M. Fjeld, M. Bichsel, F. Voorhorst, K. Lauche, H. Krueger and M. Rauterberg (1999): Designing graspable groupware for co-located planning and configuration tasks. EACE Quaterly, Vol. 3/2, pp. 16-21.

Designing graspable groupware for co-located planning and configuration tasks

MORTEN FJELD[1], MARTIN BICHSEL[2], FRED VOORHORST[1], KRISTINA LAUCHE[3], HELMUT KRUEGER[1] and MATTHIAS RAUTERBERG[4]

[1] *Institute for Hygiene and Applied Physiology (IHA), Swiss Federal Institute of Technology (ETH), Clausiusstr. 25, CH-8092 Zurich, Switzerland*

[2] *Institute for Design and Construction Methods (IKB), Swiss Federal Institute of Technology (ETH), Tannenstr. 3, CH-8092 Zurich, Switzerland*

[3] *Institute for Work and Organisational Psychology (IfAP), Swiss Federal Institute of Technology (ETH), Nelkenstr. 11, CH-8092 Zurich, Switzerland*

[4] *Center for Research on User-System Interaction (IPO), Technical University Eindhoven (TUE), Den Dolech 2, NL-5612 AZ Eindhoven, The Netherlands*

E-mail: fjeld@iha.bepr.ethz.ch

1. Introduction

This paper shows some of the vital steps in the design process of a graspable groupware system. Activity theory is the *theoretical foundation* for our research. Our *design philosophy* is based on the tradition of Augmented Reality (AR), which enriches natural communication with virtual features. Another important part of our *design philosophy* is the use of coinciding action and perception spaces. We developed groupware for layout planning and configuration tasks called the BUILD-IT system. This system enables users, grouped around a table, to cooperate in the design manipulation of a virtual setting, thus supporting co-located, instead of distributed, interaction (Rauterberg et al., 1997a, 1997b, 1998; Fjeld et al., 1998a). The multi-user nature of BUILD-IT overcomes a serious drawback often seen with CSCW tools, namely that they are based on single-user applications (Grudin, 1988). We believe that co-location is an indispensable factor for the early stage of a complex planning process. Input and output, however, can be prepared and further developed off-line (Fjeld et al., 1998b), using any conventional CAD system.

2. Goal directed and exploratory action

In the field of work and organisational psychology, a prominent manifestation of activity theory is the German tradition of action theory (Hacker, 1994; Frese and Zapf, 1994; Volpert et al, 1989; Frese and Sabini, 1985). From Hacker's (1998) point of view, work is the most important kind of activity, more important than learning and play. Work is part of the society's production process and highly influences humankind and individuals. Therefore, in his theory of action regulation Hacker focuses on goal-directed actions. A *complete action cycle* (Fig. 1) for goal-directed pragmatic action consists of:

(1) re-defining the given task into an individual goal,
(2) planning according to the conditions of execution, including selection of

tools and preparation of actions necessary for goal attainment,
(3) physical (or even mental) performance and
(4) control according to the set goal via different sources of feedback.

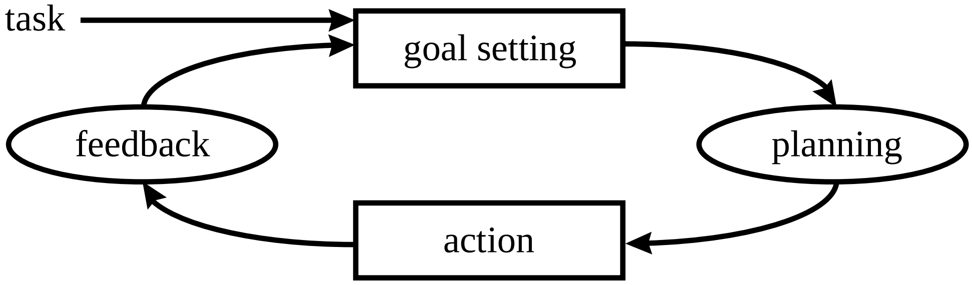


Figure 1. A *complete action cycle* for goal-directed pragmatic action as suggested by Hacker, 1994. Action is derived from goal setting.

Both our own groupware design process *and* the planning task for which we are designing the groupware are not exclusively goal-directed; they also have exploratory elements. Exploratory epistemic (Kirsh and Maglio, 1994) actions are performed to unveil hidden information or to gain insight that otherwise would require a great deal of mental computation. Exploratory action means that no specific goal is available for initial action. Only after feedback, which gives information on the means available, can a goal be generated. Based on this goal, a new planning stage and a new action phase can be initiated. Thereby, an alternative kind of *complete action cycle* emerges (Fig. 2).

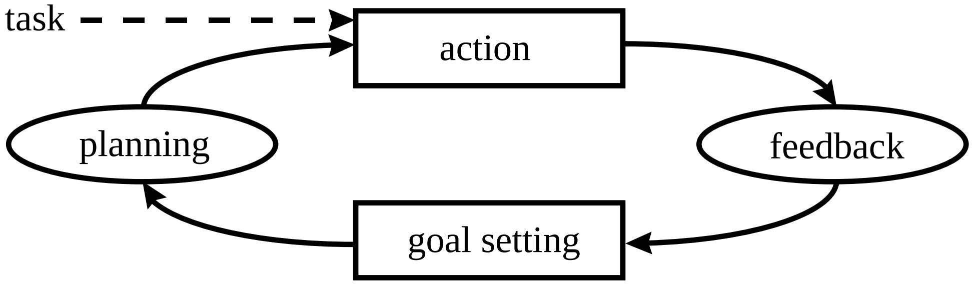


Figure 2. A *complete action cycle* for exploratory epistemic action. Goal setting is derived from action.

Based on these ideas, our aim is to design for goal-directed pragmatic *and* for exploratory epistemic action.

3. Design philosophy

In this section we present our design philosophy, which is based on coinciding action and perception spaces, in its relation to AR.

3.1. AUGMENTED REALITY

Computer-supported group work has allowed for distant and asynchronous communication between people and has helped build bridges in our global economy. This has brought about many well-advertised advantages, ranging from economic benefit to less status-oriented network communication. However, with many CSCW applications users hardly interact with their physical environment. They deal with virtual objects only, which is also the case for most single-user applications. Sometimes users are even embedded in a fully virtual world, unable to draw on any attributes of the tangible world. Much of the users' mental capacity is employed to adapt to the virtual world, leaving less capacity for actual task solving.

An alternative approach is to bring the *virtual* world of computers into the *real* world of everyday human activity. This approach includes aspects of natural communication which serve as mediators for mutual understanding: eye-contact, body language and physical object handling. It is *non-intrusive*, using no gloves or helmets, and thereby respects the body-space (Rauterberg, 1999). At the same time users can still draw on the advantages of a virtually enriched world, which is of particular importance to planning tasks. The activity of planning is intrinsically virtual because it involves reflecting on and modifying objects that only exist in the future. Virtual objects can be more easily changed than physical objects, can be stored in external computer memory and can be visualised for interaction purposes. Thus both physical and virtual methods have their rightful place in a planning process. A specific aim of our project is to study ways to integrate the real-world and computer-mediated activity. This is how we came to work within the tradition of AR, where computer-generated and real-world objects are handled in one workspace.

Figure 3. AR means that a real workspace (left) is augmented, or enriched, by a virtual world (right). Even when users interact with the projected, virtual objects, they do not leave the real world context (e.g. sketching) and tools (e.g. pencil).

AR was first described by Wellner et al. (1993). The goal of AR is to ”allow users to continue to use the ordinary, everyday objects they encounter in their daily work and then to enhance or augment them with functionality from the computer” (Mackay et al., 1995). According to Mackay, AR means that computer information is projected onto drawings so that users can interact with both the projected information and the paper drawing (Fig. 3). The first brick-based AR system was described by Fitzmaurice et al. (1995).

3.2. ACTION AND PERCEPTION

Another important aspect of our design philosophy is the coincidence of action and perception space (Rauterberg, 1995). When handling real objects, the space in which we act coincides with the space from which we receive visual feedback: we can see what we do. This is not the case for virtual object handling with a mouse-keyboard-screen interface, where there is a *separation* between action and perception spaces. Input and output devices are separated. To overcome this separation, Rauterberg (1995) suggested an alternative approach to interface design, an approach where action space and perception space *coincide*. Support is given by Hacker and Clauss (1976), who found that performance increases when task relevant information is offered in the same space where action takes place. This principle not only applies to visual but also to haptic or tactile feedback. Akamatsu and MacKenzie (1996) showed how tactile feedback might improve task-solving performance.

4. The BUILD-IT system

BUILD-IT is a planning tool based on state-of-the-art computer vision technology. This tool enables its users to cooperate in a virtual planning process for a real-world setting, such as a room, a school, a factory or a piazza. Grouped around a table and employing real bricks, users can select and manipulate virtual objects within the setting which they are planning. At all times the users have two up-to-date views of the setting they are creating and manipulating: the plan view and the side view. The plan view is the bird's eye view from above - which is projected onto the table. The side view is projected onto a wall near the table. In the case of the side view a virtual camera, which can be either outside or inside the plan view, allows the users to choose from which position the side view is to be projected. The side view can also be zoomed. In the case of the plan view the entire projection of the setting can be shifted from side to side, rotated or zoomed. The plan view also contains a virtual storage space for objects not in immediate use. It allows users to create multiple object instances. Objects brought back to the storage space are deleted.

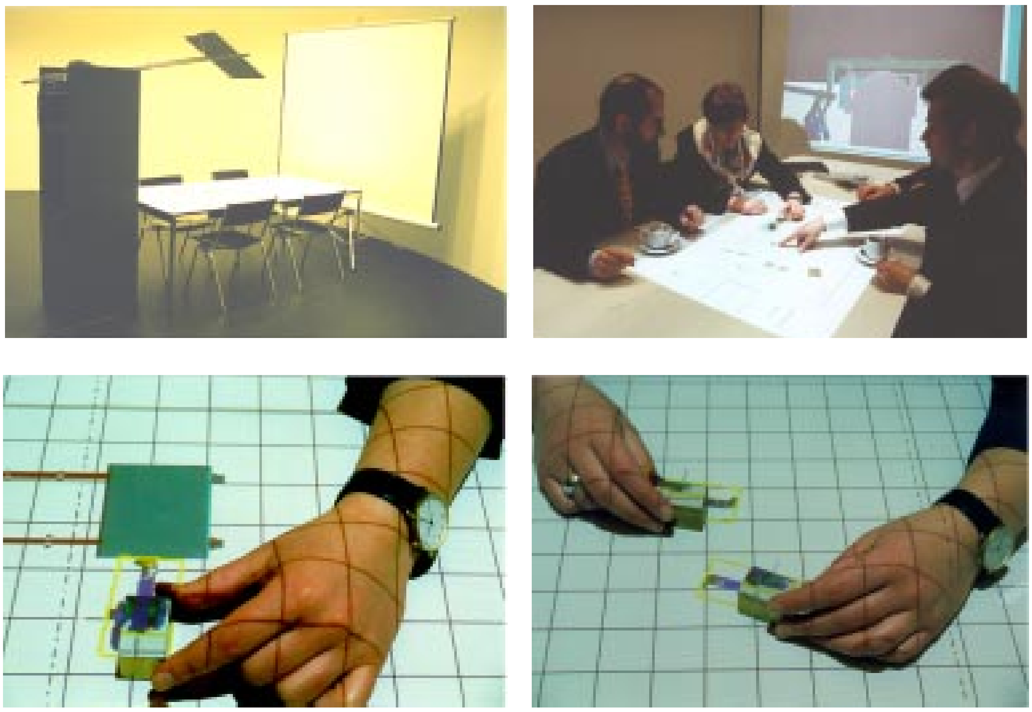


Figure 4. BUILD-IT consists of a rack, mirror, table, chairs and a screen (top left). In addition to a high-end PC, the rack contains two beamers, a video camera and a light-source. The system offers two perspectives of the same setting: a horizontal *plan view* for combined action and perception and a vertical *side view* (top right). Objects projected in the *plan view* can be rotated and positioned using a brick (bottom left). Bimanual interaction is a vital part of the interaction concept (bottom right).

Real bricks represent a new way of interaction. This approach was first explored using tethered (Fitzmaurice et al., 1995; Fitzmaurice and Buxton, 1997) and wireless (Ishii and Ullmer, 1997; Underkoffler and Ishii, 1998) bricks. It was shown that a brick-based interface is significantly easier to use and more intuitive than a mouse-keyboard-screen (Rauterberg et al., 1996).

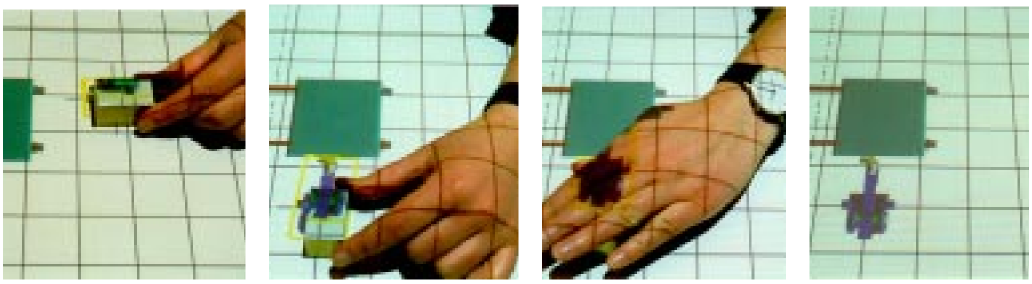


Figure 5. The basic steps for user manipulations with the brick.

In BUILD-IT mediation between users and virtual worlds follows a cyclic order (Fig. 5). Users select an object by putting the brick at an object position. The object can be positioned, rotated and fixed by simple brick manipulation. An object is de-selected by covering the brick. Then, another object is selected or the brick is left idle inside or outside the plan view.

4.1. GROUP INTERACTION WITH BUILD-IT

The system is inherently multi-user and its full potential is realised as a *mediator among members of a work group* (Fig. 6). Basic usage of the system is acquired within minutes. Therefore, it may stimulate people possessing different sets of skills and different levels of knowledge to work closer together and thereby enhance their verbal exchange. Also, since the system forces people to work with shared resources, it has a capacity to reveal potential *contradictions* among them (Holland and Reeves, 1996). A *collective learning process* can be triggered through the unifying workspace. This was actually experienced by our design team during system development work.

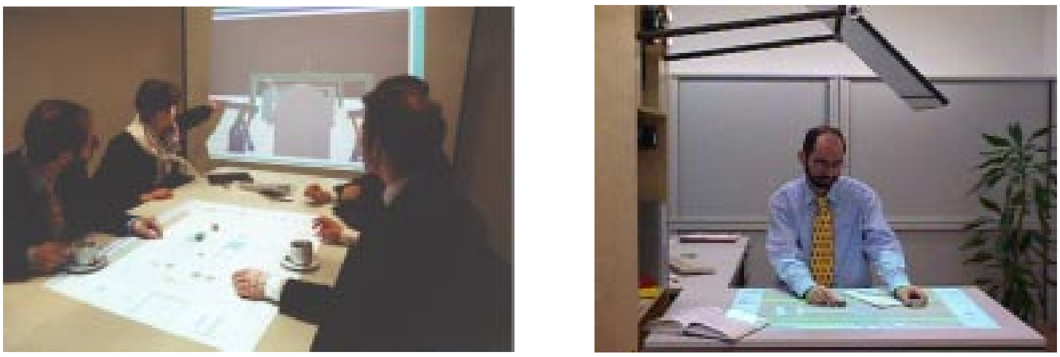


Figure 6. Typical multi-user (left) and single-user (right) situations. Interaction and display take place in the plan view, whereas an additional perspective is offered by the side view.

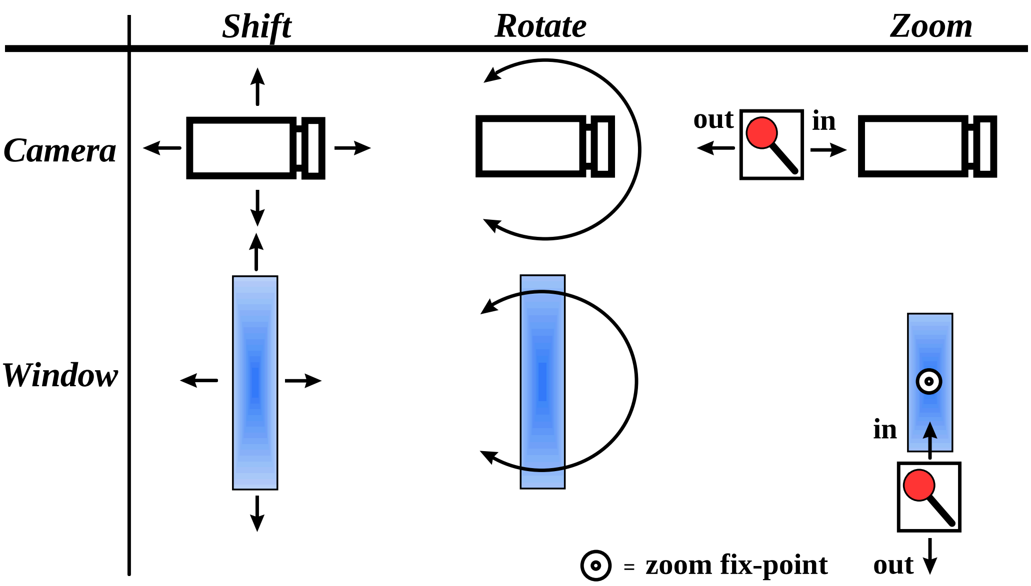
Although we have designed a co-located, multi-user groupware system, the real and virtual tools presented in this paper may be important steps towards a multi-site, multi-user system and therefore represent a technological foundation for CSCW. Based on standard software and hardware, the system will allow for a distributed networking CSCW application in the near future. Initial configuration will be transferred at start-up, then brick data only will be transferred at real-time. This will allow the use of standard, commercial communication channels.

4.2. DESIGNING FOR EXPLORATION

Our design philosophy tells us to allow exploratory behaviour and this is literally what we do with the tools presented. Another aspect of these tools is that they are partly based on two-handed, or bimanual, interaction. By using both hands a higher degree *exploratory latitude* can be reached.

The innovative feature of BUILD-IT, beyond the brick-based interaction, is that the objects are part of a 3D setting. 2D brick-based interaction has already been explored (Fitzmaurice, 1996). Also, bimanual camera handling and object manipulation in 3D graphics interfaces has been investigated (Balakrishnan and Kurtenback, 1999) using two mice, a keyboard and a screen. Here, we combine the strengths of these two approaches. The use of the multimedia framework (MET++, Ackermann, 1996) allows for full 3D interaction, including *shift*, *rotation*, *zoom*, *tilt* and *roll*. However, planar interaction with bricks provides only position and rotation but not height information. Hence, there is a need to bridge the gap between planar interaction and 3D view handling.

Table I. Camera and *Window*. The handle is drawn as a magnifying glass.



Window and *Camera* are two alternative approaches to navigation of the side view. *Window* is based on the principle of handling the virtual setting, *Camera* is based on handling a virtual observer. Based on task solving performance, we plan to test which of these two handling principles is the more powerful one (Fjeld et al., in press).

The *Window* and *Camera* objects have a fixed height referring to *virtual subject* view point (1.6 meters above the ground level). One brick offers shift and rotation, a second brick activates zooming (Table I). *Camera* (Fig. 7) sets the virtual camera of the side view. The distance between the handle and *Camera* determines the zoom factor. *Window* (Fig. 8) sets the side view border. Scaling *Window* by the handle determines *Window* size and, thereby, the zoom factor.

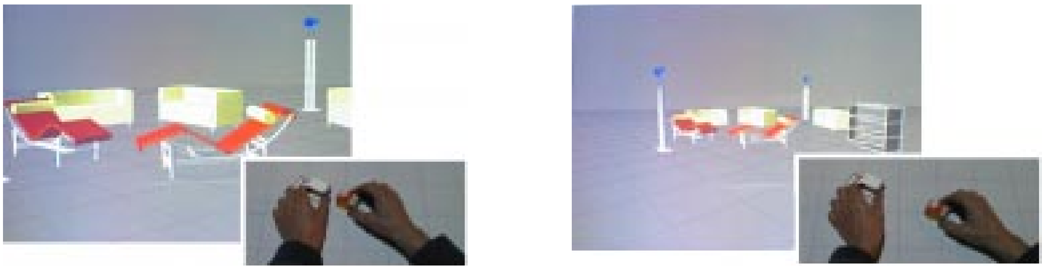


Figure 7. Camera handling: Zooming in (left) and out (right).

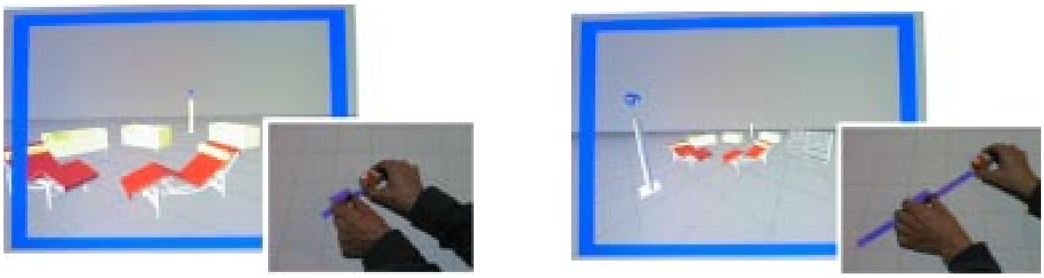


Figure 8. Window handling: Zooming in (left) and out (right).

5. Discussion and perspectives

As a result of task analysis, we identified three situations in which a graspable interaction tool could be useful. The first is c*ooperation among planning experts with different sets of skills (multi-user)*. If several planning experts are involved, the possibility of collective action regulation is fostered by gathering around the BUILD-IT table. The second is c*ommunication with customers (multi-user)*. Customers are often laypersons to planning tasks and are not used to thinking in terms of 2D views. Therefore, a play-like interaction can be the most valuable form of communication. The third is *early stages of planning (single-user)*. Though not the initial aim of BUILD-IT, it may also be used by a single person for a configuration or layout task before turning to a CAD program. For all these three situations, BUILD-IT would not be a substitute for CAD systems, but rather would serve as a pre-CAD complement in the early stages of design.

6. References

Ackermann, P. (1996): *Developing Object-Oriented Multimedia Software*. dpunkt Verlag für digitale Technologie, Heidelberg.

Akamatsu, M. and MacKenzie, I. S. (1996): Movement characteristics using a mouse with tactile and force feedback. *International Journal of Human-Computer Studies*, vol. 45, pp. 483-493.

Balakrishnan, R. and Kurtenbach, G. (1999): Exploring bimanual camera control and object manipulation in 3D graphics interfaces. *Proceedings of the CHI'99*. New York, ACM.

Fitzmaurice, G., Ishii, H., Buxton, W. (1995): Bricks: Lay-ing the Foundations for Graspable User Inter-faces. *Proceedings of the CHI'95*. New York, ACM, pp. 442-449.

Fitzmaurice, G. W. and Buxton, W. (1997): An Empirical Evaluation of Graspable User Interfaces: towards specialized, space-multiplexed input. *Proceedings of the CHI'97*. New York, ACM.

Fjeld, M., Bichsel, M. and Rauterberg, M. (1998a): BUILD-IT: An Intuitive Design Tool Based on Direct Object Manipulation. In Wachsmut, I., Frölich, M. (eds.*): Gesture and Sign Language in Human-Computer Interaction*. Lecture Notes in Artificial Intelligence, vol. 1371. Berlin: Springer-Verlag, pp. 297-308.

Fjeld, M., Lauche, K., Dierssen, S., Bichsel, M. and Rauterberg, M. (1998b): BUILD-IT: A Brick-based integral Solution Supporting Multidisciplinary Design Tasks. In A. Sutcliffe, J. Ziegler & P. Johnson (eds.)

Designing Effective and Usable Multimedia Systems (IFIP 13.2). Boston: Kluwer Academic Publishers. pp. 131-142.

Fjeld, M., Voorhorst, F., Bichsel, M. and Krueger, H. (in press): Exploring brick-based camera control. In proceedings of *HCI International'99, 8th International Conference on Human-Computer Interaction*. Munich (D).

Frese, M. and Sabini, J. (1985): *Goal directed behaviour: The concept of Action in Psychology*. London: Lawrence Erlbaum Associates.

Frese, M. and Zapf, D. (1994): Action as the core of work psychology: A German approach. In H.C. Triandis, M. D. Dunnette, L. M. Hough (eds.) *Handbook of Industrial and Organisational Psychology*, vol. 4 (2nd edition). Palo Alto, CA: Consulting Psychologists Press.

Grudin, J. (1988): Why CSCW applications fail: Problems in the design and evaluation of organizational interfaces. *In Proceedings of the Second Conference on Computer Supported Cooperative Work*. New York, ACM, pp. 85-93.

Hacker, W. and Clauss, A. (1976): Kognitive Operationen, inneres Modell und Leistung bei einer Montagetätigkeit. In W. Hacker (ed.) *Psychische Regulation von Arbeitstätigkeiten*. Berlin: Deutscher Verlag der Wissenschaften, pp. 88-102.

Hacker, W. (1994): Action theory and occupational psychology. Review of German empirical research since 1987. *The German Journal of Psychology*, vol. 18, no 2, pp. 91-120.

Holland, D. and Reeves, J (1996): *Activity Theory and the View from Somewhere: Team Perspectives on the Intellectual Work of Programming*. In B. Nardi (ed.) Context and Consciousness, MIT Press, pp. 270-275.

Ishii, H. and Ullmer, B. (1997): Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms. *Proceedings of the CHI'97*. New York, ACM.

Kirsh, D. and Maglio, P. (1994): On Distinguishing Epistemic from Pragmatic Action. *Cognitive Science*, 18, pp. 513-549.

Mackay, W.E., Pagani, D.S., Faber, L., Inwood, B., Launiainen, P., Brenta, L. and Pouzol, V. (1995): Ariel: Augmenting Paper Engineering Drawings. *Proceedings of the CHI'95, video program*. New York, ACM.

Rauterberg, M. (1995): *Über die Qualifizierung software-ergonomischer Richtlinien*, Ph.D. Thesis. Zurich: University of Zurich, p. 206.

Rauterberg, M., Mauch, T. and Stebler, R. (1996): What is a promising candidate for the next generation of interface technology. *Proceedings of the 5th International Conference INTERFACE to Real and Virtual Worlds*. Montpellier, EC2 & Cie., pp. 95-103.

Rauterberg, M., Bichsel, M., Meier, M. and Fjeld, M. (1997a): A gesture based interaction technique for a planning tool for construction and design. *Proceedings of the RO-MAN'97*. IEEE, pp. 212-217.

Rauterberg, M., Fjeld, M., Krueger, H., Bichsel, M., Leonhard, U., Meier, M. (1997b): BUILD-IT: A computer Vision-based Interaction Technique for a Planning Tool. In (H. Thimbleby, B. O'Connaill, P. Thomas eds.) *People and Computers XII, Proc. of HCI'97*. Berlin: Springer, 1997, pp. 303-314.

Rauterberg, M., Bichsel, M., Fjeld, M., Leonhardt, U., Krueger, H. and Meier, M. (1998): BUILD-IT: A Planning Tool for Construction and Design. *Proceedings of the CHI'98, video program*. New York, ACM.

Rauterberg, M. (1999): Personal communications.

Underkoffler, J. and Ishii, H. (1998): Illuminating Light: An Optical Design Tool with Physical Interface. *Proceedings of the CHI'98*. New York, ACM.

Volpert, W., Kötter, W., Gohde, H.E., Weber, W.G. (1989). Psychological evaluation and design of work tasks: two examples. *Ergonomics*, 32, pp. 881–890.

Wellner, P., Mackay, W., and Gold, R. (1993): Computer Augmented Environments: Back to the Real World. In *Communications of the ACM*, July, Vol. 36, No. 7, pp. 24-26.