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Creativity, Complexity, and Precision: Information Visualization for (Landscape) Architecture

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ABSTRACT
Drawing on ethnographic studies of (landscape) architects at work, and interdisciplinary cooperation with them, this paper presents a human-centered approach to information visualization. A 3D collaborative electronic workspace allows people to configure, save, and browse arrangements of heterogeneous work materials. A network of links between parts of documents and objects underpins this spatio-temporal order. Both spatial arrangements and links are created and maintained as an integral part of ongoing work with the 'live' documents and objects that populate these arrangements. The result is an extension of the physical information space of the architects' studio that utilizes the potential of electronic data storage, visualization, and network technologies to support work with information in context.

Keywords

Information visualization, architecture, work materials, context, spatio-temporal order, electronic workspace

1. INTRODUCTION

Architects, landscape architects and other creative professions are not often amongst those considered to benefit from information visualization (see, however, [13]). While scientists, stock traders, or logistic managers draw upon vast stores of fairly uniform data, architects and others concerned with aesthetic design assemble and assess a heterogeneous and very wide-ranging array of information types. These include, for example, textual definitions, whether of building standards or plant specifications; technical detail drawings; rough sketches and concept drawings; product data concerning, for example, the water absorption rate of different kinds of building materials, or their structural qualities; physical product samples, involving tactile and material qualities; the clients' brief; correspondence with clients and other professional partners such as community artists, structural engineers, ecologists, or manufacturing specialists; photographs of, for example, the existing surroundings for a new building; models, sketches, or images that explore aesthetic features such as color, shape, texture, or lighting; and many others. It is difficult to see how such a diverse range of 'information' could usefully be made amenable to information visualization techniques.

However, the visualization of automatically recognizable patterns in huge volumes of data – based on statistical analysis or interpretation of file meta-data such as date stamps, author, or size – is only one aspect of the newly emerging discipline of Information Visualization. The World Wide Web has been a spur to innovative imagination with a view to visualizing information differently [8]. In effect, a 'next generation of graphical user interfaces' has become possible [20]. Innovative activity focuses on several core questions: How to increase the volume of information that can be displayed? How to aid orientation? What kinds of visualizations suit which kinds of information? How do these questions relate to issues of human perception? How can we extend the possibilities to manipulate information, and support collaboration? How could information visualization dovetail with the potential of ubiquitous computing and augmented reality?

All these issues are highly relevant for work in architecture and other creative professions. Drawing on ethnographic studies of landscape architects and architects at work, and interdisciplinary cooperation with these professional partners within *Desarte*[1], we are designing a system that attempts to address these core issues in a way that is directly aimed at supporting the work of architects and landscape architects. In the following sections we provide a brief synopsis of ethnographic observations of work on a particular landscape architecture project, selectively discuss developments in information visualization systems in this light, describe the system we have developed, and a scenario of use. We conclude with a vision of information visualization in creative work.

2. CREATIVITY, COMPLEXITY, AND PRECISION

'The Deep' (Fig. 1) is a new aquatic museum near the harbor in Hull, on the north east coast of England. Its design is being developed and coordinated by a group of architects. The landscape architects are one amongst many professional partners called in to deal with particular aspects of this large and ambitious project. While they are concerned with the design of the buildings' setting, other consultants such as engineers with a variety of specialties deal with mechanical, electrical, structural, and traffic issues pertaining to displays within the museum and outside, the buildings themselves, their access routes, and the surrounding area. It is a 'brownfield' site with some minor contamination, and the ecologists on the team have specified a need to allow gases to escape. Throughout, they advise on the design to ensure the adequacy of provision for ventilation. Also

[1] See Acknowledgements, Section 6.

involved are a quantity surveyor who deals with overall cost estimates for materials at various stages, and a specialist interior design firm who create museum displays and exhibition designs, which also have an influence on the design of the exterior space.

Figure 1: The metaphor 'The Deep Plaza' captures some of the landscape architects' concepts. Prints of fossils or marine animals' footprints integrated into the hard surfaces, as well as patterns that reflect the themes and experiences inside, are to provide an atmospheric setting for the museum.

This constellation of different perspectives generates a vast amount of heterogeneous information. There are between 600-800 paper documents, and the folder containing the landscape architects' electronic work files alone contains over 500MB in ca. 150 documents. One of the principals explains that 'only about 20% of our time on this project is spent on design. The rest is eaten up by information work – waiting for information from others, providing information, exchanging information and liaising with others at meetings, sifting through the weekly gamut of information only some of which is relevant for us'. Although some of this work is concerned with supervising and ensuring that information relevant to the design is incorporated into it, a large proportion of time is spent on the onerous task of handling such a huge repository of information. Retrieval is supported by categorizations such as 'structural engineers' reports', 'environmental assessment', 'architects' drawings', etc., and other structuring conventions that reflect, for example, the time order of documents. However, the process of relating a whole host of parameters to specific design issues gives rise to another order of information structure with more flexible and dynamic categorizations. A snapshot of ongoing work to produce a 'package' of layout and detail drawings for a deadline the following day will illustrate this point.

Joanne and Vic are working together. Joanne sketches out rough notes of details on her drawing board (marked 'o' in Fig. 2). A 'rumble strip' is one example. It introduces raised rough paving into a road before and after a pedestrian crossing. Vic translates these notes into AutoCAD files. Their workspaces are only a few meters apart, and each contains a desk with a computer

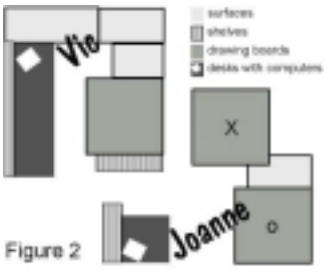
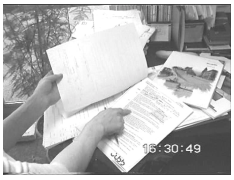


Figure 2

complemented by shelves, drawing boards, and other surfaces. There are documents and drawings everywhere – on the screens, the desks next to the computers, the drawing boards, and on the floor. Some of these are being generated in the course of work; others have been assembled from various places within the physical and the electronic information space. Let us have a closer look at Joanne's workspace.

On the drawing board to her left (marked 'x' in Fig. 2), Joanne has a collection of layout drawings. She recurrently checks how her sketched out details affect the layout and vice versa. To do so, she turns from one drawing board to the other, bringing her sketch with her. The layout drawings are also a resource for Vic, who has reduced-size copies of them on his desk, but occasionally walks across to measure exact dimensions. On some occasions this gives rise to a discussion between Vic and Joanne.

Joanne also needs to make sure that the materials she plans to use stay within the budget. In fact, she knows that there will be cuts to the budget, and that those are most likely to affect the plans for the exterior space. She anticipates them by trying to organize the design in such a way that whole self-contained parts can be scaled down if required, preferably in the specifications rather than in the drawings, which would be labor intensive to change. A copy of the quantity surveyor's draft report on her desk, stacked together with the specifications document prepared by engineers, help her in this strategic move. The specifications determine exactly how, for example, paving blocks have to be laid for a 'rumble strip', whether they are to be filled in with mortar or, more cheaply, with sand, and other details. Joanne also has a special collection of product information catalogs relevant for this project in a box that duplicate some of those in the general trade literature library. Having both specifications and the quantity surveyor's report open at the pages relating to the rumble strips, she determines a 'favorite' rumble strip block and a less costly alternative. Some pages of this brochure find their way onto Vic's desk, to enable him to draw dimensions precisely to scale.



If we examine this sequence of activity with a view to how it might inform the potential of electronic approaches to information visualization, it is striking how the meaning and relevance of work materials to the current task find expression in their organization in time and space. Assemblies such as stacks, piles, and materials collected in a box indicate that they belong together. But more ephemeral groupings, such as the sketches located in relation to specific places in the layout drawings, or the combination of specifications, cost estimate, and product catalog, also document meaningful relationships between things.

As well as these documents that are directly relevant for her current task, Joanne has a timeline for the whole of the project pinned up on her wall, and a folder where information relevant to her role as project coordinator is continuously updated. She receives a number of letters and faxes that need to be included in this folder while she is working on the details. This activity is only marginally related to the work she is currently doing and yet it shares the same workspace. It is one example of a 'layering' or archaeology of physical information spaces, where each layer contains separate, often unrelated, but individually meaningful spatio-temporal assemblies of materials. This requires careful maintenance.

Yet another aspect of the project is kept present through images. One of the conceptual threads for this project relates to all things marine – the outer space is to subtly provide an extension of the experience that awaits visitors in the museum itself. Images that evoke marine associations have been collected under the heading 'The Deep Plaza'. They have been used to form, develop, and communicate ideas and a new image has just been dropped by a colleague onto Joanne's desk (left). She pins it up on her wall, so as to avoid it being lost in the constant shuffling of materials on her desk while she is doing her work, but also to remind herself (and others) of the aesthetic possibilities that underpin the design.

This brief synopsis of ethnographic observation provides an insight into some of the strategies the landscape architects employ to weave together a complex array of sometimes diverging demands, and the ways in which ephemeral and more long-term spatial orderings reflect the landscape architects' current considerations. The spatio-temporal order of material assemblies is expressive of relations between documents and objects, and of their meaning and significance for the task at hand. This is an important resource for the organization of individual and cooperative work. In fact, in some respects, the configuration of materials *is* doing the work. However, in the physical world this spatio-temporal order is a somewhat recalcitrant ally. It is both ephemeral and persistent, and both of these have both advantages and disadvantages. The ephemerality of the spatio-temporal order is a positive feature in the sense that documents and objects can be assembled and arranged relatively easily, for different purposes. Yet the ephemerality of arrangements can also be a nuisance. When a job is done, many documents and objects are returned to their locations, others are thrown away, yet others are lost or buried under the continuous flurry of documents and objects on the move. On the other hand, the spatio-temporal order of things in physical space is persistent. Again, this can be good or bad. While it is a good thing that things once placed stay put unless someone moves them, this can turn into a disadvantage when there are too many documents and objects piling up around one. There are procedures in place that deal with these negative aspects of persistence, that 'weed out' information that has become irrelevant, has been updated, or has been incorporated into the design in a 'definite' form on shelves, in folders, but also in more short term assemblies of materials. Eventually, many assemblies are dissolved due to the constraints of physical space, either deliberately or by accident through becoming jumbled. This is an important resource lost. Many of the projects the architects deal with stretch over long periods of time, often with long breaks in-between where a set of documents that summarizes a stage of work is handed over to others – for example for a public inquiry, or for a local council to discuss and approve proposals. Eventually the architects get these back to continue the work. And it would be very useful if some of the arrangements that were constructed while the work was going on were still available.

The system we are designing builds on these observations of the informational relevancies of the affordances of physical workspaces, and of the practices that design professionals build up around them. It is conceived of as a digital 'craft workshop' or *Manufaktur* that extends and augments the physical workspace, enabling people to transpose familiar ways of creating order amongst their work materials in the physical environment, whilst mitigating some of the difficulties that arise from the constraints of the physical environment. It also introduces new features that go beyond current practice, such as linking facilities. It supports spatio-temporal orderings in electronic environments by allowing people to construct configurations of documents and objects in a three dimensional 'desktop' environment (Fig. 3), and to enhance these configurations with the potential of electronic technologies (e.g. linking, saving, taking different perspectives onto the material). Various of these are explored below.

3. INFORMATION VISUALIZATION

One of the basic requirements for effective information visualization in general is an extension of screen space. There are a whole host of approaches to this that explore different avenues. Some mainly utilize two dimensions. Distortion-oriented techniques of presentation such as fisheye views (e.g. [12]), or the Perspective Wall [13] provide a means to greatly increase the amount of visible data whilst allowing for a dynamic transition between detail and context. Recent advances in hardware, software and networking technology, as well as approaches that draw parallels with perception in real-world 3D information spaces, have pushed information visualization into three dimensions. This move coincides with attempts to capture features that go beyond 'primitive' characteristics such as the date, author, or size of a document, but also automatically recognizable content of, for example, database cells. More complex features that are bound up with people's situated discretion, such as a document's importance, meaning, or relevance in a specific context, have also become a focus for information visualization. An early example here is Workscape™ [1]. Support for 3D spatial arrangements of documents is complemented by spatial document management concepts such as 'binding', which facilitate the creation of groupings. In his paper Ballay [1] reports plans to enable documents to 'acquire a tentative, light-weight association with others just by being "put with" them' (ibid. p. 14). The underlying assumption parallels our own ideas that such arrangements and bindings make it possible to 'display, disambiguate and navigate large numbers of documents along some salient dimensions, for example: date, subject matter, or "importance"' (ibid. p. 12). Card et al. [6] have taken this approach further and applied it to the Web with the *Web Book* and the *Web Forager*. More conceptual, electronic 'spatial' binding through, for example, relative URLs or hotlists are visualized as *Web Books*. The *Web Forager* brings books, but also single Web pages together into an hierarchical workspace, where a 3D space and bookcases can be used to structure the information in terms of its relevance to a given

activity. Card et al. have also experimented with observer movement.

The activities of one or several people within large information spaces have featured more prominently in the work of, for example, [2, 21, 14]. Populated information terrains make three-dimensional information visualizations 'inhabitable' and constitute a different 3D approach to information on the Web or within large databases, such as libraries. By including avatars or traces of people's activities, they begin to address issues such as how social navigation [7, 16] – drawing on other people's activities to orient within an information space – could be introduced as a synchronous and asynchronous resource into the design of large information spaces, for example, as search trails.

However, although these approaches begin to explore the possibilities of exploiting people's actions within information spaces for information visualization purposes, there is little support for working directly with information. Although Ballay [1] hints at possibilities of editing documents within Workscape™, he does not elaborate on this feature. Yet, it is the work that is done with information that gives rise to meaningful assemblies, as we have seen in our fieldwork example. To introduce electronic support for the configuration of such assemblies in an electronic workspace, with all the benefits electronic technologies can provide to extend and augment them, we must enable people to work with their materials. Only then can meaningful configurations sediment without imposing an additional workload, which would be an unrealistic demand in the application domain we are seeking to support. Roth et al. [19] employ advances in information manipulation technologies which also offer pointers for this.

If we consider the information practices of our design professionals with a view to supporting visualization through technology, we can distinguish three kinds of use, with three corresponding philosophies of design, and corresponding means of technical realization. These are useful orientations rather than hard and fast distinctions because users will in practice weave them into a seamless whole. But, given the contingencies involved in information use, the objective of technical support can only be to provide users with the most helpful starting point for their work rather than to provide 'perfect' categorizations or methods.

The first and most conventional kind of use is of manifest information, which can sometimes be thought of as meta-data, such as a document's date, or a project title. These can be used as filing principles in the physical world; and in the digital world they can often be automatically detected and used to govern presentation – for example, by cascading documents in date order in the z dimension in a three-dimensional virtual environment.

The second kind of use is that of disposing heterogeneous informational materials around us so that their spatial relationships themselves express their interconnectedness and their relevance for the tasks at hand. In the physical world, this means the embodied, publically available, visible arrangement of working materials in a three-dimensional space, as found in our fieldwork descriptions. The digital world has so far provided only very limited equivalents of this – icons and windows in an easily-cluttered two-dimensional interface. As we have seen, these arrangements have both needs for permanence and needs for ephemerality, both of which are sometimes met and sometimes disappointed in the physical world. What is clear, however, is that the highly targeted and highly content, task and context dependent character of these dynamic arrangements means that there is little if any prospect of usefully automating either the selection or the arrangement of materials. What the digital world is potentially well equipped to do, however, is to capture and to make available the traces of the self-organization by users of the selection and arrangement of their working materials. It is the flow of the work itself that generates this visible order, and that could become available as a resource for work in a digitally-supported world.

The third kind of information use concerns the relationships *between* arrangements of working materials. If the arrangements described above are thought of as a 'first-order' visual-spatial organization, then combinations of such arrangements can be thought of as a 'second-order' organization. Here, the affordances of physical spaces are powerful but in some ways quite limited in scope. Arrangements targeted at particular tasks can be conserved by multiplying workspaces, within the limits of the space and furniture available. For cooperative working, arrangements can be shared by two or more people working on the same one, or by individual but related workspaces being inter-visible within an office. Arrangements can be 'transported' only by people moving to them, whether across a room or across a continent. Arrangements can be conjoined or combined only with great difficulty, and even then only when they are already close by. We saw examples of attempts to do all of these things in the fieldwork extract. For all of them, a good digital environment may be able to offer major advances in what is possible.

The visualization design philosophies applied respectively to these three kinds of information use can be thought of as automation, trace, and summation/subsumption. The *Manufaktur* system that we are designing addresses all of them, though in what follows we concentrate on the second and third, which are its more original aspects.

4. THE MANUFAKTUR

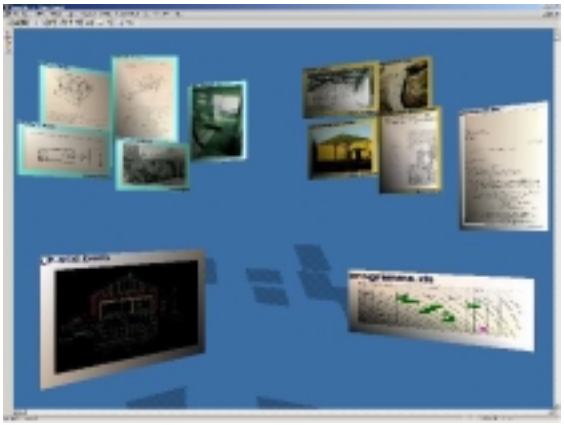


Figure 3: Interface of the *Manufaktur*
A color version is available at:
http://www.comp.lancs.ac.uk/sociology/manufakturgrab.html

Figure 3 shows a screen shot from a prototype of the *Manufaktur*. It shows an open workspace containing (references to) a set of objects. Double clicking any of the document objects will launch it in its respective application with that document, and changes to it will be updated within 3D *Manufaktur* in near real time. The objects can be sized, moved, rotated, etc; light effects may be applied; documents can be made (semi) transparent; organized into groups; and much more.

The *Manufaktur* handles workspaces, which are sets of references to objects in a certain spatial order. Thus the same object may be present in many workspaces, i.e. the same object is part of various contexts of work. Several different types of objects can populate the space:

- *Document-objects* - 'Live' documents from third party 2D applications with an ActiveX document server, such as spreadsheets, drawing programs, CAD programs, etc. The documents are displayed on objects in a 3D rendered OLE/ActiveX container.
- *3D models* – Various 3D models may be inserted into a workspace, as artefacts to be worked with, objects providing topology to the space, iconic reminders, etc.
- *'Implantations'* – objects or devices that support the customisation of a space to changing uses, for example, to create spatial partitions or for imprinting specifically expressive codes [15]. Objects to bound a space, semi-transparent objects to define areas, lighting to indicate particular features, shadows on the 'ground' to provide a sense of distance, are all examples of 'implantations'.
- *Endpoints* – representation of link anchors on document-objects. By integrating and extending the Webvise [9, 10] hypermedia system, we enable linking capability to parts of document-objects residing within Manufaktur .
- *Workspaces* – representations of sets of objects that may be manipulated as a whole. Two special objects relate to the inclusion of workspaces within workspaces:
  - *Proxy Objects* – representation of the reference to 'sub'-workspaces.
  - *Workspace Objects* – objects representing the content of a 'sub'-workspace

A workspace is the basic mechanism for creating and manipulating collections of objects and may be named and assigned a color. Furthermore, particular types of workspaces are supported. Currently, we support the basic unconstrained workspace and a billboard (where objects snap to a "board-object"). To illustrate the use of proxy and workspace objects, consider a workspace containing a billboard sub-workspace. The proxy object corresponds to the nail on which the billboard hangs, and 'lives' in the bigger workspace. The workspace object is the board itself, and the objects within the billboard workspace snaps to this board. Manipulation of the nail, e.g. moving it, will affect how the billboard workspace behaves in the outer workspace. Manipulating the workspace object, e.g. by resizing it, will affect the content of the workspace, and will thus have effects in all workspaces referring to the billboard.

A 3D environment like this not only makes it possible to have many documents visible at the same time, but it also, by spatial proximity, makes it possible to indicate the (changing) relevance of a document for work-in-progress, and its relation to other objects in the space. This means that there are in effect different 'levels of openness' of a document, which can still be identified from far away. Assemblies can be given permanence and can be manipulated as a whole through grouping or by being part of the billboard. We see this as a possibility for supporting fluent relationships, flexibility to zoom into a detail and out to see the whole, to simultaneously hold present a large number of parameters and their relationships.

As well as showing the creative configuration of physical spaces, our fieldwork examples also show the problematic and messy ways, familiar to us all, in which layers or archaeologies of meaningful spatial arrangements crowd in on each other. This problem can partly be avoided in the *Manufaktur* as a result of three features. First, views can be saved and later opened, so that there can be multiple workspaces, each targeted at a particular project or sub-project. These can be closed or minimized and later returned to, either to cope with a short-term interruption or with a longer-term break in the life of a project. Second, as document objects within Manufaktur are references to the real documents (CAD documents, Excel spreadsheets etc.), copying the references does not create multiple different document versions. Using multiple links to refer to the same document is a well-known idea and is implemented for example by the Unix symlink mechanism and by Windows shortcuts. In contrast to the physical world, simply copying a document object from one workspace into another allows the same document or drawing to exist in several places at once. Third, through reference to other workspaces, parts of, or complete, contextual arrangements can be embedded into a new context.

The consequence is that users can, in effect, inhabit as many 'parallel universes' in relation to their work – equivalent to the first-order arrangements discussed above – as they care to create. This is a very powerful feature, but it could also be confusing and disorientating in use. An important aim for the fieldwork is to discover how users choose to subdivide their digital environments, and to propose aids for navigating among them, and for recording and representing historical traces of their paths.

4.1 CLIENT ARCHITECTURE ON THE WINDOWS PLATFORM

The *Manufaktur* application on the Microsoft Windows 2000 platform builds on the Microsoft Foundation Class (MFC) framework. Most importantly, this framework provides us with a host of templates and wrapper classes for working with ActiveX/OLE. Furthermore it provides a number of classes for automating and encapsulating work with databases. For rendering 3D scenes we make use of the MS DirectX programming interface.

As already mentioned, documents pertaining to applications external to the *Manufaktur* can be attached to 3D boxes inside a workspace, communicating with these external applications through OLE linking. When one inserts documents into the *Manufaktur* (e.g. via drag-and-drop from the file explorer) we establish an OLE link to the file, thereby subscribing to update events for that file. When the external application 'fires' an event, we ask it to draw the document into an off-screen device context (the applications are 2D and so cannot draw themselves directly as 3D objects in the *Manufaktur*). We grab the content of the device context and wrap it onto a surface of one of our 3D objects.

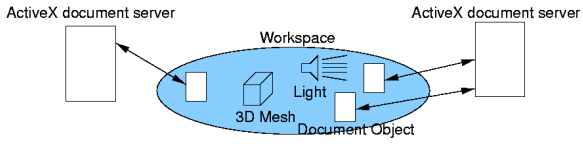


Figure 4: A schematic workspace containing various objects: a light source, a 3D mesh file (3D model), and three document objects that are linked to their respective servers

The persistent version of these 'live' OLE links is called a moniker. Through a so-called 'binding' process, monikers are resolved to the documents they refer to, thereby making a running version of them available (i.e. re-establishing the OLE link). Because we are using the distributed version of COM, DCOM, these monikers can be resolved to documents residing anywhere on a network, as long as the machine supports DCOM.

The software architecture of the *Manufaktur* is based on the MFC document/view architecture. The document part, corresponding to a workspace, holds the data, and the views handle display of the data. A number of classes provide an object-oriented model of the workspace's data. In this sense it both provides a model of the objects that can actually be rendered to a view and also a model of what is saved to the database. A view of a workspace is a scene containing 3D rendered objects. The Direct3D and DirectDraw parts of the DirectX SDK handle the rendering. Direct3D consists of two separate parts, a low-level interface called Immediate Mode and a high-level interface called Retained Mode. Careful use of the low-level interface may enhance performance. We have, however, chosen to use the high level Retained Mode interface mainly due to expected speed-up in development and its support for hierarchies. On the Windows platform, Direct3D/DirectDraw was chosen over the obvious alternative OpenGL because the COM-based DirectX was expected to be better suited for mixing with ActiveX/OLE – technologies also based on COM. The advantages have not been as obvious as expected, so we may experiment with OpenGL, and also with Direct3D Immediate Mode to gain performance.

The above is directed towards acquiring 'live' representations of users' work material. Contextual spatial arrangements of materials are a resource for mutual awareness of ongoing work, and the *Manufaktur* supports collaborative, distributed work across platforms. The *Manufaktur* seeks to facilitate users' collective self-organization of environments, spaces and traces that embody the trajectory of their work. This is in some respects a radical approach to information visualization compared to that found in most collaborative virtual environments [4]. The emphasis is far less on the visual representation, e.g. through avatars, of the collaborating *persons* – though of course that can also be realized if necessary – than on the representation of the *materials* with which people are working, and the actions they are taking with them. This can be accompanied by speech channels [18] and other affordances of activity, such as 'pointing' by identifiable participants.

4.2 WEB OF WORKSPACES

In the Manufaktur, object collections form workspaces. The workspace that has been opened will occupy the whole space in a window, and it may contain other workspaces within the larger one – providing the technical means to realize the second-order visual-spatial arrangements discussed above. Workspaces may manifest themselves in various ways in the including workspace – currently unconstrained and billboard workspaces are supported. Various other visual manifestations of workspaces may be imagined: ramps [17], heaps etc. In the future, ad hoc workspaces may also be suggested by on-line spatial parsers as in the 2D systems VIKI [15] and CAOS [3]. Spatial parsing may also be used to support the spatial organization of groups.

Workspace membership is visualized in several ways: by spatial proximity, by color and by naming. Each document object is embedded in a frame in the color of the workspace, providing users with a quick overview of which objects belong to a workspace. This supplements the effect of spatial grouping of the workspace members. The frame is also used to display the document title and the workspace name.

Workspaces may be referred to from other workspaces by means of proxy workspace objects. As workspaces may in general be large and contain many objects, including them directly may produce cluttered and unwieldy workspaces. We propose to alleviate this problem by letting the proxy objects have various states of openness. If a proxy object is fully closed it is represented visually by a single 3D icon showing only that 'here is a reference to another workspace'. A partially-open workspace is represented by two icons: one representing the proxy object and an icon identifying the included workspace. This icon could be a static picture of the main document object that is the reason why this particular external workspace was embedded in the current one. A fully open proxy workspace shows, in addition to the two icons, all the objects of the included workspace within the including workspace. Naturally, other kinds of partial openness can be envisioned. A workspace proxy may be scaled just like any other object and it scales the included workspace with it. This may be used as another form of partial openness when referring to a large workspace. Workspaces may refer arbitrarily to each other via the proxy objects except that circular references are caught: the system forbids the complete opening of a proxy that would result in a circular reference.

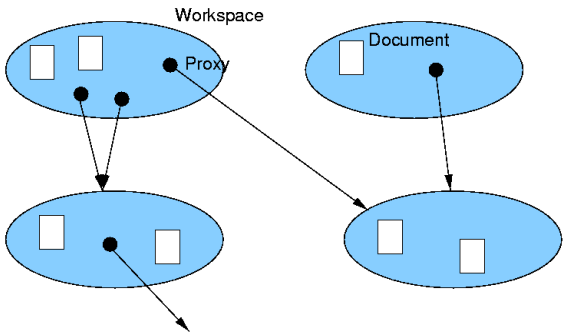


Figure 5: A diagram of four workspaces, showing how a workspace may be referred to by multiple proxies even from within the same workspace.

The state of openness of an included workspace is decided by the proxy object belonging to the including workspace, in order to allow other including workspaces to present the included workspace in other states of openness. I.e. if workspace A and B both refer to workspace S, S may be closed in A, but fully open in B since the openness is an attribute of the proxy objects belonging to A and B, not an attribute of the workspace S itself.

Interaction with both the reference and the workspace as a whole is supported by separating the objects for the referring proxy and the referred workspace. Moving the proxy object moves the contents of the included workspace within the including workspace. It has no effects on the referred-to workspace itself. Changing the colour of the proxy object changes only the colour of the proxy icon, whereas changing the colour of the workspace icon changes the colour of all the objects of the included workspace. A combination is possible, where the proxy object maintains a link to a workspace, while all or some of the contents of that workspace become new workspaces within the including workspace that can be manipulated without having an effect on

the included workspace. This is supported through copying the references. Multiple open references to the same workspace are visualized as several synchronized representations of the included workspace.

Besides support for the creation of relations through spatial arrangements, the *Manufaktur* also provides navigational link services. Linking services are provided through integration with and extension of the *Webvise* hypermedia system developed at Århus University (initially in the Esprit II and III projects EuroCoOp and EuroCODE, later in the Danish CIT project Coconut).

Webvise provides linking capability between parts of documents to parts of documents in external applications. This means that, e.g., MS Word documents stay in Word format and links are created and followed from inside Word. The links have multiple endpoints and are directional (can be followed both forward and backward). The link structure is maintained outside the linked documents, thus facilitating browsing and searching mechanisms as well as linking to and from documents to which one does not have write access.[2]

4.3 SCENARIOS OF USE

Important questions for the fieldwork and our professional partners at this stage are: 'What kinds of configurations of separate materials (first-order arrangements), but also several collections of materials in different workspaces (second-order arrangements) are there and how are they used?' These questions are best addressed through use of the *Manufaktur* in real work. We are currently implementing the *Manufaktur* at our partners' studios. In the meantime, we are able to delineate scenarios of use on the basis of interdisciplinary workshops and fieldwork.

A scenario sketched out by one of the landscape architects and spun further at different points during one of the workshops provides some useful insight into how an individual might work within the *Manufaktur*:

> A client rings and reports a problem relating to an element of a CAD drawing. I open the respective project workspace. There are 25 CAD drawings. I find the relevant drawing, zoom to the relevant place in the drawing and find that there are already links to this element of the design. I am able to check background information by following those links and discuss the problem with the client. A colleague will have to alter the drawing and I leave a note on the drawing and place it in his workspace. I follow up the discussion with a letter, which I want to link to this place in the CAD drawing. Over the next few weeks, the problem persists and develops into quite a complex set of drawings, correspondence, sketches, notes, and explorations of product information for alternative solutions. I would like to branch off a separate workspace dedicated to this, which it is also relevant to include within other project workspaces for which this is a component.

Several practical suggestions arise from this scenario:

- How could finding the relevant drawing be assisted? One suggestion would be to have a list of files belonging to a group that can be sorted by name, author, date, etc. – registers of order that could be reflected in the spatial order, e.g. with the most recent drawing at the front, others stacked behind.
- For ease of manipulation and overview – e.g. scrolling through a several page text document while being able to see the CAD drawing zoomed to the right place – it would be useful if applications could be run *inside* the workspace.
- The Post-it note has already been transposed into the electronic space of the *Manufaktur*. It can be emulated by editing a link type, where a note can be attached. The color of the anchor can be changed to indicate that there is a note. The note will flag up when the cursor is moved over the anchor.
- The persistence of the problem in the scenario is an example of how workspaces might proliferate. Here, one might want to save what was a group embedded within a workspace as a separate workspace, while maintaining a proxy icon and a reference to the workspace in the original workspace.

If we consider the example presented above, different scenarios of the use of multiple embedded workspaces arise. While Joanne and Vic are working on the layout and detail drawings, Joanne updates her project coordinator's workspace as new information arrives. Because her main focus is on a different task at the moment, she could import the project coordinator's workspace into her current workspace, carry out her work there and update the original project coordination workspace. Unlike switching between different workspaces, this would allow for fluent transitions between the current focus of work and peripheral activities. Her collection of product information would be approached as embedded workspaces with a much looser connection to their original. Some of the information she uses has been duplicated from the main library and the products specified have been used in previous projects. Some of this information is potentially useful, as problems or solutions involving particular materials will have been dealt with there. Having a reference to the respective workspaces at her fingertips, she would be able to exploit these previous experiences by following, for example, the links made from specific parts in the trade literature, or browsing the contextual arrangement they are a part of.

Vic and Joanne's work also sheds some light on the collaborative use of workspaces. Their physical workspaces are mutually visible, allowing each to gauge some information about how the other is getting on with their work. On the other hand, having information in one workspace – e.g. the layout drawings on Joanne's drawing board ('x') – means that Vic either has to walk across or use his own reduced size copies. This is not necessarily a waste of time and effort. In fact, it can give rise to important discussions. However, the landscape architects are increasingly using electronic documents and the use of multiple, potentially outdated copies can be a source of trouble. New copies are often printed to ensure they carry all the latest information, but this is time-consuming. Moreover, there are attempts to take advantage of the electronic medium through distributed collaboration between different branches of the landscape architects' firm as well as teleworking colleagues. The *Manufaktur* could be a useful synchronous and asynchronous resource for such collaboration [4].

Collaboration in professions such as architecture and landscape architecture does not stop at the studio door. Much of the material that is produced while working on a design will not just be used by the team itself but activated in meetings with professional partners and the client. A *Manufaktur* space for working on a design detail or project coordination may be used as a starting point for a carefully constructed presentation space or it may be quite spontaneously converted into one. Thus the *Manufaktur*

[2] For further detail regarding the hypermedia system see, e.g., [9], http://www.daimi.aau.dk/~kgronbak/DHM/DHMHome.html, and http://www.cit.dk/Coconut/.

could be used as a meeting support tool. This however, requires it to be portable. A staged presentation could easily be saved on a CD ROM. However, when flexibility and a transition into 'real' work with documents and objects are desired, network access and an Internet browser are obviously necessary.

5. CONCLUSION

In this paper we have, in line with others, argued that it should be part of the remit of information visualization to get close to real settings of work practice, and to address very heterogeneous informational materials. On the basis of ethnographic fieldwork examples and scenarios, we distinguished three kinds of use of information for the purposes of organization and visualization, each with corresponding philosophies of design and means of technical realization. We identified the power as a visual information resource of the disposition of materials in three-dimensional spaces. We described a system, the *Manufaktur*, that provides a 3D visual information space and captures the 'first-order' traces of the self-organization of users in arranging visual materials in that space. We identified how can be important to users to manipulate these workspaces as a whole and to relate them in various ways through, for example, multiplying them, embedding them in different forms in a flexible hierarchy, transmitting them, and concatenating them. We described in some detail the powerful and flexible ways in which the *Manufaktur* supports these interconnections between workspaces. We argue that the system provides a significant step in supporting the visualization of heterogeneous information in the real world, through distinguishing appropriate design approaches for the varying professional practices of information visualization.

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