

Spaces of Practice

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Abstract. This paper compares the properties of physical and digital workspaces in the context of a prototype of a collaborative virtual environment that has been developed with reference to work in design professions and concentrates on the organisation of work materials. Spatial properties are analysed in terms of the sociality of workspace use. Digital spaces can be engineered to mimic or to transcend various constraints and affordances of physical workspaces, and they can be given parallel, folded and tunnelled properties. We examine the consequences these have for the readiness-to-hand, intelligibility, and accountability of the resulting workspaces. We address means of interacting with these extended environments. Using case study scenarios, we demonstrate how ethnographic analysis and participatory design have informed the architecture, features and development of the system.

Introduction

In previous papers (Büscher et al. 1999, 2000a, 2000b) we have described the MANUFAKTUR, a still-evolving prototype of a collaborative virtual environment that permits the manipulation of diverse working materials in a three-dimensional digital space. The MANUFAKTUR was inspired in part by ethnographic observation of design professionals – architects and landscape architects – and has been realised in part through involving them in participatory design. They use a great variety of materials: plans, sketches, diagrams, photographs, scale models, samples of materials, catalogues, and more. We found that manipulating the presence and absence of these materials, bringing them into dynamic spatial relations, and referring between them, happen constantly and are not just a

context or prerequisite for design professionals in doing their work; rather, they are an integral part of accomplishing the work itself.

Figure 1 (disregarding, for the moment, the descriptive labels) shows an example of a simple MANUFAKTUR space. It contains references and views onto a set of objects. Double clicking any of the document objects will launch it in its respective application – which might be MS Word, Excel, AutoCAD, Photoshop, etc. – and any changes made to it will be updated in the MANUFAKTUR in near real time. The objects can be sized, and can be moved and rotated in three dimensions, giving a full 6 degrees of freedom. The viewer/viewpoint can also move freely in the space. A distinctive feature of the MANUFAKTUR as a virtual environment is that its emphasis is on representing the *materials* with which people are working, and the actions they are taking with them, and far less on the visual representation, e.g. through avatars, of the collaborating *persons* (cf Dourish et al., 1999, for a different recent approach to providing rich interaction with documents). The intention of the MANUFAKTUR is not at all to displace the physical work environment with a digital one. Rather, the system is based in the observation that design professionals (in common with many other kinds of workers) now find that they already have to spend many hours per day working with the digital forms of their materials, and have only the poorest of digital environments to support them in doing so. The aim is to maximise their choices in how to ‘flow’ their work between their physical and digital environments, and in how to bridge between them.¹

Physical and digital spaces

The particular purpose of this paper is to consider some of the properties that the MANUFAKTUR has (and which equivalent virtual environments would have) as a digital space in collaborative use, in comparison to the properties of physical spaces in collaborative use. At first sight it seems obvious that such virtual environments should seek to imitate or emulate three-dimensional physical space, for at least three reasons. First, since our starting point was observing the power for work practice of the arrangement of materials in physical space. Second, to take best advantage of users’ highly developed skills and competences in manipulating physical materials and creating dynamic order with them. And third, since one of the ambitions of the design is to make it possible to bridge more smoothly between working with materials in their physical and digital forms, the more congruent the environments are, the easier one might expect that bridging to be.

¹ The system is in the process of being redesigned and rebuilt from scratch so that the same code can run on multiple operating systems, and can function across the range from small handheld devices, through traditional desktops/notebooks, to wallsize and stereographic interfaces. The name for this new system is TOPOS™

The constraints of physical space

It is obvious that a digital environment could only have limited success in emulating its physical counterpart, since the capacity fully to reproduce just the visible dimension of the latter is still quite primitive, before going on to consider other senses; and since emulation encompasses not only the realisation-projection of the environment, but also the means of interacting with it. However, it soon becomes apparent that straightforward reproduction is not even the most appropriate ambition for a digital environment. This is in part because the physical environment has constraints that it may not be helpful to reproduce, and in part because the digital environment may be given different and helpful capacities that the physical environment cannot match. As Smith (1987) observed, there is a tension between the literalism of an interface – those of its features that are true to its metaphor – and its magic – those capabilities that deliberately violate the metaphor to provide enhanced functionality. How such literalism and magic might be applied, however, is a matter that is specific to each system and its context. In our case, the call for a ‘sliding relationship’ between realism, imaginative transposition of known spatial properties, and the exploration of entirely new possibilities (Benedikt 1992) is not one that can be answered through abstract reflection alone (see also Benford et al 1997). Appropriate features for the design of the MANUFAKTUR need also to be discovered from practice, achieved in our case through our ethnographic studies and our collaboration with professionals.

For example, the three-dimensional arrangement and manipulation of a heterogeneous array of working materials is an integral feature of work in architectural design (Buscher et al 1999). In a physical work environment this is strongly constrained by gravity, in ways that may not always be helpful. Documents etc. can only be placed on horizontal surfaces, or pinned to surfaces in other planes. Related items can be gathered together, but only in very limited numbers. In larger numbers they can be collected in a stack, which does make use of depth but is harder to handle and usually means that only the top item is visible. By contrast, in Figure 1 materials in the MANUFAKTUR are arranged in three dimensions unconstrained by gravity and related materials can ‘float’ in proximity to each other. It has become customary to refer to 3D spaces represented on a flat screen as “2.5D”, but in this quite different sense, physical materials spaces are also only “2.5D” while their digital counterparts, even on a flat screen, are in 3D.

Another constraint in a physical work environment is that of a person’s convenient reach. In conjunction with the constraints of gravity, only a small amount of material can fall conveniently to hand, with progressively more effort required to manipulate, and eventually even to see, materials further away. One consequence is to reduce the meaningfulness that can be given to the proximity and distance of materials, as embodying gradations of being more central and less

central, more urgent and less urgent. Within the limits afforded by reach, these gradations are highly compressed. As can be seen from Figure 1, in an electronic space they can be far more extended, while the materials remain accessible – one acquires ‘very long arms’.

Other constraints of arrangements of materials in a physical work environment concern both their ephemeral and their persistent character (Büscher et al., 2000b). Spatial arrangements of materials are ephemeral in that they are easily created and easily changed or destroyed. This is an advantage in following the flow of work through constantly shifting tasks and purposes. But it is also a disadvantage, in that valuable arrangements are easily disrupted by accident or buried under a continuous flurry of objects on the move. Yet spatial arrangements of materials are also persistent in that things ‘stay where they are put’. This is an advantage in that meaningful arrangements have some stability, but also a disadvantage in that they easily outlive their purpose, requiring deliberate activities to clear them up, and they easily become sedimented among other meaningful arrangements in a limited space. The result of this combination of ephemerality and persistence can easily be just a clutter in which materials are neither in a meaningful arrangement nor ‘in their proper place’.

The sociality of space

These considerations make it clear that we cannot rely simply on trying to emulate a physical workspace in an electronic space. We need other bases for considering what features of physical and electronic spaces are valuable, for whom, and under what circumstances. The ‘work’ that dynamic arrangements of work materials are doing can, analytically, be distinguished in terms of three aspects: having materials ready-to-hand; the intelligibility and organisation of materials; and the accountable and communicative nature of material arrangements in a working environment. In real activities, work practices will normally play over these aspects in a seamless and tacit fashion, but they can have different implications for design, support and use. We will now explore these aspects further with some scenarios of use drawn from our fieldwork studies.

A firm of landscape architects has been awarded a contract for the development of a major river corridor in the south of England. The *River Corridor* project brings together 16 sites with very different characteristics and requirements. Although all sites need individual schemes, they also come together as a whole and need an overall strategy. Work on the 16 sites will be scheduled in several phases. Initially, three sites need urgent attention. Site 1 is situated next to an Olympic canoeing course. It should respond to this feature in the landscape, but develop into a more informal and naturalistic wildlife reserve. Site 3 concerns the approach roads to one of the main cities situated on the river. The character of

the approach should be enhanced. Site 6 houses a derelict industrial complex and is to be converted into a new-business park development. Views of old industrial landmarks should be integrated where possible.

At a start-up meeting with the client, the landscape architects have discussed and elaborated the initial brief. They have received Ordnance Survey maps and plans, and some contour plans, from the client. In addition, several of the landscape architects have been on extended site visits and have taken around a hundred photographs.

Minimal digital spaces

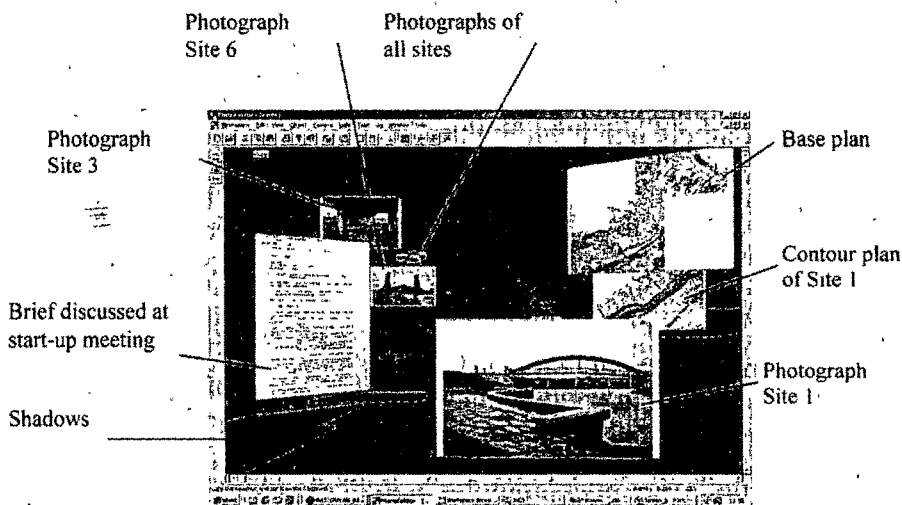


Figure 1. A minimal digital space.

NB: Colour versions of all figures are available at:
<http://www.comp.lancs.ac.uk/sociology/spaces/>

Figure 1 shows how Chris², one of the landscape architects, has brought together some of the work materials in the MANUFAKTUR, in a first attempt to develop some ideas for the individual sites 1, 3 and 6, as well as an overall strategy. He refers to the brief as it was discussed at the start-up meeting, and tries to relate the individual sites to the whole scheme through reference to the overall base plan in his workspace. From a whole array of photographs from different sites he selects

² The scenario presented in this paper has been constructed with reference to the ethnographic fieldwork, but mainly relies upon work undertaken by the landscape architects with the MANUFAKTUR. The project, for example, has been anonymised, but it is 'real', as are the workspaces shown. They were created and discussed in the course of an extended workshop in the landscape architects' studio.

studio is the result of the manipulation of materials under the umbrella of a particular 'in-order-to'. While this purpose makes for, and requires, the readiness-to-hand of working materials, it also guides the creation of contextual arrangements that make the relevance of, and relationships between, a diversity of materials intelligible. At the same time, the spatial sediments of such relevancies and relationships are themselves intelligible. They are an ongoing, contingent and accountable achievement. The notion of accountability has only recently and implicitly been extended to the material world (Heath and Hindmarsh, 2000). It is an ethnomethodological term (see, for example, Garfinkel, 1967; Lynch, 1993) that denotes the fact that human activities are orderly, intersubjectively intelligible and observable.

This includes activities that involve materials in rather interesting ways. 'Orderliness' does not at all refer to a 'tidy' workspace. Instead, it implies that when working with materials people orient towards a particular objective, activity, and/or aesthetics. This orientation – although clearly tinged by personal preferences and styles – nevertheless sediments into meaningful arrangements of work materials (afforded and limited by the constraints imposed by physical space and materials). A tidily categorised workspace is a possibility, but a tangled mess of paper, models, and tools is equally expressive and inextricably tied to the respective orientation that informed its production. Both versions are orderly and intersubjectively intelligible in the sense that members of the community of practice will be able to make sense of the material arrangements that emerge – simultaneously and retrospectively. Their accountability lies in the fact that members will assume that, in principle, any contextual arrangement is the outcome of a meaningful action, even if that is throwing everything on the floor in irate frustration at not being able to find a particular item. However, such difficult forms of meaningful and accountable spatial order lie at one end of a continuum.

If it is to go smoothly, work practice often needs to be visible (or audible, etc.) and comprehensible to others. The connections that are made through this are often serendipitous – for example, one landscape architect may glimpse another working on an area of a plan, and be reminded that she was recently on site and saw that there had been an un-notified change that her colleague needs to know about (Büscher et al., 2001). Sometimes the connections fit into a more direct division of labour, as, for example, when colleagues work side-by-side on a planting plan and a corresponding specification of species. They may share some of their working materials while also involving information that is irrelevant to the other, yet still visible to them and indicative of the kinds of considerations that are in progress. Sometimes colleagues go so far as to stage deliberate 'performances' to ensure that appropriate communication and accountability are achieved, as shown by Heath & Luff (1992) in their examples from the London Underground.

Colleagues may also leave a particular spatial arrangement of materials as an asynchronous resource for others, to enable them to answer a potential client's request while they are away, for example. Considering the work described in conjunction with Figure 1, if Chris were carrying this out in a physical workspace, it would be accountably available in all these ways. A MANUFATUR workspace retains very powerfully the intelligibility of activities for others, by contrast with conventional ways of using digital materials. If it is realised on a computer monitor that could have the consequence of privatising this work, but that could be overcome simply by projecting the workspace onto a wall screen (more sophisticated methods of achieving accountability and communication will be considered later).

Spaces with extended properties

Starting out from the 'minimal form' of three-dimensional digital space described in relation to Figure 1, we can consider progressively more complex attributes and features, looked at in terms of how they build support for the readiness-to-hand, intelligibility and accountability of arrangements of materials.

Augmented and stylised spaces

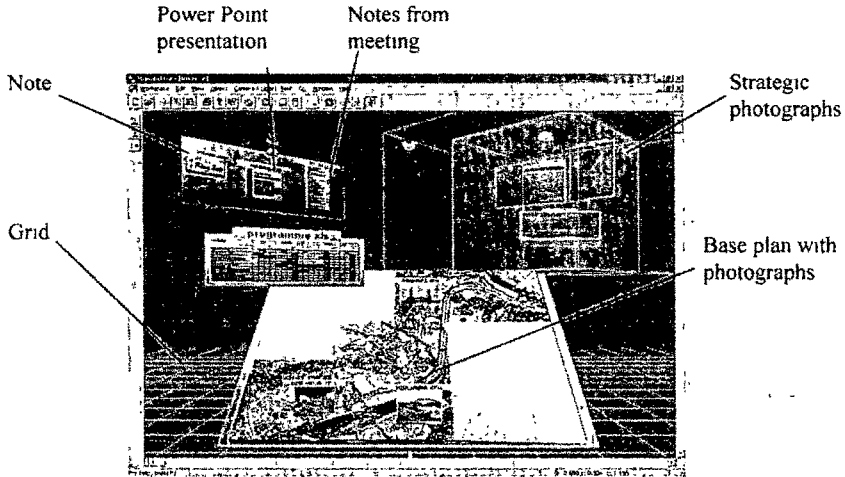


Figure 2. Extended and stylised spaces.

Figure 2 shows how Joanne, one of Chris's colleagues, takes a different approach to the same situation. She lays out the overall base plan and places the same photographs related to sites 1, 3 and 6 on the plan, close to the actual position

they were taken in. Her main focus is to develop some ideas for an overall strategy, and a set of strategic photographs from previous projects and magazines serve as an inspiration. She does not want them to intermingle with the materials actually related to the *River Corridor* and so she places them in a glass box that constrains their movement to that box. Similar reasons underpin the placement of her own notes from the start-up meeting, a PowerPoint presentation on industrial regeneration, and a note reminding her to ring an artist working on a different project with her. These three documents are attached to a billboard that confines their movement to the plane of the board (they require an extra 'effort' to pull them off). She also adds an Excel spreadsheet with an outline of the project schedule into her workspace.

This scenario illustrates some of the ways in which the MANUFAKTUR can 'play' with spatial properties to add functionality. The glass box, which can be any size, makes it possible to create a bounded space rather than an unbounded one. The billboard permits the reintroduction of 'gravity', save that now it is capable of acting in any plane. A spatial property that has little parallel in physical space is the ability to give any object a default position, to which it can be returned via a right mouse click on the object. An object can have its own behaviours (if it is a video, for example) or can be given a behaviour, such as animation. It could be made possible to 'flick' an object across the workspace, effectively reintroducing momentum and friction to objects.

This scenario also shows ways in which the space can be made less abstract and more stylised through adding features. Switching on the floor grid, for example, gives an added sense of perspective. The space could be made to look like a 'room' by adding walls, or other 'furniture'. Joanne has chosen a much more interesting variant of this by using one of the work materials – the overall base plan – as a 'static' feature of the workspace itself, on which she places other materials in appropriate positions. The plan has been made non-selectable (and therefore non-moveable) in order to facilitate its function as an 'anchor' for the photographs. This could equally be done, for example, with a 3-D model or wireline of a building or a landscape, so that it would become its own space for the placing of relevant materials. The transparency of objects can be set at any value, so that such features can be 'toned down' if they become too obtrusive and obscure other materials.

The design features of the MANUFAKTUR discussed here are meant to communicate the affordances of the space and the work materials in a way that can be intuitively understood (Gaver, 1991). The walls of the glass box, for example, are easily, and, after initial exploration, visually experienced as boundaries. The way in which the photographs contained within it are ready-to-hand is made visible. The readiness-to-hand of the plan within the MANUFAKTUR allows it to withdraw as 'equipment', that is, as a background onto which other materials can be placed. These placings add intelligibility to the individual

photographs – they refer to ‘real’ locations. Once this order has been evoked, the combination of map and photographs becomes highly intelligible (and desirable as a shared resource) and accountable (a picture positioned wrongly would be noticed). In constructing her workspace in these ways, Joanne has not only produced a particular intelligibility through these arrangements of materials, but she has also produced a graded distinction in their readiness-to-hand which is tailored to their, and her, purposes. Equally, this is an arrangement with enhanced accountability, in that a colleague glancing at Joanne’s workspace will find her orientation to the task ‘made flesh’ in her division and organisation of materials. the order she has produced ‘shouts’ at them from the screen.

‘Quantum’ spaces

So far we have considered spaces that are continuous and unitary. In the digital environment, however, we can have spaces that extend or breach these constraints in various ways. 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 a given point in time. In the MANUFAKTUR 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’. Since these are multiple references and views onto the same object, they do not give rise to copies and inconsistent versions (though for opening them, their behaviour is dependent on the file locking and sharing implementations of their native applications).

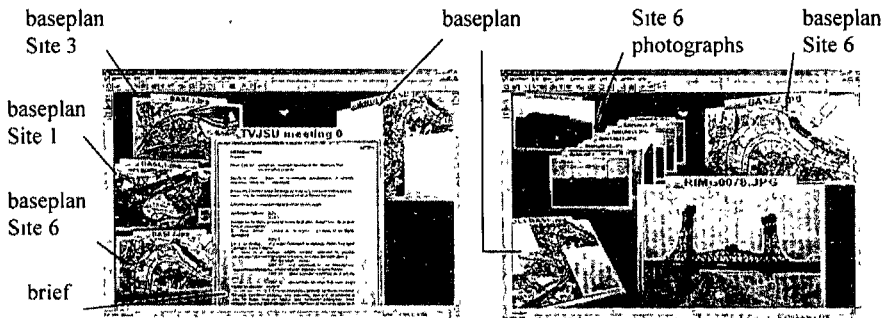


Figure 3. ‘Quantum’ workspaces: Chris (left) and Dave (right).

Figure 3, developing the same scenario, shows a pair of workspaces with partly overlapping materials. The workspace on the left is being used by Chris to develop the overall strategy for the development of the three urgent sites. It contains the brief, the overall baseplan, and the baseplans for sites 3, 1 and 6. The workspace on the right is being used by Dave, who is working on the detail of site

6. It also contains the overall baseplan, so that he can retain the context, and the baseplan for site 6; hence these two objects are simultaneously present in both workspaces. Dave has a range of other relevant material, including a set of photographs which he has got the system to cascade in date-time order, because that also corresponds to the route he took to explore the site. If Dave moves baseplan 6 in his workspace it will not move in Chris's workspace; but if Dave makes a visible change to baseplan 6, this will also be visible to Chris, and helps him to maintain a 'watching brief' on progress. Of course, individuals can themselves also have multiple workspaces that use the same materials in different ways – Chris, for example, might have an 'administration' workspace and a 'strategy' workspace, both of which contain the overall baseplan. Here, then, we see a particular spatial mechanism – the capacity of an object to inhabit parallel spaces – used explicitly as a mechanism for accountability: changes made to an object in one workspace can be visible in another. We will see this tactic extended much further later on.

'Wormhole' and recursive spaces

Up to now we have only considered individual objects placed in individual workspaces. Evidently, however, it will often be useful to deal with collections of objects together. Initially, we provided for the collection of objects into groups, and for groups to enter into hierarchical relationships. Our approach now is somewhat different. The only spatial entity that we use is the *workspace*, which comprises, in essence, the set of three-dimensional spatial relationships that obtain between a workspace object and a set of documents/materials objects that are its members. A workspace can contain an arbitrary number of objects in arbitrary spatial locations and, as we have seen, objects may simultaneously be members of an arbitrary number of workspaces. A workspace can be opened or closed – when it is closed its contents are collapsed so that only a proxy object is visible (see Figure 4).

Workspaces can contain other workspaces. A workspace shows all the objects of an open included workspace within the including workspace. Workspaces may contain other workspaces at any place, in arbitrary directions and to an arbitrary depth of levels. This is without any constraint via their proxy objects, but circular references to workspace contents are caught: the system forbids the opening of a proxy that would result in a circular reference (Büscher et al., 2000b). Workspaces are in principle unbounded (except for specialised workspaces such as boxes and billboards) and do not monopolise space within their extent, and so can interpenetrate. Hence a workspace does not open in a 'window' or a demarcated space in another workspace; its objects can be mingled freely with the objects and workspaces that are already there. This is, therefore, another instance of how digital spaces can usefully extend or breach the constraints that apply to

physical workspaces. Here, space is no longer unitary, but ‘lumps’ can be torn out and inserted in other places, the space can be ‘folded’, and ‘wormholes’ can be opened from one space onto others.

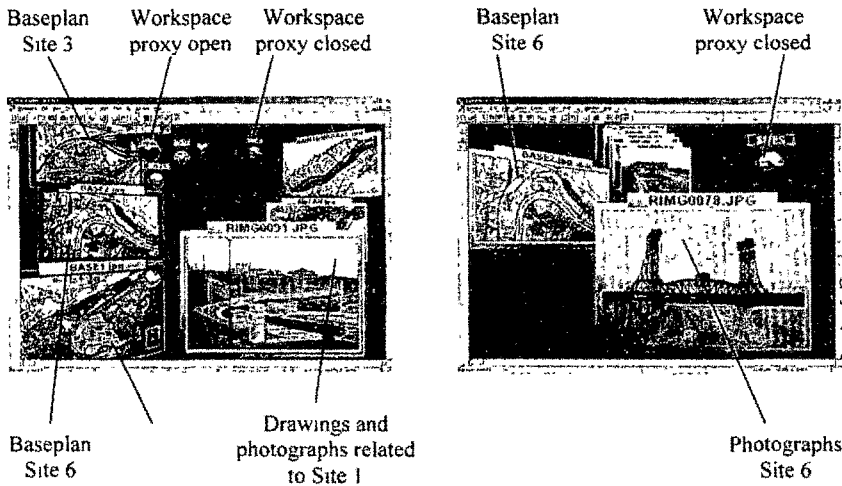


Figure 4. Folded and tunnelled spaces: Chris (left) and Dave (right).

Figure 4 again shows a pair of workspaces. In Chris's workspace on the left, he has created a new workspace, "Sites", which contains the baseplans for the three urgent sites, 1, 3 and 6. He has given it a colour, deep blue, which shows on the workspace icon and on the borders of the objects that are its members. He has placed the overall baseplan and the brief in an "Administration" workspace which is closed, showing only its proxy icon, and pushed to the background. He also has present some Site 1 materials that he is working on. In Dave's workspace on the right, he has created a workspace for his detailed work on Site 6, which he is now working in, showing yellow borders on its materials. He will need, from time to time, to relate his work to what is happening on the other urgent sites, so he has also imported Chris's "Sites" workspace, but it is currently closed.

The potential complexities of these extended and 'breached' spaces call for extended means both for making them intelligible and for interacting with them effectively. We have already seen a simple example of this in the identifying colour that can be given to a workspace and to the borders of its objects. Users can act on a workspace and all its contents as a collectivity in other ways, for example, by moving or rotating it, by giving it a default location, and by returning it and all its contents to their default position from a single right-click selection. A key way in which these issues are addressed in the MANUFAKTUR is through the

distinction between a workspace object, represented by the lower half of a workspace icon, and a workspace proxy object, represented by the upper half of a workspace icon. If a workspace is inserted in an including workspace, then one can think of the workspace object as representing the included workspace itself, and one can think of the proxy object as the 'hook' in the including workspace on which the included workspace 'hangs'.

This is an important distinction because actions performed on the included workspace icon (e.g. re-sizing the whole workspace) or on objects within the included workspace (e.g. bringing forward one of its objects) are performed for all of the instances of that workspace wherever else they occur. Actions performed on the proxy object, by contrast, are only performed in the including workspace. For example, if a user multiple-selects all of the objects in an open included workspace and moves them left, they will also move left in all other instances of that workspace. This means that actions carried out in a workspace owned by someone else remain accountable in a way that mirrors the accountability of actions carried out in shared physical workspaces. But if a user selects the proxy icon for that included workspace and moves it left, then it and all its objects will move left only in the including workspace.

The MANUFAKTUR makes sharing of workspaces and real-time distributed interactive collaboration possible through its network distribution architecture (Büscher et al. 2000a). Geometry and textures of 3-D objects are stored in one or more shared relational database servers. Collaborating MANUFAKTUR clients interact via a collaboration server that is used to distribute messages about object updates among session participants.

Shared awareness

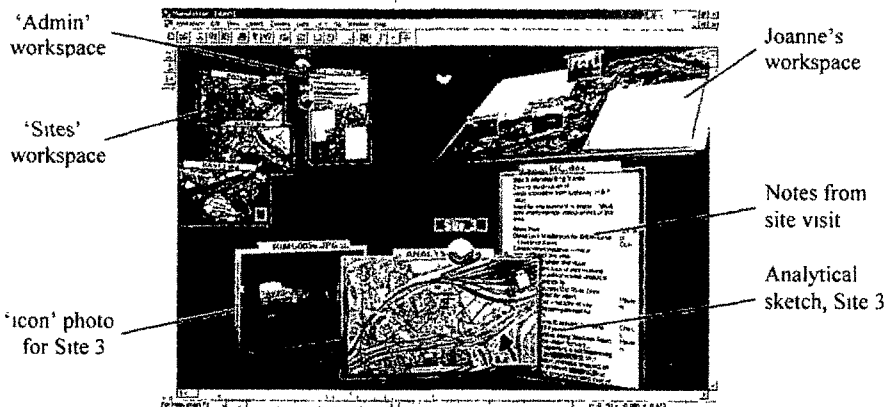


Figure 5. Networked spaces.

Figures 5 and 6 take up some of the issues concerning the complexities of extended and breached spaces, means for making them intelligible, and means for interacting with them effectively, through pursuing our scenario with some slightly more complex workspaces. John and Peter, both junior landscape architects, share responsibility for site 3. In Figure 5, John collects a workspace from Chris, which itself contains two open workspaces: the “Sites” workspace with the baseplans for the three urgent sites (deep blue borders), and the “Admin” workspace with the overall baseplan and the brief. He also collects one workspace from within Joanne’s workspace (cf Figure 2) which contains the overall baseplan of the whole river corridor (again), but which Joanne has used as a setting on which to place characteristic photographs. His own working materials include the ‘icon’ photograph for site 3 – a picture of a motorway bridge that obstructs views from an adjacent public footpath, which is also marked by a red arrow on the analytical sketch on the base plan of site 3 – and some notes from a recent site visit.

Peter’s workspace proxy closed, but ‘oscillating’ to show that there is activity in this workspace

Joanne’s workspace

Open workspace with a sketch and inspirational photographs for Site 3



Figure 6. Communicating spaces.

In Figure 6, Peter takes a different approach, but relates it to the overall strategy by including the whole of Joanne’s workspace (cf Figure 2) in his own workspace, set well in the background. Like John, Peter is concerned with the experience of travelling through site 3. But unlike John, who concentrates on pedestrian access in the surrounding area, Peter noticed the speed at which most vehicles move along the approach roads to the main city on the river. Pictures of landmark features that are at their best when perceived at speed begin to populate his workspace. Peter and John need to coordinate their work on site.3 so Peter has included the whole of John’s “Site 3” workspace in his own. However, Peter would find it too distracting to have it open. The workspace is closed, but

nevertheless communicates – as explained below – when John, who is also working on other projects, has a flurry of activity on site 3.

We are currently experimenting with such awareness mechanisms, to the extent that we have found it necessary to supplement the collaboration server with an ‘awareness server’ to cover these functions. When workspaces are open, awareness is, among other means, provided through the visibility of the work that people are doing on objects within them. When workspaces are closed and only the proxy is visible, some awareness is provided by the awareness server through the proxy. In the current implementation, when objects within a closed workspace are manipulated, the proxy is animated and ‘oscillates’ a bit around its own centre: the more activity the more oscillation. This is a quite subtle and unobtrusive way of indicating activity here and now, but it does not help to signify whether there has been activity since the user last paid attention to the proxy, e.g. during a coffee break. At the moment, this is afforded through a simple colour scheme for the titles of the workspaces (displayed above the proxy). The normal way of displaying the title is yellow on a blue background. If activity occurs within a closed workspace, the colour of the title becomes orange, until the workspace is opened again. A red title indicates that the workspace under the proxy has been deleted altogether.

If these awareness mechanisms are successful they could easily be extended. For example, the way that the proxy moves (instead of just oscillating) may indicate the sort of activity; and the colour scheme may be elaborated, e.g. by providing an almost continuous colour-change from yellow to deep orange according to the amount of activity that has taken place. These are methods of trying to get objects to display affordances in digital spaces that have no equivalents in physical workspaces. In this respect they are attempting to take over in some regards the mechanisms of accountability that apply when people occupy physical workspaces. Another way of thinking of an affordance in these circumstances, perhaps, is as an accountability practice for actants (Latour, 1996; Law, 1992).

The ongoing manipulation of working materials within the MANUFAKTUR allows people to be, effectively, in several places at once. Or, to put it in other words, it creates a window or ‘wormhole’ onto activities elsewhere. This may be within the space of the studio, where Peter and John, for example concentrate on work on their own screens. Whereas work with physical materials makes general allowance for peripheral participation, computer screens generally do not. A wormhole onto someone else’s workspace may alleviate this privatisation of work on the screen. But a wormhole can be cut to engage with the work of a colleague located at home, on site, or at a client’s office. Not unlike the way in which the MANUFAKTUR extends a person’s reach (giving them ‘long arms’), it also augments their vision. Remote people, places, and materials become ready-to-hand, and accountable parts of an expanded ecological intelligibility. Of course,

these possibilities raise serious issues of surveillance, security, and control. At present, we rely in part upon the existing mechanisms for file permissions, and in part upon the emergence of new kinds of conventions among relatively small groups of design professionals who already share their work environments. Moreover, ‘real’ mutual intelligibility in physical spaces relies on the reciprocity of perspective of co-present actors. This is not easily transposed into any collaborative environment.

Parallel representations

We have shown how the MANUFAKTUR can create extended and ‘breached’ non-uniform digital spaces with ‘quantum’, folded and ‘wormhole’ properties, which offer powerful functionality. In some respects these strange spaces are surprisingly intelligible for users and are easily navigated by them. In other respects, however, they can be confusing. For example, one might easily lose track of who else is also using a ‘popular’ workspace. It will usually be preferable to try to cope with such issues with awareness mechanisms that are experienced as ‘inside’ the shared MANUFAKTUR environment. Sometimes, however, it may be helpful to provide parallel mechanisms for overview and navigation.

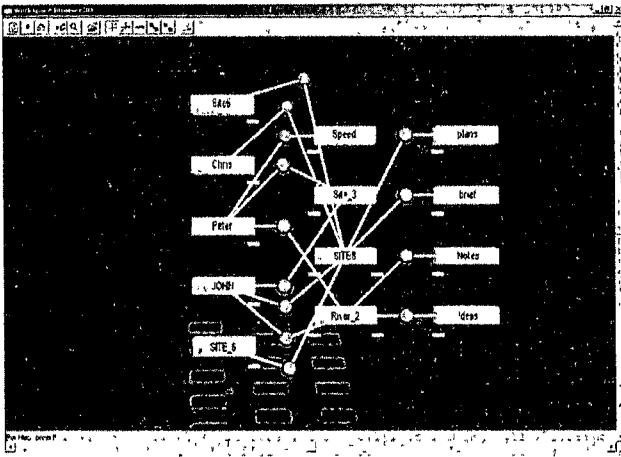


Figure 7. Workspace browser.

Figure 7 reflects the structure of the shared work environment we have outlined above. It shows the three-dimensional workspace browser provided by the MANUFAKTUR (itself, in fact, a specialised workspace), which provides an overview of workspaces and relations between workspaces. It shows that a workspace can have multiple children (e.g. Joanne’s River_2 workspace has ‘Notes’ and ‘Ideas’ as sub-workspaces), and can also have multiple parents (e.g. Site_3 is part of Peter’s workspace and of John’s workspace). This non-

hierarchical structure is the backbone of our 'tunnels', 'wormholes' and 'quantum' spaces. Workspaces can be opened from any point in the workspace browser. There is an equivalent object browser for objects within a workspace, providing a different kind of comprehensive listing, and making it possible to find, retrieve or go to objects that are 'lost in space'.

Conclusions and future developments

We started from the 'naïve' premise that the more digital workspaces resemble physical workspaces, the more users will be able to 'inhabit' them with ease. On examination we found, of course, that our capacity to mimic physical workspaces is still inadequate; but also that physical workspaces have constraints that digital workspaces can helpfully breach. This leads to the problem of deciding what kinds of digital workspaces to try to 'engineer'. This is not a problem that can be addressed purely in the abstract, and we described how our work with design professionals has underpinned the development. We claim that it is crucial to approach the problem in terms of the sociality of workspace use, here considered under the three aspects of readiness-to-hand, intelligibility and organisation, and accountability and communication.

We tried to show that these aspects can be usefully addressed in different ways and for different purposes: sometimes with a 'minimal' form of digital workspace, which users need never move beyond if they do not wish to; sometimes by reintroducing emulated physical properties such as gravity, stickiness, momentum and friction; sometimes through new behaviours for objects such as returning to a default position, or animation; and sometimes through extended properties that can be given to digital spaces, such as parallel universes, folding and tunnelling. These, and especially the last, mean that simultaneously and in productive ways, objects can occupy different spaces, spaces can occupy different spaces, and people can occupy different spaces. They also mean that users may experience the system as 'beyond being there' (Hollan & Stornetta, 1992), i.e. that the additional functionality may tempt them to use it even when working in proximity to each other.

The distance that this takes us from 'naturalistic' spaces, however, means that appropriate ways of inhabiting them need also, in part, to be 'engineered'. These, too, have emerged through participatory design around social use. They can be divided, approximately, into, (1) metaphorical extensions of familiar uses of space; (2) affordances as metaphors designed for and through new appearances and behaviours of objects (behaviours that indicate 'activity', for example); (3) parallel representations such as workspace browser nets; and (4) menu or shortcut selectable commands. One of the aims of the ongoing development is to find useful ways of 'migrating' functions upwards through this list, making the space itself more intuitively 'ready-to-hand' (cf Shipman & Marshall, 1999). The power

that design professionals gain from the disposition of materials in three-dimensional space means that this can usefully be retained as the foundational metaphor for the digital workspace, rather than, for example, seeking to decompose it into myriad 'spatial functionalities' each serviced with a specific tool. But the metaphor must also be critically decomposed to explore the points at which it breaks down and can helpfully be reconstituted or extended.

Our future work around these themes will continue to be anchored in the real work practices of design professionals. It will focus on building better bridges between digital and physical work environments, with three key aspects. Augmenting the design *environment* is about new means – including large scale and stereographic projection and new interaction devices – for designers to inhabit and interact with mixed physical and digital workspaces, collaborating in both co-located and distributed modes. Augmenting *objects* is about making bi-directional connections between physical objects and their digital counterparts, their contexts of use, and their users. Spatial computing *in the field* is about making digital and mixed environments highly portable, so that they can take advantage of 'knowing' their position when users wish to tailor these parts of their work environment according to exactly where they are, whom they are with, and the capacities of the devices that are available to them.

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