The *ColorTable* – A Design Story

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ABSTRACT
The paper describes the design story of the *ColorTable*, a tangible user interface in support of urban planners and diverse stakeholders collaboratively envisioning urban change, which was developed in an iterative process of design-evaluation-feedback-redesign in a series of workshops with users in the context of real urban planning projects. It seeks to clarify a number of more general design issues related to tangible user interfaces – how to make use of material and spatial properties in designing both, physical interface and multiple and simultaneous interactions; how to handle the complexity of urban projects while keeping interfaces and interactions simple and transparent.

Author Keywords
Tangible user interface, interaction design, collaboration, participatory design.

ACM Classification Keywords
H.5.1 Multimedia Information Systems, H.5.2 User Interfaces

INTRODUCTION
In this paper we describe a tangible user interface designed to support groups of urban planners and diverse stakeholders in collaboratively envisioning urban change, using a set of mixed-reality technologies. This is a challenging setting, since urban planning projects are enormously complex; they involve the expertise of a diversity of stakeholders that need to agree on a myriad of technical and aesthetic issues.

The purpose of the design of the *ColorTable* is to

- Provide an urban planning collaborative with a TUI for co-constructing mixed-reality scenes (ideally on the site) against a background, which is produced by a photographic panorama, a life video stream or a see-through installation;
- Support them in building, animating, and changing the scene with different types of content that reflects their purposes and perspectives (architectural/expressive, visual/sound, and so forth);
- In order to jointly elaborate and understand a project, compare and discuss solutions.

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In this paper we account for a series of design decisions based on an iterative, user collaborative process. We think that the design story of the *ColorTable* is worthwhile reporting as it helps clarify a number of more general design issues related to tangible user interfaces:

- How to support users in the collaborative creation of mixed-reality configurations;
- How to make use of material and spatial properties in designing both, physical interface, as well as multiple and simultaneous interactions;
- How to handle the complexity of urban projects while keeping interfaces and interactions simple and transparent.

The paper describes the development of the *ColorTable* in an iterative process of design-evaluation-feedback-redesign in a series of participatory workshops with users in the context of real urban planning projects.

RELATED WORK
Quite a number of tangible tabletop systems deal with design issues related to tangible user interfaces and also report on the learning provided through engaging with users. The design of the *Envisionment and Discovery Collaborary (EDC)* is based on participatory design efforts with the use of physical simulations applied to community design with specific neighborhoods, which have been described in a series of publications. Arias et al. [1] emphasize how they have gained critical insights in the manipulation of physical objects and the need to support collaboration in these joint design sessions. Advanced prototypes of the *EDC* were evaluated e.g. by Eden et al. [5[, with additional and detailed insights concerning its features.

The concept of *Tangible Tiles* [17] has been evaluated in a series of user studies with a focus on learning how users perform relatively simple collaborative tasks involving digital imagery. The idea was to compare the tangible tiles system with a commercial touch screen and real paper prints. The *Luminous table* [10] was developed as an extension of the *Urp* software, a system that supports a number of basic urban planning functions. The authors report on their observations of how the system was used in an urban design class and what design improvements they suggest for the future. *Tangible Viewpoints* [13] is an interface for multimedia storytelling. The system has been used in different storytelling projects, and further development decisions have been taken based on user feedback.

While these (and other) publications give some insight into the process of developing a tangible user interface using different approaches (e.g. iterative development versus comparing different interaction media), our paper accounts for and documents the entire development process of the *ColorTable*, with all its intermediate steps, where each design decision is based on results of observations of users working with the application in a real setting. Moreover, it uses the design framework for encouraging collaboration through tangible manipulation, spatial interaction, embodied facilitation, and expressive representation developed by Eva Hornecker's work [7] in analyzing the design decisions around the *ColorTable*.

METHOD

The research presented in this paper is part of EU project IPCity, which has urban renewal as one of its showcases. In this showcase a multi-disciplinary team collaborates with experienced and highly engaged urban planners in exploring urban issues, developing concepts for technology design, developing scenarios for evaluation workshops, and re-designing, in a typical participatory design process.

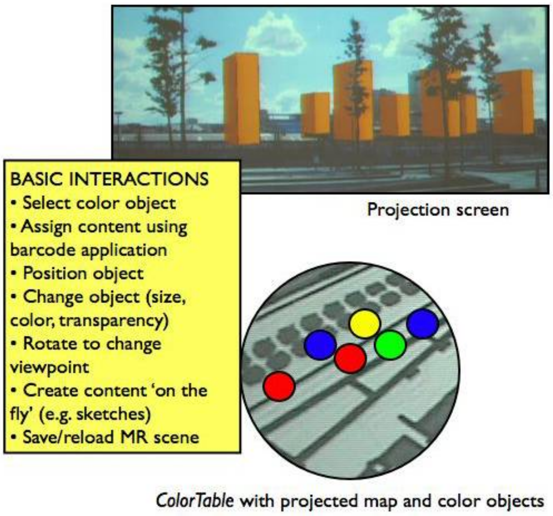

Figure 1: Overview of basic interactions

The mixed-reality tools we are developing in this project are a rather complex assembly of *ColorTable*, barcode interface, tangible 3D visualization, sound application, and *Urban sketcher*, all of them hosted in a *MR (mixed reality)-Tent* [12]. The *ColorTable* is the basis for a number of prototypes. It provides users with the possibility to arrange and position tokens on a surface, representing a 3D scene. A tabletop projection augments the surface of the table by a map, which provides a bird's eye view of the site. A vertical projection renders the scene against a background, which is produced by either a real time video stream, a panorama image of a site or a see-through installation.

Consecutive versions of the *ColorTable* were presented to users in a series of participatory workshops, almost all of them connected to ongoing urban planning projects, with the aim to learn from their engagement with the tools and their evolving functionalities. One of these workshops took place in cooperation with the urban renewal office of Vienna's 16th district (Sep 2006); two workshops (June 2006, March 2007) were carried out on the premises of the psychiatric hospital of Sainte-Anne in Paris, which is undergoing a ten-year renewal process; the last workshop (Sep 2007) was organized in the context of the planning of a new courthouse (TGI de Paris) and the surrounding area in Paris.

For each workshop we studied the site, selected participants, prepared scenarios a well as content – panoramas from different viewpoints, architectural models, and other content – and developed an 'experimentation protocol' for the participatory sessions. The workshop sessions, altogether seven sessions of about three hours each, were video-recorded, and transcripts of significant episodes were produced. We, in addition, used several digital cameras to capture interesting situations and included saved images of visual scenes in our analysis. 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.

THE DESIGN STORY

The first prototype

The *ColorTable* approach is based on a worlds in miniature (WIM) paradigm [16], where the table and the color objects serve as representations of different elements of a mixed-reality world. The first prototype of the *ColorTable*, which was modeled on this approach, consisted of a white surface (the table) with two configuration areas, a series of color objects, and a barcode interface. The basic interaction (Figure 1) consisted of 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, with which they are associated.

The color objects, in the beginning flat geometric shapes in seven different colors, may represent all kinds of content, with each color defining a different virtual object. In Figure 2 (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.

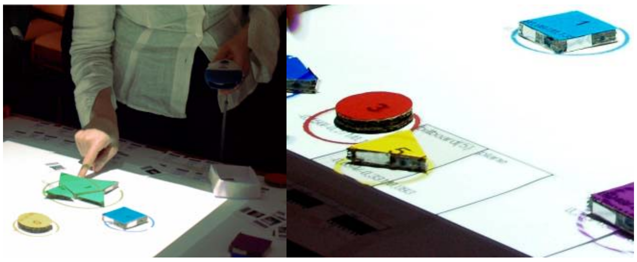

Figure 2: Enlarging a virtual object (left); selecting an object by placing it in the *configuration area* (right)

The first *ColorTable* prototype had a specific area for activating a color object, which was marked on the table by a squared projection. Users had to place the selected color object in the *configuration area* (Figure 2 right). 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 to the viewpoint) or 'plane' (which can be rotated manually). The idea was to allow users 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 3 left).

Figure 3: Reading in barcodes representing content (left); table littered with barcodes (right)

Observations

When introducing this very simple prototype, we made useful observations and received feedback that led to a first decisive re-design. 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.

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 pointed to the need for a different design of the color objects that invites users to grasp them from the side instead of touching them from above.

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.

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*, picking out barcodes, it was impossible to keep them in order.

The second prototype

Rotating the table

One of the main design decisions after the first workshop was to construct a rotating table in combination with a *panorama* as background. The rotating table consists of a turn-tilt plate covered with a white, circular disk (Figure 4). An optical computer mouse is placed upside down under this plate in order to track the relative angle of rotation. 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.

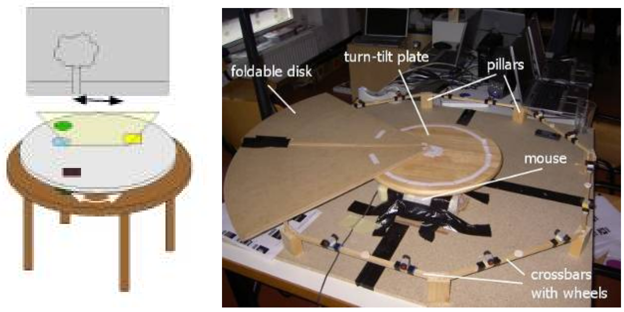

Figure 4: The rotating table

The decision to use a rotating table 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). It is still possible to place (and track) all objects on the table, however only those objects currently within the viewing frustum (visible in the sketch in Figure 4) 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, participants in the second workshop considered the possibility to change the viewing angle and to look at different parts of the mixed-reality scene by rotating the table a significant progress. 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 [2]. We observed how in exploring a scene they wish to travel faster, while in building or changing a scene they travel 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 5 (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. Other modifications of the map (zooming, translation) are not supported as the positions of the colored objects cannot be adapted dynamically.

Figure 5: Placing objects on the projected map (left); working with command posters (right)

Introducing command posters

We also had to find a better 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 5 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 onto the surface of the table. This also offers a solution to the problem of users forgetting what each color object represents.

Observations

With this new version of the *ColorTable*, which was evaluated in two workshops with some re-design in between, we could observe more varied and meaningful interactions. In particular in Sainte-Anne participants for the first time collaboratively constructed and performed mixed-reality scenes (described in detail in [12]). One of the key observations was how the size and materiality (haptic quality) of the color objects influenced the way participants interacted with them. The new shape of the color objects – cylinders that users can grasp and firmly hold in their hands – supports this.

Participants' problems with the configuration area came to our attention. It took some time to learn not to just pick up a color object and associate content with it but to first place it in 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 detected 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 se 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. These observations led to a major re-design effort.

The third prototype

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 6). This 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 6: Tangible selector

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 7 left). The info screen also gives feedback on which object currently is selected by which of the two *tangible selectors* (through color coding) and with which content it is associated. 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.

Figure 7: Info screen (left); paper map for changing viewpoint/panorama (right)

Enlarging the interaction area

Another important step forward was to enlarge the interaction area. The rotating table requires the viewpoint to be positioned in the center of the table, so that the objects can turn with the screen. As only one sixth of the table can then be used to place objects within the current field of view, we introduced a second mode, in which rotation of the table is suspended. This allows users to make use of the whole table for placing objects in the scene as the (virtual) 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 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 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. Figure 8 (left) shows how the map space is used for introducing a flow of (virtual) people (associated with the red/green color object), represented as moving dots, and how they use the orange object to direct the flow. The image on the right shows the projected mixed-reality scene.

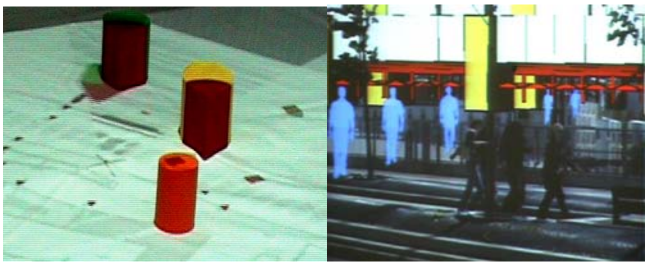

Figure 8: Introducing and directing a flow of people (in blue)

After each zooming or modification of the map, 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 at the positions they had before, and we support them by projecting the position and shape of the objects onto the table (Figure 8). We use the same mechanism when restoring previous settings, to allow users to continue their work.

We introduced a small paper map with barcodes indicating the different viewpoints, from which the different panoramas have been produced in support of users switching between these panoramas, hence being able to look at a mixed-reality scene from different viewpoints (Figure 7 right).

Re-designing the color objects

We also redesigned the color objects. 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 two-colored shapes which are pointed and are used for rotating objects.

DISCUSSION

Issues of interaction design

The story of the *ColorTable* design highlights some general issues concerning interaction design for tangible user interfaces. We can say that the opportunity for spatial interaction and embodied facilitation are crucial for collaboration to happen around the *ColorTable.* 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 [9]. We could see how the size and shape of the table are relevant. As Patten and Ishii [14] and Stanton et al. [15] observed, a large working space encourages or even enforces collaboration since there is no way for a single person to manipulate all objects. We observed how the round shape of the table together with the possibility of rotating the table were highly conducive to people gathering around and interacting.

Also the spatial arrangement of table and the associated workspaces 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. One important step in this direction was the move from giving feedback to users through projected thumbnails to display information on the info screen. In our last workshop (TGI de Paris) we could see that users found it quite easy to understand which object was selected. On a screen more and specific information can be presented in a clearly readable way. Moreover, the information no longer interferes with the tracking.

Despite of these improvements, there is a need for further workplace re-design. As can be seen in Figure 9, the current positioning of the different devices and materials within the activity space around the color table needs to be re-thought. There are too many of them and their spatial organization in relation to participants' interactions is not clear. Hornecker talks of embodied constraints as subtly leading users to collaborate. We agree with her experience that "seemingly trivial design decisions (such as system size, placement and number of tools) had a huge impact on group behavior, session dynamic and atmosphere" [7].

During our last workshop (TGI de Paris) there was some discussion of the barcode interface. Users found that there were too many barcodes lying around and that in particular manipulating object attributes with barcodes is cumbersome. We agree with the latter point but maintain that a barcode interface is a good solution for selecting content in contexts in which users want to have access to and work with large numbers of media objects. In a previous project [3] we have observed how users (in this case students of architecture) produced special layouts of content and commands they wanted to work with by cutting the barcodes into parts, rearranging them, gluing them onto posters, and adding annotations. We think that having users make their own arrangements of media content they want to use for a particular task may be a good way for them of ordering and maintaining an overview of the content.

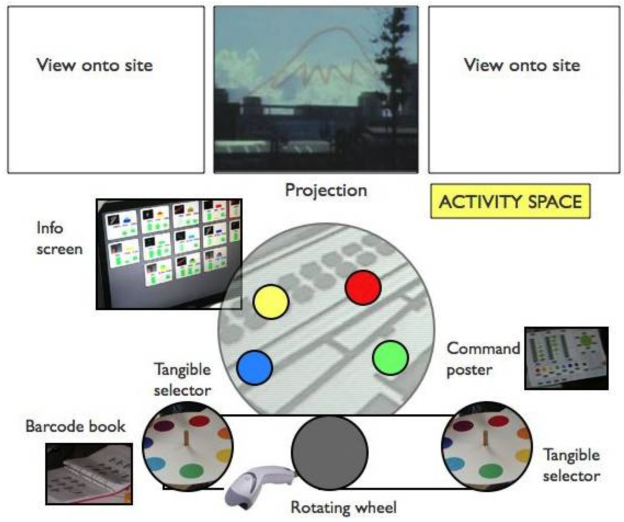

Figure 9: Workspace organization

As we described, the current *ColorTable* prototype makes use of so-called 'command posters' for modifying object attributes. Their advantage is that they can easily be produced, multiplied and modified, all characteristics that support fast prototyping also during workshop sessions. However, workshops participants found them cumbersome, in particular when changing the size of objects. We are aware of other types of interface. We are currently looking into a graspable interface with mechanical sliders for modifying object attributes [4].

Although the color objects are one of the well accepted features of the *ColorTable*, one of our key observations is to do with the limitations of the color objects as we use them now. Computer vision algorithms based on color cannot provide the same amount of precision as for instance optical markers [11]. As color recognition is highly sensitive to light conditions, a certain threshold tolerance is needed. Moreover, the amount of different colors that the system recognizes is restricted (seven, eventually a few more). Also the position and size of tracked color objects may not be exactly detected. Our use of color tracking is, again, a compromise between how people like to work and what computers can do, in this case opting for supporting the free positioning of graspable color objects on a map.

There are alternative technical solutions for tracking objects. The PITA-BOARD [6] for example consists of a grid that registers RFID tags embedded in objects. However, the constraint of a grid would interfere with the articulated need of participants in our urban planning workshops to freely place and move physical objects on the projected map. Similar thoughts can be applied to the color objects themselves. Color objects of any size are easy to produce from cardboard, which again supports fast prototyping. Another advantage of color objects, as compared to e.g. optical markers, is that the color of the physical object already provides a name or identifier for the virtual object participants manipulate and discuss.

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. One participant expressly talked about the color objects as 'thinking tools' [12]. We conclude from this that the color objects are easy to understand, invite participation, and are sufficiently neutral so as not to privilege particular perspectives onto an urban project. They can be used by expert and non-expert users alike.

The context of urban planning

Revisiting the story of the *ColorTable* also makes us aware of the influence that the context of our project – urban planning – has on our design decisions. Architect users from the very beginning stressed the importance of scale and of the exact positioning of virtual objects. Their expectation was that the relative positioning of physical and virtual objects be perfectly aligned. This is one of the reasons why we introduced the map to be projected onto the table. Moreover, the larger the urban site to be overlaid with a visual scene, the more obvious the gap in scale between physical and virtual. For example, a very small movement on the table will be translated into a large shift of the object in the projected scene.

Even for architects it is somehow unusual to simultaneously manipulate the bird's eye view and the perspectival view. Ideally, the architects amongst our users would like to simultaneously see an overview map of the whole area, the detailed map on which to enact a visual scene, and the projected scene itself. Also the fact that the relative size of virtual objects and their position in space are so critical for architects had an influence on our design decisions. Our first idea to play with the size of the physical objects as being representative of the size of the different virtual objects users may want to create, was far too imprecise. We now even moved from relative sizes to absolute measures, allowing users to determine the exact height of an object in meters and think that a slider interface may support seamless adjustments of size.

We can see from these considerations that the context of urban planning poses specific requirements concerning spatial interaction. Users perform embodied interactions in several dimensions – placing color objects on the projected map, switching viewpoint and panorama, and at the same time viewing the changes on the projection screen. Mapping these distributed interactions in different scales is a complex task.

A second peculiarity of the urban planning scenarios workshop participants enacted is to do with the fact that the scenes they want to construct may differ widely. Participants in the psychiatric hospital of Sainte-Anne, for example, wanted to fill a relatively empty real space, represented by a photographic panorama, with many virtual objects. Here some of the constraints of the current *ColorTable* prototype came to the fore, such as the limited amount of colors that can be used and the need for much smaller color objects that quickly cluttered the restricted space of the projected map. In the last workshop around the project of a new courthouse in Paris, participants wanted to place and modify a few selected objects, each with its own controllable attributes. They not only wanted to manipulate the size and transparency of the objects but apply different textures, rotate, tilt, and so forth; and they expected to be able to precisely position each of these objects. This poses a dilemma for interaction design, since so many interaction possibilities may result in lack of transparency, hence confusion. These challenges will require additional conceptual work.

SUMMARY

We have given a rather detailed account of a series of design decisions, as performed in several development-evaluation-feedback-redesign circles with users, aiming at clarifying some considerations of general interest to designers of tangible user interfaces. Some of these design decisions may appear rather mundane but they are crucial to the usability of the interface. Summing up the 'lessons learned' from this design story, we want to point to several issues:

- The participatory mode of working in design-evaluation-feedback-redesign cycles favors simple and sometimes even ad-hoc solutions and much effort is needed to achieve coherence (e.g. of interactions and workspace organization);
- The aim to support 'immediacy' - the ad-hoc creation of mixed-reality scenes as an integral part of participants expressing and experiencing ideas – presupposes a high degree of alignment between tangible interactions (positioning and manipulating color objects on the map) and the resulting projection.
- Mapping distributed interactions in different scales is a complex task, although users expressed the need for different scales to create density and more precise placement it is difficult for them to map and align interactions at different scales.
- In a context, such as urban planning, with different participant stakeholders, complex, partially conflicting requirements arise, which potentially undermine the desired simplicity and transparency of interactions;
- The design decisions we describe (as well as the underlying technology solutions) reflect these diverse expectations and requirements; they are in some cases 'compromises' to be able to test different scenarios and find optimal design solutions for each in the future

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