Architecture and pervasive computing
when buildings and design artifacts become computer interfaces

Peter Gall Krogh & Kaj Grønbæk

Introduction

In the article ”The End of the Mechanical Age” [22] Ezio Manzini describes how the act of designing has developed during the 20th century based on the premises of technology, while considering technology throughout history as an inseparable part of design. The article is written in response to articles that acclaimed the victory of the man made world over nature, among others Hannes Meyers article “Die neue Welt” [23] and later Sigfred Gideoens article, “Mechanization takes Command”[8]. In the article Manzini argues that the premises of mechanization has come to and end, it is no longer adequate to

> …simplify and clarify…complex phenomenon’s …based on reductionistic and deterministic models…that define precise and unambiguous relationships of cause and effect… and that the observer always can be regarded as external to the system observed.

Manzini concludes the article by arguing

> Matter…has become ductile and malleable into every conceivable form

and that

> we are no longer confronted with a given taxonomy of materials and manufacturing techniques, but a continuum of possibilities.

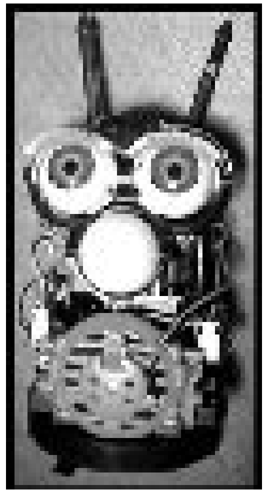
This leads to the conception that materials can no longer be regarded as a premises for design, a notion which is supported by the present increasingly use of IT in new products. IT, though being real i.e. endowed with properties that can be sensed, its character is immaterial.

One of the main areas of architecture is buildings design, and we will focus on the impact of pervasive computing in this area. The breakthrough of the Internet has triggered a significant increase in what is often called intelligent buildings[1] in recent years. Due to development in pervasive computing we are on the brink of an even greater increase: IT components and systems for intelligent buildings will change from being proprietary, specialized solutions with a narrow market to be part of the developing mainstream mass market for pervasive computing. This paper will illustrate the development of pervasive computing with examples of from industrial design and, intelligent buildings, and interactive workspaces. The examples relate mainly to our Laboratory for Interactive Workspaces (http://daimi.au.dk/ispace) but also to other activities our Center for Pervasive Computing (CfPC) at University of Aarhus.

The "Fourth Machine Age"

By relating Manzinis article to Reyner Banham's [2] "Theory and Design in the first Machine Age", one could say that we live on the border of the fourth machine age. Large and heroic machines like cars, airplanes and heavy industry characterized the first machine age, and the second utilized the mechanics of the first to invent small and pervasive mechanics like the refrigerator, vacuum cleaner and other household machines. The third machine age is characterized by the emergence of the computer originally designed for specialized use in work settings, a tool for work from technologist to technologist. Today the computer seems to undergo a development equal as to what happened to mechanics in the second machine age, they become ordinary and penetrates into every object of our daily lives.

The notion of this paper is to pick up where Ezio Manzini left in 1990, and to continue the development of theories and descriptions of the contours of the "Fourth Machine Age" as among others done by Anthony Dunne in the book "Hertzian Tales" [6]. The aim is to describe what might be some of the premises of design of this "Fourth Machine Age", by taking departure in the fact that IT increasingly enables and represents the qualities of products. This "augmentation" of our environment alters the premises of design and architecture. Traditionally within design and architecture material is considered the basis of form, and a guiding parameter for the realization of form. When including IT in the design of physical artifacts, the field is not enriched by a new material, but rather extended with a set of properties yet unrelated to form, though that form might mediate the properties derived from the use of IT. The act of designing artifacts with IT properties can merely be thought of as the design of a use situation or the circumstances under which and artifact is to be used. Thus design no longer mainly leads to the



creation of physically finished static works of art, but merely to the emergence of dynamic artifacts and spatial constructions that develop through their usage. IT enhanced artifacts are dependent of their context of usage, informing and influencing the expression related to its architecture and design.

An example of a class of industrial design artifacts that has become "intelligent/smart" could be toys, e.g. "Furby" [7] a cute small teddy that has been stuffed with electronics, sensors, actuators and a communication port fig. 1. Natively the toy arrives with the ability to speak "Furbish", but enabled by Artificial Intelligence software the toy is capable of "learning" up to 1.000 English words and sentences. Furthermore it is capable of relating its speak to a context e.g. is it hugged, tickled which is detected by its built-in sensors and hereby the toy is capable of mediating a sort of feelings, seemingly generated by the toy. By the appearance of the Furby independent web sites have emerged informing how to hack the Furby and extend it with new software!

The cultural and aesthetic premises of design are changed when objects of design no longer can be regarded as solitary entities but as artifacts which are comprised by activities mediated by networks and/or direct human manipulation and interacting with the our context. Our perception of space will be challenged while having to include both physical spaces, the symbols and metaphors that resides in them as well as metaphysical dimensions as mediated by e.g. media spaces [14]. In such an environment space can no longer be comprehended by the notion of physically demarcation, but merely as an environment defined by social and cultural relations among the involved people and occurring activities.

The dynamic nature of IT has always been the work premises of computer science. But until now developments within Computer Science mainly have been aimed at the usage of applications running on PCs or controlling large machines equipped with displays serving as interface between man and machine. The ever decreasing size of IT hardware while at the same time an extreme acceleration of capacity enables the aforementioned penetration of IT into almost any object. The interface to the underlying software changes from being screen-based and/ or based on dedicated bottoms to be extremely complex i.e. tracking of ordinary human activities e.g. speech, gestures etc. and the handling and placement of physical objects. By means of proximity networks as i.e. Bluetooth devices are network enabled and small units will be able to form network and interface to large IT driven complexities as e.g. buildings and even townscapes, comprising situations where information and properties can be exchanged between the single user and a whole community. This field of research embraced among others in the denotation of Intelligent Buildings.

Intelligent buildings

Intelligent buildings have been in focus in many different contexts during the last decade. Different perspectives have been applied, for instance experiments in intelligent control of energy consumption. Two Danish examples are DTI's Office Vision [28] and Villa Vision [34]. Several research labs around the world have focused on intelligent support for the work that takes place in buildings, e.g. MIT MediaLab [24], Stanford University [14] in USA, GMD [1] in Germany, and Sony [29][30] in Japan.

Many labs and companies focus on intelligent homes. Besides energy this work has included surveillance, audio/video, dishwashers and other hardware. Recently, all of these have been connected to the Internet and a broad spectrum of IT-support is being added. Among the examples are the Aware Home in Georgia (www.cc.gatech.edu/fce/ahri), the Internet houses in London (CISCO) and Stockholm as well as the 'Future Home' which has been constructed at Fornebu outside Oslo (Telenor) [32]. Moreover, companies like Echelon [18] and X10 [38] are marketing operating systems and equipment for intelligent homes and office buildings etc. Such an operating system called LonWorks is in use in Unibank's new headquarter in Denmark [33]. However, the examples mentioned only represent the beginning of this development.

The development in both network standards and communication standards between computational units is going through a dramatical development. We expect a few powerful standards similar to TCP/IP, HTTP and XML to be widely agreed on. This will create a rapid developing marked based on the convergence between technologies and sectors. Energy management, surveillance, audio/video, media, IT, etc. will be based on a few central networking technologies, and they will do so across sectors like home, office, business, and manufacturing. Moreover, our infrastructures in terms of cities and roads will be included.

Research and development in the construction sector show an increasing activity in the area of applying IT in the industrialization of the construction process. This is, in particular, seen within projects in an EU context, please refer to section 5 in this paper. The results so far are modest and limited compared to other sectors such as flight and ship manufacturing. But the current initiatives show promise of improvements in near future.

Finally, it is anticipated that an important factor in the IT-based industrialization of the building construction process is the integration of environmental sustainability both in the process and the final products. The interplay between pervasive computing, IT-based construction processes and environmental management may create important synergy in augmenting buildings with useful and sustainable technologies.

The above-mentioned examples serve as illustra-

tions of the shared interests, challenges and merging properties of architecture, design and computer science. It is with the prospects of the examples and developments like the above that a laboratory for interactive rooms, the Laboratory for Interactive Workspaces, has been established, though the work in the laboratory has less focus on autonomous systems as it has on enabling and showing the actual relations between physical objects and related actions performed by computers comprising into an transparent and information rich environment with an overall notion of enabling intuitive interaction with computation.

Research Fields in Intelligent Buildings and Interactive Spaces

In the following, we identify five fields of research and development of intelligent buildings and interactive spaces. We do not claim that they span all research in intelligent buildings, but they represent areas where research activities are emerging. The five fields are: 1) Live models of building infrastructure, 2) IT-infrastructure for buildings, 3) Interaction between buildings and the city or landscape 4) Dynamic architecture and adaptive buildings 5) Supporting users' activities and along the way, we give examples of research activities in the Center for Pervasive Computing that contribute to these research perspectives. The emphasis will be on activities in the Laboratory for Interactive Workspaces. The idea behind establishing the Laboratory was to experiment with interactive environments for the support of the work practice of designers and architects, taking departure in making the computer disappear into elements constituting the room as well as objects residing in the room. The initiative builds upon inherent knowledge represented by the interdisciplinary research team formed by people coming from multimedia science, computer science and architecture.

Live models of building infrastructure

Self-supporting buildings may include ubiquitous information about the building's construction in terms

of CAD-models including pipe and cable diagrams which are kept up-to-date such that personnel repairing and maintaining the building can access the information in context. This requires engineers and architects to establish a live building model as part of the construction process, moreover, repairs, tailoring, and re-modeling of the building needs to be registered in the database. The information can thus be accessed and updated from mobile devices like the one envisioned in Figure 2, where an electrician with a mobile device that can visualize the always-updated database over the building infrastructure, e.g. pipes and cables in the floor. Such intelligent building support requires development of engineering and architectural standards for modeling the infrastructure of buildings, which in turn requires the manufacturers of building components to adopt these standards. An example of first attempt at such a system is Sony's Cybercodes [29] where an advanced barcode with built-in directionality allow mobile devices to display location dependent information to users while reading cybercodes at the given location.

IT-infrastructure for buildings

In the future, the physical infrastructure of a building, i.e. heating, ventilation, doors and access control, is controlled via a network of computers, sensors and actuators. The same network may be the carrier of control for audio and video as well as carrier of audio/video content and other data traffic. The network will combine wired and wireless components. Companies like Echelon [18] and X10 [38] are marketing such operating systems, network and equipment for intelligent homes and office buildings, an example of such an operating system is LonWorks marketed by Echelon. Among other things such operating systems support remote control of buildings via standard Web interfaces, see fig. 3.

An important motivating factor for introducing an IT-infrastructure in buildings is an efficient handling of a wide spectrum of environmental issues. This may be illustrated by two examples: 1) In the domain of intelligent energy, the focus is on the optimization of utilization of energy-based on the entire chain from producer to user. This provides the possibilities of tailoring

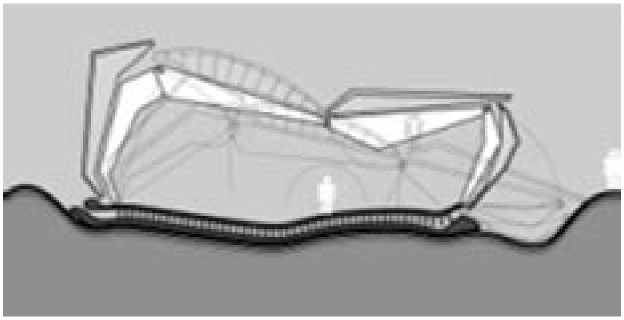
the use to periods where energy is cheaper, and coordinated use of energy for a coherent area (building, city area, county, or state). Through monitoring of resource usage, weather conditions etc. it is expected to be possible to adapt the usage of energy to cheap periods. In buildings with pervasive computing support, the required infrastructure will largely be in place, and thus it will be possible to achieve a considerable save of effort in the implementation of intelligent energy support for buildings. Efforts in achieving this will not only be aimed at providing the sufficient technology, but with equal focus on the educational effects in the user experience in the consumption of energy 2) In many cases, it often appears that the indoor climate in buildings is unexpectedly negative. Through the development of better models for assessment of the effect of peoples use over time, it may be expected that environmental improvements can be devised both in terms of better design and in terms of dynamic management of relevant parameters.

In this domain CfPC collaborates with manufacturers of pumps, heating, etc. Work includes the construction of embedded software, e.g. Java programs, which can be executed on small 8 and 16 bit computers [16]. Grundfos and Danfoss are involved in these activities. In addition, we work with control of diverse plants via small mobile devices such as Palm PC's and cell phones.

The interaction between buildings

and the city or landscape

Depending on the purpose of a building it may play different roles in the landscape or townscape. It might have large projection surfaces with commercials, information and entertainment. It might support communication to mobile devices in the neighborhood Such communication may be information about activities in the building, how to find your way in the building or information about other services provided by the building or the organizations it hosts. Such services to mobile devices are a special case of location-based



services, where users of mobile devices may receive information based on their physical location. The information may be received by people entering the building or passing nearby via cell phones, radio LAN or Bluetooth. Users may have personal profiles on their devices filtering location based information receival.

Digital models of buildings and cities can also be used to make the living and democratic processes in cities more interactive and tangible. An example of this is the Karlskrona2 project [27], which is a digital mirror of Karlskrona aiming at creating a forum for debate among the citizens about the development of the city. The digital environment of Karlskrona2 is not fully implemented, but has been run in a limited functional version. The digital mirror of Karlskrona is intended to be accessible from web browsers, large projection screens and kiosks in the city. Citizens may discuss changes to the city through concrete proposals in terms of model elements entered into the digital mirror of Karlskrona. Such proposals can then be discussed via a 3D chat environment. In this way, citizens in the real city may also become "citizens" in a proposed virtual city, where an ongoing debate about the real city takes place, see also[37].

Some types of buildings, e.g. supermarkets, manufacturing plants, play special roles in relation to transportation and logistics in the environment. Drivers who need to deliver goods need to be able to get information about access conditions, preferred delivery entrance, other trucks in line etc. Building information systems and transport information systems need to be integrated, and the domain of intelligent transport has become a big focus area e.g. in the US [13].

Dynamic architecture and adaptive buildings

Dynamic architecture is known from experiments made e.g. by the Archigram group [5] in the 1960'ies. Here the purpose was to re-think how we live and work based on high-tech buildings, using technological possibilities as inspiration while challenging our conception of what is desirable and viable. In relation to intelligent buildings, focus has been on manufacturing, monitoring and use of intelligent materials. The development of intelligent buildings and pervasive computing will of course play and important role in the development of dynamic architecture concepts. Figure 5 shows an example from a project at the Aarhus School of Architecture, about an intelligent building that adapts to a particular landscape's climate conditions [19].

Building features supporting the users' activity

The research in this area is related to the purpose of the building. If it is a private home the focus is on support for family life in the building, including access to relevant information and entertainment as well as support for using the home as base for work.

If it is an office building the focus is on support for people's collaboration around documents and objects. If it is a building for manufacturing or an airport, the focus may be on different forms of robots and transport technologies that have to be integrated in the building.

Finally, design and development support requires integrated support for working with physical models and prototypes in combination with digital documents. These technologies have recently been coined with the term Roomware [31].

In the Lab. for Interactive Workspaces (http://www.daimi.au.dk/ispace/), we have developed room-sized prototypes combined with a concept for how information and materials can be brought in and out of the room, and for shift between private and shared forms of information and materials [11]. The prototypes take advantage of the Open Hypermedia application "Manufaktur" [4] as interface in the prototypes. This interface provides a link structure that supports users working with "live" documents and objects in a 3D environment where "workspaces" are used as a structuring mechanism. Furthermore the application supports annotations in the shape of notes and as separate sketches or at notes attached to documents.

All interaction with the prototype applies an IR-pen and a wireless keyboard. The room has interactive walls with rear projections fig. 6, serving as enhanced whiteboards. The interactive wall can be used as an ordinary 2D white-board and seamlessly move into a 3D mono interface allowing users to place documents and objects in the background, in clusters, on top of

each other, etc.; creating more room for work while maintaining awareness of collaborative manipulation of other relevant documents and objects. It further contains a designer's workbench fig. 6 with a projection in the tabletop showing the projected workspaces either in 2D or 3D. Moreover, it supports a seamless transition to passive stereo visualization of digital models (requiring polarized glasses), such that digital models of design objects can be directly compared to physical models and previous versions placed on the table. The Designers' Workbench attempts to fill the gap between visualization systems and pure 2D digital desks in that it provides support for ordinary 2D documents and 3D models in the same integrated environment.

Through palmtops users can bring electronic link structures to and from the room, to be accessed on the palmtop or on walls and boards elsewhere. Objects can be moved between walls, the table and the personal palmtop.

Two of the prototypes in the Laboratory for Interactive Workspaces i.e. the "interactive wall" and the "designer's workbench" has been evaluated with users performing a brainstorm session [3] fig 7. The evaluation showed benefits such as: enabling the accumulation of knowledge, sharing of materials that can be directly referred to in discussions and altered if needed, and an immanent possibility for rearranging materials to fit a collective view of the project at hand. The evaluation also showed a series of needs yet not implemented, especially regarding the interaction with the materials displayed. When wanting to rearrange the materials the users expressed a wish to do that by just grabbing the document by hand and moving it, while when they wanted to ad content to a document they'd want to use a pen or alike, patterns of actions known from manipulating physical documents.

Construction and manufacturing processes

The research fields described above of course impact the design and programming of the buildings and elements in the building. But the construction process per se, will also undergo changes and it is a research area in its own right. There is an emerging focus on industrializing the building construction and element manufacturing process similar to what has happened to ship and aircraft manufacturing. In the building construction process, focus needs to be on development of standards and application of 3D models in the management of the process. There is a huge activity in this domain in the EU, as mentioned in section 3, represented by the projects: Distributed Virtual Workspace for Enhancing Communication within the Construction Industry (IST-1999-13365), Electronic Communication in the Building and Construction Industry: Preparing for the New Internet (IST-1999-10303), Intelligent Services and Tools for Concurrent Engineering (IST-1999-11508), Open System for Inter-enterprise Information Management in Dynamic Virtual Environments (IST-1999-10491), Satellite-Based Remote Multi-Project Reporting and Controlling in the Construction Industry (IST-1999-20488).

In this domain the researchers from CfPC have experience from former EU projects entitled EuroCoOp (1991–92) and EuroCODE (1993–95), where documentation, coordination and communication supporting tools such as open hypermedia systems, coordination tools and mediaspaces were developed and evaluated in the context of the construction of the Great Belt Link. This work has later been elaborated in the Octopus project in collaboration with Det Norske Veritas and Norwegian Computing Center, Oslo, in a project on quality and maintenance information for 3D vessel models.

When considering new methods for constructing buildings and intelligent buildings it is of special importance to take into account the integration of pervasive computing technology, since it is very important to develop the electronic infrastructure in an interplay with the rest of the construction process if one wish to achieve an integrated solution at a reasonable price. The implication is that a cross-fertilization of the methods for software/hardware construction and architecture/engineering is necessary to accomplish future buildings constructions efficiently.

Future research and new approaches

The Laboratory for Interactive Workspaces in at CfPC was established to work with augmented reality [21] in particular the notion of computer augmented spaces and fields. The work in the Laboratory for Interactive Workspaces has revealed the need for an extended concept of the relation between spaces and computation, which we develop in the recently started research project WorkSPACE (http://daimi. au.dk/workspace).

We call such augmented work environments Spatial Computing Environments emphasizing: 1) that computing takes place inside many components/components of the distributed spaces and fields; and 2) computing tracks objects and people and affects the physical spaces through projections, sound, light etc. Spatial computing take advantage of the more general notion of spatiality and enhance it by tracking spatial arrangements in the real world and combine it with the enabling of spatial arrangements in the computer while emphasizing that computing takes place inside many components/components of distributed spaces and fields and recognizing e.g. that the spatial arrangement of documents and objects in our environment often is used to prioritize and show the significance and importance of the materials in e.g. an office. Computing isn't confined to dedicated rooms and places but can and will occur almost anywhere in time and space.

The emerging research fields indicated in this paper, among others the concept of Augmented Reality is often considered based on interdisciplinary ways of working. Though the WorkSPACE project takes departure in known and well-documented research methods derived from computer science, sociology and architecture the ambition within the project is to challenge these methods by applying a post-disciplinary approach rather than an interdisciplinary approach. By the concept of post-disciplinary research methods we seek to establish a common research approach that is comprised of selected methods derived from the involved research disciplines, while adding new ones that can bridge the disciplines and become common to all the involved parties. Through this approach we aim to enable the description of aspects, which today goes beyond each discipline e.g. how to design experiences, how to design for users unforeseen and creative use of provided artifacts. One of the major challenges within the project is to work with the experience of the dynamic environment that will emerge when implementing Augmented Reality. To perceive and react it is necessary to be able to relate sensations to something known and/ or learned, but how can we endower points of reference in a dynamic context and how will they manifest them selves in a dynamic environment where the possibilities at hand constantly is evolved through users interactions and manipulations changing the cultural framework for the perception of an artifact or the whole environment. Dealing with questions as above will indicate the possibilities for forming a new design paradigm embracing the never concluded design artifact and what in the future will be subject to design while products alone cannot be regarded as the result of a design process, but merely designing the act and limitations of using an artifact inspiring and enabling the user to form the provided artifact.

Architectural research and IT, towards a new discipline

As indicated above not only design and architecture faces new challenges but almost any other discipline will be affected by the increased use of IT. Concepts and fields of research touched on in this paper will influence architectural research both on the level of what can be examined and analyzed by means of new applications and devices changing the way of presenting architecture and design from abstract representations as plans, facades and cardboard models to enable a more accurate verification of the architectural initiative in context. But perhaps most evidently the change will happen in that design and architectural objects will be tied to the use of IT as an inherent property of the product as well as IT will mature from being aimed at specific tasks confined to a grey box with which one only can interact through mouse and keyboard. On the one hand applying design and architecture to IT the concept of interacting with computers will change to being a more integrated element of the environment. On the other hand the introduction of IT in buildings and design artifacts in most cases relate to a functional purpose, which cannot alone be determined and decided upon from aesthetic considerations by the designers and architects in a vacuum. Integrating IT functionality calls for the use of participatory design [9][10] methods involving prospective users actively in the design of the artifact or building, as well as the inclusion of cultural and social parameters in the totality of the experienced design solution.

The research initiatives described in this paper together with a wide range of projects and competencies involved in research at the Center for Pervasive Computing situated at Katrinebjerg in Aarhus forms a plateau for proposing a new education denoted with the working title e-Design. The education will be at master's level and carries the ambition to comprise diverse competencies ranging from art and aesthetics, architecture and design, multimedia, computer science, media and information science potentially forming a new discipline. While taking advantage of the academic skills and approaches of the students achieved by a bachelors degree from either of the mentioned disciplines e-Design will focus on common challenges that bridge disciplinary boundaries while enabling the students to maintain and extend their basic approach being either aesthetic, technical or humanistic.

The challenges of augmented reality and pervasive computing are interdependent between disciplines e.g. computer science will increasingly have to support the use of arbitrary objects e.g. ordinary paper, furniture and accessories as means of interaction with computers as well as to support customized interaction tools, while the challenge within architecture and design is to manage the plethora of properties inherent in both physical objects and in IT products to form consistent and perceivable atmospheres related to the activities conducted in the environment enabling appropriate feedback to computational systems. Furthermore other disciplines will have the focus on how information is displayed and what kind of activities this might initiate. These challenges can be conceived to form spheres of contact between the user and artifacts emphasizing that many types of activities can be related and connected to computation. These challenges have been

Peter Gall Krogh, Assistant Professor
Aarhus School of Architecture
Center for Integrated Design
Dept. of Communication Design
Email: Peter.Krogh@a-aarhus.dk

Kaj Grønbæk, Professor
Center for Pervasive Computing
Dept. of Computer Science,
University of Aarhus
Email: kgronbak@daimi.au.dk

indicated though not fully dealt with in research areas as interactive rooms and buildings, wearable computing, ambient media, tangible bits e.g. described by [15][25].

With respect to education the main effort needs to be targeted towards engineers and architects. These professions need to develop basic knowledge about the role of IT in relation to buildings and construction processes.

With respect to research, universities and companies have started focusing on pervasive computing. Center for Pervasive Computing at Katrinebjerg in Aarhus, Denmark, has initiated the largest activity in Denmark on pervasive computing, including technologies for the development of intelligent buildings and interactive workspaces. In the center, computer scientists, architects, engineers, multimedia researchers, aesthetic researchers and students work together on common projects. The lab facilities including competencies are gathered: 3D-visualisation and simulation, embedded object oriented systems (Java), interactive workspaces, architecture and industrial design, mobile and wireless systems, HCI, robotics, hypermedia and internet-technology as well as research on New Ways of Working. Intelligent buildings will be among the focus areas for research in the Danish Center for Pervasive Computing.

The various aspects that will be a part of the new education will take departure in the approach of supporting work or task related activities by means of IT, but this approach will be challenged by the fact that not all we do as human beings can be related to a specific functions or needs. Today IT supports work, consumption and leisure, but there is much more to human life than this. Much of our activities are related to social chitchat, irrational thinking and even idiosyncratic behavior. How these aspects can inform and inspirer the design of augmented reality environments and pervasive computing will be one of the major issues in the coming years of teaching and research with this emerging discipline of e-Design.

Conclusion

In this paper we have illustrated the emergence and the impact of pervasive computing on architecture and industrial design. We have given a number of examples of related research fields and given specific project examples from the Center for Pervasive Computing at the University of Aarhus. The illustrations and examples have served as the motivation for establishment of a new post-disciplinary research and educational domain, which we denote with the term e-Design, and which will give rise to a new educational initiative combining Architecture and IT.

Acknowledgements

We wish to thank our colleagues from the Laboratory for Interactive Rooms as well as colleagues from the projects contributing to the work. The work has been supported by the EU ESPRIT LTR Project 31870 'DESARTE', the Danish Research Council's Center for Multimedia (project no 9600869), the Danish Center for Pervasive Computing, the Danish Center for Integrated Design, and the EU IST-2000-25290 project 'WorkSPACE'. We also thank reviewers and conference participants for the their comments on the papers [10][17] that has inspired this paper.

References

1. Ambiente, GMD Germany, (www.darmstadt.gmd.de/ambiente/)
2. Banhams, R. (1960): Theory and Design in the first Machine Age. Architectural Press, London
3. Bødker, S., Krogh, P. and Petersen, M.G (2001), The interactive design collaboratorium. to appear in: Proceedings of Interact 2001
4. Büscher, M., Christensen, M., Grønbæk, K., Krogh, P., Mogensen, P., Shapiro D., and Ørbæk, P. Collaborative Augmented Reality Environments: Integrating VR, Working Materials, and Distributed Work Spaces. In proceedings of CVE2000, San Francisco, Sept. 10–12, 2000.
5. Cook, Peter. Archigram. Princeton Architectural Press. September 1999. pp 135. http://www.papress.com/books/1568981945. html
6. Dunne, A. (1999) Hertzian Tales, RCA CRD London
7. Furby and AI: http://ai.tqn.com/compute/ai/library/weekly/aa101398.htm
8. Gideoens, S. (1948): Mechanization takes Command, New York
9. Greenbaum, J., & Kyng, M. (1991). Design at Work: Cooperative Design of Computer Systems. Hillsdale, NJ: Lawrence Erlbaum Associates.
10. Grønbæk K., Krogh P. & Kyng M. (2001). Intelligent Buildings and pervasive computing – research perspectives and discussions. Architectural Research and Information Technology, Nordic Association for Architectural Research, Århus School of Architecture 2001. pp. 33–39
11. Grønbæk, K., Gundersen, K. K., Mogensen, P., & Ørbæk, P. Interactive room Support for Complex and Distributed Design Projects. In proceedings of Interact 2001, Tokyo Japan, July 2001.
12. Grønbæk, K., Kyng, M., & Mogensen, P. (1993). CSCW Challenges: Cooperative Design in Engineering Projects. Communications of the ACM, 36(6), 67–77.
13. Intelligent transport association (www.itsa.org/)
14. Interactive Workspaces, Stanford University, USA, (graphics. stanford.edu/projects/iwork/)
15. Ishii, H. and Ullmer, B. (1997): Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. In proceedings of CHI97
16. JAVA CLDC and the K Virtual Machine (KVM) (http://java.sun.com/products/cldc/)
17. Krogh P. & Grønbæk K.(2001). Roomware and Intelligent Buildings – obejcts and buildings become computer interfaces. Architectural Research and Information Technology, Nordic Association for Architectural Research, Århus School of Architecture 2001. pp. 63–68
18. Local Operating Networks (LON), Echelon and LonWorks: (www.echelon.com/) and (rust.lbl.gov/~torschmied/lw_summ. html) and http://www.lonmark.org/solution/building.htm.
19. Løssing, T. (http://www.kollision.dk/rubjerg/)
20. Mackay, W. E. (1998). Augmented Reality: Linking real and virtual worlds: A new paradigm for interacting with computers. In Proceedings of the ACM Conference on Advanced Visual Interfaces (AVI '98). New York: ACM.
21. Mackay, W. E. (1999). Media Spaces: Environments for multimedia interaction. In M. Beaudouin-Lafon (Eds.), Computer-Supported Cooperative Work (pp. 55–82). Chichester: Wiley and Sons.
22. Manzini, E. (1990): End of the Mechanical Age, History of Design 1919 – 1990, The Dominion of Design pp. 34–55
23. Meyer H. (1926) "Die neue Welt". In C. Schnaidt, Hannes Meyer, Niglei Teufen, 1965
24. MIT medialab Intelligent Room (www.ai.mit.edu/projects/hci/)
25. Mitchell, W. J. (1999): e-topia, MIT press, Boston 1999
26. Mogensen, P. and 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.
27. Nielsen, R., Architect, AAA, and Superflex: Karlskrona2 project (www.karlskrona2.org) and (www.superflex.dk)
28. Office Vision, DTI, (www.it-vision.prod.dti.dk/officeV.htm)
29. Rekimoto, J. and M. Saitoh. Augmented surfaces: A spatial Continuous Work Space for Hybrid Computing Environments. in CHI '99. 1999.
30. Rekimoto, J. Pick-and-Drop: Manipulation Technique for Multiple Computer Environments. in UIST'97. 1997.
31. Streitz, N.A., et al. Roomware for Cooperative Buildings: Integrated Design of Architectural Spaces and Information Spaces. in CoBuild '98, Cooperative Buildings – Integrating Information, Organization, and Architecture. 1998. Darmstadt, Germany.: Springer: Heidelberg.
32. Telenor's Future home (http://www.telenor.no/fou/

english/prosjects/fh/hjem.shtml)
33. UniBank's new headquarter (www.lonmark.org/solution/building/ unibank.htm)
34. Villa Vision, DTI, (www.kulturnet.dk/homes/gldok/data/031/1/text.htm).
35. Weiser, M., „Some Computer Science Problems in Ubiquitous Computing," Communications of the ACM, July 1993.
36. Wellner, P., Mackay, W., & Gold, R. (1993). Computer Augmented Environments: Back to the Real World. Special Issue of Communications of the ACM, 36(7), 24–26.
37. Wolfsburg2 project (www.wolfsburg2.org/main.html.)
X10 wireless home networks (www.x10.com/)