“Physical Hypermedia”: Organising Collections of Mixed Physical and Digital Material

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ABSTRACT
This paper addresses the problem of organizing material in mixed digital and physical environments. It presents empirical examples of how people use collectional artefacts and organize physical material such as paper, samples, models, mock-ups, plans, etc. in the real world. Based on this material, we propose concepts for collectional actions and meta-data actions, and present prototypes combining principles from augmented reality and hypermedia to support organising and managing mixtures of digital and physical materials. The prototype of the tagging system is running on digital desks and walls utilizing Radio Frequency IDentifier (RFID) tags and tag-readers. It allows users to tag important physical materials, and have these tracked by antennas that may become pervasive in our work environments. We work with three categories of tags: simple object tags, collectional tags, and *tooltags* invoking operations such as grouping and linking of physical material. Our primary application domain is architecture and design, thus we discuss use of augmented collectional artefacts primarily for this domain.

Categories and Subject Descriptors
H.5 [**Information Interfaces and Presentation**]. H.5.1 [**Multimedia Information Systems**] augmented reality; H.5.4 [**Hypertext/Hypermedia**]

General Terms
Documentation, Design, Experimentation

Keywords
Spatial hypermedia, augmented reality, tagging, physical and digital, collections of materials

1. INTRODUCTION
In many application domains activities are characterized by the fact that people have to deal with information that exist on a mixture of physical and digital media. Even though much information become digital and exist in computing environments many people work with paper printout and create annotations and sketches on paper. Moreover many professions work with diverse sets of larger physical objects that they need to link to information and annotations. Examples of such professions are architecture and design, which we discuss in detail in this paper, in these domains wood and foam models as well as building material samples are examples of non-paper physical material that needs to be related to project descriptions, drawings and specifications. But also public administration, hospitals, and manufacturing are examples of domains where rich mixtures of digital and physical material that need to be dealt with in daily work routines. Here case folders, pills, pictures, X-ray pictures etc. need to be handled as an integral part of the total information system. Typical problems are that physical material temporarily disappear, papers or pictures get detached from their case folders, important annotations made in the physical world are not associated with the digital material etc.

Such application domains challenge the traditional pure digital hypermedia systems such as open hypermedia systems, spatial hypermedia, and the Web. We need to develop techniques which make objects from the physical world into first class objects in hypermedia systems; this motivates focussing on what we will call “physical hypermedia” in this paper.

1.1 Ubiquitous and Pervasive Computing
Inspiration for dealing with the problem of physical hypermedia may come from ubiquitous and pervasive computing research. However, in the ubiquitous and pervasive computing research communities [1], [12], [23], [29] the main attention so far has been on the development of infrastructures for dealing with display enabled devices in a variety of different scales, from interactive walls to PDAs, cell phones, and wrist watches etc. There has been far less focus on how to associate computing with familiar physical artefacts such as paper, folders, binders, models, samples etc. as being used in many work domains.

Furthermore, the development of the Web has put focus mainly on digital information, and made linking of digital documents ubiquitous in people’s work and life. The Web has empowered us with the ability to distribute and share digital information both for work and leisure. But the Web doesn’t emancipate us from managing the physical world with all of its important carriers of information.

In this paper we focus on ordinary physical objects of work. Through examples of how people use physical artefacts in the domain of architecture and design, we will illustrate the need for focusing on augmenting these artefacts with pervasive hyperme-

HT’03, August 26–30, 2003, Nottingham, United Kingdom.

dia interfaces, in order to make the visions of Pervasive and Ubiquitous Computing [12], [29] come through.

1.2 Augmented Reality

The Augmented Reality (AR) research area [11] focuses on linking digital information to physical objects, places (indoor and outdoor), and spaces. AR aims at bringing IT-capabilities out of the traditional computer and embodying them in the physical environment that people work and live in. Typical applications are to link and display digital annotations on top of objects and places by means of some identifying code (bar-code etc.). An example is Cybercodes by Rekimoto [18] allowing information to be linked to objects tagged with a two-dimensional bar-code label, which is interpreted by a camera-based reader. Another example is augmented paper by Mackay [11],[12] where digital layers of information can be attached to physical paper.

A third example is the eTag system by Want et al [27], providing a simple connection between e.g. a book and an action or a piece of information on the Web, such as the related Amazon page. A final example is the FindEntity system [www.thax.de/english/frame.html], which provides support for locating physical material inside buildings and offices using Radio Frequency Identification (RFID).

While AR takes steps in the direction we are aiming at, the focus is still on superimposing, tagging and tracking single objects, and development of new materials such as augmented paper (e.g. eInk and Anoto). In the following we will take these approaches a step further and also apply those to IT supported organisation and management of collections of physical and digital material.

1.3 Hypermedia and Spatial Relationships

Hypermedia research focuses on supporting organisation of information through concepts like, links, composites, hierarchies, groupings, typing, meta-data etc. [6]. In recent hypermedia research there has been a focus on spatial organisation of digital information. Spatial hypermedia (e.g., Aquanet [15] and VIKI [14]) which can be thought of as using a big 2D space (a canvas) for sorting information or organizing brainstorm notes for writing. Spatial hypermedia supports this kind of organization by allowing items or "cards" to be generated and placed on a "table" (space). Cards may be tailored by changing their size, shape, colour, or other visual characteristics. Cards may contain content or point to external content. Additionally, some systems allow cards to be "opened" to reveal another space that also may contain many different cards. Proximity between cards determines relationships.

This approach to information organisation has in Topos [2],[7],[9] been brought into 3D. Topos is the infrastructure we use for the prototype presented in this paper. Topos supports 3D organization of models and documents; it can be used to support both abstract spatial hypermedia with open unfurnished spaces and concrete spatial hypermedia using a building or landscape as a “background” for relative placement of material. Topos integrates existing applications, supports real-time collaboration across the Internet and runs on Windows 2000/XP and Linux. The central concept in Topos is the *workspace*. Workspaces are sets of spatially related and placed materials (documents, CAD drawings, 3D models, notes, other workspaces, etc.). A main strength of Topos is its support for internet sharing and collaboration in spatially organized material. This is particularly useful in the architectural domain, where users are used to think in 3D and organize material spatially in the real world.

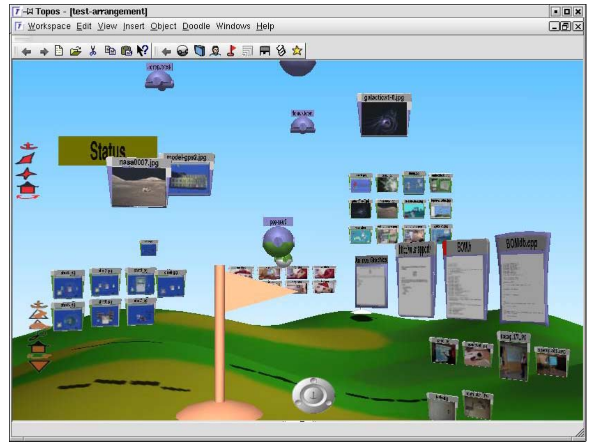

Figure 1: A Topos workspace with a terrain as background and documents organized in various spatial groups.

Task Gallery [19] shares similarities with Topos in that it is a 3D window manager for organizing tasks (a task being a collection of documents and applications) that exploits human spatial memory to keep track of a large number of tasks at once. But it limits spatiality to a fixed room with walls with predefined roles.

The work in this paper is taking place in the EU project WorkSPACE. The empirical studies have mainly taken place at the Scottish landscape architecture office, DLP (www.dlp-plc.co.uk).

1.4 Organisation of the Paper

The rest of the paper is organised as follows. In section 2, we briefly introduce the challenge of physical hypermedia and the prototype environment. In section 3, we present examples of the use of artefacts in the domain of architecture and design. In section 4, we discuss abstractions of the actions involving physical artefacts. Here the focus is on collectional actions and on meta-data actions. In section 5, we discuss the possible relationships between digital and physical objects. In Section 6, we present our prototype work environment, and discuss integration with the Topos infrastructure. In section 7, we discuss related work. Section 8 concludes the paper.

2. THE CHALLENGE OF BRIDGING BETWEEN PHYSICAL AND DIGITAL MATERIAL

In the real world people use a rich variety of artefacts, such as paper, clipboards, clips, squeezers, folders, dossiers, wood and cardboard for their work. These physical materials often relate to digital material in terms of directories and documents of different types. However, today there is very little support for maintaining this relationship.

We have built a RFID tagging system and integrated it with the Topos spatial hypermedia system, which provides support for creating, manipulating and maintaining this relationship in an interactive work environment [7] for e.g. architects and designers consisting of ordinary desktops, interactive walls and augmented desks (see Figure 2). This integrated system provides hypermedia support in the physical world through linking physical material to digital material, registering, grouping, and annotating physical

Figure 2: The experimental interactive work environment where our physical hypermedia system is integrated with interactive walls and desks.

material and tracking where physical material was last seen in the work environment.

In the following sections we will provide examples of how architects and designers manage physical materials in their working environment today, as well as give more details on the design and implementation of the physical hypermedia system.

3. EMPIRICAL STUDIES

This section presents the studies that form the foundation for discussing and describing the organization and management of material in a specific work setting of landscape architects. The studies focus on the use of physical means and space for organizing material, and are used to ground and present our initial ideas and to inform the design and development of prototypes. The findings are mainly based on previous ethnographic studies [3], as the starting point for identifying the roles of everyday artefacts in the process of information management. Each of the presented situations will draw attention to (sets of) everyday artefacts, and reveal some of the inspiration that underpins the presented prototypes of augmented artefacts as well as scenarios of their usage.

3.1 The Work Contexts of Designers and Landscape Architects

In order to be able to reach the vision of seamless support for the management of materials in a mixed digital and physical environment, we have studied how architects and designers manipulate physical materials and digital information in a variety of contexts.

Our studies indicate that approaches to organizing material vary with the degree of formalization of procedures. In some work contexts (e.g. hospitals, manufacturing and large construction projects) [8] formal and legal conditions dictate the approaches. In other more self-organized work contexts (e.g. typically design, research, and studying), it is more open to the individual or group to define their own approaches to management of material. Further examples of these organisation approaches will be described in sections 3.3 and 3.4.

3.2 Utilizing Space – Spatial Organisation

Studying the work context and work praxis of especially architects has revealed a plethora of very often diverging organisation demands [3]. This is often vividly expressed in the physical space of design studios, and in the constant manipulation of contextual arrangements of documents and objects. Even within the studio designers often have a nomadic style of work; an intricate choreography of movements from place to place and from individual work to collaborative work.

Organising material and information is related to a whole host of different concerns that closely intertwine natural, material, and social concerns. For the landscape architects we have studied, physical space is not just used for organising with the purpose of re-finding material; it is also widely used as an exhibition of ongoing work, as well as creation of an inspirational and creative atmosphere. In this perspective, physical space is very rich in terms of the different materials it can comprise, and the different means it supplies for organisation and management of material and information.

The extensive utilization of the physical space implies that an efficient tagging system may require many tag-readers of different sizes and shapes to be integrated in desks, walls, shelves, etc.

3.3 Organizing Physical Objects: Documentation, Inspiration and Management

A significant part of the work in the contexts we have studied, is concerned with collecting, finding, producing and organising

(a) **(b)** **(c)**

Figure 3: Real world spatial organization of physical materials such as hand models and material samples.

(a) (b) (c)

Figure 4: Assigning meta-data to physical material by stamping and writing.

physical material of many different kinds. For the researchers and office workers the relevant material is typically paper (even often narrowed down to size A4) and books, whereas for designers and architects, the range of forms and materials is much broader including cardboard models, A0 drawings, bricks, plants etc.

The pictures in Figure 3 show three different examples of use of space and organisation of physical objects for inspiration and work. Figure 4(a) shows a collection of materials related to a specific design process in relation to office and interior design. The models are used to inspire and document the design process, and kept as reference and prototype models for future work. Figure 4(b) shows the material library of the landscape architects at DLP, containing different sorts of stones, bricks, tiles, gravel etc. The stones are numbered and organised in different types, in order to help referencing in specific projects as well as re-finding material. Figure 4(c) shows the model productions of an architect working on a larger design project. She has her workspace covered with small cardboard models related to the present project.

3.4 Meta-Data and Annotation

Our studies have revealed three main purposes for organising physical material and objects: *documentation*, *inspiration* and *management*. For all three purposes it most often is a significant concern to be able to re-find and recognize material for later use, and to place it in relevant – often multiple – contexts. This aspect is therefore supported in different ways, in the use of space and artefacts as well as in the work practices. Moreover, the ability to add annotations and keep them related to physical objects is important in many of the studied work situations.

In the example of the architect and her cardboard models, each model is neatly time-stamped and placed in a specific order in the physical room (Figure 3(c) and Figure 5(a)). This supports her sense of progress and it also provides opportunities to backtrack in the design process to see where specific design decisions were made and possibly reconstruct the rationale.

Another example is the labelling and numbering of the materials in the sample "library" mentioned above. A more formalised example is keeping track of documents and official correspondence (Figure 4(b, c)). To support this process a number of simple, but effective, measures are in place e.g. date-stamps and project identification codes etc. In the example shown in Figure 5(b) incoming paper mail is date stamped, entered into a log of project correspondence, annotated with a project code and passed on to the relevant people.

3.5 Collectional Artefacts

Studying organisation and management of physical material and information brings focus on a range of methods, and subsequently on the artefacts used for supporting this process. In order to manage the large amounts of material used in a variety of changing work contexts, different artefacts and methods are chosen depending on individual choice, specific demands set in specific work contexts, by form-factors presented by the materials that need to be organised, and finally by the degree of formalisation of the work processes. In our studies the typical collectional artefacts range from shelves, walls and entire rooms to boxes, folders, tape, clips etc. (as illustrated in Figure 5).

Each collectional artefact can be individually studied and described in terms of the range of materials and information they are suited for organising, and in terms of the ways in which they afford different aspects of collectional and organising actions. Some artefacts are very flexible in terms of the forms of materials they can comprise (e.g. shelves) others are very specific, some are mobile others stationary, some link objects more or less permanently together (e.g. staplers), and others are more loosely combining materials (e.g. paperclip) etc. But in order to create an environment for organising and managing mixtures of physical and digital materials, we need to not only describe and understand the collectional artefacts and their individual affordances, we need to analyse the concrete use of them in relation to the collectional actions performed in the studied work contexts.

4. ABSTRACTIONS OF COLLECTIONAL ACTIONS

In this section we discuss how the handling of physical artefacts and materials may map onto the handling of digital material. This is to illustrate the kind of design choices that we are facing when working on how to integrate actions on physical artefacts with a

Figure 5: Examples of collectional artefacts (squeezers, boxes, binders and tubes) in the real world

digital semantics. Finally, it summarizes what we see as general challenges and implications for the design of our software infrastructure and the development of new appliances.

4.1 The Notions of Space in the Mixed Physical and Digital Environment

The Topos infrastructure representing the digital environment for our prototypes provides key features supporting spatial organization of digital materials. The concept of a workspace is the main structuring mechanism for organizing material in different types of metaphorical or literal collections supported with free-form arrangement or specific graphical arrangements such as rows and tables. This infrastructure in itself supports spatial memory, as well as management of different kinds of digital material. In this way it supports a better conceptual understanding of mapping the digital and the physical organisation of material and information, but it does not in itself provide direct links between acts of organising materials in the digital and physical environments.

We have taken the basic operations of organizing physical material as the starting point for design of the software, i.e. abstractions of collectional actions and collectional artefacts, and looked at various ways of making collections, adding meta-data and arranging physical materials in real world settings (see section 3). The next step is to map these physical organizing actions to a semantics supported by the hypermedia system. In the following sections we discuss examples of actions involving augmented artefacts, what their implication in the digital world should be, and whether these implications should happen by default or as result of a conscious choice.

4.2 Understanding Collectional Actions - Implications for the Digital Environment

As we have seen in the situations described earlier, designers and architects use a rich variety of artefacts to hold together what belongs together in the physical world and the practices of use of these collectional artefacts range from prescribed logging methods to quite personal methods. Regardless of how and why the collectional actions are performed, they are related to explicit or implicit meta-data actions, i.e. where category information or content-based notes are added to the material or the collectional artefact being used, e.g. sticking a label with a title on a plastic dossier while entering some sheets into it, attaching a post-it note to a collection of papers while stapling it, or inserting material into a folder with a certain colour, thereby relating it to a larger group of materials.

4.2.1 Collectional and meta-data actions

Following the argument above, carrying out collectional actions and meta-data actions imply some sort of reasoning based on categorizing, choosing and associating materials motivated by a specific purpose for example based on development over time, specific themes, projects, actions or people. These actions may vary in the degree of formality, persistence, and longevity, mapping them to affordances displayed by different collectional artefacts (as mentioned in section 3.5). For example the collectional action performed through stapling documents, is typically representing a more permanent relationship than the use of paper clips or dossiers. A formal example is a legal document, which is typically stapled (sometimes with a seal), and the people who sign it may even put their initials (meta-data action) on each page to indicate that the page has been read and agreed on with a signature. In terms of persistence the different parts of a legal document are also very tightly connected, as one part usually refers very closely to the other (e.g. appendixes to a report etc.). An example of an informal collection is a person preparing for a meeting, collecting a number of different papers and putting them into two or three different dossiers of different colours or with simple single word labels. The materials put into dossiers may be copies of original paper or digital documents, which are printed just for the purpose of making a temporary collection to bring to a meeting. In terms of persistence and longevity, these documents may permanently belong in other and very different collections, and the present collection is therefore only temporary, but in the context of this particular meeting this specific collection may be relevant to remember – and therefore more permanent.

These situations are just examples of collectional actions, and it is hard to generalize the semantics of people's usage of collectional artefacts, and their performance of collectional actions and meta-data actions, because they are very individual and context dependent. Thus we are not aiming at hardwiring physical collectional actions or artefacts to a specific semantics in the digital world, but wish to create an open space of possibilities for coupling collectional actions with e.g. a stapler or a dossier to a range of meaningful actions in the digital context. In addition to this, the mapping of collectional actions and artefacts also inspires discussions of how to express actions over time, map materials and their relations to different collectional contexts etc., and how this can be illustrated and utilised in a shared physical/digital environment as we describe in section 6.

5. RELATIONSHIPS BETWEEN PHYSICAL AND DIGITAL WORLDS

When we wish to develop hypermedia support for creating and maintaining relationships between physical and digital materials, we need to analyse the different potential types of relations between these materials that would make sense in a mixed world. Based on abstractions of collectional actions, we see the following possibilities ranging from purely physical to purely digital.

1. Physical-only: Only physical object, the digital world has no trace of the object, at all.
2. Physical-with-digital-id: The digital world posses an ID plus some meta-data relating to the physical object but no digital representation; for example: a stone or a brick with an RFID tag on it.
3. Physical-with-low-resolution-digital representation: for example: a pen tracked drawing, a scanned document or a photo of an object.
4. Physical-generated-from-digital: a printed map, drawing or report.
5. Digital-only: Content that cannot be printed or otherwise made physical/tangible, e.g. a video, sound or source files (they may be stored on removable media like CD/DVD, but the content cannot be accessed in the non-digital physical world).

Depending on the kind and status of the material regarding the above categorization, collectional actions and meta-data actions have different effects, and can be carried out and expressed in different ways in the mixed physical/digital world.

A collectional action on objects from category 1) are quite difficult to map to a semantics in the digital world, the only choice we have is to make a digital description of the object and its properties with an indirect relation to the object; to stamp, tag, or label the object such that is transformed into an object of category 2) that has a digital identification. Objects of category 2) can be identified and described by meta-data actions, and they can be grouped through collectional actions, but that means they will have no distinct visual or auditory appearance in the digital representation. Objects of category 3) have "low resolution" digital representation, which allows them to appear in workspaces similar to full-blown digital documents, but they do not have a dynamical and editable digital representation. These types of objects allow collectional and meta-data actions in the physical world to be mapped directly to digital actions. Objects of category 4) correspond to the common kinds of documents that we are dealing with today in for example Topos. If we produce identifiable physical prints of such materials, then collectional and meta-data actions on the physical representations may be mapped to digitally mirrored actions. These materials may have many physical representations, corresponding to the same unique ID of the digital document. If meta-data, such as annotations, are made in the different printed copies, they should be associated with the same unique ID in the digital world representing the material. Meta-data actions in the real world will thus add additional and identifiable layers of digital meta-data to their digital counterpart. A collectional action on an object of category 5, mapping it with physical material can be done through establishing an indirect relation to the digital object (e.g. a screen dump from a video clip or a transcription of a sound file placed in a paper file), and/or the physical object can be augmented with a metadata ID referring directly to the digital material. This ID tag is recognisable by a device that display the digital material when the tag is recognised. It is important that the relationship between the physical materials, the collectional artefacts and the digital world is configurable by the users. For instance it should be possible to temporarily attach/remove a physical tag or clips without having the digital action performed. Although such disabling of the digital action may cause inconsistency, we strongly believe that the users need to be in full control of what happens.

6. WORKING WITH "PHYSICAL HYPERMEDIA" PROTOTYPES

We have taken the above observations as the starting point for designing, constructing and testing prototypes of a set of augmented organisational artefacts, which can bring the physical materials and their organisation into being in the digital world as well – bridging from physical to digital.

The first experiments with the prototypes, took place in a three-day workshop with 4 landscape architects from our user organization DLP. The architects were presented with a real world design task related to a nearby construction site, and were given material and time to prepare before the workshop. During the workshop they were asked to solve the design task as they would normally do, but utilising the digital and physical environments and prototypes developed in relation to the WorkSPACE project. Through elaborate discussions and observations of their work in the laboratory, we got a first iteration of user feedback on specific design issues, as well as feedback on the general concept of bridging between physical and digital materials.

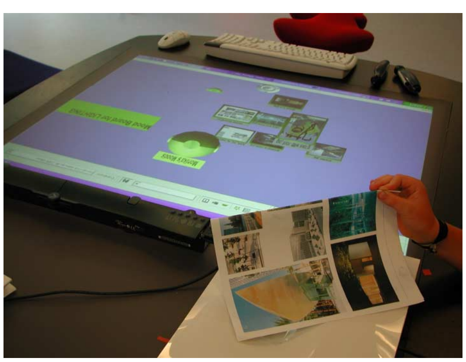

Figure 6: A collection tag. Putting a tagged object on the tag-reader to open a workspace.

In this section we present the working prototypes, and explain how these are functionally integrated in the Topos spatial hypermedia infrastructure.

6.1 Tagging – Registering Material and Detecting Collectional Actions

Similar to the eTags system [28] we use RFID tags to register physical material, but we extend the concept to support grouping of physical material into collections and to link between physical materials. The vision is to provide the user with a 'Tagger' appliance that supports easy attachment of RFID tags to papers and other objects, in order to keep track of and trace them both within the office and within the electronic project workspaces. Tagging could, for example, take place during or after meetings, as new documents are created. Meta-data – such as date, project code, author, etc. adds to the physical incarnation of the document, and it may also automatically generate a digital ID-representation in e.g. Topos. It is also possible to add annotations to the physical material by associating them with the digital representations in Topos, either as typed text or freehand doodles.

In the current prototype we employ an RFID tagging system (Philips I-CODE) that allows simultaneous, contactless, detection of a number of tags bearing a unique ID to register a piece of material or to register that a collectional action has happened in the close neighbourhood of an RFID antenna (Figure 7).

In the prototype, the "Tagger" appliance is implemented as a bunch of inexpensive adhesive RFID tags placed in a cup on the working table. Tags can be associated with a singular digital object (object tag), or with a digital collection (collection tag) i.e. a Topos workspace. Tags on collectional artefacts may be associated with digital collections, whereas a tag on a single stone sample often is associated with a single digital object in Topos.

Currently, one associates a tag with a Topos object by selecting the digital object, right-clicking on one of the tag-IDs present at the antenna in the tag-browser in Topos, and selecting "associate with tag". It is also possible to use the Snapscanner to make

Figure 7: Interactive desk with tag-reader and snap-scanner as implemented in the initial test environment.

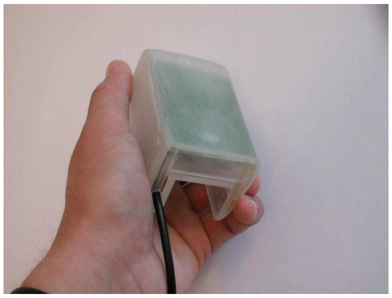

Figure 8: The small hand-held RFID tag-reader.

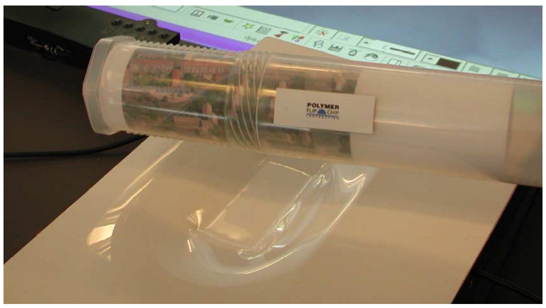

Figure 9: A tube with an associated collection tag is placed on the tag-reader.

associations as explained later. We have also enabled Topos to pop up workspaces or digital objects corresponding to tags when tagged items are put on the tag-reader antenna (Figure 9).

If some physical objects (object tags) have been removed from a collectional artefact like a tube, a folder or a dossier, then their linked digital counterparts are marked by a red upper left corner as shown in Figure 10, such that the user can see that a physical item is missing from the collection. (An object whose physical counterpart is present, is marked with a green corner.) Moreover, the user may inspect the meta-data of the missing physical item, and find out when and where it was last seen by a tag-reader.

To make the use of the system flexible we experiment with two kinds of RFID readers: a larger "desktop model" capable of recognizing several tags at once, and smaller hand-held readers that can only recognize a single tag at a time (Figure 8). Modes of interaction that are appropriate for the desktop reader are not applicable for the hand-held reader and vice versa. We allow the hand-held reader to be used in two modes: one where it emits "tag arrived" and "tag left" events when the physical events occur, and one where it delays the "tag left" event until the next tag is seen. This last mode allows the reader to be used in a mode, where the user reads a tag, puts the reader down, and works with the linked material or the digital representation that appears on his screen, without having to maintain contact between the reader and the tag.

6.1.1 Experiences with Tagging and Collectional Action Support

It seemed straightforward that the collectional actions performed in the physical domain should be directly reflected in the digital domain: when physically grouping a set of materials, their electronic counterparts should be grouped as well. However, our first iteration of user tests, indicate that this is confusing without immediate feedback to the users. People do not expect that combining a few printouts has immediate consequences for their electronic workspaces, and as we are (currently) not able to provide immediate feedback when the linking is being done away from computers and tag-readers, we do not do so. To account for actions taking place away from the tag-reader system we have implemented ways of informing the user that something has happened with the collection, since it was last detected by the tag-reader. For example, if a recent tagged item appears together with other grouped materials, Topos will ask the user whether the electronic counterpart of this new item should be moved to, linked to, or copied to the same digital collection as the others.

6.2 Representing Physical Material - Snapscanning

Digitalizing the contents of physical documents is an important part of a design process bridging between physical and digital material, leading back to our identification of five different types of relationships between the physical and the digital material (categories of section 5). For the landscape architects the bridging can be part of a process of developing a design through cycles of translations involving physical as well as digital material – moving from hand drawn sketches to CAD drawings, to annotations and more sketches, and back to the CAD representations. Tagging the physical material and simply linking it to digital materials and collections is one way of bridging the two worlds (category 2 relation). At other times, it is useful to be able to introduce a ‘snapshot’ or digital ‘alter ego’ into the electronic space, for example as a reminder of important sketches (category 3 relation). When the process of entering such representations is facilitated, the use of tags will be much more efficient and flexible.

Figure 10: A document object in Topos. A red corner (top left) indicates that a tagged item is linked to it but not present at the tag-reader.

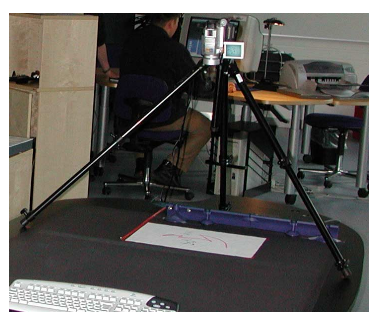

Figure 11: The first working prototype of the “Snap-scanner” allowing taking a snapshot and linking a tag to the physical material in one operation.

The prototypes of the Snapscanner (Figure 11) and the desktop tag-reader (Figure 12) make it possible to quickly add a digital endpoint (an ID and a visual representation) to the physical-to-digital link from the physical material (a wooden model, a collection of inspirational objects, etc). The desktop tag-reader can identify the ID of a tagged sample in the zone of the Snapscanner, and pushing a button on the table takes a snapshot of the sample. The ID and the snapshot are automatically linked together in Topos. The digital side of the link now has an ID and some metadata, and also an image of the sample. Given that many sketches, e.g. during a design brainstorm are actually made at quite a large scale (e.g. on A3 paper or even larger) these would be quite recognizable and useful representations.

6.2.1 Experiences with Snap-Scanning

In our initial prototype we used a DV video camera for the Snapscanner, so that video from the camera could be displayed inside Topos to help the users place their material under the scanner. However, the snapshots taken by the DV camera proved to be of too low resolution to be really useful for the architects. Our second prototype uses a still image camera with much higher resolution to provide more useful snapshots. With the still image camera we still provide a low resolution, and low frame rate preview of the material to be scanned. In the first version we had to tag the scanned object in a separate operation on the tag-reader, which is cumbersome. To make the Snapscanner efficient it can be integrated with a tag-reader such that pushing the scan button will register the tag glued to the object and take a picture in a single operation. Tests of the prototype also indicate that, ideally, the Snapscanner should be portable at least within a room or a building, and allow rotation to take snapshots of papers and other objects on different surfaces such as a table, a wall, the floor, etc.

6.3 Tooltags – Physical Cues for Linking and Grouping

To make interaction more tangible, and to further utilize the combination of physical and digital properties, we have developed a set of special tooltags. A tooltag is an RFID-tag which is coupled to a command in the Topos hypermedia system rather than to a piece of information. This allows us to issue commands in Topos by placing the physical tooltag on the tag-reader (Figure 12) alone or together with a piece of physical material.

For instance, we have tooltags that bring Topos objects to the front and back again, and a tooltag that control doodle mode (doodle mode allows users to make annotations and draw free-hand sketches on top of document objects inside Topos). To support physical hypermedia operations, we introduce tooltags that link and group physical objects and their digital 'alter-egos' when put on a tag-reader that is able to sense multiple tags. The 'link' tooltag establishes a multi-headed link between the set of tagged items on the antenna, whereas the 'group' tooltag creates a new workspace referencing the digital alter egos of the tagged items on the antenna.

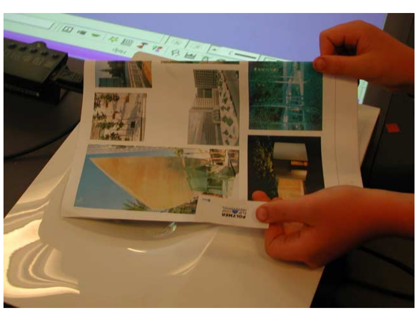

Figure 12: Invoking a command on an object by placing object and tooltag on the RFID reader.

Tooltags allow for tangible interaction, and makes a number of hypermedia commands readily available, when one is using the tag-reader and is away from the keyboard and mouse. The tooltags share some similarities with 'phicons' as introduced by Ullmer and Ishii [27], but phicons mixes properties from our simple object tags and tooltags, in that the phicon is a physical representation of a digital document, and at the same time the phicon offers a number of operations on the digital document such as zooming and moving. In contrast tooltags are aimed at representing general functionality to be applied globally or on specific digital objects linked to tagged objects. The 'link' and 'group' tooltags may in a future implementation be integrated in clipsers or squeezers, and the tags may be modified with buttons as described in [20] allowing users control over exactly when the tooltag operation is invoked.

6.3.1 Experiences with Tooltags

The system has been tried out by several architects in our lab environment and some initial experiences have been gained. One experience is that it is difficult to utilize the tooltags on pure digital objects, since they provide no means of pointing and changing the current selection. Thus you can only operate on the most recent selection or use another tool like a pen to make selections. Another issue is that one can accidentally apply two or more conflicting tool-tags at the same time. This has to be detected and handled; otherwise it may lead to unexpected behaviour. We therefore do not propose that tooltags serve as the only interaction mechanism, but that they are useful in addition to other, more traditional interaction forms.

The software and the initial hardware has been developed for undertaking realistic experiments in real work settings, however, in order to make the interaction more natural, the tagging devices, the tag-reader, the Snapscanner, and the general integration of these in the work environment needs to be carefully designed and evaluated in the further development process. We find the approach promising for invoking hypermedia operations in a mixed physical and digital system.

7. RELATED WORK

In this section we briefly discuss research related to the Augmented Reality approach presented in this paper.

Streitz, et al. [22] describes a future office environment, *I-Land*, with interactive walls and tables. The Dynawall is a large wall

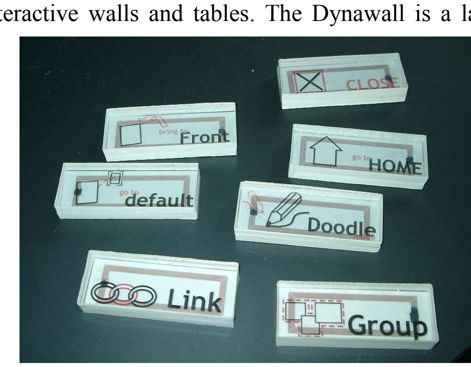

Figure 13: Tooltags: specific RFID tags have been associated with commands to be invoked via the tag-reader.

consisting of a number of coupled touch-sensitive displays. Applications allowing informal note taking and hypertext linking similar to DOLPHIN [21] are supported. Moreover windows can be "pushed" from one end of the wall to the other, when more people are working in parallel on the wall.

The Interactable is a small table with a display in the middle allowing users to discuss documents retrieved directly on the table, and to enter notes etc. directly into a computer by means of the Interactable and a wireless keyboard. The passage system provide the user with the ability to use a physical proxy for a single digital object and carry the digital document from one device to another by means of the physical proxy. However, I-land does not support integration of physical material like paper, collections of paper or other physical artefacts in the system.

Rekimoto et al [18] describes a hybrid system, *Augmented Surfaces*, where digital information can be superimposed on physical material being moved around on a table. The physical material needs to be tagged with a kind of two-dimensional bar-code, called a CyberCode. Moreover, snapshots can be taken of physical material lying on the table and the snapshots can be dragged into the digital environment and linked to digital information. Although covering some of the territory we are working on, the Augmented Surface approach does not provide support for using the physical material and familiar physical artefacts for organising material digitally.

Ullmer et al [24],[25],[26] describes the *MediaBlock* system that supports users in pulling writings on a digital whiteboard or video taken with a camera to small LEGO brick sized blocks, which can be organized physically and carried around between different media devices such as displays and printers. Compared to our approach MediaBlocks - similar to the I-land passage system - supports assigning digital information to physical objects and not vice versa, ordinary physical objects are not integrated and supported with the Media Block approach. The phicons also introduced by Ullmer and Ishii [27] also share similarities to our approach, but phicons are designed to both act as a container for digital data and as a handle for certain application specific behaviour such as zooming or moving a building on top of an underlying map. Thus phicons are more complicated to implement and they require precise location tracking on the desk.

Several *digital desk and workbench systems* have been implemented in recent years. They fall in two main categories: The first category is augmented reality systems building bridges between digital information and paper-based information [10],[30],[31]. These systems support linking of digital information to physical material like paper and drawings etc. The material is tagged with bar-codes or the like. The links and notes associated with the physical material are superimposed on the material while it is placed in a certain position on the digital desk. DigitalDesk research thus takes an important step towards integrating the familiar material into a digital information system. However, it is still focusing primarily on a single document at a time and there is no physical controls supported for organizing the material.

Want et al [27] introduces the *eTags* system which provides some of the same mechanisms as the simple tags, that we have introduced, but eTags do not provide support for creating links and collections of mixed physical and digital collections, neither does it provide commands to be invoked on objects like our tooltags do. eTags provides specific actions tied to specific objects.

8. CONCLUSIONS

We have argued for the need to extend the notions of digital hypermedia to better integrate the familiar physical artefacts and materials that we apply for work, and thus create a better connection between the physical and the digital objects of work. Based on empirical studies of materials and artefacts in use in the architectural domain, we have identified a set of abstract collectional and meta-data actions to be supported by "physical" hypermedia. We have developed a prototype demonstrating how such actions can be supported on augmented desks and walls in a working environment for architects. The physical hypermedia prototype consists of an RFID tagging system integrated in the Topos infrastructure that we are developing in the WorkSPACE project.

It has been our goal to develop the physical hypermedia system in such a way that it can become pervasive and ready to hand for users, and appear in the environment in the same familiar way as collectional artefacts; labels, clipsers and dossiers appear in the real world. RFID antennas and tags are still fairly big and power consuming, but we see promise in the development of RFID systems, which provides cheaper and smaller tags and devices. The potential transition from bar-codes to RFID tags in grocery stores will push this development and make RFID tagging a routine activity applicable also in the domains described in this paper. Even though the current RFID tags may be a little disturbing to the work material and in the working process as it is, the design experiments and the first user evaluations have worked well in order to test the basic concepts of supporting organisation of mixtures of digital and physical material. With these experiences we see lots of potentials in providing support for managing collections of mixed physical and digital material in future work and living environments.

ACKNOWLEDGEMENTS

We wish to thank all of our colleagues in the EU IST Project WorkSPACE (www.daimi.au.dk/workspace). The work has been funded by the WorkSPACE project and the CIT Center for Pervasive Computing (www.pervasive.dk).

REFERENCES

[1] Abowd, G.D., Brumitt, B., & Shafer, S. (Eds.): Proceedings of Ubicomp 2001: Ubiquitous Computing Third International Conference Atlanta, Georgia, USA, September 30 - October 2, 2001, Proceedings. LNCS 2201. Springer Verlag.

[2] Büscher, M., Christensen, M., Grønbæk, K., Krogh, P., Mogensen, P., Shapiro D., & Ørbæk, P. Collaborative Augmented Reality Environments:Integrating VR, Working Materials, and Distributed Work Spaces. In proceedings of CVE2000, San Francisco, Sept. 10-12, 2000, pp. 47-56.

[3] Büscher, M., Mogensen, P., & Shapiro D. Spaces of Practice. In W. Prinz et al. (Ed.), Proceedings of the Seventh European Conference on Computer Supported Cooperative Work.. Bonn, Germany: Kluwer Academic Publishers, 2001, pp. 139-158.

[4] Castro, P., Chiu, P., Kremenek, T., & Muntz, R. A Probabilistic Room Location Service for Wireless Networked Environments In Abowd, G.D., Brumitt, B., Shafer, S. (Eds.): Proceedings of Ubicomp 2001. Atlanta, Georgia, USA, September 30 - October 2, 2001, Proceedings. LNCS 2201. Springer Verlag, p. 18 ff.

[5] Gibson, J. J. The Ecological Approach to Visual Perception. Boston: Houghton Mifflin, 1979.

[6] Grønbæk, K. & Trigg, R.H. From Web to Workplace: Designing Open Hypermedia Systems. MIT Press, Boston Massechussets. July 1999, 424 pp (ISBN 0-262-07191-6).

[7] Grønbæk, K., Gundersen, K.K., Mogensen, P. & Ørbæk, P. Interactive Room Support for Complex and Distributed Design Projects. In proc. of Interact 2001, Tokyo Japan, July 2001.

[8] Grønbæk, K., M. Kyng, & P. Mogensen, CSCW Challenges: Cooperative Design in Engineering Projects. Communications of the ACM, 1993. 36(6): p. 67-77.

[9] Grønbæk, K., Vestergaard, P.P., & Ørbæk P. Towards Geo-Spatial Hypermedia: Concepts and Prototype Implementation. In proceedings of the 13th ACM Hypertext conference, June 11th - 15th, 2002, University of Maryland, USA, ACM, New York, 2002.

[10] Koike, H., Sato, Y., Kobayashi, Y., Tobita, H., & Kobayashi, M. Interactive textbook and interactive Venn diagram: natural and intuitive interfaces on augmented desk system. In Proceedings of the CHI conference on Human factors in computing systems. The Hague, The Netherlands, 2000, pp. 121-128

[11] Mackay, W. Augmented Reality: Linking real and virtual worlds. A new paradigm for interacting with computers. In: Proceedings of AVI’98, ACM Conference on Advanced Visual Interfaces, ACM Press, New York, 1998.

[12] Mackay, W.E., Pothier, G., Letondal, C., Bøegh, K., & Sørensen, H.E. The missing link: augmenting biology laboratory notebooks. In proc. of UIST'02, ACM, NY, 2002, pp. 41 – 50.

[13] Mark, W. Turning pervasive computing into mediated spaces. In IBM Business Journal. Vol. 38, No. 4, 1999

[14] Marshall, C., & Shipman, F. Spatial hypertext and the practice of information triage, In Proc. Tenth ACM Conference on Hypertext (Hypertext '97). (Southampton, UK, Apr, 1997), pp. 124-133.

[15] Marshall, C., Halasz, F., Rogers, R. & Janssen, W. Aquanet: a hypertext tool to hold your knowledge in place, In Proc. Third ACM Conference on Hypertext (HT '91). (San Antonio, TX, Dec, 1991), pp. 261-275.

[16] Mogensen, P. & Grønbæk, K. Hypermedia in the Virtual Project Room - Toward Open 3D Spatial Hypermedia. In proceedings of ACM Hypertext 2000, May 30 - June 3, San Antonio, Texas, USA.

[17] Norman, D. A. The Invisble Computer: why good products can fail, the personal computer is so complex, and information appliances are the solution. The MIT Press, Cambridge, Massachusetts, USA, 1998.

[18] Rekimoto, J. & Saitoh, M. Augmented Surfaces: A spatially Continuous Work Space for Hybrid Computing Environments. In: Proceedings of CHI'99 Conference on Human Factors in Computing Systems (Pittsburgh, Pennsylvania USA) ACM/SIGCHI, New York, NY, 1999, pp. 378-385

[19] Robertson, G.M., Dantzich, V., Robbins, D., Czerwinski, M., Hinckley, K., Risden, K., Thiel, D., & Gorokhovsky, V. The Task Gallery: A 3D Window Manager, in Proceedings of ACM SIGCHI'00, 2000, Pages 494-501

[20] Sokoler, T., & Edelholt, H. Physically embodied video snippets supporting collaborative exploration of video material during design sessions. In proceedings of NordiCHI 2002, October 19-23, 2002, Aarhus, Denmark, ACM: pp. 139-148.

[21] Streitz, N. A., Geißler, J., Haake, J. M., & Hol, J. DOLPHIN: integrated meeting support across local and remote desktop environments and LiveBoards. In Proceedings of the Computer supported cooperative work (CSCW '94), 1994, pp. 345 - 358.

[22] Streitz, N., Geissler, J. & Holmer, T. Roomware for Cooperative Buildings: Integrated Design of Architectural Spaces and Information Spaces. In proceedings of the First International Workshop, CoBuild’98, Springer-Verlag, Amsterdam, 1998, pp. 4-21

[23] Thomas, P., & Gellersen, H.W. (Eds.): Proceedings of Handheld and Ubiquitous Computing Second International Symposium, HUC 2000, Bristol, UK, September 2000. LNCS 1927, Springer Verlag.

[24] Ullmer, B., & Ishii, H. "mediaBlocks: Tangible Interfaces for Online Media." In Extended Abstracts of CHI'99, May 15-20, 1999, pp. 31-32.

[25] Ullmer, B., Ishii, H., & Glas, D. "mediaBlocks: Physical Containers, Transports, and Controls for Online Media." In Computer Graphics Proceedings / SIGGRAPH'98, July 19-24, 1998, pp. 379-386.

[26] Ullmer,B., & Ishii, H. Emerging Frameworks for Tangible User Interfaces. In Human-Computer Interaction in the New Millenium, Ed. J. M. Carroll, Addison-Wesley ACM-press, New York, 2002, pp. 579 – 598

[27] Ullmer, B. & Ishii, H. The metaDESK: Models and Prototypes for Tangible User Interfaces. In Proceedings of UIST '97, October 14-17, 1997, ACM 1997.

[28] Want, R., Fishkin, K., Harrison, B., & Gujar. A. Bridging Real and Virtual Worlds with Electronic Tags, In Proceedings of ACM SIGCHI. May 1999, Pittsburgh, pp. 370-377.

[29] Weiser, M. Some Computer Science Issues in Ubiquitous Computing. In: Communications of the ACM, 36 (7), 1993, pp. 74-84

[30] Wellner, P. Interacting With Paper on the DigitalDesk. Communications of the ACM, 36(7), 1993.

[31] Wellner, P., Mackay, W., & Gold, R. Com-puter Augmented Environments: Back to the Real World. Special Issue of Communications of the ACM, 36(7), 1993, pp. 24-26.

[32] Wisneski, C., Ishii, H., Bahley, A., Gorbet, M., Braver, S., Ullmer, B., & Yarin, P.: Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information: Cooperative Buildings. Springer Verlag, February 25-26, 1998.