the urban themes to be dealt with.

Developing a complex tangible user interface for real life situations means to deal with a long and interdisciplinary design process. The separate analysis of the four domains related to the tracking technology, the application functions, the interaction space and the real use help to understand possibilities and limitations for design. The two proposed frameworks dealing with *A-Tokens* and with constraints make the link between these themes and support the description and comparison of different design solutions. We believe that a structured analysis of a TUI design, centered around the above design decisions, supports the different parties being involved in a design project to better articulate and understand each design issue, to analyze the related consequences and to find an adequate solution which is best for the overall design, including all aspects of the related disciplines.

APPENDIX A

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APPENDIX B

Curriculum Vitae

Personal

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Education

1994-2000	Secondary School, Lycée Robert Schuman, Luxembourg Diploma in Mathematics
2001-2004	Vienna University of Technology, Austria Bachelor Degree in Media and Computer Science Bachelor thesis: 'Automatic Generation of Graphical User Interfaces in Studierstube'
2004-2006	Vienna University of Technology, Austria Master Degree in Computer Graphics and Digital Image Processing Master thesis: 'Tangible Interaction in Mixed Reality Applications'
2006-2010	Vienna University of Technology, Austria PhD in Computer Science PhD thesis: 'The ColorTable: an interdisciplinary design process'

Experience

10/2003-08/2004	Internship Institute of Software Technology and Interactive Systems, Vienna University of Technology
02/2005-07/2005	Internship University of Leiden, Netherlands
01/2006-03/2010	Project Assistant Institute of Design and Assessment of Technology, Vienna University of Technology

Publications

- Wagner I., Basile M., Ehrenstrasser L., Maquil V., Terrin J., Wagner M. **Supporting community engagement in the city: urban planning in the MR-tent** In *Proceedings of Communities and Technologies, June 25 - 27, University Park, PA, USA, 2009.*

- Boerner A., Maquil V. **Enhancing synergies between computer science and urban disciplines: Semi-automated applications for tangible user interfaces, a case study** In *Proceedings of CAAD Futures 2009, June 17 - 19, Montreal, Canada, 2009*

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- Maquil V., Psik T., Wagner I. **The ColorTable - A Design Story** In *Proceedings of TEI 2008, Feb 18-21, Bonn, Germany, 2008*
- Maquil V., Psik T., Wagner I., Wagner M. **Expressive Interactions Supporting Collaboration in Urban Design** In *Proceedings of GROUP 2007, Nov 4-7, Sanibel Island, Florida, USA, 2007*
- Maquil V. **Tangible Interaction in Mixed Reality Applications** Master Thesis, Institute of Design and Assessment of Technology, TU Vienna, 2006
- Maquil V. **Automatic Generation of Graphical User Interfaces in Studierstube** Bachelor Thesis, Institute for Software Technology and Interactive Systems, TU Vienna, 2004

Talks

- **The ColorTable - An interdisciplinary design process**
  University of Luxembourg, April 15, Luxembourg, 2010
- **The ColorTable - A Design Story**
  Conference on Tangible, Embedded Interaction, Feb 18-21, Bonn, Germany, 2008