

# SPATIAL COMPUTING AND AMBIENT COLLABORATIVE ENVIRONMENTS FOR DESIGN AND CONSTRUCTION

**Dan Shapiro**

*d.shapiro@lancaster.ac.uk*

*Department of Sociology, Lancaster University, Lancaster LA1 4YD, UK*

**Monika Büscher**

*m.buscher@lancaster.ac.uk*

**Preben Mogensen**

*p.mogensen@daimi.au.dk*

**Michael Christensen**

*toby@daimi.au.dk*

**Peter Ørbæk**

*poe@daimi.au.dk*

*Department of Computer Science, Aarhus University, DK-8200 Aarhus N, Denmark*

## ABSTRACT

The paper describes interdisciplinary research that has produced systems and devices to support the work of architecture, engineering and construction. Spatial computing facilitates the production of abstract and literal spaces for collaboration and teamwork, modelling and experimentation with 3D sites and terrains, bridging between digital and physical materials, mobility, and ambience, with the flexible combination of systems and devices as they are needed.

**Keywords:** Ambient computing, collaborative environments, participatory design, spatial computing, terrain modelling.

## INTRODUCTION

An interdisciplinary group of researchers, aided by European Union funding, have been bringing a range of advanced techniques to bear on supporting the work of professionals in architecture, engineering and construction. These techniques include:

- ethnography, to understand in detail the work of design and construction professionals and their needs for further technical support (Luff et al. 2000).
- participatory design, to ensure that the technologies developed are practical and useful (Büscher, Gill et al. 2001; Büscher et al. 2002)
- spatial computing, which provides a powerful substrate and medium for information systems, services and devices (Ørbæk 2003).

Landscape architecture has provided the principal research domain, with the results generalisable to a wide range of activities in engineering and construction.

## SPACES FOR TEAMWORK

If design professionals are observed in their work<sup>1</sup>, one can immediately see (Figure 1):

- that it is teamwork, done collaboratively
- that it is heavily dependent on the spatial arrangement, and continuous dynamic re-arrangement, of a wide range of materials: plans, sketches, diagrams, photographs, scale models, samples of materials, catalogues, and more

(colour versions of all figures can be seen at [www.ist-palcom.org/publications/files/aec2005.pdf](http://www.ist-palcom.org/publications/files/aec2005.pdf)).

This is also the case for most areas of work, but it is more visually striking in the design and engineering professions. The fact that all these materials are instantly

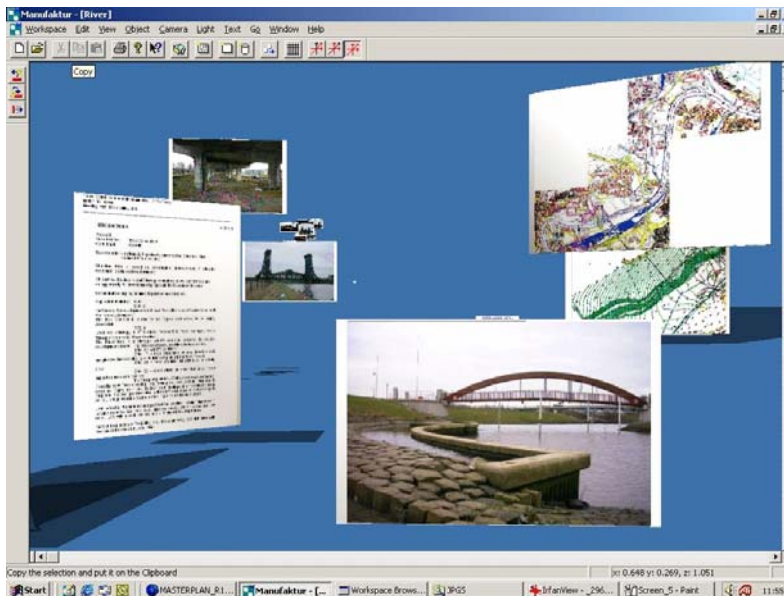
recognisable helps to make the spatial arrangement, and the ‘state of play’ of the work, intelligible at a glance. This is well supported in the physical environment. But professionals increasingly have to work with the digital versions of their documents and materials, and there they have had no comparable supporting environment.



**Figure 1: Design professionals at work**

### **A simple digital space**

In Figure 2, a simple 3D workspace has been produced using a spatial computing software prototype, MANUFAKTUR.<sup>2</sup> It contains references and views onto a set of objects, which were ‘drag-and-dropped’ into the space, e.g. from folders. Double clicking any of the document objects will launch it in its own application – which might be MS Word, Excel, AutoCAD, Photoshop, etc. – and any changes made to it will be updated in the workspace view in near real time. The objects can be sized, moved and rotated in three dimensions, giving a full 6 degrees of freedom. The viewer/viewpoint can also move freely in the space.



**Figure 2: A simple 3D workspace**

Workspaces are continuously saved, so a particular configuration can always be returned to if work is interrupted. Objects in a workspace are references to the underlying materials, not the materials themselves, so that workspaces can be composed for particular purposes, altered at will, and deleted, without affecting at all the underlying organisation of those materials, e.g. in a directory structure.

### Sharing materials

The workspace in Figure 2 can be worked on simultaneously by multiple distributed users.<sup>3</sup> More distinctively, though, in physical space, there can only be one instance of the same object (which is not a copy), and an object can only be in one place at one time. In the 3D workspace, however, we can create ‘quantum’ spaces or parallel universes, in which the same material can simultaneously be in different places and different contexts, and encountering different ‘experiences’.

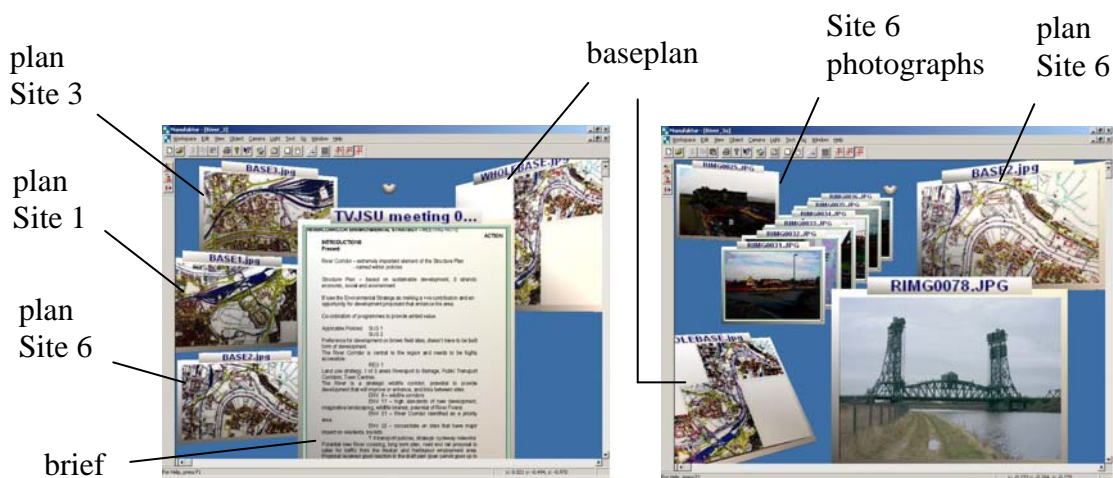


Figure 3: Workspaces with partly overlapping materials

In Figure 3 we have a pair of workspaces with partly overlapping materials, being used by two people with partly overlapping work (or, equally, by the same person for different partly overlapping tasks). If A (left) moves ‘plan Site 6’ in his workspace, it will not move in B’s workspace; but if A makes a visible change to ‘plan Site 6’, this will also be visible to B, and helps her to maintain a watching brief on progress. A and B could be in different offices, or indeed on opposite sides of the world.

### Grouping materials, and spaces within spaces

It is often useful to group materials together. In Figure 4, A, on the left, has grouped plans for three urgent sites (1, 3 and 6) into a workspace. They all have dark blue borders, as does their proxy icon, and they are inside the containing workspace of the screen. B, on the right, also has an ongoing concern with the urgent sites, so she has the same workspace inside her workspace too, but she doesn’t need it at the moment, so it is closed. Workspaces are opened or closed by double-clicking their proxy icon, and all the documents in them can be moved together by moving the icon.

### Awareness and communication

The 3D workspace aims to approximate, in the digital environment, the background awareness of each others’ work that people naturally have in an open plan office. Here (below), A is using two ways of doing so. He has one of his own workspaces open, and he is using it. He also has B’s workspace open, but pushed well to the back in the

top right corner. Any activity in B's workspace will be visible to A, but in the background. A also has C's workspace present inside his own, but it is closed. Even so, he can maintain a minimal background awareness of what C is doing because the proxy icon changes colour when activity is happening in it. Coloured corners on the individual documents also show if someone has changed it since you last looked at it.<sup>4</sup>

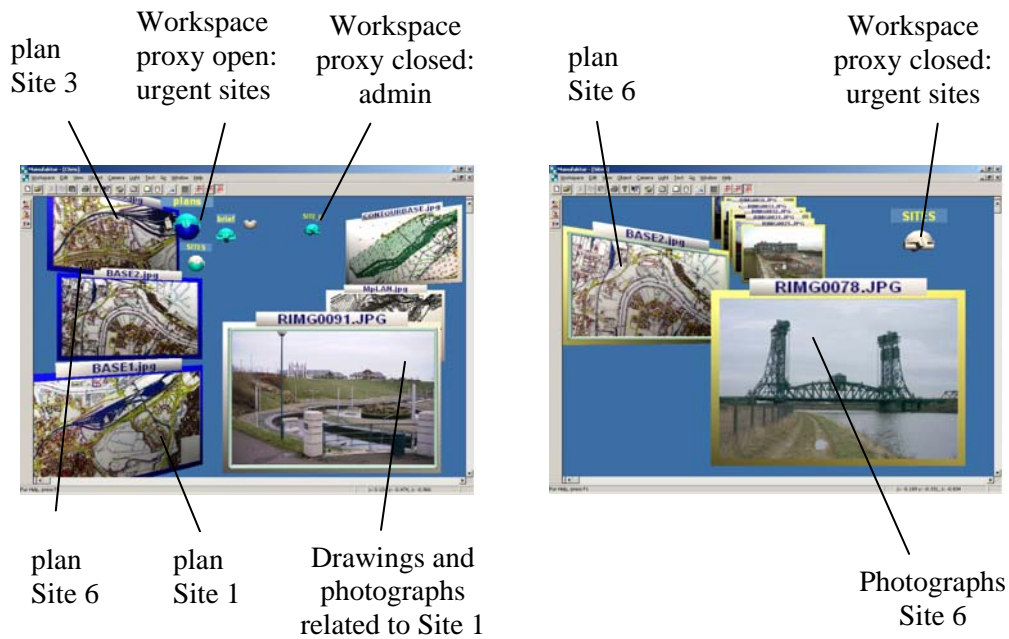


Figure 4: Workspaces with grouped materials

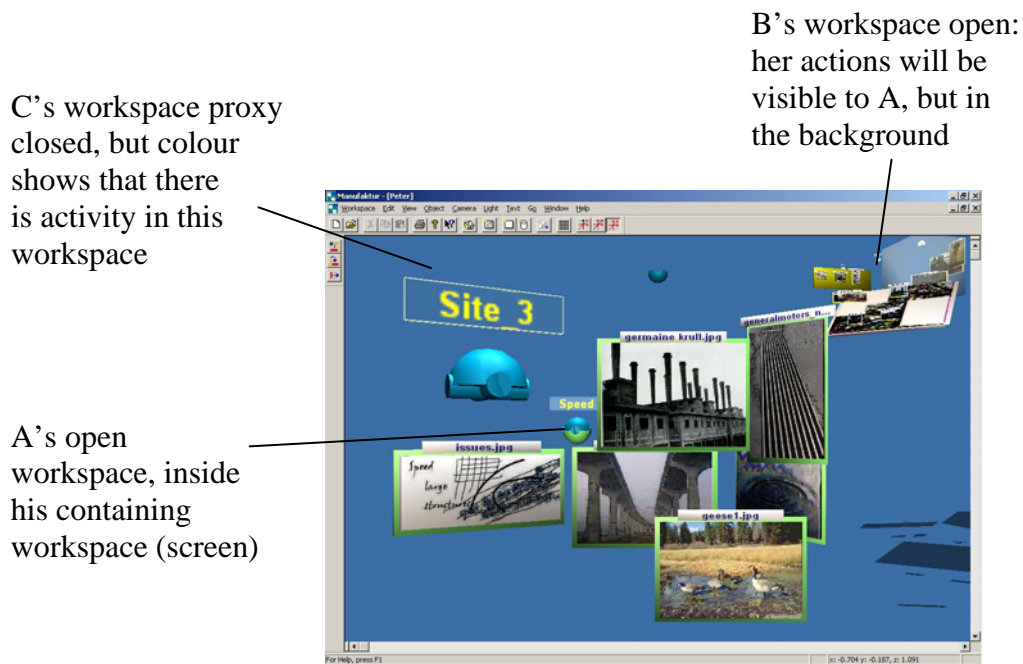
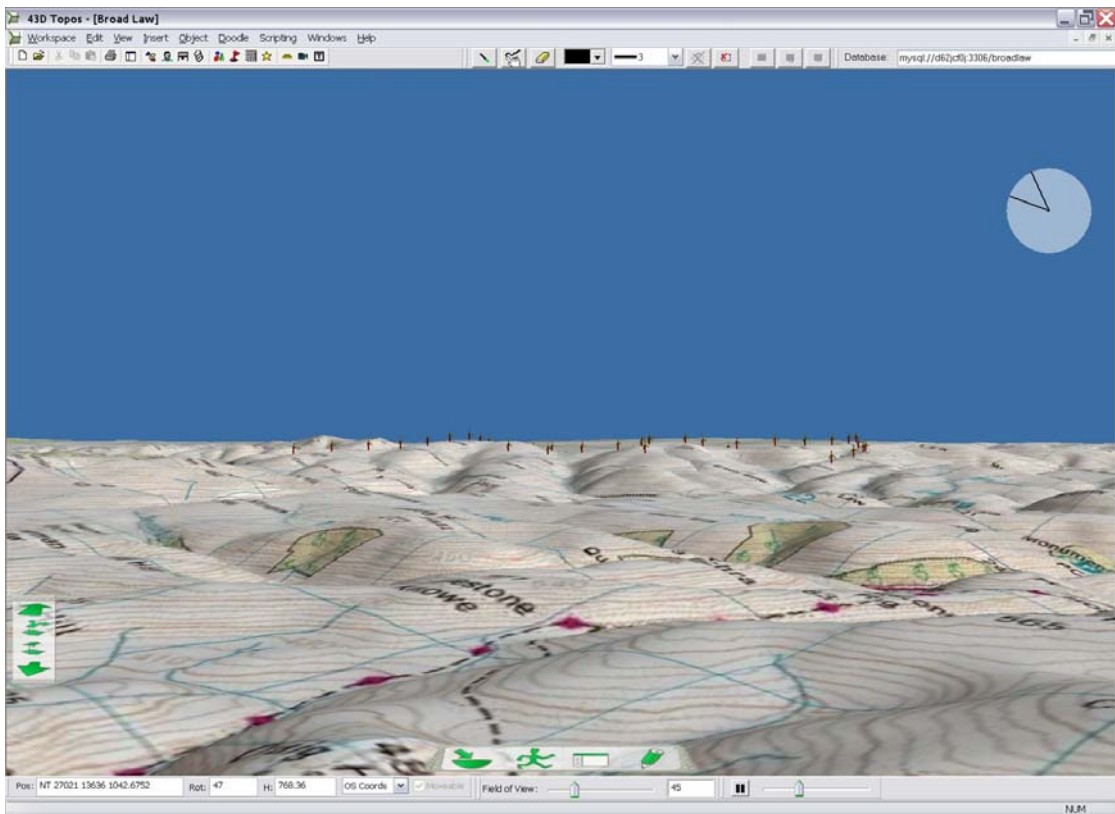


Figure 5: Mechanisms for awareness

## REPRESENTATIONAL SPACES

The previous section showed the use of the workspace as a metaphorical, abstract 3D space – a collaborative virtual environment – in which materials could be freely arranged. However, the software has also been designed to be capable of the highly accurate and highly efficient 3D representation of real spaces, which may range from a large area, such as a 80km x 85km windfarm terrain (Figure 6), through a construction site, to an individual scale model.



**Figure 6: Topos with terrain model and windfarm**

Topos<sup>2</sup> enables users to combine existing features with envisioned changes and allows for a high degree of flexibility, for example supporting on-the-fly change and experimentation with 3D visualizations. Multi-part models (e.g. of windfarms, commercial, housing and other developments, telecommunication masts and pylons in urban or rural areas, etc.) can be placed and manipulated in real time in real-data terrain models. For example, each turbine in the figure below can simply be grabbed and moved, and accurate position information is tracked and displayed dynamically. Maps, satellite photographs, and GIS data can be mapped onto the terrain. There is support for creating key viewpoints and paths for animated fly-throughs, rendering realistic impressions of walking, driving or flying through the landscape, with the option of always looking towards the development. Because this is at the same time a general Topos space, as in the previous section, other documents, e.g. photographs, can be freely placed in the space. Equally, these spaces can be shared for distributed collaboration, and the efficiency of the program and its message-passing arrangements mean that high bandwidth is not required for simultaneous use.



## WORKING ON SITE

Topos can be used anywhere with a Notebook computer, and with a fixed or mobile data connection this includes remote collaboration from the site. However, an appropriate assembly of devices enables additional on-site functionality and ways of working, which have their basis in the real problems encountered in everyday work.

### The Site Pack

The prototype Site Pack device in Figure 7 includes a tablet PC, GPS, and a digital compass, and it can display the terrain seen from the position, and looking in the direction, where it is located. This is very helpful for orientation and – for example – for choosing viewpoints in what may be a confusing terrain where the constructed objects do not yet exist.



Figure 7: Site Pack



Figure 8: Geo-referenced photographs and sketches

Another example of the use of the site pack (Figure 8) is that the planning and supervision of most development projects involves taking many photographs on site, which must then be referenced to their location and orientation. When a picture is taken using the site pack, it is positioned by the information from the GPS and digital compass on a 2D map or 3D model, thus saving much annotation on site and reconstruction at the office. Similarly, sketches can be drawn which are related to the GPS coordinates where the sketch was made.

### Feature tracking and augmented reality

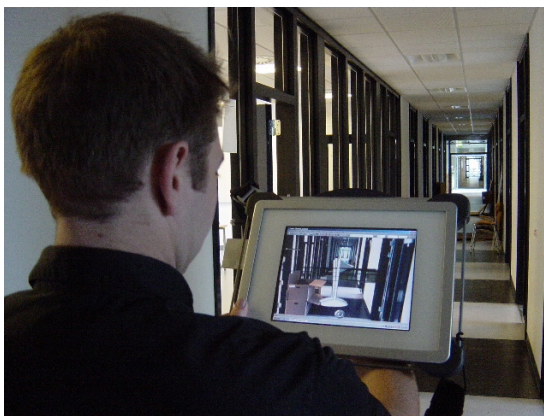
The Site Pack device in Figure 7 also contains a video camera which can display its live image on the tablet PC screen as the Topos background. Using feature tracking, Topos can place a 3D digital object (e.g. the design of a new building) in its “real life” position in the real time video picture, and thereafter one can move with the camera, while the 3D object stays in its correct “real life” position. It does this by being taught to recognise planar features in the landscape (see Figure 9). This has obvious value for planning, visual impact assessment, and presentation. As an alternative to feature tracking, determining the position can be supported by visual tags located on the trigonometry points used by site surveyors. These offer a useful supplement to GPS for calibration.

Another example is for facilities maintenance, using the overlay to show the positions of concealed services and installations (Figure 10).



**Figure 9: Overlaying live images with designed objects**

Remote collaboration is supported with the site pack, just as with Topos on any other platform, so issues to do with the planned construction in its real setting can be explained to others and addressed ‘live’. Topos also supports real-time two-way ‘doodling’ or sketching to support collaboration (saving these as layers that are kept in register with their corresponding image) (Figure 11).



**Figure 10: Overlay for facilities management**

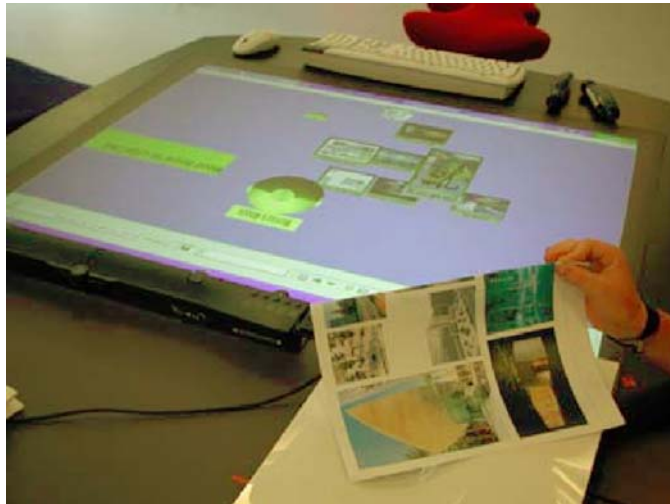


**Figure 11: Two-way remote sketching**

## **BRIDGING DIGITAL AND PHYSICAL MATERIALS**

Providing a congenial digital environment for working materials, as in the section on Spaces for Teamwork, was one ambition. A further ambition is to support bridging between digital and physical materials (Grønbaek et al. 2003). Some examples of doing that on site were already shown with the superimposition of designed elements onto a live video display. In Figure 12, a physical document has a cheap RFID (radio) tag stuck to it, and bringing it up to a ‘SpaceTable’ display causes the workspace containing the digital version of the document to open.

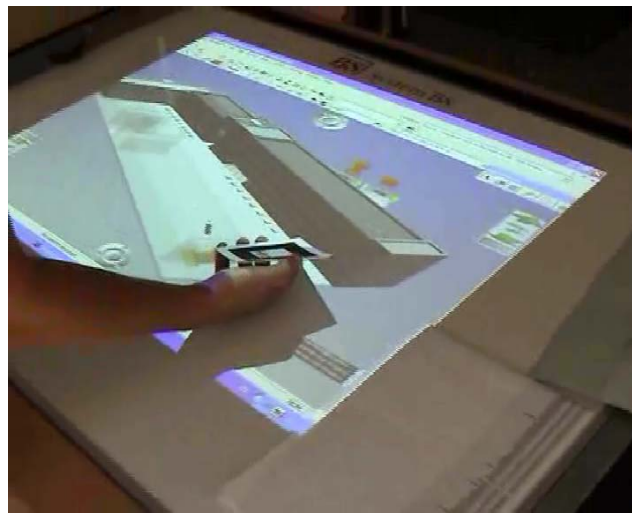
The ‘ProjectTable’ (Figure 13) makes it possible to project digital images onto physical materials on a modified draughtsman’s table. The table can also digitally capture (scan) physical materials. Moving a visual tag (Figure 14) manipulates the projection of a 3D model of a building onto the ProjectTable.



**Figure 12: A tagged paper document opens its corresponding workspace on the 'SpaceTable'**



**Figure 13: The 'ProjectTable'**



**Figure 14: Manipulating projection with visual tag**

## **AMBIENT ENVIRONMENTS: ASSEMBLING DEVICES AND FUNCTIONS**

The fields of ambient, ubiquitous and pervasive computing, and of the 'disappearing computer', cover approximately equivalent areas of information technology research. Following the inspiration of Mark Weiser (1991), they are to do with 'exploding' computing and communication power out of the standard processing and interface devices, and embedding them in large or small devices and in the environment where they can be of greatest benefit.

The Site Pack discussed above was a development in this direction, through making the inputs and outputs of processor, screen, video camera, GPS, compass, and wireless communication available to each other. Similarly with the ProjectTable (above), computational power to manipulate objects is 'lent' to a small square of paper because the scanning camera can recognise it as a visual tag. Topos also provides a range of location-based ambient services so that, for example, a portable device can recognise the presence of large wall- or table-size displays and can 'colonise' them for its own use.



In our current research with the site pack we are taking this further, investigating how the decomposition and recombination of devices and services could address problems that are actually encountered in day-to-day work. The example below follows our observations of the difficulties and frustrations of driving to and fro across a large terrain trying to identify the best (worst) viewpoints for visual impact assessment of a proposed windfarm. A video camera on the roof of the car could point constantly towards the proposed development, storing GPS location with the image, and taking higher-quality still images when required. Theoretical viewpoint candidates (from Topos) could be compared with actual images to reveal, for example, that it is actually obscured by vegetation or buildings. An audible tone could identify when one is in the 'red' (100%) portion of a zone of visual influence (ZVI). The landscape architect might leave the car and walk just with the display, with the processing carried out remotely. Most of our prototypes begin with lo-tech mock-ups such as these, with domain practitioners as co-designers.



**Figure 15: Low-tech prototype of a rooftop camera with constant direction**

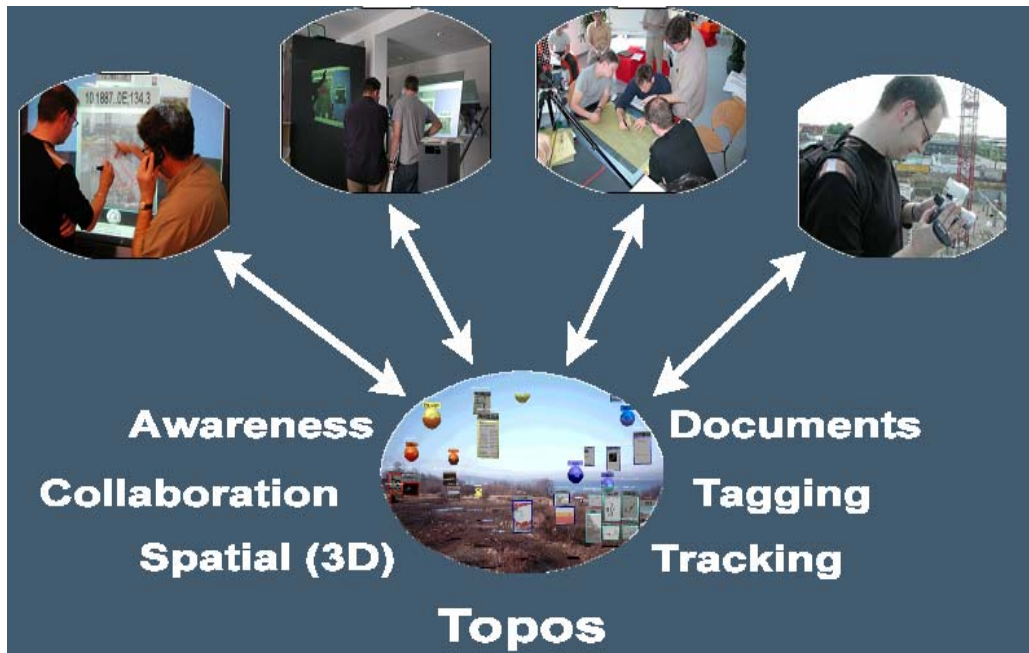
## CONCLUSIONS

The programme of research described in this paper originates in the disciplines of computer-supported cooperative work (e.g. Dourish, 2001), participatory design, and ambient computing. A key purpose was to show that innovative research in these fields can produce innovative resources and tools for architecture, engineering and construction. This is achieved in part through the combination of computer science and social science methods, so that new technologies are solidly anchored in real work problems and practices, even when they are highly radical. This has resulted in powerful software for spatial computing and for collaboration. This same underlying software, combined for some purposes with various novel devices, is capable of supporting a wide range of the activities of design and implementation professionals. These include:

- abstract and concrete spaces for collaboration and teamwork
- modelling and experimentation with 3D sites and terrains
- bridging between digital and physical materials
- mobility
- ambience, with the flexible combination of systems and devices.

These innovations have the capacity to significantly enhance the quality and efficiency of architecture, engineering and construction work, as well as helping in

early resolution of potential differences among interested parties, by making it easier to generate, experiment with and present alternative solutions.



**Figure 16: Spatial software underpinning diverse uses and devices**

The prototypes described in this paper are in various stages of development. A single-user version of Topos, oriented to the kinds of uses discussed in the section ‘Representational Spaces’, will be launched by a spin-off company in August 2005.<sup>5</sup> A client-server version of Topos with collaboration support will be launched by the same company within the following year. Development of some of the physical devices may follow. The further ambient computing developments discussed in the section ‘Ambient Environments’ are still in the early stages of research within the EU IST project ‘Palpable Computing: a new perspective on ambient computing’.<sup>6</sup>

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- Framework Programme 6 Information Society Technologies, Disappearing Computer II Programme, project 002057 ‘PalCom: Palpable Computing – A new perspective on Ambient Computing’

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## NOTES

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<sup>1</sup> A 20-second video showing this sequence of work activity can be seen at [www.ist-palcom.org/publications/files/2seats.mpg](http://www.ist-palcom.org/publications/files/2seats.mpg)

<sup>2</sup> MANUFAKTUR was an early prototype developed in the FP4 DESARTE project, 1998-2001. Topos™ is its successor, developed in the FP5 WorkSPACE project, 2001-2003.

<sup>3</sup> Topos achieves sharing in the virtual environment through a collaboration server which broadcasts movement information to subscribers to a workspace. As the movement messages are economically conveyed, collaborative use of workspaces does not require large bandwidth.

<sup>4</sup> Topos achieves this through an awareness agent that monitors activity across users and workspaces.

<sup>5</sup> 43D ApS, see [www.43d.dk](http://www.43d.dk)

<sup>6</sup> See [www.ist-palcom.org](http://www.ist-palcom.org)