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Supporting Collaboration Ubiquitously: An augmented learning environment for architecture students

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Abstract. While CSCW research has mostly been focusing on desktop applications there is a growing interest on ubiquitous and tangible computing. We present ethnographic fieldwork and prototypes to address how tangible computing can support collaboration and learning. The student projects at the Academy of Fine Arts in Vienna is a relevant case to study, for the variety and distributed character of the cooperative arrangements, and for the richness of interactions with heterogeneous physical artefacts. After describing current practices, we propose qualities of the environment that support collaboration and learning: creative density, multiple travels in materials and representations, re-programming (seeing things differently), and configurability. We then describe several prototypes that address in various ways these qualities. Finally we discuss how tangible and ubiquitous computing supports collaboration in our case by providing *intermediary spaces*, and *dynamic objectifications*.

Introduction

This paper uses fieldwork in a specific learning environment – an architectural master class at the Academy of Fine Arts in Vienna[1] – for exploring the relevance

1 The fieldwork was carried out as part of the IST Project ATELIER (http://atelier.k3.mah.se/).

of a ubiquitous computing environment for collaborative work. We use ubiquitous computing[2] as an umbrella term for describing an environment, which reaches beyond the desktop, integrating the physical environment of space, objects, and people. As collaboration takes many different forms inside and outside the Academy, and students, teachers, and design representations are in continuous movement, we are interested in an environment that allows creating layers of and connections between spaces, objects, events, and people with ease. As part of this we focus on prototyped technologies as well as spatial arrangements that are simple and easy to use.

While most of the work in CSCW focuses on desktop applications, attention has been given recently to some aspects of such an environment, namely: the importance of physical objects and embodied interactions (e.g. Luff and Heath 1998, Heath et al 2002); the possibilities of connecting physical objects with digital objects and media (e.g. tangible bits; Brave, Ishii, Dahley 1998); boundaries between realities (e.g. the physical world and 3D environments) and how to manage them (Koleva, Benford, and Greenhalgh 1999); mobility (Orr 1996, Bellotti/Bly 1996, Luff/Heath 1998) and mobile devices (e.g. Berqvist et al. 1999). Dourish (2001) refers to tangible computing, which "expands the ubiquitous computing vision by concentrating on the physical environment as the primary site of interaction with computation". He proposes a new framework for HCI introducing embodied interaction, which he defines as "the creation, manipulation, and sharing of meaning through engaged interaction with artefacts" (p. 126). Embodied interaction as a paradigm for HCI and CSCW requires to free computing from the desktop and to take account of the social embedding of people's interactions with artefacts in systems of meaning.

We position our contribution in this debate on how to better integrate the computational into the physical world, focusing on people's embodied interactions with it, and contextualize it in a particular case. The architectural master class is particularly relevant for ubiquitous and tangible computing, as it is rich of interactions with heterogeneous artifacts in different media, with the physical space as an important resource. The variety and distributedness of cooperative arrangements makes it an interesting place for studying cooperation.

Important for understanding the learning practices at the Academy was previous ethnographic work studying architects' work practices (e.g. Büscher et al. 1999, Lainer/Wagner 1998, Schmidt/Wagner 2002). This helped us see students' work as an enculturation in professional design practices. It drew our attention to issues such as the conceptual nature of design, the role of design representations in a process, which is non-linear, informal, and highly cooperative, and the need to transform and re-program. Working with architects

2 Ubiquitous or more recently pervasive computing is connected to the vision of "a physical world richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network." (Weiser, Gold, Brown 1999).

also helped understand the relevance of the physical space for collaborative work – the students use the space for exhibiting their work and maintaining it visible but also for physically exploring qualities such as scale, dimensionality, and ambience.

After an initial phase of intense field work, we started exploring the idea of a ubiquitous computing environment in a hands-on way, using simple technical solutions and early prototypes with an emphasis on concept-creation and exploration, asking ourselves what such an environment could possibly be and offer. We also approached this question through describing the environment in terms of particular atmospheric, material and spatial *qualities* that should be created. For this we analysed examples of inspirational environments from architecture and the arts. Finally, we produced a series of scenarios of use and set up a space with materials and technologies for students' ongoing work. In all phases we drew upon the creative potential of the students and their teachers.

In this paper, we will report on these quite intense experiences in several steps: We will illustrate learning practices at the Academy, using some examples from the field work; we will propose current and desirable *qualities* of the environment in our specific case to support learning and collaboration; we will briefly describe some prototypes we developed that in different ways integrate computing and interactivity in the environment. Finally we will discuss how our case is relevant for CSCW research, by showing how including the physical environment of artefacts and spaces in design thinking gives rise to new forms of support for learning and collaboration.

Observations of learning as cooperative work

Learning at the Academy takes place in the 'master class' - a universal, complexly linked didactic concept. The master class is the place where students carry out their manifold activities, most of them project based. Here they learn how to mobilize a diversity of resources – art work, concepts, metaphors, analogies, fieldwork experiences, project examples, samples of materials, technologies, etc. – for generating project ideas. Here they get to know the techniques and standards of their field that help them translate their ideas into architectural designs. They do this through engaging in different forms of individual and cooperative activities. Teachers at the Academy do not lecture (or not primarily so). They define the requirements, they introduce topics, roles and observational techniques that direct and facilitate students' learning. They give continuous feedback, commenting on students' work and suggesting different ways of viewing, and they through their interventions communicate and represent the historically grown and culturally mediated practices of the field.

Paraphrasing Kjeld Schmidt's statement 'taking serious work seriously' (Schmidt 2002) we might want to ask if this kind of learning is cooperative work.

It is, in several ways. Students' work is distributed, in time and space, conceptually, and in terms of control. There is a common field of work, which evolves in the design process and is pre-defined by the semester programme and student projects. Architectural work is different from many other types of work insofar as the field of work does not exist in advance but is constructed in and through the process of design which "proceeds through the architects' producing successive objectivations of the design and interacting with them in a variety of ways" (Schmidt/Wagner 2002). Much of the students' interactions with each other and their teachers is mediated through the diversity of design representations they produce. Another peculiarity of architectural work is the relevance of physical artefacts for the development of a design and the extensive use of space as a resource.

The following paragraphs describe the practice of learning at the Academy, using episodes from a variety of student projects. The first round of fieldwork at the Academy was carried out in the first half of 2002. The methods used were observation and informal interviews. We observed and interviewed students working on seven different projects. In some projects we tried to observe aspects of the whole life cycle. For other projects we constructed snapshots of the current work. Interesting episodes were recorded with a digital video camera or a digital still camera. The second round of fieldwork took place from November 2002 to January 2003 when we introduced our first prototypes of space and technologies into students' work.

The diversity of design representations

Students' project work proceeds through developing a large number of design representations. These are characterized by the expressive use of a diversity of materials and are sometimes animated and presented dynamically.

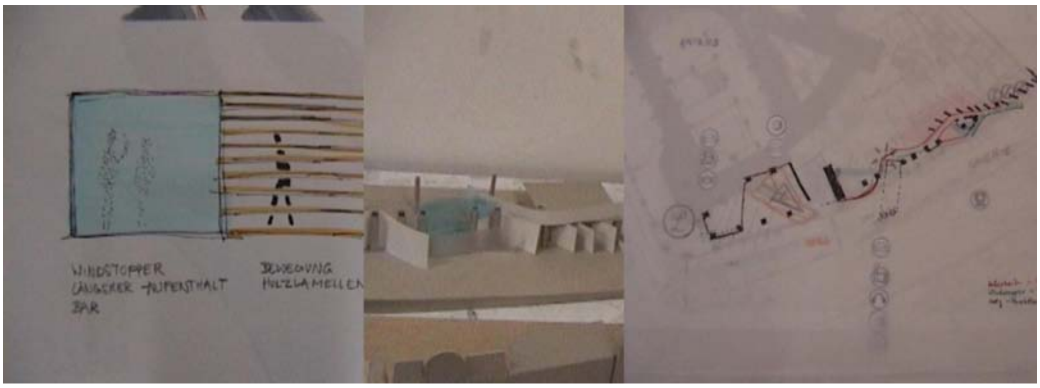

Figure 1: A diversity of design representations

As an example two students worked on a façade for ‚Möbel L' (a furniture house who sponsored a student project for their main inner city building). The students envisioned the façade of the building as a threshold between inside and outside. On their table are sketches of the form of the façade, detailed plans, drawings visualizing atmospheres and situations of use, 3D models, diagrams - a collage of visual and tactile material (Figure 1). One reason for this diversity of representations is that changing media and scale adds to the quality of the design process, with different techniques allowing to explore different aspects of the design idea. These heterogeneous representations are often manipulated simultaneously and they evolve in different versions. While working the students continuously switch between representations, as for example in Figure 2 where they work on a 3D model of the concept (left), on drawing and sketches (middle) or with the 3D model and diagrams in parallel (right).

Figure 2: Switching between design representations

The students' common field of work is constituted through this diversity of design artefacts and their relationships. These relationships are not fixed, they evolve over time, such as for example the notion of a façade 'to lean and sit on' (Figure 1d), which became stable – incorporated into their final drawings - only towards the end of the project. A crucial aspect of the design process is to maintain evidence of all the material that has been produced. It is essential to be able to read and re-read the material from different points of view and to be able to go back to a moment when a particular issue emerged.

Figure 3: Layers grouped together support different perceptions of a complex design problem

Architectural students' field of work is highly complex and they constantly invent and probe techniques for representing this complexity. One example is this representation of an urban planning project with layers for each type of elements (roads, rivers and lakes, railroads, settlements, industrial buildings, etc.) (Figure

3). The layers are made of transparent slides and collages of materials. There are two stacks of layers, one corresponds to the current situation, the second one visualizes the proposed interventions, e.g. populate an area, or extend roads. The model is animated and presented dynamically allowing to explore the relationships between elements as well as between current and future states through grouping and ordering the layers.

The distributed character of learning

As Lave and Wenger (1999) phrased it, learning takes place in a participation framework. It is a process by which newcomers become part of a profession. A good learning curriculum consists of situated opportunities for the improvisational development of new practice in a diversity of role configurations.

Students' learning happens in different places and in different cooperative arrangements. It is typically distributed in space and time. Activities take place in an environment, which is rich of interactions between students and with the teaching staff and external professionals. Students work individually or in small teams. Sharing a room with other project teams facilitates a 'ping-pong' of ideas, the exchange of knowledge and experiences across teams. They work at different times of the day, sometimes staying over night.

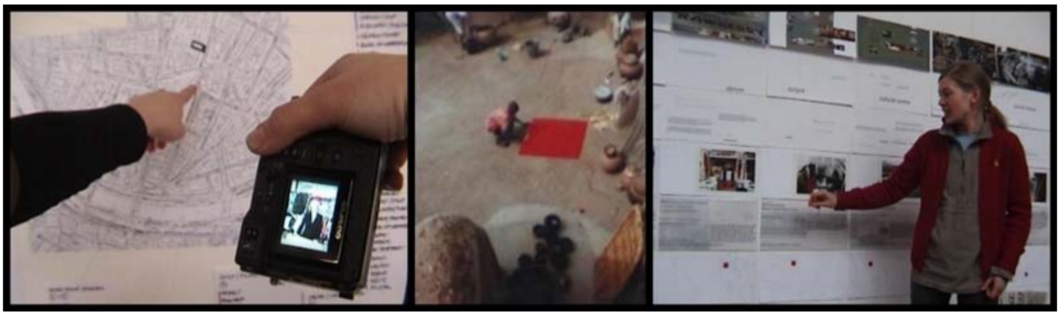

Figure 4: a) Digital pictures and recorded audio around a diagram, b&c) Multiple traveling - the picture of an event and its re-viewing in the context of a presentation

An interesting aspect of this distributedness is students' need to feel connected with the outside space of city, project site or people. Built into their work are excursions to the outside world, e.g. the site of a project, where they collect video and audio material, pictures, sketches, and objects, such as in the case of this project, which deals with redesigning an inner courtyard. In the first phase of the project the student interviewed people living in the area. She represented each person with a list of keywords and symbols around a map. Each list had a pin and a thread connected to another pin in the map showing where the person lives. When presenting the model she used electronic devices to augment her diagram, a digital camera and an audio recorder (Figure 4 a). Her diagrammatic representation of the project was connected to a whole range of material collected at the site.

Students and their teachers use the notion of 'multiple travelling' to capture this distributedness. The first journey when a project starts is to the place of an intervention itself with the aim to experience the authenticity of the place. A student who has travelled to Ghana as part of her project mentioned that, although she took pictures, made notes, carried out interviews, and produced videos, it was hard to capture the richness of the experience while being there: "It is your body that subconsciously absorbs the place. Back home you perform your second journey through the collected material, remembering with your body even subtle things like the smell of a place". This journey through the material has to be repeated again and again, with different layers and aspects coming to the surface (Figure 4 b,c).

Apart from this distribution in time and space, learning is distributed conceptually as well as in terms of control. Although supportive of students' ideas, teachers at the Academy constantly challenge their concepts. Creative work, they argue, requires to transform and re-program - to explore solutions and contexts, to shift perspectives, to carry out experiments, to present and perform, to have time and space for free play and day-dreaming, and to generate a 'different view'.

Figure 5: Examples of how students learn to see a place in a different way

An example is a feedback session with a student who proposed an underground parking space in her project of re-vitalizing an area with immigrant workers. Her teachers challenged her approach, asking her to transcend the traditional categories trying to combine them in new ways. To, for example, work with contradictions – 'the mosque, outside lively, inside an oasis of tranquillity'; to let market and street reach into the park; to use empty shops for parking; to connect living with the car, its sound machine being used in the living space. Other examples can be seen in Figure 5 where an ugly industrial skyline has been photo-montaged into a ship and a table in a deserted courtyard turned into an elegant dinner arrangement. It also shows representations of a student idea for a temporary installation in a courtyard, which sets traces for future possible projects. Their project is an intervention rather than a finished plan for something to be built, challenging the notion of the 'completeness' of architectural solutions.

This juxtaposition of perspectives and questioning of concepts is supported in different ways. Students use their multiple travelling experiences, they are encouraged to collect and mobilize inspirational objects, to experiment with atmosphere and context. For example, one student, while working on a project about the beach, "started seeing beaches everywhere, also where the sunlight was reflected on the road. These constant changes of context helped her think differently about beaches".

Uses of space as a resource

Students working on a specific semester program are co-located in one of the Academy's large, high-ceiling spaces. Students' workspaces are spread through the room, with project-related material filling the tables, the moveable boards and the walls. Even in the absence of students there are physical traces of their work to be read in an open exhibition.

Artefacts such as large scale models are sometimes shared. They offer a platform for group discussions. This was the case in the project 'Learning from Tibet' where a series of interventions into an alpine environment was held together by a large plaster model which served as a point of reference for discussions, with students placing material such as threads or tape to mark forms of paths, and rivers on it. Each time we visited the project space we found new traces of students' discussions (Figure 6 a).

Figure 6: a shared model b) Placing elements in the shared model to demonstrate their relationship to the environment.

Students' work environment is in constant reconfiguration. Activities range from working alone or in groups, with different representations and materials, to having coffee, listening to music, partying and occasionally sleeping over night. One occasion for rearranging the space are project presentations or feedback sessions, which are often held in students' workspace. We observed a presentation of the work of first semester students whose project was to re-design their own working environment (Figure 6 b). A large shared model of the project space had been placed in the middle of the room. During the presentation students positioned their own models inside this space, demonstrating and arguing the relationship of their designs to the shared workspace. Some students used mobile furniture for their models, e.g. moving the model from a position where it was visible to the audience and could be pointed at to a position where it could be directly touched and modified (models are often composed by movable parts).

Student's flexibly adjust their workspace to the changing needs involved in developing a project, producing and exhibiting design presentations. Introducing a PC into the workspace reduces this flexibility, as the PC takes up much space and attention and is difficult to move with all its cables. This is one of the reasons why individual workspaces are not equipped with computers except when students bring their own laptop.

The PC also diminishes the presence of important aspects of work, hiding the work of some students to others. Figure 7a shows two students browsing pictures of a trip on a PC. Due to the particular position of the PC and the fact that the object of work (the pictures) is only accessible on the computer screen, this activity remains separated from what others in the room are doing. Moreover, when the computer is switched off, no traces of students' work are left. In contrast, browsing through printed photographs or slides on the table (Figure 7b and c) creates the kind of visibility that allows others to participate, directly or by being peripherally aware.

Figure 7: a) Browsing pictures on a PC, b) browsing printed photographs, c) browsing slides

One student group spread their pictures from the trip on the table, sorting them in rows. Other students came by, asking questions and together they started remembering, evoking encounters, telling each other stories (Figure 8a). All of a sudden, what had been constrained to the desktop, was available to all. He then played sound from a football stadium in Mexico. These interventions completely changed the atmosphere in the project space, evoking some of the common aspects of students' work.

Figure 8: Making work visible a) on the table, b) and c) by projecting work on the PC onto the walls

Towards a ubiquitous computing environment: qualities and supporting technologies

Our aim is to develop an environment that reaches beyond the desktop computer, integrating the physical environment of space and objects. It is obvious that there is no single technical solution for complex learning processes such as the ones we briefly described. It even does not make sense to think primarily in terms of technical solutions but to look at the learning environment as a whole – the changing places and their characteristics, the multiple cooperative arrangements, the diversity and materiality of design representations, the need for experimentation and for seeing things differently.

Based on the analysis of the observations and of interviews with a small number of practicing architects we specified a set of qualities of the environment:

- creative density - the multi-mediality and diversity of design representations and their sharing
- the connecting of design-relevant materials – chronologically, conceptually, narratively, randomly, etc. – multiple travels that help create and explore different perspectives
- re-programming – to play with context, atmosphere, dimension
- configuring – the adaptability of a space to a diversity of uses and identities.

These qualities capture the crucial aspects of students' learning environment. They specify the ways, in which students explore, develop, share, criticise, and concretise their ideas. For the project team of designers, ethnographers, and architects the description of these qualities – through metaphors, text, images, video clips – served as key design representations, inspiring the design of the prototypes of space and technologies as well as helping to define and evaluate them.

Qualities

Multi-mediality and creative density: The multi-mediality of design representations plays a crucial role in envisioning particular aspects of a design. A conceptual model in its abstractness and lightness asks the architect a different question than a plan, a diagram or a model in a different scale. In many cases the nature of the materials chosen for a model play an important role, with their physical features carrying meaning and enabling students to represent more abstract kinds of information, such as fragility, denseness, atmosphere (Ormerod/Ivanic 2002). Fieldwork observations showed how engaging in an immersive mass of material – design representations in different media, inspirational objects, etc. - supports intensity in design situations. One aspect of this creative density is the chance to encounter surprising or interesting combinations of objects. Another aspect of creative density are spatial limitations or constraints that may provide stimulating perspectives, with things and spaces overlayering each other.

Connecting – multiple travels: Work at the Academy is distributed in time (covering several weeks or months), place (students move within and between the Academy and places outside), and conceptually (their concepts develop, teachers bring in their views). Students go back and forth between media and representations, 'circulating references' (Latour 1999) throughout the design process. One important aspect of connecting is the necessity to maintain the design material physically present so that it can merge with the ongoing design work, visible also to passers-by who are invited to comment. Often the sheer amount of material makes this impracticable. Here the notion of multiple travels is helpful as the possibility to create different perspectives and views of design-relevant materials. Drawing maps of one's own work is a way of connecting. Putting it on top of someone else's map, may help perceive one's own patterns differently. The connections the traveller forges may be of varying nature and quality: chronological, narrative, based on some random selection, driven by the desire to contrast and confront.

Re-programming: Part of the architectural students' training consists in learning to see things differently. This implies changing familiar images - mutating the city, the landscape, and objects of everyday life. An example is the students' projects for a Fitness Centre in a high rising building – e.g. inviting mountain bikers in, varying the temperature in the building so that different training conditions are provided. Students may vary the context of an object through simple projections, e.g. place a railway station in the midst of a jungle or igloos in the desert (without having to do complex renderings). They may play with dimensionality, scaling up and scaling down, changing familiar objects and thereby arriving at unexpected uses.

Configurability - adaptability to a diversity of uses and identities: Setting up one's own project space becomes one of the first opportunities for reflection.

Being able to configure and personalize it is part of opening up the design space. This includes playing with different contexts and media. The variety of cooperative arrangements together with the intensity of work make it desirable to be able to use the space for multiple purposes, solitary work as well as group discussions and presentation. An important experience is that a perfectly furnished space is often not the best solution to creative work. The students need to appropriate the space, struggle with its constraints, finding their own interpretation and set-up. Adaptability of a space means the possibility to reconfigure a space so that you can personalize, exhibit, build models, collect, have a nap, make coffee, interact with material and odd objects, etc.

Experimenting with space and technologies

We are currently pursuing a variety of technical and spatial solutions with the idea that these should be considered 'components' of a future ubiquitous computing environment that the students should be able to combine and tailor. First opportunities to introduce these components to students and teachers presented themselves from November 2002 to January 2003 in the context of a workshop and a series of individual projects.

The configurable space: An architectural space is not static, it constantly changes with people's activities. This is why the architects focused on the spaces at hand in the Academy, their re-programming for changing activities and needs (rather than creating new typologies). The space that was selected for the project within the Academy offers some possibilities for creating these conditions. It is located in one of the four towers of the Academy building that was constructed by Theophil Hansen. It is "far from perfect and cannot do everything". For example, it has no windows, with the light coming in from openings in the roof, and it has no natural ventilation. However, the lack of perfection, the spatial constraints are important, since they stimulate the creative appropriation of the space for different activities.

Four types of interventions in the space have been designed: a ‚*grid*', an ‚*interactive wall*' for storing models, materials, (technological) components, typological furniture, etc. (currently available as a mock-up), and, for the future, adjustable platforms (allowing to position objects at different heights or people to assume positions from unusual perspectives), as well as an elaborate lighting system. Multiple projections play a large role in the architects' vision of configurability. Here, for example, one of the teachers enjoys the atmosphere of the garden into which he will design a building (Figure 9a). The grid supports the visualizing, scaling, colouring, etc. of spaces, objects, and people. It is a simple infrastructure, which has been mounted on the ceiling. A sliding-door system provides the space with frames for multiple projections and for layering walls. The frames serve for hanging textiles and other materials, objects, plants, etc.

Figure 9: a) life size projections b) multiple traveling

We observed how a student group configured the workspace for a multi-media presentation, fixing a data projector for floor projections high up on the ceiling and hanging up double layers of translucent cloth. In their presentation the students created a very effective immersive environment, which worked really well with contrasting images of different qualities – sharp and blurred, narrative and symbolic (Figure 10a and b).

Figure 10: a) and b) Creating an immersive environment with multiple projections,

Another student group presented a movie of their trip, integrating the space into their performance. Seats were arranged like in the underground and passengers that had to stand were provided with a handle made from orange plastic. In this configuration they watched the movie which alternated sequences of traveling the underground (which accelerated, growing noisier and more hectic) with the presentation of stills at a calm and slow pace (Figure 10)[3].

Texture painter: Using a brush, which is tracked with a video camera, this is a tool for 'painting' objects such as models or parts of the physical space, applying

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[3]: Another component, the *atmosphere configuring tool* enables students to configure the physical space - lighting and sound system, air conditioner, fans, projectors, etc. – helping them create and reproduce different atmospheres.

textures, images or video, scaling and rotating them. Students started animating their models with the help of the *texture painter*. One student studied soccer games to identify the most exciting camera views and to understand which kind of atmosphere the players need. He used the camera views to find out where to place few spectators so that the stadium looks jammed. He built a simple model of a stadium and used model and images together with the *texture painter* for projecting different atmospheres into this ‘fragmented stadium’ (Figure 11a and b). Another student painted images of his interventions onto projected images of two residential buildings, projecting detailed plans onto the space between them.

Figure 11: Painting a) spectators , b) a background onto models of a stadium, c) interventions into a space between two buildings.

The tool allows creating a kind of intermediary space between the physical and the digital, to connect the physical object (a model) with a digital representation (e.g. the rendered model, a video, an image). This gives the rendering a haptic, sensual quality.

Animating barcode: Reminiscent of Webstickers (Ljungstrand et al. 2000) the *animating bAR code* has a barcode reader attached to a PC on which a Java program is running that associates pictures, sounds and video clips to barcodes. The pictures are displayed with a projector so that users do not have to be near the PC screen. Students use the *animating barcode* as a tool for connecting and story-telling. For instance, one student in preparation of a feedback session attached barcodes to parts of his model, with the idea to make his model self explanatory, inviting the audience to discover the model. Another student used barcodes as a tool for turning her diary, which she had filled with notes, sketches, small images and objects collected during a trip, into “a book that speaks”. Touching a sensor at the back of the book initiated the reader’s journey with the possibility to turn the pages, activate the barcodes and triggered a series of projected images (Figure 12a).

Also two of the teachers used the barcodes for creating associations between pictures and a model of a building which they are planning, the site being a large garden with fruit trees and an old house. With the barcode reader they animated the model with sound and with projections of images of interiors of the old house, and of different perspectives onto the surrounding garden (Figure 12b).

Figure 12: a) Barcodes on the pages of a diary of a visit; b) on parts of a model

Touch sensors and sensitive samples: We are experimenting with various types of sensors to augment physical objects. For example, sensors have been installed inside a wooden box that recognize actions such as shaking, knocking, and stroking, with different actions activating different types of material – sound, images, video, and wind (Figure 13a). The “book that speaks” is equipped with a sensor that, when the book is picked up, activates instructions how to read the diary using the barcode scanner (Figure 13b).

Figure 13: a) Box with sensors inside, b) sensors on a diary c) Sensors connect a moving object (ball) with images and sound

One of the students prepared an elaborate presentation of her design ideas for an ‘extreme stadium’ in the area between Vienna’s two large museums. She had prepared a soccer field and two slide shows, with one screen displaying cultural aspects of soccer (images, sound, video) and the second screen displaying her design ideas ‘in the making’. The slide show was operated through a sensor that had been fixed underneath the soccer field. The presentation itself was designed as a soccer-game, with the building sites being the teams - stadium versus museums, explaining the design ideas being the team-tactics, and herself as the referee, with a yellow card and a whistle signaling a ‘bad idea’ and shooting a goal a ‘good idea’. When the ball touched the goal a sensor triggered off a reporter’s voice shouting ‘goal, goal’ and the cheering of the visitors (Figure 13c).

The Jacket: The *Jacket* is a machine that supports people during visits to create a personal perspective of places of interest. The *Jacket* helps collecting video, audio and information from sensors like the location, the direction from an electronic compass. This data is combined with information of time and visitor's actions. Particular actions of the visitor are also recorded like taking a picture or recording a sound. The multimedia path, which is created during the visit, can be then visualized and edited in the Atelier environment. The *Jacket* consists of two main components: the *Jacket* as a recorder that is worn to visit a place (iPaq, GPS receiver, digital camera, and sound recorder), and a 3D visualization tool for navigating, manipulating, and editing the collected information back in the studio (Figure 14 a and b).

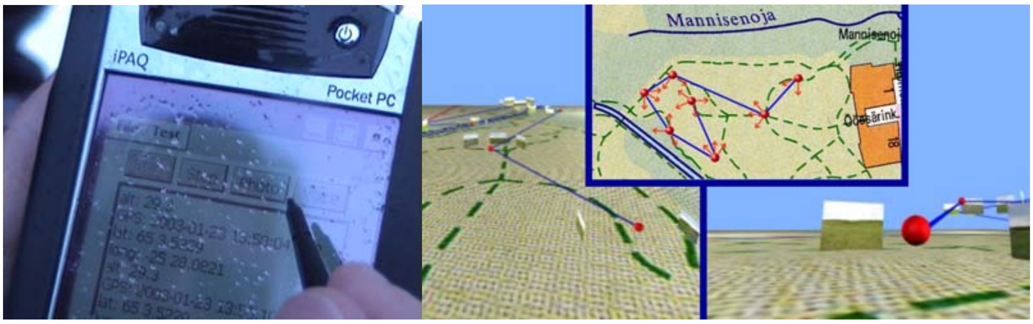

Figure 14: The prototype of the *Jacket* a) pocket PC with GPS to record a path, b) a 3D visualization application to navigate and manipulate the path on maps or plans.

Discussion

We explored two aspects of ubiquitous computing – (i) mixing physical objects and digital media and (ii) widening the possibilities of using space as a resource. Our interventions helped amplify aspects of architects' practices in several ways: Spatial design and technologies supported students' re-arranging and re-configuring of their workspace for different purposes; they helped preserve and enrich the landscape of design representations and enlarged the spectrum of media, integrating sound, video and digital pictures into students' predominantly physical work environment; finally, the possibilities of connecting and multiple traveling strengthened and enriched students' collaboration with each others and with their teachers.

Previous observations of practices and their settings within CSCW were used mostly, with some exceptions, to design features of desktop applications. Ubiquitous computing gives the opportunity to include the physical environment in the design thinking. This probably means that we will continue to observe practices in the same way but we will draw different design implications because we expect technology to support collaboration in a different way. Why and how can ubiquitous computing better support collaborative work? This question is new for CSCW research and will be debated in the next years as ubiquitous computing and its use will become observable.

Intermediary spaces

The *Animating bARcode* and the *texture painter* are examples of technologies where the physical object is part of the interface when interacting with digital media. For example, the *animating bARcode* makes it possible to access project files while maintaining the physical model present. The *texture painter* allows to animate the physical object itself. People's interactions with physical objects (and the associated) material are related to the physical space and available to others. These integrations of physical elements of the work environment with digital presentations preserves the reversibility of perception, a term Merleau-Ponty introduced for describing "the complex intertwining between the perceiver, the perceived and the physical environment that is the essential condition for our interaction with the world and with others" (Robertson 2002). These forms of embodied interactions support understandings of technological artifacts and social actions emerging in concert with other people (a phenomenon referred to as intersubjectivity; Dourish 2001). According to Dourish embodiment "offers opportunities for a much more direct apprehension of the modulating, mediating effect that computation plays in interaction", with the active nature of computers being important not as independent agents but "as augmentations and amplifications of our own activities."(p. 166)

Here the role of life size projections, intensified by multiple screens and data projectors (the 'grid') needs to be emphasized. Students re-experience their ride with the metro while watching the video of their trip and their teacher *is* sitting in the garden while looking at the model of his design and thinking about it.

Another interesting aspect of these intermediary spaces, that the mixing of physical and digital creates, is the transient and ephemeral way in which artifacts, people, and ambiences are encountered. This resonates with what architects see as an important aspect of their work – the peripheral presence of events or objects, with short-time events, fast, assembled, ad-hoc, such as film, video and fashion photography being important inspirational resources. (Wagner 2002).

Dynamic Objectifications

Students produce objectifications of their design ideas. These objectifications constitute the common field of work and they are the stuff that mediates their interactions with other students and teachers. The prototypes we presented support the objectification and concretising of the design in dynamic and interactive ways. The *texture painter* provides a fast and highly interactive way of experimenting with scale, colour, background, and social use of physical objects (introducing animated scenes of e.g. spectators into a stadium) – in the language of the architects their *re-programming*. The a*nimating bAR code* and touch sensors/sensitive samples allow connecting physical artifacts, such as a model or sample of material, with a diversity of multi-media objects. Moreover the *Jacket*, in combination with the 3D visualization tool, helps students to connect the studio with places, people, and artifacts outside. More importantly it supports them in creating digital representations through a performance in the physical environment. These connections can be configured and evoked in multiple ways, creating different stories or walking paths.

Conclusions

What did tangible computing support?

Interaction between students and with the staff, hence collaboration in learning, was observed in presentations and review meetings but also as an intricate part of students' everyday work. While in the context of our first experiments the prototypes were mainly used for presenting material in an interactive way, we can see more complex modes of support for collaboration.

Firstly, the prototypes (*animating bARcode*, *sensitive samples*, *texture painter*) help preserve and even extend the *multi-mediality* and *diversity of materials* and representations. More importantly, they help create and share different views onto the common field of work. We described as an important quality *creative density* - having the 'sea of design material' physically present so that it can merge with the ongoing design work, and be made available to others (students, teachers). This is an important aspect of learning at the Academy, as is making the trajectory of students' projects visible in the project space so that everyone gets a quick overview.

Secondly, the prototypes - not only sensors, barcodes, and projections but also the *Jacket* as a tool for sharing and *re-experiencing* visits – increase the possibilities of *connecting* work that is distributed in time and space, but also conceptually. From current observations we can already discern more experimental and also interactive ways of '*re-programming*' a design, material or place, playing with context, atmosphere and dimension. This is partly to do with the hands-on way, in which all kinds of material can be integrated into the flow of work and connected, partly it is to do with the embodied and 'performative' nature of how physical artefacts and digital objects are made to play together, integrating the physical space. This creates a high level of intensity and involvement.

Reviewing our method

To design and integrate computation in a physical environment we have carried out observations of current work, inferred current and desirable qualities of an environment in support of learning and collaboration, implemented a variety of simple prototypes, and experimented with them. Our analysis of students' first experiments with the prototypes maintains a view on the learning environment as a whole. This means that rather than focusing on a particular requirement and (prototypal) technology, we took account of the multiple facets of students' learning, trying to understand how and what the prototypes add to them. This experimental and explorative approach to enriching a learning environment with a variety of technologies provides us with some grounding for discussing useful features of tangible computing. The 'qualities' we defined and sought to amplify, although specific to our case (and to design work[4]), contribute to explaining the diverse roles artefacts, materials, and spatial arrangements may play in collaborative environments. We are aware that we have still a long way to go in order to create a ubiquitous/tangible computing environment in support of learning, which is sufficiently complex to add dimensionality to students' work and easy to use.

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4 Our project partners in Malmö are using the 'qualities' for conducting and evaluating similar experiments within students of interaction design.

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