Supporting Configurability in a tangibly augmented environment for design students

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In many environments the landscape of space and artefacts is evolving and changing with the tasks at hand. Integrating digital media and computation in these environments has to take into account that users will configure space, functions and tools according to the situation, organizing use in unexpected ways. In this article we present and discuss how the issue of configurability is dealt with in a series of field trials with design students. The aim of these trials was to construct for architecture and interaction design students a mixed media environment for inspirational learning. We give examples from two rounds of field trials. In the first round emphasize was given to introduce components integrating dynamic digital media into the design studio practice of the students. One of the important findings from this first round was that integration becomes particularly useful when it facilitates the creation of composite representations called mixed objects blending digital and non-digital media in one design artifact. We did however also find that configurability has to be supported at different levels (infrastructures, artefacts, functions) and across physical and digital realm. From the second round of field trials examples are presented of component assemblies that provide a tangible formatting of the mixed media environment suitable for design work and two different approaches to end-user configuration of these component assemblies are described. Based on the results from the second round of field trials the concluding discussion suggests design principles relevant when integrating digital media and computation in design studios.

Physical Interfaces, tangible computing environments, configurability

Introduction and Background

Computing environments will in the future be populated by a rich and diverse set of devices and networks, many of them integrated with the physical landscape of space and artefacts. Since Weiser introduced the term ubiquitous computing and issued his call for computational technologies being at the same time available and configurable for the user in her everyday environment and calmly fading into the background of attention, it has been clear that new modes of interaction and presence of interactive systems have to be sought for [1]. Early attempts to take the desktop metaphor of graphical interface design back to the real desktops and whiteboards by exploring new semantics of interaction was pioneered by Weisers

group as well as by Buxton and others [2, 3, 4]. The idea to have a new and more complex set of physical handles to digital media promised an extended bandwidth in the interaction between people and technology, and in line with Engelbarts pioneering work on direct manipulation for graphical user interfaces a new set of generic interface building blocks would open up a new realm for design of interaction technologies.

In parallel to the work of Weiser, Wellner and colleagues argued for a new and broader interpretation of augmented reality turning computational augmentation into an enhancement of practices well established with the interaction of more mundane artifacts [5]. Fueled by ethnographical studies of work researchers such as Mackay et al suggested augmented environments where computational resources were brought into play as extensions of for example the paper flight strips traffic controllers used to control airplanes as they passed through different traffic sectors [6]. Such an approach is not in opposition to the development of new interaction modalities but it shifts the balance from generic interaction scheme to situated embodiment of interactional possibilities. Ishii and his group forged these two approaches into a wider program for tangible interaction [7]. With the ambition to create seamless interfaces between 'people, bits and atoms', Ishii and others have expanded the new field of design to include an integrated re-shaping of desks, board and rooms.

The growing number of experimental ubicom installations has helped shift the attention of interactive systems away from individual work settings and towards larger collaborative environments traditionally the realm of other designers. After some years where automatically generated context information created high hopes to how computational technologies could be made to match the complexity of user behavior [8], we are increasingly seeing suggestions such as HP's Cooltown project for open infra structures and end-user configurable systems, which may have a lower intensity of computational monitoring, but on the other hand appear more easily extendable to wide spread real life settings [9].

This new type of extendable systems with open boundaries provide traditional HCI research with important new challenges [10,11]. In many environments the landscape is evolving and changing with the tasks at hand and users will most likely make use of functions and tools in unexpected ways and expect to be supported in doing so. Newman et al. argue "that systems should inherently support the ability of users to assemble available resources to accomplish their

tasks. In a world of richly embedded and interconnectable technologies, there will *always* be particular combinations of functionality for which no application has been expressly written" [12] This view reflects our experiences within IST Project *Atelier*[1] which develops a set of architectures and technologies in support of inspirational learning in two areas - architecture and interaction design. We observed how students configured and reconfigured their workspace as well as the relationships between design representations. This motivated a design approach, which focuses on configurability as an important feature of tangible computing environments.

The article starts with an analysis of observed practices of configuring. It then presents three design examples that highlight different aspects and levels of end-user configuration. The discussion part summarizes the diversity of configurations, and investigates in particular how in augmented or tangible computing environments configurations of digital media extend into the physical setting and into the qualities of the objects created.

How design students work

For architects configurability is connected to the properties of a space. *Flexibility* connotes the possibility of relatively simple changes to a design so as to adapt it to different or shifting social uses (e.g. moveable walls). *Variability* means that a designed space or artifact, without elaborate transformations, can accommodate a variety of functions [13]. The *backstage* and the *garage* stand for spaces in which everything is possible. But there are also some quite elaborate examples of configurability, such as a building under construction by Diller and Scofidio, which has been conceptualized as "a fundamentally updateable, technologically and profoundly re-arrangeable (physically)" building set up. The architects used the metaphor of open source code for modeling the building as a space "capable of being rewritten, upgraded, reprogrammed, reconfigured to accomplish previously unanticipated tasks" [14]. The building is to be interactive, not only in the exhibition and informative parts, but also architecturally. A visitor, entering the building physically or on line, can manipulate parts of the façade. "Smart walls", made from liquid crystals between conductive film and glass panes, allow for an electric current to regulate the level of transparency, and daylight

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[1] IST-2001-33064 Atelier - Architecture and Technologies for Inspirational Learning Environments http://atelier.k3.mah.se/, part of the Disappearing Computer Initiative of the FET area of the IST research program.

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conditions within the building.

Configuring and re-configuring, although with much more mundane means, is also part of students' practice. Students voice a strong need to adapt their workspace so that they can exhibit, perform, engage in group work or work alone, build models, have a nap, make coffee, interact with material and odd objects, etc. At the beginning of a project the architecture students set up their workspaces. As the project progresses, they become dense with design material which is exhibited on the surrounding walls and on parts of the desk space. Sketches, plans, model, a panorama print of a site and the computer are all assembled in one desk space (Figure 1). One student has put two desks on top of each other to make room for a desktop computer, turning the desk into a three-dimensional space. Here configuring spatial elements and tools is very different from the pre-designed mobile and flexible 'individual workstations' that have become part of office design [15].
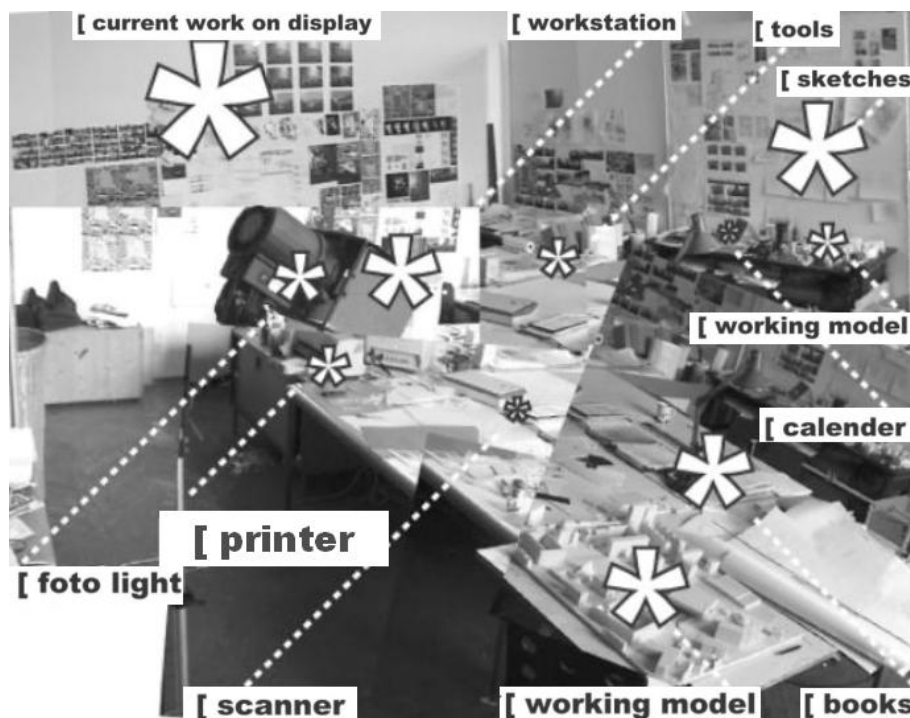
Figure 1. Workspace of a diploma student

These are highly personalized workspaces, whose features and components grow over time, expressing students' identity as well as the progress of their work.

The concept of configuring can also be applied to the ways students arrange and re-arrange design materials. Project work proceeds through developing a large number of design representations. These are characterized by the expressive use of materials and are sometimes animated and presented dynamically. As each of these representations exhibits and clarifies particular aspects of the design, it is important to forge and maintain connections between them. In many instances

students configure and re-configure design materials so as to read and re-read the configuration from different points of view and to be able to go back to a moment where a particular issue emerged. In the process of conceptualizing and detailing the design representations and their relationships change continuously. Arranging and re-arranging material in the work space is an essential part of this process, with the physical landscape of things on the walls and tables being in constant movement. This resonated with earlier findings on work practices in (landscape) architecture, where we argued that: "What emerges is that manipulating the presence and absence of materials and bringing them into dynamic spatial relations in which they can confront each other are not just a context or prerequisite for doing the work; rather, they are an integral part of accomplishing the work itself. *To manipulate the context **is** to do the work*. Typically, what is important is not just to create or change a document or other materials, but to do so in the presence of and in relation to others" [16].

Configuring as a practice is intricately linked to the fact that in evolving environments, such as the architecture class or the interaction design studio, the boundaries of activities are continually moving [17]. Our observations helped identify two meanings of configurability:

- Adapting a space to a diversity of uses and identities – which is achieved through e.g., appropriating a space, personalizing it and configuring it in support of diverse arrangements, such as solitary work, group discussions, performing and presenting, building models.
- Configurations of artefacts within the physical space – with artefacts changing their position in relation to others and different configurations being expressive of conceptual, chronological or narrative links between them.

Embedding digital media in physical environments cannot be simply understood as an extension of practices we observed in the physical world. Things need to be designed so as to support "the ability to improvisationally combine computational resources and devices in serendipitous ways" [1]. The following chapters examine several tangible computing prototypes with the intent to better understand the requirements of end-user configuration in mixed media environments.

Mixing Media in the Design Studio

The first widely published examples of tangibly augmented environments made it clear that such environments are a much more complex mixed media setting than the preceding individual workstations [18, 19]. Hereby they also made it evident that a new set of building blocks have to provided to designers in order to let such environments flourish. Myers et. al argues in a review of past and present toolkits

that we probably have to operate in a very open field for many years to come. One of the obvious needs identifiable to day is however that the design material for leading edge augmented environments have to integrate hardware and software in ways that reflects the fact that the digital and the physical domains are no longer separated in these environments [20]. Greenberg and Fitchetts suggestion for a widget-like toolkit of Phidgets giving designers building blocks to control and combine the operation of basic interactional elements like contactors, servomotors etc. have in student trials resulted in interesting new examples of mixed media interfaces [21]. In a slightly different direction Ballagas et al. have developed a kit of generalized tangible interaction devices for an intelligent room making it possible to easily design more aggregate interactional systems [22].Strommen has suggested yet another type of toolkit linking computational agent behavior to an actual embodiment of doll-like physical artifacts that can be freely placed in the environment of use [23]. Of particular interest to us is the work on embodiment of electronic tags pioneered by Want et al. that embodies basic computational functionalities in border objects that can operate both as handles and as actual media in settings rich in both physical and digital media [24].

The problem with most attempts to provide designers with the components from which mixed media environments can be made is however that they still appear to be products of engineering labs. As pointed out for example by Djajadiningrat et al. tangibility may be new to computer engineers but it is certainly a well-known challenge to product designers [25]. Designers will need toolkits that opens up rather than seals off the embodiment of interactional components. Further more other voices from the designer community claim that even basic computational functionalities have to be made accessible and mouldable for exploration of the interaction designer [26]. There may be different ways to pursue the exploration of form and function of interactional elements. Hutchinson et. al report on a playful and experimental strategy of probing for new interaction experiences in the home setting by embodying basic technological possibilities in ways that can be grasped by collaborating families [27]. Although inspiring this approach has the limitation that the embodiment tend to become too casual and ad hoc to form the basis for a genuine genre of interaction design relevant for example in design education. In the *Atelier* project we gave design students the opportunity to explore and appropriate new combinations and linkages between digital and non-digital media in on-going projects. As in the work of Want et al we supplied them with possibilities to tie digital media to physical objects through the use of RFID tags. Similarly we provided them with simple applications for associating barcodes or particular manipulations of touch sensors to computational resources. Sensors, tags, and barcodes provided a simple way to associate media files with

the environment of space and objects. Associations of physical input, digital media and output could be edited and loaded through configuration tables that are stored in the database. Associating a physical input to digital media, can result in a diversity of configurations. For example the input component attached to a barcode scanner can be configured to read one barcode as input or a series of barcodes. Moreover, the media output can be configured to display one digital file or several in a row.

Mixed media spaces: Sensors, tags, and projections

Trials were organized at two sites: at the Master Class of Architecture, Academy of Fine Arts in Vienna, and the Interaction Design Studio, Malmö School of Art and Communication.. At each site groups of students (in each trial between 10 and 20 students in small groups) were carrying out their practical projects in the Atelier environment. The trials lasted between two and four weeks. The results of the first cycle of trials were different configurations of physical inputs and digital outputs, and a variety of projection set-ups. Students came up with a wide range of ideas of how to integrate interactivity in physical objects. They used the space as a resource, e.g. by re-creating elements of remote places in the studio. Multiple projection surfaces were arranged through "bricolage" in the space. Students used barcodes for creating associations between media files and parts of a physical model of a building. In Figure 4 (left) the site represented by the model is a large garden with fruit trees and an old house. The students animated the model with sound and projected of images of interiors, of the old house, and of different perspectives onto the surrounding garden. Touch sensors were also integrated in parts of models (Figure 4 right) to create interactive models or navigation artifacts for presentations.

Figure 4. a) barcodes placed onto models, b) touch sensors integrated into model

In preparing a project presentation one of the architectural students plotted out her

CAD plans with barcodes on them. In one of her printouts she had integrated the barcodes into a diagrammatic representation (Figure 5 in the right corner). She presented her work using multiple interactive artefacts that triggered the playing of sound and visual media on a projected screen (Figure 5 up right). Barcodes were integrated into posters, which displayed plans and diagrams (Figure 5 up left). A physical model of the section of the stadium was made interactive with touch sensors (Figure 5 bottom).
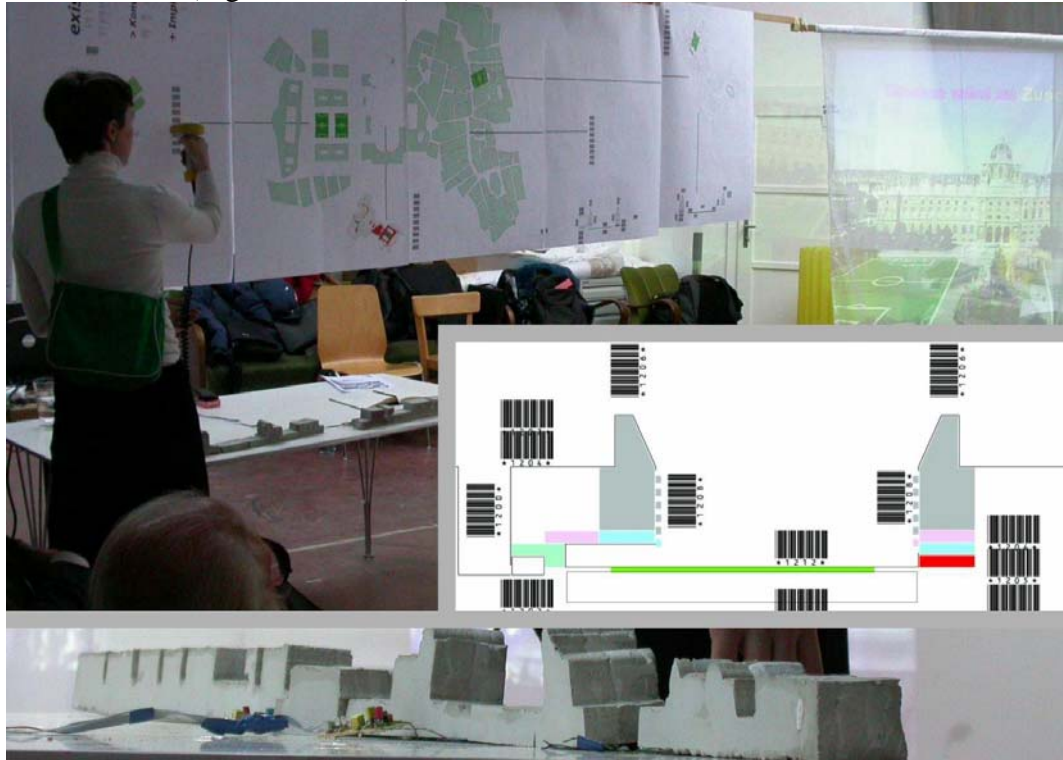

Figure 5. Configurations of sensors, artefacts, digital media and projections

Configuring Spatial Elements

The use of multiple projections invited students to use the space as a resource. Students arranged their own projection set-ups, such as for example the student who projected images of two residential buildings with two beamers onto double layers of cloth, which he arranged in the curved shapes of the buildings. He visualized the transformation of the balconies into seating arrangements for viewing a soccer game in the space in-between, performing these changes while the class was watching. The detailed plans of his interventions in the buildings were projected onto the space between them (Figure 6). The students recreated aspects of a remote place, by for example using projection screens and hanging posters in the shape of this place.
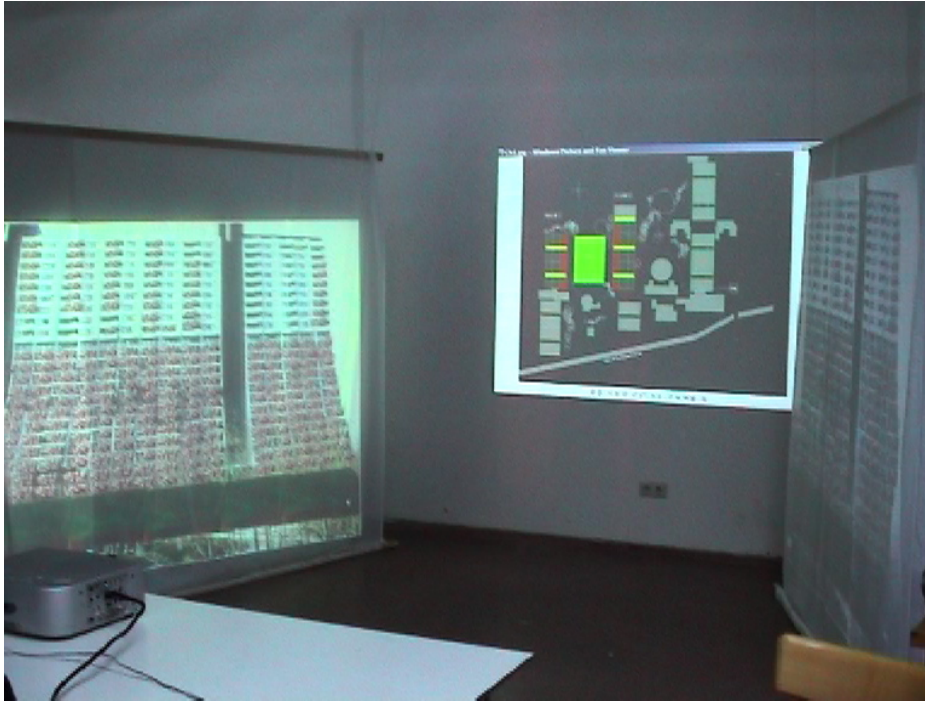
Figure 6. creating spatial elements with projections

One of our interventions in the physical space was a grid in support of configuring the workspace for different activities (Figure 7). The grid facilitated isolating smaller partitions of the room to be used for smaller groups and installing diverse projection-set-ups. Most importantly, it supported students in furnishing their project spaces in whatever way they wanted and in re-arranging them, whenever activities changed. These arrangements could be performed in a varied topography in the space, with the possibility to experience things from above or below.

Figure 7. Physical infrastructure for projection spaces

A new multimodality in design representations

The design students' experiments revealed to us the importance of supporting the spatiality of configurations. Students created immersive installations by arranging

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projections spatially and they introduced a new multimodality in their representations where different media were explicitly connected: the physical model through touch sensors, the barcodes printed in posters, tags in cards, all were connected with pictures, sounds and video on multiple projectors. New hybrid forms of design representations emerged in the work of the students mixing issues of scale by shifting between for example plan drawings and full-scale imagery. Also the possibilities to mix static and dynamic representations were explored in projections of live images on scale models.

Tagging physical models or drawings with barcodes associated to digital media was particularly popular. This bears similarities to the use of barcodes on papercards to activate digital presentations as suggested with the paper palette [28]. But unlike the paper palette the students did not develop their use of barcodes for a pre-formatted type of presentation like a power point show. Instead they integrated barcodes as a graphical element in their drawings and plans and they adopted stage like practices of projecting images often on to non-standardized surfaces in order to convey particular immersive perspectives on their project.

Both physical and digital materials were collected and explored during the students design work in a variety of ways. Digital images collected on field trips were used for projection on various mock up materials and images could be used both for establishing a context or for capturing particular interesting textures. In this way new constellations of physical and digital material were concurrently sought for involving re-linking and re-tagging materials. In the first trial this was poorly supported by the technology we provided the students with, as they were not able to make such re-configurations on their own.

In general the experiments indicated that design work in mixed media environments provided the students with a new and rich setting for exploring truly mixed media representations where the most promising results were obtained when digital and non-digital materials were forged together into new hybrid objects often with dynamic behaviour. The use of tags and sensors to invoke digital media meant that existing practices of sketching and modelling with physical materials were enhanced without having the students to switch to GUI type interfaces.

Even if the students experiments were promising, it also became clear during the evaluation sessions that the students found it difficult to work with the environment we provided. Students lamented that they had to adjust projectors and surfaces every time they started working again after another group (tape was used to mark position and height of projectors). They complained about the complexity of coupling digital and physical configurations. They also found it

problematic that several weeks of work remained distributed in the environment and were not easily portable outside the environment, and could not be documented properly in their portfolio of projects.

In a second round of trials we addressed these problems by developing prototypes that provided basic formats for collecting, configuring and documenting mixed media representations. We made available more complex applications to mix physical and digital objects, physical infrastructures supporting configurations of space, and configurable furniture. A section describes the "Tangible Archive", configurable furniture we used in the trials of the second cycle. The section entitled "Mixed Object Table" describes more complex applications we developed to mix physical and digital objects.

A Tangible Archive

When designers work they collect inspirational materials in different media. This collection of materials forms an important resource base for much of the design work. As we have already mentioned designing can be seen as a kind of bricolage where different materials are brought together to explore and envision design possibilities. Some of the authors have in a previous project written about the problems in organizing digital materials in ways that facilitate a designerly exploration, and have suggested the 'Wunderkammer' as a metaphor for such collections [29]. The problem encountered when working with mixed media representations is even more urgent if the availability of collected materials cannot be made tangible in the design environment. In the initial trials with design students we provided them with a tagging of selected design materials, but as already mentioned it became a major obstacle that the collection and storing of these materials depended on our support. Further more some of the most promising experiments made by the students involved setting up and exploring dynamic immersive environments for their design representations often in scale 1:1, and in doing this the students found it tedious and often too difficult to sketch early ideas in this way.

To overcome this problem we developed together with a group of master students, what we called the *Tangible archive*. The Tangible Archive can be seen as a configurable working area where designers can store, organize and manipulate design material in different media gathered for a particular project or set of projects. The basic principle is as in the earlier experiments to use tagging of physical objects as a way to connect to digital material and computational resource, but in the archive with an emphasize on providing components and configurable component assemblies that embody more general affordances and interactional schemes. As Grönbäk we search for components that can form the

glue in mixed media objects and extend our conception of hypermedia as well as provide a basis for new configurations of the design environment [30]. Our goal was however not to accomplish new types of augmentation that can provide a new tooling of conventional design practices as demonstrated for example in the Workspace project [31]. For us the Tangible Archive is not meant to be a fixed setup but rather a collection of design patterns from which the design students can gradually transform their collected design materials into exploratory full-scale mock ups.

We were apart from the work already cited on tagging, inspired by the mediaBlocks project by Ulmer et al., where an environment for manipulation digital video can be prototyped by a combination of container type media blocks and appliance-like manipulators [32]. But unlike Ulmer et al. we did not want to target a particular kind of media manipulation. We wanted on the one hand to provide a very open frame for exploration of design materials. On the other hand we attempted to provide the starting point also for interaction semantics somewhat in the direction of the concept of DataTiles suggested by Rekimoto et al. The DataTiles provide a basic set of interaction semantics combining the (designable) physical form of tiles with an (exemplary) systemic scheme for how tiles can be combined to form more complex interactional patterns [33]. We did not take it as far in terms of emergent functionality, but wanted also to address issues of physical embodiment.

In the first version of the Tangible archive developed by a group of master students, a bookshelf with trays could be filled with physical objects tagged with RFID tags. One or more digital files were associated to each tagged object, and interaction points equipped with tagreaders made it possible to display or print digital material associated to the tagged object placed on the tagreader. What commands were executed depended on special tagged command cards placed at an additional tagreader. The command cards also made it possible to copy and delete digital material from the tagged objects. Finally a digital camera was associated to the archive to enable users to add new digital material to tagged objects. Compared to earlier student experiments we found that this group in a more generic sense had been able to take advantage of affordances of the physical environment, like organizing tagged objects in particular trays. They also made concrete embodiments of mechanisms for connecting, displaying and copying digital materials associated to physical objects. As a finished design the technologies used may not be the final choice, but we here had an example of a student group who had been able to go through a design process gradually turning the technologies they had available into a design which made use of the possibilities of the mixed media environment we had made available to them.

In our research group we developed the concept further to see if we could use the tangible archive both as a family of design patterns and as a concrete toolkit for other design students to work with. We saw the tangible archive as consisting of an overall pattern for keeping and organizing collected material that may eventually be turned into mock ups of a final design. We suggested to the students to start their work by establishing this pattern as an actual literal storage for the materials they collect on field trips etc. Then on a more fine grained level the archive consists of other patterns that we labelled *zones.* A zone is an area in the tangible archive, which combines a set of input and output devices such as tagreaders and projectors in order to accommodate certain activities such as entering or organizing material. Finally we developed the first steps towards a collection of interaction semantics for individual *interaction points,* that could also form the starting point for design patterns.

Practically the *Tangible Archive* consists of physical objects such as models, material samples, pictures or 'objets trouvés', and digital files organized in a Hypermedia database, either as individual files or hypermedia documents or projects. The physical objects are linked to the digital files by either barcodes or RFID tags. The basic principle is that every digital file is associated to a physical object. The *Tangible Archive* has as a minimum an organizing zone, where digital media associated to the physical objects can be displayed and copied, and an entrance zone where new digital materials can be entered and linked to physical objects. The archive frame (Figure 7) is built up of modules 48x48 cm of either plywood, transparent Plexiglas or semitransparent Plexiglas (for projection), all 4 mm in width. The modules can be combined to form cubes, shelves and vertical or horizontal working or projection areas, in a scale appropriate for working in scale 1:1 according to the needs in the project. Modules are joint together manually by readymade joints.

By supplying the students with such a practical building kit we wanted to ease the process of transforming the initial archive into relevant stages for exploring and presenting design ideas. For the zones we prepared special plates with holes for placing input and output devices and the individual interaction points could be moulded on top of a set of basic building elements consisting of small tagged objects (to be connected to other objects) and matrices for the plate wholes to signal which objects could go where. The underlying technology including the infrastructure and hypermedia database was the same as in previous experiments.

Figure 7. The tangible archive as it was shown at an exhibition in Ivrea

Basic interaction principles – tags and tag readers

In the archive digital media associated to physical objects can be displayed and manipulated by moving the tag on the physical object to a tag reader. The resulting action depends on the configuration of the tag reader. In the archive all RFID tag readers are placed stationary in the archive to form pre-configured action spots, whereas barcode readers are used when digital media must be invoked where the barcodes are placed.

Figure 8. Tag reader integrated in the furniture (left); building different forms of furniture with modules (up right); the configurator deck of cards (down right)

Physical objects tagged with RFID tags are in the archive associated to what we call a *carousel* of digital media (corresponding to a hypermedia document

optionally consisting of more than one file). The action associated to a RFID tag reader will be active, as long as the RFID tag is placed on the tag reader. Physical objects (such as print outs with thumbnail pictures and barcodes) tagged with barcodes are in the archive only associated to one digital file (corresponding to an object in the hypermedia database). The action associated to the barcode will be active until a new barcode is red by the barcode reader.

Entering new materials in the archive

There are two types of entrances to the *Tangible Archive*, which makes it possible to bring in new digital media (new digital media may also be generated in the archive by manipulating other media but this is not covered here).

The *drop-entrance* is a dedicated work zone where media from USB enabled devices such as digital cameras can be entered by connecting the device and placing a RFID tagged object on an associated tag reader. The device is treated as an external hard drive and the files on the drive are stored in the hypermedia database and associated to the tagged object as a carousel of files. These may later be copied (or deleted) and manipulated in other zones.

The *email-entrance* is a dedicated work zone made tangible by a printer printing barcodes (possibly also with thumbnail icons). Emails with attachments emailed to a particular address will be parsed by the email entrance service so that individual media files (possibly with meta information) are associated to individual barcodes. The files may later be copied (or deleted) and manipulated in other zones.

The configurator deck of cards

The archive may be used by several people at the same time. A part of the archive reserved for one particular activity is called a *k zone*. The most simple zone consists of two tag readers and a display. One tag reader identifies, which media should be displayed/manipulated, and the other tag reader offers the possibility to copy what is displayed to the tag placed on this tag reader. There may be a number of different ways to display media. They can be in different form, like visuals or audio. Media in for example a carousel may be displayed sequentially, by placing and lifting the tag from the tag reader, or superimposed, by displaying all media in the carousel or from different carousels simultaneously. In order for the people using the archive to be able to configure it according to their needs, a configurator deck of cards is provided for each possible type of work zone. The deck of cards has an individual card for all the components that can be combined. The card does not only represent a specific piece of hardware (like a tag reader) but also an associated service (like display sequentially). The cards are

graphically designed so that they when placed on or close to the physical component gives a direct indication of the configuration. Each deck of cards also has an overview card briefly stating the function and interrelations between components. At a later state the configurator deck of cards can be used for dynamic configuration of the archive. Barcodes on the cards and on the hardware can be subsequently red by a barcode reader to invoke the configuration.

From Archive to mock up

Design students worked with the tangible archive in a two-week design workshop. During the workshop the student worked in groups to explore what we called semi-public places (a public library, a playground in the city gardens and café's on a public square) and they were asked to design an interactive installation that conveyed what they found to be interesting qualities of the places they had studied.

They made video, audio and still image recordings of the places they visited and they collected physical items from the area. After an introduction to the tangible archive they build a first version of the archive for the collected material.

The students used the archive frame to set the scene for exploration of their material. The group working with playgrounds made a table-like archive where collected digital material were connected to tagged leaves gathered in a heap in the middle of the table. Images and videos could be displayed on a sphere mounted above the heap and people where supposed to sit on the floor in a circle around the heap. The group working with café's created a closed cinema-like space where one could wander along the café's. The group working with the library build a counter-like structure using barcodes and barcode readers in ways similar to the way library staff register books.

As the groups continued their work they experimented both with the physical frame and the interaction zones to try out ideas. One group was particularly interested in the e-mail entrance and the possibilities to use this in connection with a public billboard for buying and selling stuff between people in the city. Like in the original version of the tangible archive they made it up to the people actually present in front of the bill board to pick up announcements e-mailed to the board from the printer and put in on the board. The announcements were printed out at the board with a barcode connected to additional contact information. Another group originally working with the heap of leaves made a variation of a display zone where two people placed with some distance to one another had to collaborate to puzzle together four pieces of an image when each of them only controlled two of the puzzle pieces.

In general we found that the tangible archive made the students able to work in

quick iterations with full-scale mock ups of interactive installations. The students tended to make smaller variations of the zones we had provided for them. They did not develop conceptually new zones (even though we encouraged them to do so), and even with the set-ups we had demonstrated to them they tended to work further with those that they already had a familiarity with. For example we found that the students preferred working with barcodes and barcode readers rather than with rfid tags. Even if this to some extend may be explained by the fact that the barcode technology in our setting was more reliable than the rfid tagreaders, we found that the rfid tagreaders and tags also in the students view where more difficult to embody in their design without considerable efforts to develop appropriate interaction schemes.
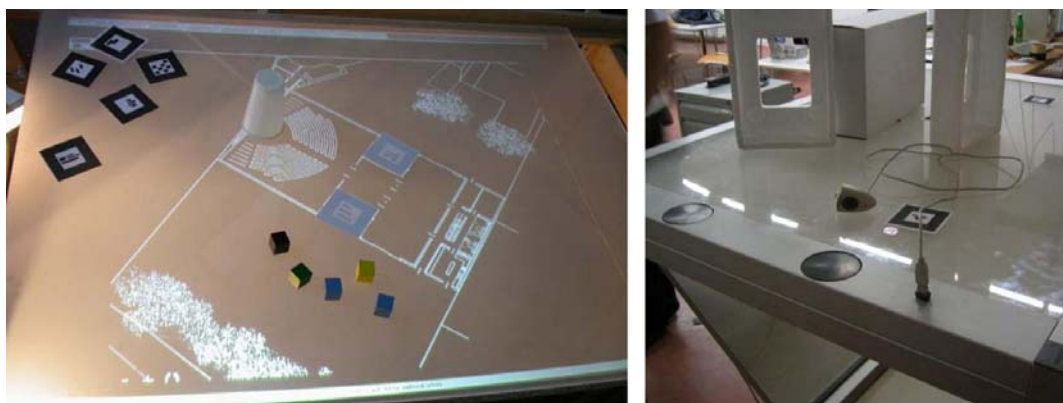
Mixed Objects Table

Where the tangible archive and its exploration in the student trials addressed the design students practice of working with mock ups in scale 1:1, the initial trials also showed a considerable interest among the students in working with mixed media in connection with table-top scale models. Already in the first trials the architect students used digital imagery to capture and work with a visual texturing of physical 3d models. For the second round of trials we wanted to facilitate this way of working further by providing a more elaborated setting for work with table top models. Others have been working with augmentation of table-top models. For example Underkoffler and Ishii have suggested a luminous-tangible workbench where calculations based on visual tracking of the physical model in made tangible by projection of shades indicating for example noise levels or sun shade in the surrounding of the modelled buildings [34]. Hornecker et.al have been working with similar set-ups where digital technology is used to keep allignment between a digital and a physical 3D model [35]. Our purpose was however not so much to invoke computational resources for calculation or relate to digital models, but rather to enhance the manipulation of the direct visual appearance of the physical 3d models. Work in this direction has been carried out by Bandyopadhyay et al [36] and by Raskar et al [37] emphasizing the visual possibilities in overlaying physical models with projected digital imagery. Their work does however not in the same way as ours take its starting point in the way design students normally work with table top scale models.

For our purposes we developed the *Mixed Objects Table*. It is a table with a semi-transparent glass table-top which is a projection screen. A mirror is mounted underneath, making a back-projection system. Users can combine the table with different projection set-ups. In the *Atelier* space at the Academy, for example, several movable large-size projection screens are available. Those screens can

enhance the table projection. Moreover, the *Mixed Objects Table* can be coupled with the *Texture Brush*. The Texture Brush is a tool ,which makes it possible to "paint" objects, such as models or parts of the physical space, applying textures, images or video, scaling and rotating them. The texture brush uses a real brush, but a virtual "paint". Finally, ARToolKit [38] optical markers can be used in the *Mixed Objects Table* environment.

Table and projection set-up

The table itself is a movable (it is equipped with wheels) piece of furniture with an integrated mirror. Two tag readers and sockets for USB devices, e.g. for web cams, a scanner or a printer, have been integrated into its frame. The table can be easily adapted to different uses. The simplest one is playing media by projecting them via mirror onto the table. Projecting the desktop turns the table into a workspace, with the peripherals being directly attached to the table. Furthermore, it can be personalized, in a way which resembles Naoto Fukasawa's, design 'personal skies', which has "two elements, a chair that adapts chameleon-like to the clothing of the user, and a means of personalizing the work environment by projecting a personal ceiling above the desk (it could be an image of the sky in a choice of season or weather conditions, or of the home), sending a customized message to the rest of the office like a screen saver" [15]. At the Academy students use the table for experimenting with objects, such as scale models, in a projected environment (Figure 9). More complex set-ups include additional projection screens. Surrounding the table with various projection screens hanging on the grid, enhances the simple projection set-up, and invites the students to experiment further. The most complex setup, explored so far, is using the table with surrounding projections and texture brush simultaneously.

Figure 9. The *mixed objects* table left Projecting a CAD plan onto the surface of the table, right two tag readers and one of the USB slots with attached webcam

Texture Brush and tag reader: run-time configurability of textures in

a physical environment

Students can position their physical models on the table, e.g. on top of a projected plan, and use the *Texture Brush* for 'painting' the model using various textures. The texture brush uses a real brush, which is tracked by an infra-red camera. The brush is equipped with a simple button as well. The system projects the virtual 'paint' only where the brush passes by and the button is pressed. In this way the user has an impression of real painting. The architectural students rarely use simple colors for painting, but apply colored textures, snapshots or even videos to their models. The *Texture Brush* is an application that creates *mixed objects* [39], where integration of the physical and the digital happens within one single object. This notion goes beyond simply enriching a physical artefact by linking it with content in different media. In the case of the *Texture Brush* the link is such, that the properties of the artefact itself can be changed, by applying colour, inserting movement and context, and varying its dimension in relation to other objects in the physical space.

The students can configure the *Texture Brush* in many ways. They can manipulate the brush size and shape by selecting these attributes from a menu bar, located at the bottom of the projection area, which is constantly displayed. Working tools like "polygon fill" that are known from applications like Adobe Photoshop©, have been integrated in the *Texture Brush* application. This allows the students to work with the *Texture Brush* much in the way they are used to work with applications they know. They can choose from a number of textures to use, including animated textures (videos), and the projection of the textures can be moved, scaled and rotated. The whole interaction is done using the brush as only input device.

Tag readers and RFID tags and barcodes can be used to load the textures into the system at run-time. Any image or video, which is stored in the Hypermedia database, can be used as a texture to paint the objects with. The texture brush can be used to paint only one side of the model. If the user wants to paint model from more sides, more texture brush systems have to be used simultaneously. Some of our students used two systems to paint the models from front side and from the top. There is also an element of physical configurability, with the possibility of placing physical objects on the table and varying the background, using projection screens*,* and varying the "ground" on which the objects are placed by using the back projection of the table.

Figure 10. (left) configuring the *Texture Brush* for painting a model, on the border of the table, the menu bar, (right) a painted model from two directions with background.

Optical markers: configuring the virtual space around an object

Besides simple projections on the table (Figure 10a), the space around a model can be further enriched using ARToolkit optical markers. Optical markers are simple printouts, which can be placed on the table. A web cam is used to capture the physical model and the markers. The position and orientation of the marker relative to the camera can be estimated. Every marker represents a 3D object, (such as a tree in Figure 11), and when position and orientation of the marker is known, the object corresponding to the marker is added to the image. Students can place the real model on the table, paint it with the real brush and virtual paint, place few real markers (paper cards), project the ground level image onto the table, and capture the whole set-up with a webcam. What we get in real-time projected on a display, is the movie of the composed scene with the 3D objects popping out of the markers. In this way we have a real object standing on the real table, but with the virtual textures on the object (which have been painted using a real brush). Furthermore we have a virtual playground for our object, real markers, which do not make much sense in the real world, and virtual 3D objects corresponding to the markers, visible only in the real time movie. The wall on the backside of this arrangement may be simultaneously used for creating contexts against which the model can be viewed. It is part of architects' practice to take pictures of these experimental set-ups and to merge them with the other design material.

Figure 11. Using optical markers for inserting a virtual tree into a physical model

The 'configuration poster'

Configuration of the space with such a variety of projection possibility is not trivial. Students have to configure the system so that specific images are projected to the specific projection screen, or used as a texture in texture brush, or as a tabletop image. We have designed a simple physical handle to configure the space. The *configuration poster* uses barcodes to specify the receiver of a texture or any other input. This approach is similar to the solution in the *Tangible Archive* example. But instead of using a dedicated tag reader and a set of command tags, a poster displaying the possible connections between inputs and outputs using barcodes can be used to configure the system. There is a barcode for each command. In this way the tag reader and the barcode reader input can be configured to for example display the media file associated to a specific tag or barcode on either the desktop or to use it as a texture with the *Texture Brush* (Figure 10b). Additional barcodes have been added to specify printers and projections on the cave corner as other output components. Also other tag readers can be connected to other outputs – for example one tag reader is connected to the *Texture Brush* and the other is connected to the desktop projection. These connections between input and output persist as long as they are not reconfigured by the students. The configuration and re-configuration can be performed at any time, dynamically changing the set-up of the workspace, using only configuration poster, barcode reader, and barcodes that correspond to the images stored in the database. This allows students to adapt the set-up to their current needs, while they are working, making the configurability part of their work with the set-up. As the *Mixed Objects Table* uses the same hardware as the *Tangible Archive* (tag reader, display, etc.), with similar functionality being available, students can choose the space configuration – table or archive – that suits their current working situation best.

The *mixed object table* provided new ways of mixing digital and physical objects. Students used the table and surrounding projection screens as a stage for their models. Nine groups of two students used the Atelier environment to experiment with virtual textures and background for white model of buildings they built. Near thousand digital pictures and videos were entered in the database and were used to paint the white models and background. The groups created several configurations of textures and backgrounds for each model, some of which were conceptual other very realistic like a video of moving water for a pool (Figure 10 right). The students often were using the *texture brush* from two different directions running two separate applications (Figure 10 right). After having painted and experimented for several hours the student took digital pictures inside and outside the "painted" models from different directions. These were then projected on large screens during final presentations creating immersive spaces with multiple projections. The students were enthusiastic about the texture brush but mentioned several difficulties in the interviews. As each model was of different size and was painted from different direction each group had to rearrange the table and projectors in different positions (also parameters on the projectors were changed as the size of the picture). This resulted in the impossibility for some group to restore the sessions juxtaposing exactly the painted texture and the model. In the presentations some groups had to paint the model from the start, and some could show only the pictures they took.

Discussion

We started out with a notion of configurability, which was shaped by the architectural concept of adaptability of a space to a diversity of uses and identities on the one hand, of our observations of 'dynamic spatial relations of design materials' as an important aspect of design practice on the other hand. The three examples we provided explore different aspects of configurability of a mixed media environment: associations of inputs, media, and outputs; spatiality and integration with artefacts; configuring furniture and work zones (*Tangible Archive*); real time configuration of mixed objects (*Mixed Objects Table*).

Our first example shows how, using physical interfaces such as sensors, tags, barcodes, and projection set-ups, a space can be configured to form *mixed media stages*. Physical interfaces are integrated in diagrams and physical models. Projection set-ups, disposed in the space, create spatial elements that provide a stage for enacting scenarios, performing presentations, or travel through media material. In contrast to a dedicated meeting setting with one projector and one projection surface, our experimentations reveal ways of using the space as a

resource for varying purposes.

The *Tangible Archive* is an example of a configurable platform-furniture made of plywood or Plexiglas modules. The furniture can be used as a surface for doing work (with work zones being reserved for particular activities), as shelves for storing materials, or for projections. Cards are used for defining and loading specific configurations for the different work zones.

The *Mixed Objects Table* is a platform for creating and manipulating mixed media objects. As in the previous example, *configuring* is hardly distinguishable from proper *use*. Configuring and selecting textures to be painted and virtual objects to be moved on optical markers happens as part of the experimentation process.

In all examples configurability includes interventions in the physical landscape of space and artefacts. The complex activity of configuring unfolds, and therefore has to be supported, on different levels and across different aspects of the environment: spatial arrangement (e.g. grid for fixing projection surfaces), furniture (the *Tangible Archive* with its modules, the table), the landscape of artefacts (which can be tagged, furnished with (hidden) sensors or (visible) barcodes), electronic components and devices (scanners, readers, connecting and plugging input and output devices), digital components and their interactions (digital infrastructure, associations of inputs, outputs and media content in the database).

This large variety of means can provoke confusion in the users that are unable to find a rationale to deal with the new qualities of the space where they act as well as in the designers, who miss the compositional grammar for creating their devices and arrangements. Even the weaknesses of the space offered to users (recalled briefly in the evaluation sections above) can be attributed to the lack of a conceptualisation shaping the design of tangible computing environments. We were, therefore, somehow forced to enter into a discussion of the qualities the artefacts we were designing had and/or should have. This discussion on the one hand, has created a deeper understanding of what we are doing in Atelier, on the other, indicates new possibilities for the design for configurability that we have not yet pursued in our research. In this section we report briefly the first outcomes of this discussion.

Mixed Boundary Objects

Most of the experiments the students did during the first and the second trial of Atelier focus on improving and enriching the presentation of the outcomes of their design exercises to teachers, visitors and other students. The artefacts we provided them were in fact used to create absorbing and dynamic environments where what they had done could be brought forth their audience.

The grid, the tangible archive, the mixed object table, the texture brush as well as the physical models and/or project plans enriched with barcodes and/or touch sensors are all examples of *boundary objects* [40] and/or allow the creation of boundary objects. A boundary object is anything that can help people from different communities to build a shared understanding. Boundary objects will be interpreted differently by the different communities, and it is an acknowledgement and discussion of these differences that enables a shared understanding to be formed. While it should be immediately clear why models and plans are boundary objects helping visitors to understand what students do in their projects, considering the artefacts we have created to support multimedia representations as boundary objects merits some more comments. They are boundary objects, since they allow visitors to share with the students the knowledge abount their design space (and the contraints and the opportuinities it offers) as well as they allow students to create boundary objects representing their work.

Brian Marick [41] lists some interesting facts about boundary objects:

"- If x is a boundary object, people from different communities of practice can use it as a common point of reference for conversations. They can all agree they're talking about x.

- But the different people are not actually talking about the same thing. They attach different meanings to x.

- Despite different interpretations, boundary objects serve as a means of translation.

- Boundary objects are plastic enough to adapt to changing needs. And change they do, as communities of practice cooperate. Boundary objects are working arrangements, adjusted as needed. They are not imposed by one community, norby appeal to outside standards."

Our artefacts support this mixture of commonality and diversity offering the possibility to move from one representation to another, either changing level of abstraction, or changing supporting medium or, finally, changing viewpoint. Several different representations users can access make reference to one unique thing (the designed building and/or device, the planned territory and/or space, etc.), whose they are different affordances.

In our approach, boundary objects are intrinsically multi-affordances objects, where commonality is supported by the emergence of one unique object and diversity by the multiplicity of affordances through which users can access and manipulate it. Considering the experiments we have done in Atelier, some of them deeply adhere to this concept (e.g. the texture brush) while other have not yet fully developed it (in some cases any representation seems to have its own life and its links with other representations of the same object are not highlighted).

Our boundary objects, therefore, are often and should always be *mixed objects*, i.e. objects coupling physical and digital qualities [39]. Mixed objects are characterized, at least, by having both physical and digital affordances (the plans enriched with barcodes) , at most, by having mixed affordances (the building model painted with a digital texture).

Even the concept of boundary becomes broader than in its original definition by Leigh Star: it refers to the contact line not only between different communities, but also between the physical and the digital, and, as a consequence, between the different (spatio-temporal) situations of any user.

Openness, Multiplicity and Continuity

It is possible to continue this discourse at a higher level of abstraction, focusing of the qualities mixed boundary objects should have. One of the authors of this article in [42] considers openness, multiplicity and continuity as indispensable qualities of what physical, digital and mixed artefacts are becoming in our everyday life. These qualities appear to be particularly appropriate for mixed boundary objects and settings with evolving physical landscapes and activities.

Openness refers to how accessible and learnable an artefact is, and to its capability of being combined with other artefacts. Moreover openness refers to the capability of an artefact (an affordance) to have different, potentially unlimited, ways of being used and perceived. Our experience of providing students with simple prototypes, helping to extend them and furnish them with more complex functionality is an example of openness to appropriation and use. Another crucial aspect of openness is the possibility for an artefact to be combined with other artefacts. Integrating barcodes, tags, and touch sensors in physical models and diagrams helped create interactive and in some cases innovative combinations of physical and digital objects, being perceived and used in many different ways. The *Texture Brush* and optical markers, applied in combination with physical objects and projections, resulted in rather intriguing kinds of *mixed boundary objects*.

Multiplicity refers to the capability of a space or artefact of being made of different components having different qualities. Multiplicity can be seen in the combination of input (sensors, tag and barcode readers, scanners, etc.) and output (displays, printers, projectors, etc.) devices characterising the work-space of the Atelier students, and/or in the multiplicity of affordances offered by mixed boundary objects.

Continuity refers to the capability of moving from one affordance to another, from one representation to another, without changing artefact, without interruption in space and in time. In some sense, Multiplicity and openness are contradictory as multiplicity creates distinctions and "thus boundaries between one function and

another, whereas openness breaks down all borderlines to encompass all functions in one whole." [43]. One of the arguments that may guide such integrations is that the new objects populating augmented places need to combine openness and multiplicity through *continuity*. Continuity can be achieved by putting resources on the borders of objects, so that the borders act as both, separators and connectors [44].

The new types of sophisticated *mixed boundary objects*, we are experimenting with, could be achieved by putting resources on their physical borders – on the borders between their physical and virtual components. One of the challenges we are still working on is to be able to support all activities in embodied interactions without the use of conventional GUIs. Another challenge is to support users in carrying out configurations flexibly, accountably, and with ease. The integrations of physical interfaces with existing and evolving landscapes of physical objects we described, were aesthetically appealing and inspirational, but some of them were handcrafted and co-developed 'on the fly'. Although grid and sliding frames supported the spatial configuration of projections, this still required artistry and bricolage (which architectural students are quite capable of). The furniture we designed is with wheels and modular, but more flexible ways need to be found of integrating electronic components in it. Integrating sensors into artefacts has improved since our first trials from wired prototypes to wireless components, but still need to be customized into (sometimes) fragile solutions. End-user configuration at all the levels we have identified, poses a series of challenges for architectural, industrial and interaction design (including the need for robust and open electronics components).

Configuring as staging mixed places

The potential of physical interfaces reaches beyond 'mere embodiment'. They provide people with the means for producing configurations that change spatiality, interactivity, and physical landscape in ways that help experience, explore, present, and perform. At the beginning of the field trials the space was non intentional and had to be appropriated. This was also part of the pedagogy, assuming that a perfectly furnished space is often not the best solution for creative work. Students need to appropriate the space, struggle with its constraints, and find their own interpretation and set-up. This is why they found the space almost completely empty, apart from an infrastructure of networks, furniture, grids for projections, tag/barcode readers, computers, and other electronic equipment. They were asked to bring their own stuff – pictures, video material, scale models, diagrams, and collages. With these resources at hand, students configured and re-configured space and artefacts to accommodate diverse activities – from browsing

through pictures, to discussing a design concept or performing a scenario of use. We can understand these configurations as forming an evolving set of temporary and in some ways ephemeral layers onto this neutral, almost empty environment. . This captures what current research on enriching the physical space is aiming at - not to provide new functionalities for users but to transform their social experience at its roots. The space metaphor does more than provide a resource for analysing human behaviour and designing for it; it also shapes the language through which we speak about ourselves. Just as it allows designers to describe relationships in social interaction, it provides a common framework for those actually engaged in interaction. When people share an enriched portion of space and a language to talk about their experience, they transform the former into a place.[2]

So what could *mixed places* be? They provide qualities, some of which cannot be found in physical space and are utterly new. One quality of mixed places that emerges from our trials is the capability of being reconfigured dynamically and radically. The configurability of a space depends on its layout, the design of the infrastructure, and the design of the artefacts that populate it. With regard to the configurability, of artefact, we have argued, that they would have to combine openness and multiplicity through *continuity*, producing the right interplay between infrastructures, mixed objects, and activity. As to the configurability of a space, we could learn from good architectural design that often plays with an ambiguity in the relationship between spatial configuration and functional program, where "the allocation of functions or uses is malleable, they are fitted into the spatial configuration. While some of them find ample space, others might have to be squeezed in, overlap, extend into neighboring spaces, thereby creating 'natural' connections or meeting 'fixed' boundaries. This not only allows to suspend or transgress the usual hierarchy of functions and rooms. Also, the boundaries between interior and exterior space are designed as permeable and fluent" [13]..

Acknowledgements

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[2] Harrison and Dourish argue that a place is a portion of space 'invested [through language practice; authors' remark] with understandings of behavioural appropriateness, cultural expectations and so forth' [45]

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