Supporting Cooperative Design through "Living" Artefacts

Dhaval Vyas[1], Anton Nijholt[1] and Gerrit van der Veer[1,2]

[1] Human Media Interaction
University of Twente, the Netherlands
d.m.vyas | anijholt @ utwente.nl

[2] School of Computer Science
Open University, the Netherlands
gerrit@acm.org

ABSTRACT

We present findings from a field trial of CAM (Cooperative Artefact Memory) – a mobile-tagging based messaging system – in a design studio environment. CAM allows individuals to collaboratively store relevant information onto their physical design artefacts, such as sketches, collages, story-boards, and physical mock-ups in the form of messages, annotations and external web links. We studied the use of CAM in three student design projects. We observed that CAM facilitated new ways of collaborating in joint design projects. The serendipitous and asynchronous nature of CAM facilitated expressions of design aesthetics, allowed designers to have playful interactions, supported exploration of new design ideas, and supported designers' reflective practices. In general, our results show how CAM transformed mundane design artefacts into "living" artefacts that made the creative and playful side of cooperative design visible.

Author Keywords

CAM (Cooperative Artefact Memory), Design Studio, Living Artefacts, Product Design, Twitter

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

The design studio culture has been central to the education and practice of design disciplines such as architecture and industrial design for several decades. Typically, design studios have a high visual and material character, where studio walls and other less permanent vertical surfaces are full of design artefacts such as sketches, posters, collages, storyboards and magazine clips for sharing ideas and inspirations. This ecological richness of design studios stimulates creativity in a manner that is useful and relevant to the ongoing design tasks [3]. This kind of organization of design studios is not coincidental. In fact, it is deeply rooted into design practices. Lawson [12] suggests that designers use 'synthesis' when it comes to problem-solving, whereas traditional scientists use 'analysis'. Designers' way of thinking focuses on quickly developing a set of satisfactory solutions, rather than, producing prolonged analysis of a problem [4]. As a result, designers frequently use and produce a relatively high number of representations such as, design sketches, drawings, story-boards, and collages. The studio organization is also important for supporting and inviting design critiques [24] as is the strongly embedded designerly practice of showing work and eliciting feedback early and often [4]. Such practices also encourage discourse and reflection during the design process [21].

Bringing a ubicomp technology into design studio environments would require a much deeper understanding of design practices that are undertaken in these settings. Using ethnographic methods, we studied academic and professional design studios over the period of eight months and developed a set of design implication (discussed briefly in the next section). Using these design implications, we developed a low-tech, mobile-tagging based messaging system called CAM (Cooperative Artefact Memory). CAM allows designers to collaboratively store relevant information onto their physical design artefacts, such as sketches, collages, story-boards, and physical mock-ups in the form of messages, annotations and external web links. In a sense, CAM allows design artefacts to have an individual digital profile on the Internet where relevant information can be added, updated or changed collaboratively by designers. Our current prototype of CAM integrates WiFi enabled camera phones with Microsoft TagReader clients; a set of 2D barcodes generated using Microsoft Tag's online services; and a JAVA web server application that uses Twitter API.

In this paper, we describe the results of a field trial of CAM in an educational Product Design studio in three different design projects. We invited three design teams to use CAM for their one week long design projects. Our intention was to use CAM as a *probe* to gain insight into the kinds of communication practices supported by CAM. We observed that CAM facilitated new ways of collaborating in design projects. The serendipitous and asynchronous nature of CAM facilitated expressions of design aesthetics, allowed designers to have playful interactions, supported exploration of new design ideas, and supported designers' reflective practices.

NordiCHI 2010, October 16–20, 2010, Reykjavik, Iceland.
 ISBN: 978-1-60558-934-3...$5.00.

Our results show that the *life* of a design artefact includes narrative, aesthetic, playful, coordinative, explorative and reflective characteristics. The result in general suggests a new perspective on looking at design artefacts as no longer being static objects but active participants in the design process. We can enrich design environments with this kind of analogy where design artefacts can expand their basic nature from being static to more dynamic and experiential. Our results do not suggest better results in design, but a different perspective on design. In the following we briefly describe the four implications used in the design of CAM.

Design Implications used for CAM

We carried out longitudinal ethnographic fieldwork [25, 26] in academic and professional design studios over a period of eight months. We aimed at understanding everyday collaborative practices of designers and design students in their natural settings. We used methods such as contextual interviews, naturalistic observations and video recorded live design sessions. From the results of our fieldwork, we developed the following implications to inform the design of CAM:

- *Artefact-mediated Interaction*. Designers develop a multitude of design artefacts in the form of paper sketches, drawings, physical models and so on over the course of their design projects [19]. The materiality, stigmergy, public availability and knowledge landmarks left on design artefacts help to establish and support communication between designers. We believe that a system should be able to incorporate these artefacts (at least partially) into its design space so that its natural and experiential qualities can still be exploited by designers.
- *Utilize Spatial Resources*. The way designers keep these artefacts and organize them in their workspace affects their work organization, communication and coordination practices. It is this spatial flexibility of, for example, sticking sketches and drawings on a shared office wall, that allows designers to discuss, criticize and explore new possibilities of their design work. In order to provide technological support for spatial flexibility, we need to think beyond desktop computers and involve the spatial and dynamic aspects of design studios, as shown in [19].
- *Creative Explorations*. We observed that designers spend a considerable amount of time in exploring new ideas and concepts by utilizing different techniques and design representations (also shown in [11]). Our fieldwork suggests that for creative explorations there is a need for a technological infrastructure that allows designers to collaboratively generate innovative ideas.
- *Social Flexibility*. We observed that the use of design artefacts and physical space allowed a level of flexibility in designers' everyday social interactions. This helped designers to discuss and talk about things anywhere and anytime. We believe that a Ubicomp system should not impose social order onto the designer, on the contrary it should allow designers to bring about and establish new practices for design.

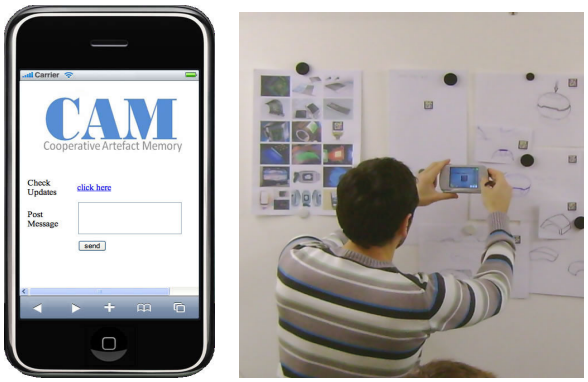
RELATED WORK

In the literature, there are several examples of applications that link physical objects to digital contents. In these applications, RFID, barcodes, or other sensing technologies are used to augment physical objects so that digital information can be linked to these physical objects. One of the earliest technologies was the eTag system by Want et al. [28] that used electronic tags on items such as books and posters linked to online information and actions. These authors demonstrated the utility of linking the electronic services and actions that are naturally associated with their form. In the WebStickers system [13], barcode stickers were attached to physical objects – making them act as bookmarks to the WWW. WebStickers enabled users to take advantage of their physical environment (e.g. by sticking these stickers at different places such as office doors) when organizing and sharing bookmarks. AURA [2] was a PDA and barcode based system for linking digital content to physical objects. It integrated a wireless Pocket PC with a barcode reader so that users can scan books, CDs, DVDs, packaged grocery products and other barcoded objects and then view, store and share related metadata and annotations. The term 'physical mobile interaction' describes interaction styles in which a user interacts with a mobile device and the mobile device communicates with objects in the real world [16]. These objects generally have some sort of tags (e.g. NFC, RFID, visual barcodes) that have communication abilities [8, 16, 18]. They enable the ubiquitous use of mobile services that are connected with smart objects. The usage of physical mobile interactions simplifies the discovery and use of mobile services, enables new kinds of object, person or location-based applications and overcomes several limitations of mobile devices. O'Hara et al. [14] studied the use of a location-based mobile-tagging application in the London zoo and found that their subjects used the system for supporting non-instrumental aspects such as identity creation and play.

In the design studio context, Grønbæk et al. [7] developed a set of Physical Hypermedia applications that extended the well-known web navigation paradigm. Within the domain of Architecture, they used RFID tags and readers where users can tag important physical material and could track these materials by antennas within their work environment. Blevis et al. [3] and Jacucci and Wagner [10] developed ubicomp technologies that could support and enhance inspirations and creativity, by utilizing spatial aspects of the design studio environment. In all these examples, we observed that supporting joint activities through a technology was missing.

COOPERATIVE ARTEFACT MEMORY (CAM)

CAM is a mobile-tagging based application, with which designers can send and store messages, annotations and other relevant information onto their physical design artefacts using mobile phones [27]. The messages and annotations pertaining to a design artefact can be accessed by all members of a design team. CAM is meant for



(a) (b)

Figure 1: (a) CAM running on an iPhone; (b) Reading a design sketch using Microsoft's TagReader client.

supporting communication and collaboration amongst team members in co-located design studio settings.

The current prototype of CAM uses low-tech, off-the-shelf tools such as Microsoft's mobile-tagging application TagReader, 2D high capacity color barcodes and a JAVA web server that uses Twitter API. In a typical scenario, when a designer scans a 2D barcode with his mobile phone camera, a web browser running CAM application starts. Using the user interface of CAM (Figure 1a), the designer can read messages pertaining to that particular design artefact or can choose to write a new message onto the artefact. CAM has a very simple user interface and has two functionalities: reading messages and sending messages. The "Check Updates" link allows viewing of all the messages written and stored onto a design artefact. The "Post Message" text-box allows one to write and send a new message to a design artefact.

Using CAM, a design artefact can have an individual digital profile on the Internet where relevant information can be added, updated or changed by all designers. The central idea in CAM is that it associates each 2D barcode to a Twitter account. Hence, when one reads a 2D barcode attached to a design sketch (Figure 1b), for example, one can read a set of messages about the object in the Twitter interface.

FIELD TRIALS

In a Product Design studio, we studied the use of CAM in three different design projects. We asked three student design teams to use CAM for their one week long design projects. All teams had four members. Table 1 shows the details of our design participants and their design projects. We gave them each a WiFi enabled camera phone. We created several temporary Twitter IDs and the same number of 2D barcodes generated using Microsoft Tag. The participants were first given a demonstration about how CAM works and how they could send and receive messages. During the period of their projects, they were asked to use CAM as a tool to support their design projects. At the end of their projects, students were given twenty Euros each as a token of appreciation.

Design Team #	Educational Year	Design Subject	Number of Participants
1	1st Year	Remote Control	4
2	3rd Year	Alarm Clock	4
3	5th Year	Intelligent Lamp	4

Table 1: Details of participants

As we mentioned earlier, our intention was to use CAM as a "probe" to learn how it influences, and possibly supports, the design process in design studio environments and not to test CAM as a fully functional technology. We left it completely to the design teams to use CAM in their preferred ways. They were encouraged to use CAM as much as possible. We also encouraged them to use the Internet from the mobile phones. Throughout the course of the three design projects, we videotaped their design sessions and interviewed team members at the end of the sessions. We collected the logs of the 2D barcodes and used Tweet logs in our analysis.

OBSERVATIONS

The three design teams were able to easily integrate CAM into their everyday design practices. Participants attached 2D barcodes to their design sketches, physical mock-ups, collages and Post-it notes and using CAM they added annotations, messages and other relevant information to these artefacts. Since all the team members had access to the Internet via the mobile phones, they also added web contents in their messages. Figure 2 shows one of the design teams that utilized a whiteboard to display their design sketches and discuss ideas during their face-to-face meetings – a theme seen in all three design projects.

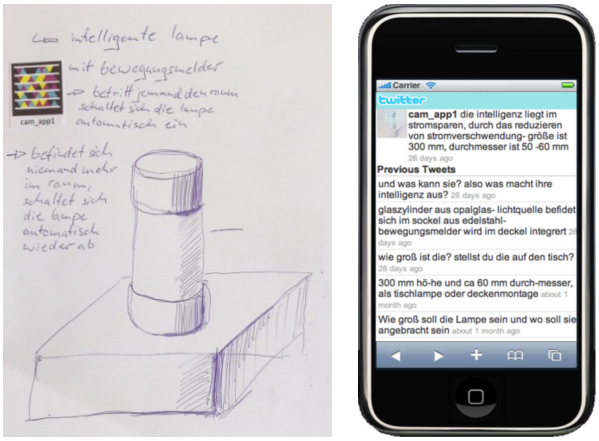
Figure 2: In the Product Design studio, a whiteboard full of design artefacts with 2D barcodes.

In the following, we provide the results of our qualitative data analysis, describing 1) how CAM was used by our participants and 2) how CAM supported their design activities.

RESULTS I: HOW CAM WAS USED…

We first start by providing an example of a tagged design artefact and show how it was used by our participants. Figure 3a shows a design sketch that describes the concept

of an intelligent lamp. The sketch shows the form and shape of the lamp and an annotated description of the lamp. The creator has attached a barcode to it and added a further description onto the digital profile of this artefact. Over the course of the design project, other members have read these messages and added their own comments and suggestions about this particular design sketch. When one reads the 2D barcode on a mobile phone, one is be able to see a complete log of comments as shown in Figure 3b. This log shows the dialog and negotiations that took place between co-participants. In Figure 3b, one could read the description about the size of the lamp and its functionality. Importantly, the log also shows questions and issues raised by co-workers such as: "where the lamp should be placed", "what material should be used" and "what should its size be".



(a) (b)

Figure 3: Tagged sketch of an Intelligent Lamp concept (a), and Tweets sent by the co-participants to provide a design description, written in German (b).

In the three design projects, we observed that not all the design artefacts were tagged with a 2D barcode. Participants tagged their artefacts only when they wanted to show or to communicate their ideas to the others. Remarkably, once the participants tagged an artefact they *never* made any changes in the original artefact. Hence, tagging gave a design artefact its own identity.

Digital Extension of Physical Objects

As shown in the above example, one of the advantages of CAM for our participants was to be able to extend a static physical design artefact to a digital space where dialogues between participants can take place. Clearly, a paper-based design sketch has a limited physical space, so in order to provide comments or to make changes in the artefact; a designer would have to create an additional design artefact. What CAM does is that it adds a digital layer of communication on the physical design artefact, where information pertaining to the artefact can be collaboratively stored and negotiated. Several participants commented that they saw Tweet messages as an extension of their physical design objects. One of the participants commented: *"For me, it is an extension to the usual way we work. It is just like sending an SMS to somebody, but the messages are stored on the object."*

This digital extension also seemed to provide organization cues to our participants' everyday work. CAM was described as a tool for setting reminders, triggers, notices, exhibits and resource sharing. Additionally, the use of CAM was also seen as storing "minutes" of a particular design session, as relevant information can be read easily. A team member suggested: *"These 2D barcodes provide immediate access to the information to what you want without a need to switch on the computer."*

Design narratives

We observed that the narration and description of design activities during the course of design projects can be traced through the Tweets that were sent using CAM. Although the technological limitations (140 character limit on message length) would influence the narrative structures, these narratives did provide a clear indication of how design was carried out. One of the important aspects of these design narratives was their 'cooperative' nature. The design narratives in the form of Tweet logs represented different views expressed by participants in a particular design project. This form of interaction provided an opportunity for collaborative concept creation. The design narrations depicted in the form of Tweets provided information about the design process that was used by the design teams. When asked about what they thought of these design narrations, a designer had the following comment: "*In my opinion, this is like making a design story. Maybe not a complete story. But it has a great deal of information about the conversation that we had while we were working*".

Design archive

CAM was also seen as a tool to archive design related information, as a design artefact, with a barcode, could store information about different design activities that took place earlier. Several of our design participants thought that after the current project, they could use their old sketches as design archives. One participant said: "*If I have to design a new alarm clock again, I can go back and retrieve all the information that is stored in this sketch and see how I can continue with that.*" This showed the value of CAM for design students.

Types of tagged artefacts

In each of the 3 groups, we identified four distinct types of design artefacts that were tagged to support different design activities, differing in the amount of *physicality*: 1) 3D Physical objects, 2) 2D Sketches, 3) Textual descriptions, and 4) "Abstract" references. See Figure 4.

1. The *physical objects* are three-dimensional objects or models made from wood, foam or cardboard that product designers create once their design ideas become concrete. Figure 4a shows a foam model of an intelligent lamp (team 3), tagged with a barcode.

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

Figure 4: Different types of design artefacts tagged during design sessions. (a) a physical model of a lamp, (b) a sketch of a remote control, (c) a written note, and (c) a reference object for planning.

2. The *paper-based sketches* are representations of design, mainly used for exploring and communicating design ideas amongst co-designers. Figure 4b shows a tagged design sketch of a remote control.
3. The *textual descriptions* varied from specifications of an early design solution to a collection of brainstorming ideas, see Figure 4c.
4. The *abstract references* do not contain much information as such, but they point to ideas and discussions on the digital profile. Figure 4d shows an artefact that was created by designers to refer to all planning and coordinating activities. Its actual meaning during the process (i.e., the history of messages sent to it) could only be accessed using mobile phones.

Comparing the four types of artefacts in this order reveals a transition from physical, information rich artefacts to artefacts that do not contain information themselves but refer to a set of content available only through CAM. These design artefacts are by their very nature *boundary objects* [23] in themselves. If we take the example of the physical model of the lamp (Figure 4a), one can get information about its form, texture, and size, and one can physically experience and interact with the lamp. Hence, at one level, the physical object itself can provide important information to co-participants. On the second level, when one reads the tag, one can collect information about the product as described by participants and the dialog and information exchange that subsequently took place between them. If we move to sketches (Figure 4b), notes (Figure 4c), and abstract references (Figure 4d), increasingly information needs to be inferred, which, however, is supported by the messages stored to the artefacts. In the case of abstract references, the actual information is in the digital form and can only be accessed though CAM.

Statistics of use

Inspection of Tweet messages and Microsoft Tag's usage log reveal that between the three design teams a total of 53 design artefacts were tagged with barcodes, 197 Tweet messages were sent to these artefacts and these were read 488 times in total. The team-wise distribution is presented in Figure 5. The high number of "Objects Read" in all three design teams was because reading a design artefact was always the first step to understand the ongoing and new activities. Hence, participants frequently read updates from design artefacts. Additionally, participants preferred

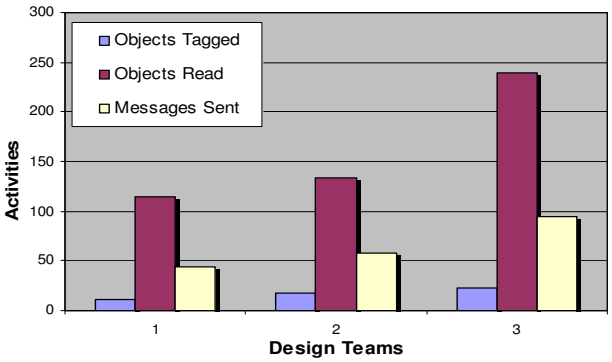


Figure 5: Team-wise usage of CAM.

reading old messages before commenting or making suggestion about an artefact (i.e. "Messages Sent"). In our field trial, we invited participants from different educational levels; which might be the reason why Group 1 (first year students) tagged only 11 design artefacts whereas Group 2 and 3 (senior students) tagged 19 and 23 artefacts, respectively.

RESULTS II: HOW CAM SUPPORTED DESIGN…

Communication and Coordination

Communication is central to any design process. While observing the use of CAM, we discovered several interesting coordination and communication patterns. Supporting interaction though artefacts was a central logic behind CAM (design implication 1). CAM sustained the sanctity of physical design artefacts, and hence supported a kind of interaction that was mediated through these artefacts. Several ethnographic studies have shown that material artefacts play an important role in supporting communication between co-workers [1, 9, 15, 17, 19 & 22]. However, with the use of CAM, design artefacts such as a sketch developed an added channel for communication between participants. Participants could access messages attached to different design artefacts, make comments about each other's work and could negotiate specific design ideas using CAM. One of the participants commented: "*CAM makes the sketch interactive not only because of the details of the sketch but the communicational support it provides us, because all the team members can read what others have written about a particular design object.*"

Secondly, the use of CAM allowed participants to get a quick overview of the ongoing design activities. This helped them to coordinate their ongoing design activities. As we showed in Figure 1, all three design teams used large vertical surfaces such as a whiteboard to display their design artefacts so that all team members could see and comment about each other's work. The spatial flexibility (design implication 2) and ease of access supported by CAM allowed participants to quickly scan individual design artefacts and understand the narratives of ongoing design activities. Here is a comment that we received during the group interview sessions: "*If you stand in front of these things and scan everything, it helps to think about and*

understand what's going on in the project." The issue of public availability [17] played an important role in supporting coordination.

Figure 6 shows a "Planning" object that design team 1 developed in order to make a specialized access point for organizing and planning their ongoing project. Table 2 shows the Tweets that were sent to this object over the course of the project (latest message at the top). We have translated the Tweet log into English for better understanding. The purpose of this design artefact was to divide work responsibility, create a work schedule and for sharing important decisions between themselves. We observed during the course of their project that the design team iteratively added contents to this object. This kind of practice led to participants frequently checking the "Planning" object in order to 1) review their previous activities, 2) coordinate their ongoing activities and 3) create milestones for future activities. This showed how participants appropriated CAM to support their local needs.

Figure 6: A "Planning" object

Tweet log of "Planning" object
>> Thursday: Grigorios - presentation Sketch >> Thursday: Eric - technical drawing >> Thursday: Tarek & Julia - finishing the design model >> Make technical drawing >> Wednesday: planning, task distribution. Grigorios >> Wednesday: Braille design with Eric >> Proposals on the buttons: Payment Volume Channels Program Selection >> Joey's? >> What else should we add for supporting touch-based facilities? >> I would very much like to order pizza for tomorrow. Better designs with full stomach >> Touch screen OUT. Agreed on the use of Braille writing system. Any proposals on the form? >> How many keys does a blind remote control require? >> I propose that we combine both the concepts, your form and our concept of designing for "blind people"

Table 2: Tweet log for Planning of a project for the design project 1. (translated from German)

In this example, one can read how different activities were assigned to participants and important decisions were made public to support coordination.

One participant suggested that CAM could also be suitable for large groups of people collaborating over a long period. In large corporations, where teams from different disciplines work together on a project, CAM can provide additional and relevant information of a multidisciplinary nature. He commented: "*In a scenario, where we have to hand over our work to product developers and engineers, these 2D barcodes can help these professionals who have not been closely informed about the kind of design process that we have applied to these design objects. So, I think CAM could also be helpful for inter-team collaborations*."

Expression and Aesthetics

By making connections between a physical design artefact and relevant messages – as its digital extension, CAM provided an interesting opportunity for the participants to express aesthetic qualities, something that they would not express during their everyday cooperative design sessions. Figure 7 shows a sketch and concept developed by one of the groups. In this case, a designer wrote a poetic message to express the aesthetic quality and functionality of the lamp. See Table 3, where we describe the original poetic messages in German and then the English translation.

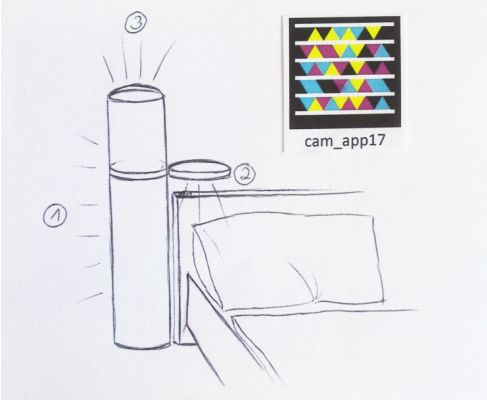


Figure 7: The final sketch of a conceptual Intelligent Lamp.

German	strahlemann, der strahlt uns an. ob tag und ob nacht, wäre hätts gedacht
English	the Shiny-man, who shines on us. whether day or night, no matter what.
German	die sonne am morgen, die sterne am abend, die langsam begleitend in den schlaf uns tragen
English	the sun in the morning, the stars at night, slowly accompany us into sleeping tight.

Table 3: A set of poetic messages adding aesthetic qualities to the Intelligent Lamp concept shown in Figure 7. (with added English translation)

This example shows how the need to express aesthetic and poetic design ideas was supported by CAM. During the final group interview session with the design team, we asked about these poetic exchanges. The following was their response:

D1: "The poem shows the poetry of the product. It is something about having a good night sleep and a nice way for waking up."

D2: "I think it makes the concept of our lamp more romantic and magical, if you like."

D3: "Somebody wrote a poem about the lamp. It's just funny. It describes the lamp in an artistic way. And the cool thing is that you are totally anonymous. This is something that makes this sketch beautiful."

D4: "I didn't know who wrote it. And when I first discovered it, I thought look somebody wrote a poem. It was really amusing. It could be something to tell the customers who might buy this lamp. This could be something that separates this product from others."

The way designers used CAM and wrote messages onto their design artefacts had expressive and aesthetic qualities. Some of the Tweets that were written on the design artefacts showed enthusiasm and affection. A participant commented: "*Sometimes you do see an enthusiasm of the designers in their messages. In some cases, I have seen detailed descriptions of a design sketch in the messages and sometimes its not detailed enough.*" The following is a comment of one of the participants who intentionally wrote messages to get co-workers attention. "*I would like to know if others like my sketches and design ideas. What do they think about my work? When they don't have a chance to speak to me, they can write something on these sketches using CAM.*"

We observed that on certain occasions team members preferred being anonymous and on other occasions wanted to be identified. This characteristic of CAM allowed participants to express their views in different ways. In particular, the anonymity supported by CAM was seen as a useful phenomenon, as one of the participants said: "*I think that sometimes this anonymity turns out to be better. I think it is less emotional and less personal when somebody tells you something through these design objects. You don't take this so personally. So, when I was asked if my design idea for an alarm clock was for children, I found it funny. So, this feels less confronted or attacked*". This example shows how CAM supported flexibility in expressing ideas to other participants, without being too personal.

Playfulness

The expressive nature of CAM seemed to provoke a degree of playfulness and creativity. By playfulness, we do not suggest unproductive or non-work activities, but carrying out the design process using creative and non-conventional approaches. We observed playful ways of using CAM while working on the design projects. One of the important aspects of the playfulness of using CAM was its inherently 'open' setting. The participants enjoyed the freedom of tagging any kind of physical design artefact and writing messages onto it. At the same time, CAM introduced limitation on dealing with mainly textual messages of 140 characters, since it utilized Twitter. As a result, the messages were written in a way that could communicate ideas in *quick-and-dirty* ways. This kind of interaction often led to surprising and intriguing reactions amongst the team members. Since all the design students were given individual mobile phones, we observed that on many occasions messages represented different perspectives on design. The 'open' setting on CAM facilitated participants to balance the information storage on the physical design artefact and its digital extension. This allowed participants a choice to represent their design ideas in two different ways.

The asynchronous and serendipitous nature of CAM also added to the playful effect. CAM had a level of asynchrony, in a sense that messages and updates were only accessible when a participant went to a design artefact and read its barcode. This actually added an element of surprise and curiosity during the interaction with CAM. In some cases, participants intentionally kept information in the digital from by writing messages. One of our participants expressed this playfulness in this following comment: "*To me it's a fascinating experience to read the details about the lamp that we designed in a mobile phone. It is like seeing the same thing in a different way.*"

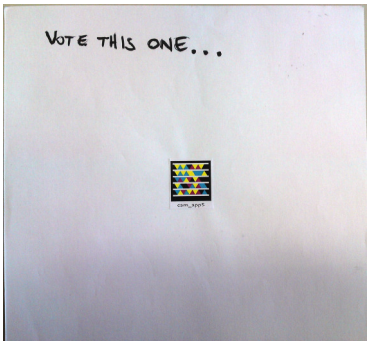


Figure 8: An empty paper with barcode used as a "Voting" mechanism for different versions of design ideas.

Figure 8 is another example of a playful act of carrying out an important design activity. In this instance, participants in group 2 individually developed conceptual sketches for an interactive alarm clock. After their discussion and constructive criticism of each other's work, they decided to tag an empty sheet of paper and asked each other to vote for their choice of design idea. See Figure 8 where CAM was used as a "voting" device to select the best design idea. Central to this activity was the importance of anonymity and asynchrony supported by CAM. Here, we see an intertwined relationship between design team members' pragmatic activity of completing a design task and utilizing CAM as a tool to support expressive and playful interactions.

Creative Exploration

CAM supported and to an extent encouraged design explorations. Previous research has indicated that designers do not work in a pre-determined, mechanical fashion [4, 11]. In fact they apply different approaches in different situations, involving different media (ranging from paper, foam, and wood to digital tools) to understand and explore their design problems. Being able to explore and try out new design ideas is central to their design work. We observed that the social and collaborative nature of CAM triggered all members of a design team to actively participate in the exploration process (design implication 3).

In one instance, a team member developed several concept sketches for the Intelligent Lamp project (Figure 9). Sketching is clearly one of the quicker ways to express and communicate design ideas to co-workers. However, in this particular case, the team member's intention was to gather co-workers' comments about different exploration ideas that she developed. Figure 9a was meant to explore different shapes of lamp; 9b and 9c show the ways to apply intelligence into the lamp; and 9d explores different projection styles for the lamp. The intention here was to have a discussion via sending views and ideas onto the design artefacts and discuss these during the face-to-face meetings. Here is a comment from that design member: "*CAM does help in creative thinking. Sometimes when I am drawing, I wouldn't know all the technical details. So after reading these comments about my sketches, I did find some tips about changing my original ideas.*"

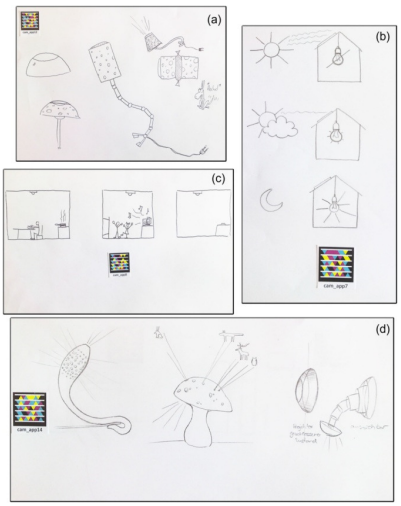


Figure 9: Design sketches to explore ideas for an Intelligent Lamp.

By receiving comments from each other, members of design teams collaboratively learned and improvised their ongoing design projects. A participant commented: "*The useful thing about CAM is the new ideas that we get from others. I found this very stimulating for my creativity. For example, Max had this function of pushing in the alarm clock and I had a separate switch. From Max's design and my design we merged the interesting ideas and came up with a combination in the final design idea.*"

Here is another example (Figure 10), where a team member developed a design sketch, where a lamp can detect activities of people and adapt its light projection in a room. When somebody is reading in the room then it changes its focus to the reader's book.

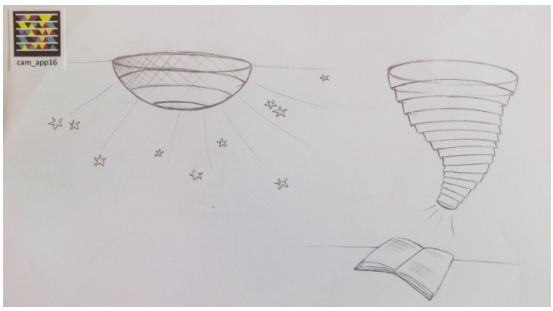


Figure 10: A design sketch representing an Intelligent Lamp.

Here is the Tweet log of the design sketch (Table 4) which shows how the concept was discussed and negotiated by the co-participants. These Tweets suggest how collaborative exploration took place, ideas were exchanged and in particular how participants built on each others suggestion to make the explorative process work.

Tweet log of the sketch in Figure 10
>> are both concepts for the same lights? GP >> Light Modes: Reading-mode, Sleeping-mode, Waking up-mode. Dimensions: no larger than 40cm in diameter! >> good question, as we see in the Submarines: Blue for normal and Red for danger >> what are the exact dimensions in the various positions? >> which light color for what mood? >> lights recognizes the mood in room. >> So, more work to follow on Monday... would be more comfortable... please ... >> looks like a reading lamp >> extensible, recognizes in the mood in the room and projects light accordingly (color, intensity).

Table 4: Tweet log for sketch shown in Figure10. (translated from German)

Reflection & Critique

Reflection is described as a tacit phenomenon that professionals exhibit in the form of knowing-in-practice [21]. Reflection as a mechanism for learning from experience is an important aspect of professional design practice. In the field trial, we observed that the use of CAM facilitated participants to critically look at their own work and the work of others. As CAM encouraged participants to write down their activities in the form of messages, this provided a reflective platform to evaluate ongoing activities. The Tweet log provided information about past activities of all the co-workers, which inherently helped participants to constantly review, plan and refine future activities in a global sense. This also helped participants to organize their ongoing design projects and to be accountable. One of the team members said: "*I think it might be a good thing if we can write down what we are*

thinking about during the process of making sketches. This would be a good practice as well." Additionally, the movement from the physical design artefacts to their digital profile and back again successfully scaffolded creative and reflective thinking. This facilitated our participants to look at their designs from two different points of view: what it is and what is said about it.

Criticism is a highly important aspect of studio based design [4, 24]. CAM not only provides a dialogue for constructive design criticism but its spatial flexibility supported and encouraged designerly criticism. Since it was quite easy for our participants to display their design artefacts such as sketches on whiteboards, this deliberate act invited and made it easy for other participants to provide design criticism.

Critical and reflective dialogues were also triggered by the Tweets sent by the co-workers about some previous design activities, which contained comments and suggestions that led participants to critically look at their design artefacts. Sometimes, these reflections seemed to prompt decision-making and sometimes leading to face-to-face discussions between team members. The asynchrony and serendipity of messages and comments helped design teams to reflect on their own work as well as to learn from, and constructively criticize, each other's work. One of our participants commented: "*The system does help you to reflect on what you designed and what you wrote about it. At the same time what others have said about your work.*"

DISCUSSION – "LIVING" ARTEFACTS

CAM incorporates all the four design implications generated from our ethnographic fieldwork. First, it sustains the sanctity of material design artefacts and at the same time provides a channel to support communication between participants. Second, it offers a kind of setting that is not dependant on the physical space and instead allows participants to utilize space to support their work. Third, it offers a level of flexibility by which designers can support exploration and playful interactions to bring quality to their work. And fourth, it does not impose any social order to the design participants and fits into the everyday practices of designers.

Our main intention for carrying out the field trial of CAM was to apply it as a *probe* and to be able to understand the possibilities and consequences of tagging physical design artefacts to allow communicating to, and through, these. The main question here was: Can this type of technology enrich the design process? As our results showed, tagging design artefacts provided 1) communicative and coordinative resources, 2) expression of the aesthetic qualities of the design artefacts, 3) support for playful interaction between designers, 4) exploration support, and 5) allowed designers to reflect on and critique each other's work.

The use of CAM showed that tagging design artefacts can expand their static nature to create more dynamic and active objects. As we explored during our field trial, the design artefacts became a "living object". These objects received a special status at the moment of tagging, where they were no longer a person's private artefact, hence, they were no longer changed. They now had their own "identity". From this moment on they were communicated to, which resulted in the tagged artefact developing its own history of communications. The history could, and in fact was, frequently read by the team members and was added to. The history of these artefacts showed that they were considered "living" identities reflecting the team's growing understanding, discussions, and expressions. Design participants continuously scanned the barcodes to gather updates from these "living" artefacts.

CAM supported design teams to establish a creative working culture. Reading the design artefacts triggered building on and learning from each other's work. The collaborative and social nature of CAM fostered creativity amongst the group of designers. The anonymity of Tweets played a role in establishing curiosity and playfulness. Designers were triggered to reflect on their own as well as each other's work in a critical manner. One of the important aspects of the logs generated by CAM was its communicative and coordinative abilities. Using their mobile phones, participants were able to read updates of different design artefacts and were able to get a sense of what was going on in the project. The "Planning object", described in Figure 6 was an example of a design team's organizing activities.

In the following we provide two approaches through which the notion of "living" artefacts can be further developed.

Internet-of-Things

Although not implemented in the current version of CAM, we propose a mechanism by which individual design artefacts can be linked to each other with some semantic relationships. These kind of connected objects are sometimes referred to as the "Internet of Things". Internet of Things [6] can be seen as a sub-vision of Ubiquitous Computing [29], where objects are connected to each other and are aware of each other's status and activities. In design studios such a vision could mean that design artefacts that are scattered around a design studio can be connected to each other. The connections can be established based on chronology or version control, across different multimodal and spatio-temporal aspects.

Object Memory

In the current version of CAM, we have used Twitter as a storage tool. Although Twitter has a limitation on the length of messages one can write (140 characters), its use allowed us to quickly find out whether CAM has a potential in the design studio culture. There certainly is a need for more

robust and reliable ways of storing and retrieving object related information.

In the domain of logistics and supply chain, researchers have been working on approaches to develop appropriate information storage structures for smart environments [5]. This kind of data structures are often referred to as Object Memory or Product Memory. One such approach is used in *object memory infrastructure* [20]. In the current version of CAM, information is not automatically collected and stored. However, using the product memory approach this can be easily achieved.

CONCLUSION

Our current study is a proof of concept. We used a simple technology that is currently available, specifically to probe and find out how CAM would affect design teams when physical artefacts are an important part of the design studio ecology. We did not intend to improve the end result of design but to find out how this new approach could enrich the context and support new forms of collaboration. We are fully aware of the ad hoc nature of our technical implementation. More sophisticated approaches need to be developed (one such mentioned in [20]). In the future we will investigate whether the *enrichment* as observed here could also lead to "better" team collaboration and "better" design results.

ACKNOWLEDGMENTS

This work is supported by an EU project AMIDA (FP6-0033812). We thank Alexander Kröner, Michael Schmitz, Tim Swartz, Roger Ngeufang and Lynn Packwood.

REFERENCES

1. Bardram, J. E. and Bossen, C. A web of coordinative artifacts: collaborative work at a hospital ward. In *Proc. GROUP '05*. ACM, New York, NY, (2005), 168-176.
2. Bernheim Brush, A. J., Combs Turner, T., Smith, M. A. and Gupta, N. Scanning objects in the wild: Assessing an object triggered information system. In *Proc. UbiComp '05*, Springer-Verlag (2005), 305--322.
3. Blevis, E., Lim, Y., Ozakca, M., and Aneja, S. Designing interactivity for the specific context of designerly collaborations. In *CHI '05 Ext. Abst.* (CHI '05). ACM, New York, NY, 1216-1219.
4. Cross, N. *Designerly Ways of Knowing*. Springer. 2006
5. Decker, C. et al. Collaborative Business Items. In *Proc. of the 3rd IET International Conference on Intelligent Environments* (IE' 07), Ulm, Germany (2007) 40–47.
6. Floerkemeier, C. et al. *Proc. of 1st International Conference on Internet of Things* (IOT '08). Zurich, Switzerland, March 26-28, Springer-Verlag, 2008.
7. Grønbæk, K. Kristensen, J. F., Ørbæk, P., and Eriksen, M. A. Physical Hypermedia: Organizing Collections of Mixed Physical and Digital Material. In *Proc. of 14th Hypertext´03*, (2003), ACM: NY, 10-19.
8. Häikiö, J., et al. Touch-based user interface for elderly users. In *Proc. of MobileHCI '07*, ICPS, vol. 309. ACM, New York, NY, (2007) 289-296.
9. Hutchins, E. *Cognition in the wild*. MIT Press, Cambridge, USA. 1995.
10. Jacucci, G. and Wagner, I. Supporting Collaboration Ubiquitously: An Augmented Learning Environment for Design Students. In *Proc. of ECSCW '03*, Kluwer Academic Publishers, (2003), 139-158.
11. Jacucci, G. and Wagner, I. Performative roles of materiality for collective creativity. In *Proc. of International conference on Cognition & Creativity* (C&C '07). ACM, New York, NY, (2007). 73-82.
12. Lawson, B. Cognitive Strategies in Architectural Design. *Ergonomics*, 22(1), 1979, 59–68.
13. Ljungstrand, P., et al. WebStickers: using physical tokens to access, manage and share bookmarks to the Web. In *Proc. of Designing Augmented Reality Environments*. (DARE '00). ACM, New York, NY, (2000), 23-31.
14. O'Hara, K., et al. Social practices in location-based collecting. In *Proc. CHI '07*. ACM, New York, NY, 1225-1234.
15. Randall, D., Harper, H. and Rouncefield, M. *Fieldwork for Design – Theory and Practice*. CSCW series, Springer-Verlag, London. 2007.
16. Rekimoto, J. and Ayatsuka, Y. CyberCode: designing augmented reality environments with visual tags. In *Proc. of Designing Augmented Reality Environments.* (DARE '00). ACM, New York, NY, (2000), 1-10.
17. Robertson, T. The Public Availability of Actions and Artefacts. *Computer Supported Cooperative Work,* 11(3-4): Springer-Verlag, Berlin, 2002, 299-316.
18. Tomitsch, M., et al. Accessible real-world tagging through audio-tactile location markers. In *Proc. of NordiCHI '08*, ICPS, vol. 358. ACM, New York, NY, (2008) 551-554.
19. Schmidt, K. and Wagner, I. 'Coordinative artefacts in architectural practice'. In *Proc. of COOP'02*, IOS Press, Amsterdam, (2002) 257-274.
20. Schneider, M. and Kröner, A. The Smart Pizza Packing: An Application of Object Memories, In *Proc. of 4th Int'l Conf. Intelligent Environments* (IE 08), Inst. Eng. and Tech., 2008.
21. Schön, D. *The reflective practitioner: How professionals think in action.* NY: Basic Books, 1983.
22. Sellen, A. and Harper, R. *The Myth of the Paperless Offices*. MIT Press, MA. 2002.
23. Star, S.L. and Griesemer, J. Institutional Ecology, Translations' and Boundary Objects. *Social Studies of Science*, 1989, 19(3), 387–420.
24. Uluoglu, B. Design Knowledge Communicated in Studio Critique, *Design Studies*, 21(1), 2000, 33-58.
25. Vyas, D., Heylen, D., Nijholt, A. and van der Veer, G. Experiential Role of Artefacts in Cooperative Design. In *Proc. of C&T '09*. ACM Press: NY. 105-114.
26. Vyas, D., Heylen, D., Nijholt, A. and van der Veer, G. Collaborative Practices that Support Creativity in Design. In *Proc. of ECSCW '09*. Springer Verlag, 151-170.
27. Vyas, D., Heylen, D., Nijholt, A., Kröner, A. and van der Veer, G. Remarkable Objects: Supporting Collaboration in a Creative Environment. In *Proc. of UbiComp'10*, Copenhagen, Denmark.
28. Want, R., et al. Bridging Physical and Virtual Worlds with Electronic Tags. In *Proc. of CHI '99*, ACM Press (1999), 370-377.
29. Weiser, M. The computer for the 21st century. *Scientific American*. 265 (3), 1991, 66–7.