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Work Practices Surrounding PACS: The Politics of Space in Hospitals

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Abstract. This paper uses a case study of collaborative work practices within the radiology department of a hospital, for examining the usefulness of spatial approaches to collaboration. It takes a socio-political perspective on understanding the shaping effects of spatial arrangements on work practices, and seeks to identify some of the key CSCW issues that can be addressed in spatial terms. We analyse the spatial settings or layers (physical, digital and auditory) within which work takes place, and the qualities of connections between them, examining in how far they support (professional) boundaries or help maintain a sense of context. Guiding themes are the relationships between space and the visibility of work, and how to accommodate social world needs through spatial arrangements.

Key words: CSCW, ethnographic case study, health care, space

1. Introduction

Interest in spatial approaches to CSCW has grown over the last few years. Spatial metaphors are used for understanding how to enhance existing workspaces on the one hand, and how to create virtual spaces for collaboration on the other. This interest in space is grounded in the understanding that spatial arrangements provide a context for work. A space can be designed to reflect important aspects of context. It may be connected, reflect other places and times. It may be internally regionalised, established as an enclosed site, subdivided into areas that have been designated to specific persons and activities at the exclusion of others. Spaces are not neutral, they provide actors with a "view from somewhere" (Haraway, 1991), a special vision. They reflect power relations, and issues of power can be addressed in spatial terms (in terms of inclusion, exclusion and confinement, unequal furnishings, (lack of) connections to other places) (Wagner, 1999).

This paper uses a case study of collaborative work practices within a hospital for examining the usefulness of spatial approaches to collaboration. The case study focuses on work practices surrounding PACS (picture archiving and communication system). This is a system, which supports the storage, distribution, communication, display, and processing of radiographic image data. Embedded in a networked environment, it facilitates the sharing of these image data across organisational and professional boundaries. Images can be archived and organised in central units and be accessed and used co-operatively by locally distributed actors.

Hospitals are good places for studying large-scale cooperation. Cicourel (1990), among others, has emphasised the distributed nature of clinical decision-making. Organising diagnostic and therapeutic action is a complex task and hospitals are places of multiple work sites. When introducing a technology such as PACS, one of the crucial questions is how to create shared workspaces for those who collaborate in the production of radiological images and their interpretation.

While analysing social uses of a large-scale technology as PACS can be seen as an aim in itself, the paper also addresses more general issues. It takes a socio-political perspective on understanding the shaping effects of spatial arrangements on work practices, and it seeks to identify some of the key CSCW issues that can be addressed in spatial terms.

2. Spatial approaches to CSCW

The study of the social organisation of space figures prominently in social science literature, in particular in urban sociology and in the work of social geographers (Gregory, 1994). Their focus is on issues of culture, power, knowledge, and spatiality. We attempt here to briefly give an overview of concepts and approaches that we consider useful for an analysis of cooperative work.

2.1. THEORETICAL BACKGROUND

An early example of spatial analysis of human interaction is the distinction between the front and back regions of a place, which has been used by Goffman (1959, 1961), as part of his dramaturgical model of human action, and Hall (1959). Both define the 'front' as the space of high visibility in which actors display their public face – the mask or façade – whereas the 'back' is the place for the hidden or private aspects of one's personality. Wider sociological interest in space was spurred by the work of Lefebvre (1974), Foucault (1975), and more recently Giddens (1984). Giddens, who in his theory of structuration introduces space-time, argues that space is not simply an arena where social life unfolds. Space provides a context for social interaction. The specific artefacts, symbols, knowledges, and ideologies that inhabit it are resources, which both, are mobilised in social interactions, and shape these interactions. Spaces bound and structure activities. A sociology of space has to demonstrate how spatial arrangements construct, sustain, constrain, and, occasionally, transform human practices.

A second strand of thought approaches the analysis of space from a different direction – discourse analysis. In his famous studies of hospitals, prisons, and asylums Foucault (1976) analyses the changing objects and notions of a wider social discourse on medical attention and discipline their architecture reveals, arguing: "In organizing 'cells', 'places', and 'ranks', the disciplines create complex spaces that are at once architectural, functional and hierarchical. It is spaces that provide fixed positions and permit circulation; they carve out individual segments and establish operational links; they mark places and indicate values; they guarantee the obedience of individuals, but also a better economy of time and gesture" (Foucault, 1976, p. 148). In the tradition of Foucault, Prior argues that a building expresses "a domain of knowledge in so far as it embodies a spatial ordering of categories and a domain of control in so far as it involves an ordering of boundaries" (Prior, 1988, p. 92). Examples of this relationship between architectural form and human practice are the 'Panopticon' architecture of early prisons and asylums or, later, the Pavilion hospital. Prior discusses several plans of children's wards under this perspective, showing that they "encompass a series of theoretisations concerning the nature of disease, the child, pediatric medicine and nursing practice" (1988, p. 101).

Architectural form provides a particular register for social and professional discourses. But, as architect Bernard Tschumi argues, "space is not simply the three-dimensional projection of a mental representation, but it is something that is heard, and is acted upon" (1981, quoted after Nesbitt, 1995, p. 45). Spaces are spaces for *something*, not things stripped of use. Within architectural theory itself, social use is strongly connected to functionalism, and there is an ongoing debate on the appropriateness of concepts such as function and utility among contemporary critics of architectural thinking. An approach which is closer to social science's emphasis on understanding the situatedness of practice is to be found for example in Tschumi's writing. Criticising the programming of space in terms of function, he suggests to look at architecture not as an object (or work in structuralist terms), but as an "interaction of space and events" (quoted after Nesbitt, 1996, p. 162). The notion of use-as event (Lainer and Wagner, 1998) emphasises the situated, contextual, evolving, temporary, and sometimes performance-like character of activities.

A spatial analysis has also to bear in mind that the experience of physical space is multisensual, including the auditory world, and the world of smell and touch, which is connected to spatial properties such as size, shape and weight, texture, variations of temperature, the flexibility of material, and the continuity of surfaces. When analysing spatial arrangements and their role for human practices, these dimensions of physical space cannot be ignored. Sound not only provides connections between people and places within physical space. "The overlapping of a multiplicity of sounds from different sources, and probably from different locations" creates a soundscape with special spatial qualities (Rodaway, 1994, p. 86).

Finally, understanding the nature of digital spaces is at the core of a growing body of literature. The virtual, disembodied cyberworld of networked computer systems is contrasted with the worlds which seem to better correspond to our experience of reality as material, more immediately social, and contextual. Digital space is primarily visual and only peripherally auditory. It is generally smallsized, requiring focused attention. It blurs familiar points of reference such as inside/outside, chronology, and spatial connectivity. In digital space it is difficult to capture at a glance or to maintain peripheral awareness of events. In spite of these obvious constraints, digital space assumes an increasing presence within built spaces. It not only helps build partial connections to distant places. Also, as a space within a space, it can radically change and augment people's physical environment, as is demonstrated in current spatial applications, such as media spaces and collaborative virtual environments (Benford et al., 1999; Bly et al., 1993). Some CSCW research directly focuses on understanding in which ways the built physical space can be extended, modified, and connected with other spaces by technologies of various kinds.

2.2. CONCEPTS

For taking up these perspectives for CSCW, more detailed theoretical and empirical work is needed. Ethnographic studies of the ways in which space shapes social interaction have to be carried out. Here we think that work practice research (Blomberg et al., 1993; Jordan, 1995) offers both, a rich vocabulary and observational material, for talking about use as the assemblage of context and interactional contingencies into practice. One of the few ethnogaphic studies doing an in-depth investigation of space is Goodwin's (1995) analysis of cooperative work on a research vessel, where two different communities of practice and several scientific disciplines co-exist within a very small space. Goodwin studies the spatial organisation of events on the ship, the computer screen, the ground of the ocean, on maps, etc. Studies like Goodman's describe uses of space, they do not necessarily aim at theorising about the relationships between spatial arrangements and the characteristics of cooperative work on a more general level. In a previous paper (Lainer and Wagner, 1998) we discuss several aspects of this relationship as identified by CSCW research – awareness of events, people, and context, and the need for regions, boundaries, and connections.

- *Regionalisation* refers to the internal physical, social, or organisational boundaries of a specific place. Regionalisation is often related to the internal complexity of the work to be done. It reflects the specific layering of voices, important differences of knowledge, responsibility, and identity. For example, Star and Strauss (1999) use a spatial language, including the distinction between front and back regions, in their discussion of visible and invisible work. Even in a control room context (the paradigmatic CSCW setting), "there are distinct regions which are reserved for specific sets of actors and events. Still, boundaries are 'spongy' and relationships between distant actors can be easily activated through a variety of communication channels" (Clement and Wagner, 1995, p. 40).
- The notion of *boundary* (Star, 1993) focuses on the specific qualities of connections and transitions between spatial regions. A boundary can be physical,

social, or organisational. A building's façade, for example, can be seen as a boundary, which mediates between interior and exterior space. While an envelope of rocky stones hermetically encloses the inner space of a building, a translucent glass façade supports the communication of its contents to the outside world (Lainer and Wagner, 1998). In our own studies of software developers we showed how the need for boundaries on the one hand, for multiplicity and heterogeneity on the other hand, influenced people's choice of place – between more neutral environments (meeting room or coffee house), and more specific places (their workspace or the kitchen) (Tellioğlu and Wagner, 1999, 2000).

- *Awareness of context* is a particular quality of use to be accounted for in the design of space. A space can be designed to reflect important aspects of context, such as the surrounding environment, the history, the particular activities that take place in it, etc. Being co-located enables people to create and maintain the kind of peripheral awareness, which within CSCW research has been identified as a crucial element of cooperative work.

3. The case study

Danube Hospital is Vienna's most modern hospital, in many ways conceived of as a counter image to the mega-structure of the city's university clinics. The large-scale PACS of second generation, which was introduced in 1992 and extended three years later to include magnetic resonance (MR), reflects the hospital's image of efficiency and its commitment to interdisciplinary cooperation.

A large-scale PACS is built around a network connecting many departments of a hospital.[1] In *Danube Hospital* these connections are established by two additional systems – HIS (hospital information system) and RIS (radiology information system). RIS is mainly used for administrative purposes such as managing patient registration, scheduling radiological examinations, creating exposure reports (for accounting purposes), and producing radiological reports.

The decision to embark on investing in a rather costly and at that time not entirely mature technology was based on reasoning which has been extensively discussed over the last years in medical journals (Bergström and Karner, 1994; Giribona, 1991; Glass and Slark, 1990; Graßmann et al., 1994; Greinacher, 1995; Karasti and Kuutti, 1996; Kjær and Madsen, 1995; Lemke, 1990). PACS is primarily expected to reduce examination time through speeding up the reporting process, to improve the quality of diagnosis and treatment, to reduce the radiation time and dose, and to enable reliable, easy and fast access to new and old images within the whole hospital (Peissl et al., 1996). Issues of cooperative work, although not in the foreground, can be identified in all these assumed benefits of PACS technology. Planners hoped in particular that PACS would spur interdisciplinary dialogue between radiologists and clinicians.

The study was commissioned by the central hospital administration of the City of Vienna, with a prime interest in a technology assessment approach, based on collecting performance-related patient data. It was decided to do additional field-work on work practices surrounding PACS within *Danube Hospital*'s radiology department. This was done through participant observation and interviews with radiologists, clinicians, radiographers, and members of the hospital's computer department in charge of the daily running and maintenance of PACS and RIS. Altogether 240 hours (during three months in 1996) were spent doing fieldwork. As part of the project a series of small comparative studies of PACS in three other hospitals (in the UK and Denmark) were conducted (Lundberg and Tellioğlu, 1997; Tellioğlu, 1997, 1998; Wild et al., 1998a, 1998b). We will refer to one of these studies in our analysis.

Most of the fieldwork focused on the central radiology department, with a staff of 22 radiologists (including the head of the department), 34 radiographers, 4 surgical nurses, and a staff of 17 for administrative work. The department is open 24 hours a day and 7 days a week. The responsibilities of its staff include all types of radiological examinations, including those done in the hospital's casualty department, the intensive care units, the general wards, the operating theaters, and the hospital's nursing home.

In the following chapters we will use the language of space, regions, and boundaries in a four-step analysis of the uses of PACS technology as identified from our case study material. We will

- describe work practices involved in the production of radiological images and reports, and the places in which this takes place (Section 4),
- analyse how the physical arrangement of places is modified or enhanced by digital and auditory layers (Section 5),
- seek to understand if the ordering of space is supportive of cooperative work (Subsection 5.4), and
- draw conclusions regarding the role of a spatial approach in CSCW research (Section 6).

4. Work practices

Radiological work takes place within a dedicated area within *Danube Hospital*. The physical layout of the department reflects the internal division of labour between radiologists, radiographers (their technical assistants), administrative staff (mostly trained nurses) and others (typists, technicians). People's places within the department are connected electronically and through various audio channels to other places inside and outside.

We can roughly distinguish between sets of activities involved in the production of a radiological script, with different types of work being confined to particular spaces (Figure 1).

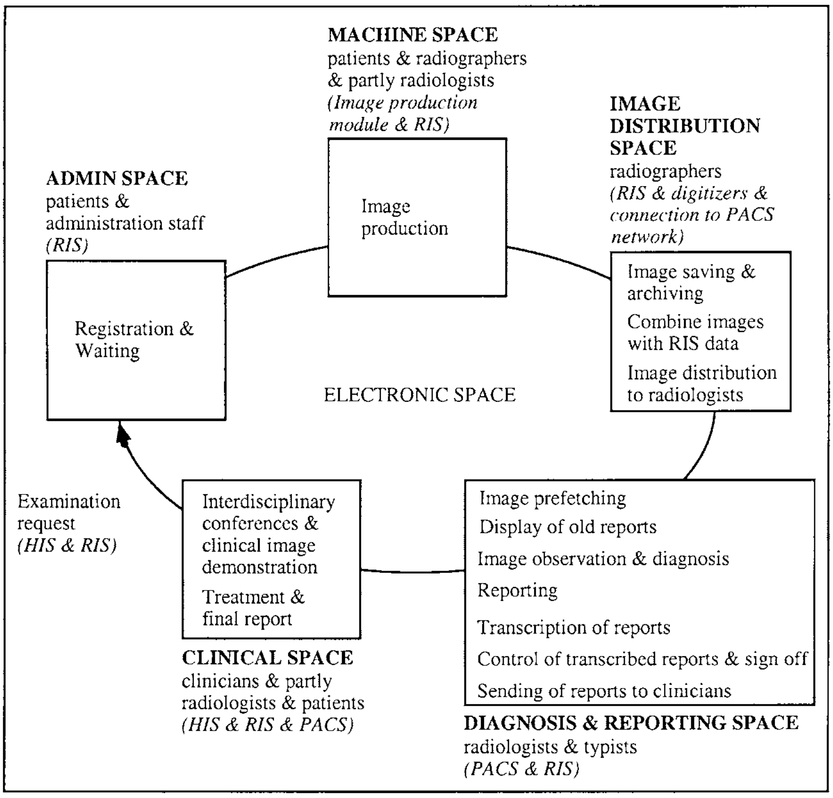

Figure 1. Spatial specialisation – mapping work activities (in boxes), actors and the systems used in support of these activities (in brackets) onto workspaces (RIS=radiology information system, HIS=hospital information system, PACS=picture archiving and communication system

- Examination requests are generated within the *clinical space* to which all radiology reports are forwarded and where therapeutic action is taken.
- The *administration space* is reserved for registration and waiting.
- The *machine space* is entered by patients, radiographers (and partly radiologists) for producing images.
- Within the *image distribution space* the images are saved, combined with the RIS data, distributed to radiologists, and archived.
- Images are compared and analysed within the *diagnosis and reporting space* where reports are created, dictated (or typed in), controlled, signed, and sent to clinicians.

4.1. THE ADMINISTRATION SPACE: REGISTRATION AND WAITING

This is the gate between the radiology department and the outside world. Whoever wants to enter radiology passes through this space – patients, medical personnel, computer technicians, suppliers. The boundaries are physical (while all the staff and outside persons just enter through the door, patients are shielded off by a window counter) and technical (there are different digital subspaces for different sets of activities).

Scheduling radiological examinations simultaneously takes place within a particular physical place and a shared digital space – the radiology information system (RIS). When a patient approaches the window counter, s/he is normally equipped with a written request. Since all patient data within RIS are linked to the patient's name, they first have to spell their name in order to register. After registration, patients are told to wait close to the examination room they have been assigned to until their name is called. By scheduling, the administrative nurse creates a particular order of activities within all other physical places. Each patient is assigned an examination time, a room, and a radiographer. The administrative nurse knows the staffing of the day as well as the special responsibilities of all radiographers who have no influence on how she allocates patients to the different machine rooms. There is the rule that the full work cycle of an examination from registration to the signing off of the report should not take more than two hours. Although priority shifting would be possible and RIS would support the optimisation of the patient flow, the work list is generated sequentially and not changed unless an emergency comes in.

While the patient flow together with the administrative nurse's interaction with RIS set the pace of registration, ad-hoc connections to the outside world are primarily regulated within the auditory space. Interactions with patients are frequently interrupted by incoming phone calls, with the telephone ringing almost constantly during the morning period (from 9 to 11 a.m.), and picking up the receiver has absolute priority. When the administrative nurse needs access to the staff within the radiology department she uses the loudspeaker for localising. She also prints out reports and is the prime contact between patients and the radiology department, reading out reports on the telephone, explaining, giving out information about procedures or next steps.

All problems with RIS are handled in the administration space. Whenever there is a network breakdown, patient information cannot be retrieved, there are two patients with the same name, etc., this is dealt with within the administration room – e.g., she gets in contact with the ward for clarification, or calls in a support person from the computer department.

4.2. THE MACHINE SPACE: IMAGE PRODUCTION

This is the main workplace of radiographers each of whom are responsible for a particular machine room with different imaging machinery – conventional X-ray which is subdivided according to the different parts of the body, computer tomography, angiography, mammography, and some ultrasound equipment. Radiographers produce the requested images, mostly in direct interaction with patients who need to be instructed, positioned properly, and often calmed down. Modern imaging technology is difficult to use and producing readable images needs a highly developed technical and also medical skill. Very often radiographers have to look at previous images and read old reports in order to know what and where to look for. To create what then can be interpreted as a pathological symptom requires an amalgam of pathological knowledge and expertise in handling the different functions of the imaging equipment (Cockburn, 1993). This is most pronounced in computer tomography, which is a slow technology. Here the radiographer has to work with the image-in-production and with the patient lying in the machine. She, e.g., enlarges an image, looks for structural information, answers a phone call in between, and works out a readable set of images. She also has to document the procedure in a book. After images have been produced, there are different optimisation techniques, such as cutting out the relevant part and increasing their quality.

Most types of examinations are performed by radiographers alone, and there is no contact during image production with the radiologists. Their presence is only required in examinations such as angiography (which is surgical), ultrasound, mammography and to some extent computer tomography. In case of these examinations, radiologists do not take part in the whole examination process. They enter the machine room as specialists. In computer tomography the radiographer will call in the radiologist to look at the images and decide whether their quality is good enough and eventually inject a contrasting liquid. In angiography (a treatment of the arteries), radiologists are focused on their special role, rarely getting themselves directly involved with the patient and only engaging in short professional exchange with radiographer and nurse (who later explain to the patient what the radiologist has told them).

Machine space within *Danube Hospital*'s radiology department is not a space for interdisciplinary exchange, but invisibly regionalised, with radiographers in charge of image production (and of taking care of the patient) and radiologists minimising their contribution to their medical role. Time in this space is dictated by the flow of patients and the rhythm and length of an examination.

4.3. THE IMAGE DISTRIBUTION SPACE

This is radiographers' second domain, and they constantly move between these two spaces – opening the door to the waiting area for calling in a patient, carrying out an examination, producing and finalising images. The distribution of images is done immediately after their production. For this the radiographer steps out of the machine room into the image distribution area. Conventional X-ray images have to be first digitised. The radiographer then combines the images with the RIS data, creating a patient folder. Before the images are sent off, she checks their quality. Although she may discover an error or insufficiency in her material, she can only improve its quality by post-processing, since the patient has already left at this time. When the folder is ready, she sends it off to the appropriate PACS workstation which is located in the diagnosis and reporting area, according to her map of responsibilities. Image distribution is a solitary activity and usually done within a few minutes. Image transmission takes time, but it is possible to look at the images during this process.

4.4. THE DIAGNOSIS AND REPORTING SPACE

This is a space of intense cooperation, reserved for radiologists only. Each of them has their particular PACS workstation for six months and each workstation represents one of four areas – pediatric cases, skeleton, intensive care, and internal medicine.

Danube Hospital's radiologists have developed a culture of mutual support. They need to pool their knowledge for solving complex problems. It might happen that one radiologist moves to the neighbouring workstation to support a colleague and then continues working with his neighbour's patient list. In contrast to radiographers, radiologists do not move (unless called outside into one of the machine rooms). Connections to the spaces outside are mainly activated through phone calls. There is a lot of talking with clinicians, radiographers and also computer support staff going on.

In this space radiologists act as physicians and as computer experts. The handling of images (Figure 2) requires highly developed technical skills. Diagnosing is tightly connected to the manipulation of images. From the image radiologists create a representation of what then can be interpreted as a pathology or the absence of illness. Conversely they can manipulate the images so that they are credible interpretations of their diagnosis.

When a patient's images are ready, radiologists will often retrieve previous images and reports from the PACS and RIS archives (Figure 3). For this preparatory work they have no administrative assistance. The presence of several monitors (four in the areas assigned to skeleton and intensive care) supports working on several patients' images in parallel. Radiologists prefer this parallel mode to working sequentially. In this way the images are present for a longer period and there is more time for viewing, reviewing, and discussing. When an image is not good enough, the radiologist may call for the original film material (which is available for a short time before it is reused), look at it, discuss it, call in the responsible radiographer and give instructions what to observe and concentrate on in consecutive examinations.

The report is dictated into a machine which is picked up by the typist and returned later via RIS. Only intensive care reports have to be typed in immediately by radiologists themselves and there are complaints about this. Radiologists have

Figure 2. A radiographic image displayed by PACS. On the right side of the screenshot several functions are made available for modifications of image display.

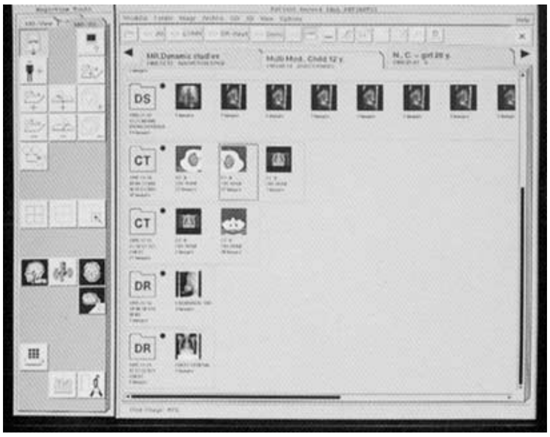

Figure 3. The patient folder with old images and radiographic reports retrieved for diagnosis work.

developed their own style of communicating their diagnosis, which a typist has to be able to interpret. After validating the transcript, the report is signed off. Each report carries the name of the responsible radiologist, but there is no reference to the radiographer, who has used her expertise for producing an image that can be interpreted, or to the typist. They remain anonymous.

Time in the diagnosis and reporting space is determined by the work list. In the morning, images cannot come in immediately, since they have to be produced and distributed. As soon as the first images arrive, radiologists also start looking repeatedly into the patient queue. This gives them a feeling of how to time their work, whether they have to work fast and in a highly focused way or whether there is time for exchange with colleagues, including coffee breaks in between. By midmorning they know their schedule for the rest of the shift (apart from incoming emergencies).

4.5. THE CLINICAL SPACE

As already mentioned, digital connections between the radiology department and the clinical areas are one way and this in both directions. All requests for images are issued by clinicians, and radiologists have little influence on the timing, the number, and the nature of these requests. They may use the early morning (before the first images arrive) for talking to clinicians about their requests. Still, there is amazingly little interdisciplinary consulting, although very often radiologists have already seen and diagnosed previous images of one and the same patient and might give advice on how to proceed further. On the other hand, radiologists do not share their images with clinicians unless asked to, or when a clinician has a problem with a radiological report.

The daily radiological conferences open up some space for an interdisciplinary dialogue, but in a rather restricted way. During these meetings many radiologists find themselves reduced to their role as PACS experts. Their job is to display images. While this gives them some opportunity for demonstrating the congruency between produced or manipulated image and report, the power to come up with an authoritative medical interpretation resides in the clinician.

5. The spatial organisation of radiological work

Our spatial analysis of work practices in these different places – from administration to diagnosis and reporting – proceeds in several steps: We first look at the overall architecture of the radiology department and at in which ways it supports the definition of regions, at the qualities of connections between regions provided by the digital layer created by PACS, RIS and HIS, and at the special role of the auditory layer created by phone and loudspeakers (5.1, 5.2 and 5.3). We then discuss issues of cooperative work we found being expressed by the spatial organisation of radiological work (5.4).

5.1. THE PHYSICAL LAYER

The radiology facilities at *Danube Hospital* are centralised and physically co-located in one part of the building (Figure 4). They occupy a rectangular area.

Radiologists' diagnosis and reporting space is located in the center of this area and physically enclosed. It can only be entered through a door. Close to it is the image distribution space. Radiographers frequently move between this area and the machine space divided into a series of small examination rooms, which are laid out around the core. They can be entered from two sides. The entrance from the core is reserved for radiographers and radiologists. The other entrance is used by the

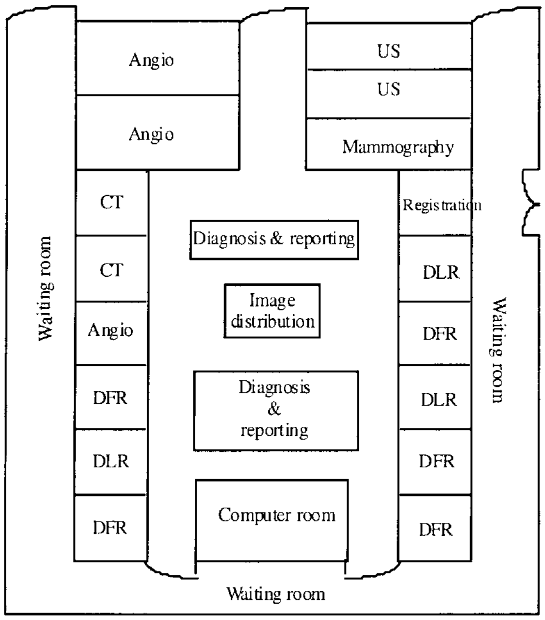

Figure 4. Schematic floor plan of the radiology department (DFR = urology, DLR = thorax, CT = computer tomography, Angio = angiography, US = ultra sound).

patients who have to wait in the surrounding space outside until they are called into one of the numbered examination rooms.

This spatial order reflects the place of each profession. It is less one of discipline and surveillance, in the way Foucault (1979) described the architecture of asylums and prisons, than one designed to assert professional boundaries. It reflects the hierarchy of knowledge within radiology, with radiologists at the top, and their supporting staff – radiographers, computer technicians and typists – having free access to but no place in the diagnosis and reporting space. It also carries a particular notion of professional community. The enclosed diagnosis and reporting space in the center expresses the idea of radiologists forming a community of practice (Jordan, 1995) in need of close and continuous contact with each other in order to be able to deploy and develop their professional expertise.

The department is spatially sealed off from the surrounding communities, including clinicians, who are perceived as receivers rather than co-producers of radiological reports. This inside-outside distinction is also visible in the transitory role of junior radiologists, who are frequently sent outside into the clinicians' territory.

We have tried to visualise the residences and paths of different types of actors in this spatial arrangement. Figure 5 shows the areas that people enter and where they temporarily meet with others either to be examined in case of patients or to in various ways cooperate in the production of radiological reports. It highlights

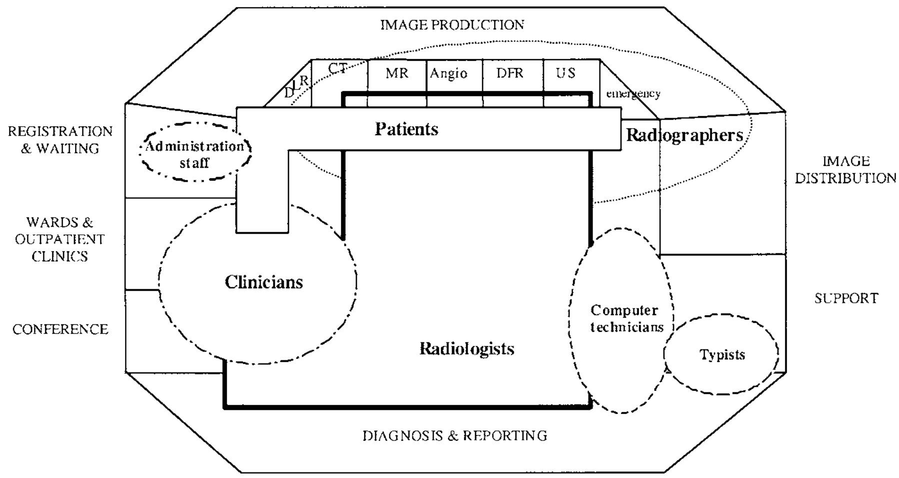

Figure 5. Boundaries and the permeability of spaces in the radiology department.

the relationships between activities and people, showing how they intersect or are kept separate. We can clearly recognise regions, their boundaries and connections between them.

Patients enter registration where they interact with administrators and wait until they are called into one of the machine rooms in which the examination takes place. Image production and distribution are the main areas of radiographers' work. Here they meet the patients and, if the examination requires it, collaborate with radiologists. Typists and computer technicians enter the diagnosis and reporting area from outside, when requested, as support staff. Clinicians' workplace is within the wards and the outpatient departments. They occasionally enter the radiology department, when they walk in or are called in to support the production and interpretation of images, and they meet members of the radiology staff in the room reserved for interdisciplinary conferences. The whole space is open to and partially occupied by radiologists who, although they mainly work with already produced images, comparing and interpreting them, can consider the whole department as their terrain.

There is also an interesting connection between people, machines, and radiological knowledge. Different machines support different parts of the overall work and this is visible in their spatial distribution. While the imaging apparatus themselves are organised spatially according to the medical topology of the body and the different imaging techniques, the location of computers used for image distribution and diagnosis mirrors the division of labor between radiologists, radiographers, and other supporting staff.

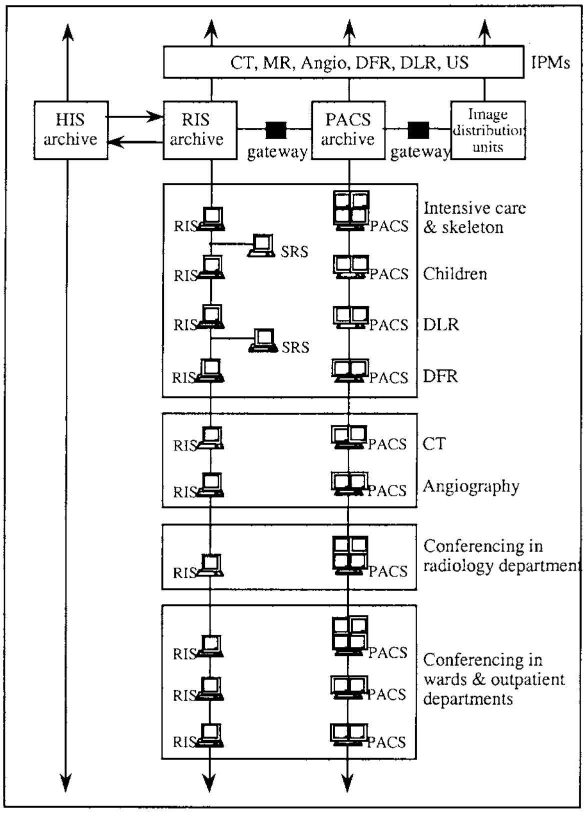

Figure 6. The network topology implemented in *Danube Hospital* aroud the radiology department.

5.2. THE DIGITAL LAYER

Danube Hospital's computer network is built around a central archive in star topology to which all departments are connected through fiber distributed data interfaces (FDDI), which in turn form a ring network on each floor.

PACS (as one of four subnets) is based on a local area network (LAN) and has an interface to RIS and HIS which supports the transmission of data to the image production units (IPM), the central archive and the connected workplaces (Figure 6). The image production units consist of two computer tomographs, one magnetic resonance equipment, three machines for angiography, three for digital lumines-censradiology, five for digital fluoroscopy, eight ultrasound, and mammography (which are not digitised and therefore not connected to PACS).

Images are stored within three different archives: while still in production (before the examination has been completed) on magnetic disks which are located on the distributed PACS workstations; for short-term storage on magnetic disks and redundant array of inexpensive disks (RAID) which ensure reliable and fast access to on-line data of current patients; and for long-term storage on optical disks in jukeboxes. IPMs have their specific software applications to create, display, and optimise the created images, i.e., gray scale or image size modifications. The interaction with IPMs is enabled through specific machine dependent input devices.

This networked digital space is regionalised. All IPMs are connected to the central image distribution unit from where images are sent to the PACS archive and the workstations in the diagnosis and reporting space. While still in the machine space, access to PACS enables radiographers to look at older images of a patient during an examination, e.g., in order to locate the area of exposure. From the image distribution space they send the images to the appropriate PACS workspace within the diagnosis and reporting room. RIS gives radiographers access to patient registration and serves as a connection to accounting.

PACS creates a shared space for digital images, which can be accessed from the associated physical spaces (machine, image distribution, diagnosis and reporting). Work within the diagnosis and reporting area happens in two parallel digital spaces (PACS and RIS). Radiologists have access to the images and may display and manipulate these images. They can retrieve previous radiological reports, including images (but not clinical reports). The work list gives an overview of the patient queue. Radiologists have no real time access to the image-in-production from their workstation. Although IPMs, PACS workstations, and RIS computers are co-located in the examination room, they are not connected. Consequently, the transmission of images to a radiologist's workstation is one-way and radiologists cannot change the location of an image without the radiographer's intervention.

Radiological reports cannot be directly entered into PACS. Since radiologists refuse to work with the speech recognition system, which can easily be linked to the RIS reporting facility, they dictate their reports for typists to be entered into RIS during the day shift when typists are available.

HIS and RIS help to build partial connections between different physical spaces (as shown in Figure 7). HIS and RIS connect the clinical space with the administration and machine spaces. They support the generation, scheduling, and administrative processing of examination requests. The link between RIS and IPMs forms a bridge between requesting and administration on one side, the production and processing of images on the other side. Digital connections between the diagnosis and reporting space and the clinical space are one-way, in both directions. The bridge between these spaces is formed by the links between RIS and HIS created by accessing each other's database. While radiological reports are automatically transmitted to the clinician, images are only forwarded if explicitly requested by clinical staff.

5.3. THE AUDITORY LAYER

Connections to places inside and outside the radiology department are supported by different auditory channels. Everybody carries a beeper machine. Loudspeakers

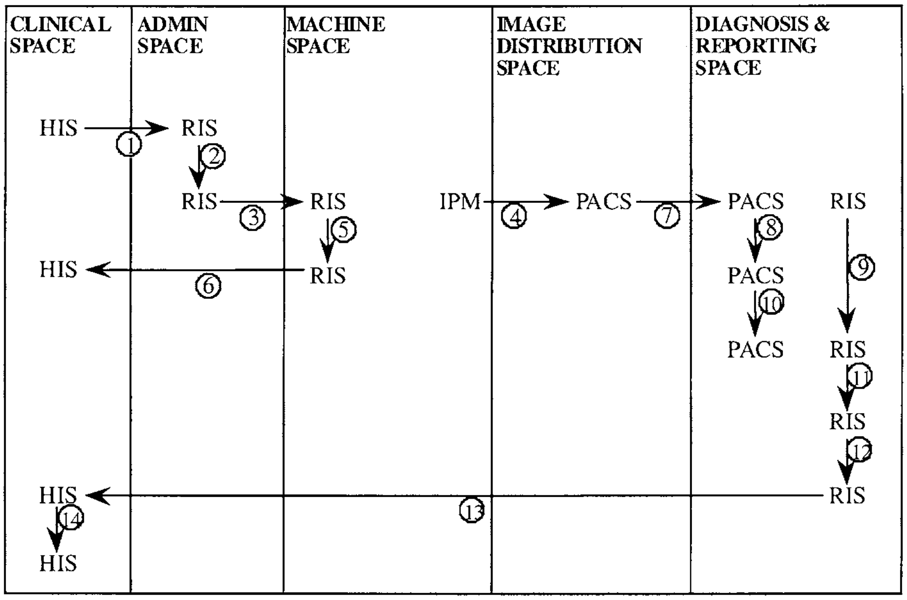

Figure 7. Work process during a radiological examination of a patient supported by different computer technologies like HIS, RIS, PACS, and image production units (IPM). (1) examination request, (2) registration and waiting, (3) creation of work list for radiographer, (4) image production, (5) exposure report, (6) accounting, (7) image saving and archiving, combine image with RIS data, image distribution to the radiologists, (8) image prefetching, (9) display of old reports, (10) image observation and diagnosis, (11) reporting, transcription of reports, (12) control of transcribed reports and sign off, (13) sending of reports to clinicians, (14) interdisciplinary conferencing and clinical image demonstration, treatment and final report.

are used for announcements and calls for particular people. Both technologies have been around for a long time and are mainly used for locating people.

The dominant communication technology is the telephone. Scheduling radiology examinations is partly done via the phone. Patients call registration for fixing a date. They may also ask the administrative staff for diagnostic and therapeutic information. She may read out parts of a report and talk to the patient, or call the responsible clinician, inform her/him, ask questions, leave a message. Radiologists frequently use the telephone during their work. When a request is not clear, radiologists contact the clinician and ask for what exactly to look. They also use the phone for communicating with radiographers during examination. There are incoming calls from the wards with requests about particular patients. As they need immediate remedy, problems with the computer system are discussed with computer technicians over the phone.

This auditory layer helps activate partial connections to people and spaces. The telephone is intrusive and does not protect professional and spatial boundaries. There is a continuous switch of control, between being called and calling. Radiologists may be in the position of intruder into a clinician's space at one moment and in the next moment be interrupted and asked to respond to a question. In contrast to the physical and digital spaces, the auditory space is relatively open and unstructured. Nearly everyone is directly accessible (even to patients, with some exceptions).

5.4. THE QUALITIES OF CONNECTIONS

As our analysis shows, several spatial settings or layers coexist within radiology. Foucault (1984) has coined the term *heterotopia* for such places. An heteroptopic space is not necessarily open and accessible and the connections between subspaces may be partial and highly regulated. We need to ask ourselves to which extent the spatial arrangement of physical, digital, and auditory layers we identified is supportive of cooperative work and how it restricts and channels such cooperation. We can address this question within the theoretical framework we introduced in the beginning of this paper.

5.4.1. *Regions, boundaries, and connections*

There is a common presumption that the technical infrastructure in support of cooperative work should ideally present as few barriers as possible, “that it should be ‘seamless’ in its connectivity” (Clement and Wagner, 1995, p. 47). However, this does not necessarily mean that the actual human communication would not often benefit from maintaining barriers and divisions. Goodwin uses the term *convergent diversity* for a situation of cooperative work, where people may “follow rather separate agendas, which may interlock at points with the agendas of others” (1995, p. 247). This is not only to do with the fact that different, complementing disciplines each pursue their own approach and tasks. As our case shows, there may be conflicting needs to be taken into account, and people may wish to protect their own expertise and particular vision by maintaining professional boundaries. On the other hand, the complexity of a task may make it necessary to accommodate multiple voices – perspectives and practices (Neumann and Star, 1996).

The spatial arrangement in *Danube Hospital* supports boundaries, at the expense of excluding or not sufficiently integrating multiple voices. The authority to produce radiological reports resides in radiologists. This is visible in both, the architecture of the radiology department and the PACS environment. An enclosed space for radiological expertise was created, where radiologists have the opportunity to develop, preserve, and protect their specialised knowledge. They have a place for themselves, which provides all the affordances of a shared work setting. Radiologists form a stable community of practice, which has developed a culture of mutual support and intense cooperation. They pool their knowledge for discussing difficult cases, and occasionally even swap workplaces. Temporarily radiologists form a cooperative ensemble with radiographers for specialised examinations (such as angiography, ultrasound, mammography, and computer tomography), but never for the whole examination procedure, and for their diagnostic work they retreat again into their own domain and space.

Radiologists' authorisation is challenged, by clinicians on the one hand, by radiographers on the other hand. The ultimate power to create a medical diagnosis resides in clinicians, although these are not co-producers of the radiological report itself. From their perspective, radiologists provide a technical service. When *Danube Hospital*'s radiologists cross the confines of their department, e.g., for taking part in the weekly interdisciplinary conferences, they often feel reduced to this service role. The computerisation of their work adds to this. Creating radiological images and reports is more and more seen by clinicians as a technical (in contrast to a primarily medical) skill. It turns into a territory claimed by radiographers.

From the point of view of radiologists, there are very good reasons to draw upon the rich resources that are afforded by the physical and digital world (walls, partitions, doors, etc.) for protecting their professional expertise. At the same time, the complexity of many cases would make hearing multiple voices necessary. This could be established through looking at the same images by clinicians, radiologists, and radiographers, each representing different domains and professional cultures.

There are alternatives to this strategy of enclosed spaces for radiological competence. In *Skejby University Hospital*, for example, radiological images are being simultaneously sent to the clinician and the diagnosing radiologist immediately after they have been produced (Lundberg and Tellioğlu, 1997). While the radiologist is working on creating helpful representations and writing the report, the clinician can have an independent view of the images, maybe converse with the radiologist, and eventually start therapeutic action. Even an integration of RIS and HIS would give clinicians more immediate access to all radiological information. Radiologists in this hospital actively shape their image as physicians. They for instance refuse to handle the preparatory and administrative parts of diagnosing and just step in front of the computer screen for creating effective displays and for evaluating them. The head of the department takes care to organise interdisciplinary conferences where the technology itself is absent and radiologists act as physicians amongst other physicians. In this radiology department the technical competence clearly resides in radiographers.

5.4.2. *Awareness of context*

All work is strongly connected to a context – of documents and objects, of people, of an ecology of organisations and institutions, of an organisational history and memory. The work is shared among people who move in and out of proximity, are more and less continuously intertwined with one's work, are harder or easier to reach through different media, are always or alternately recipients or providers of one's work. The spatial arrangements we analysed are potentially disruptive of context. This is partly to do

- with the limited visibility of people – the radiology department's architectural layout as well as digital spaces of PACS, RIS and HIS afford few vistas into other people's workspaces, and
- with the politics of invisible work – keeping work backstage (Star and Strauss, 1999).

Although radiologists are the main authors of the radiological script, their visual space is limited. From their place, they can neither look into the places in which image production physically takes place (in the machine rooms), nor into the digital space created by image production machines. Consequently, they often have no or very little control over the production of those images to which they apply their special professional competence. Conversely, radiographers, while performing an examination, have no easy access to the contextual knowledge needed to help them make a pathology visible. Technical production and medical diagnosis, although mutually supporting each other, take place in spatially segregated terrains.

This is partly to do with what Star and Strauss (1999) call "disembedding background work". Much of the work needed for producing a radiological report is "invisible or relegated to a background of expectation". It is not easy to apply the language of 'front' and 'backstage' to the situation within radiology, since visibility is limited for all actors. From the clinician's point of view the production of a radiological report is backstage work. Within the radiology department radiologists operate in the backstage of their enclosed diagnosis space and only the results of their work move to the front. Also the machine space is a backstage region with limited accessibility to others, it moves to the front when radiologists join radiographers for producing images. While waiting patients are confined to the in-between space in the shape of a long corridor. They have no clue of what goes on inside. Their only connection to the examination room is a number, an entrance ticket which indicates their position within a waiting line. Radiology is a heterotopic space, where the invisible is accessible only to those who are authorised to enter and observe.

Linked to these invisibilities and the corresponding hierarchy of knowledges is a particular pattern of ownership and authorisation. Radiological reports are signed off by radiologists who have visibly contributed to one part of their production. Only this part – with the report and image display mutually reinforcing each other – is made visible, while the process itself and all others who contributed to it remain hidden. The result of a cooperative work process is owned by its official author, the radiologist, although major parts of the script have been written by other contributors (radiographers, typists) in other spaces.

Work being made backstage also puts limitations to the awareness of context. Invisible work often includes tacit and contextual knowledge. Radiographers are in intimate contact with the patients and may collect valuable knowledge while touching, observing, and talking to a patient. The situation in which they interact with patients is different from the clinical situation, but they are not supposed to read the patient's medical history, nor do they normally share their personal impressions with clinicians or radiologists. Spatial arrangements interrupt the emerging story of patients' illness. Contextual information gets lost with the displacement of patients and the medical data that are generated, processed, and interpreted on their way through different sections of the hospital (Berg, 1999).

6. Built architectures and user interfaces: some conclusions

An ongoing debate within CSCW research is about to which extent systems need to emulate physical space with all its properties, including people's experience of presence. As Benford et al. (1998) argue: The "extremes (of this debate) are characterised by the notions of place, a containing context for participants; and space, a context that further provides a consistent, navigable, and shared spatial frame of reference" (p. 195). Some, such as Fitzpatrick et al., argue against digital spaces turning into a facsimile of the real world and in favour of working with a "more encompassing meaning of space in the virtual, independent of graphical and VR depictions, which is driven by social world needs and needs of individuals participating in multiple social worlds" (Fitzpatrick et al., 1996, p. 342).

From our analysis of work practices surrounding PACS we support this position. We can also make some suggestions as how to think about accommodating social world needs through spatial arrangements, based on architectural concepts developed in an earlier paper (Lainer and Wagner, 1998). For this purpose we introduce two such concepts – *visual relations*, and *flexible zoning*.

Visual relations: Awareness of the context of people and events can be achieved and maintained through visual relations. They may have different forms and qualities. They may be direct and close, allowing ongoing intimate contact between people who are co-located. Many problems of designing large-scale office spaces, for example, are resonant with the notion of awareness, with building the possibility of visual and auditory relations into such spaces while at the same time ensuring privacy and protection of intrusion. Visual relations can take the form of vistas – views of or points of reference to other (distant) places – or openings from a place to particular points or places outside. In urban planning architects use visual lines for constructing relational fields.

In a 2D digital space the possibilities to support visual relations are limited. Users learn from the inscriptions on the screen about the activities of others. The representations of work in the form of documents, icons, and indicators of work-in-progress shape what people perceive. Goodwin gives the example of this indirect form of awareness of context. The work-relevant activities of the winch operator on the research vessel "are available not only in the reports he makes over the intercom, but also through the way in which he moves the CTD, a process which is visible to the scientists in the lab as changes in the graphs they are looking at" (1995, p. 259).

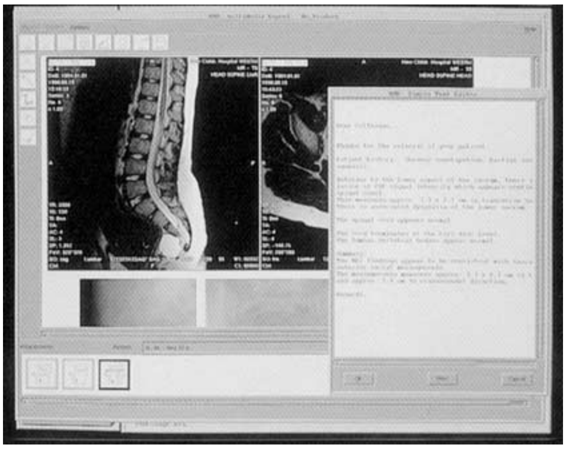

Figure 8. Representations of the work carried out by several actors (radiologists, radiographers, typists).

Similarly PACS creates representations of the work carried out by others (Figure 8). We have identified several ways in which this happens but also pointed to instances where there is a lack of awareness of the activities of others, such as:

- Radiologists can read from the worklist (RIS) how far the examination has progressed. They can also see on the screen when the transcript of a diagnosis has been finished and sign it off.
- As soon as radiographers have produced an image, linked it to the patient record, and assigned it to a radiologist, they no longer have a view of the ongoing work process.
- The status (in-progress or finished) of radiological reports within RIS provides a visual channel between clinicians and radiography.

We have also seen that, given the limited possibilities of maintaining visual awareness in the radiology department, auditory relations are much stronger than visual connections. A 3D Virtual Collaborative Environment (Benford et al., 1997; Büscher et al., 1999 and 2000) may to a certain extent compensate for these limitations. It may not only maintain a large number of documents simultaneously present. Also people may be represented by avatars and their activities and events be made visible.

Flexible zoning: We have pointed at the conflict between people wanting to preserve professional boundaries on the one hand, the need to accommodate multiple voices on the other hand. This "suggests that there should be (technical) facilities for allowing participants to erect, shift, blur, harden, dissolve, and strengthen the boundaries between spaces" (Clement and Wagner, 1995, p. 47). Architects have thought about the possibilities to introduce flexible zoning in a building which allow its inhabitants to oscillate between inside and outside, region and 'whole', private and public.

The translucent skin of a building, for example, mediates between interior and exterior spaces. An example is a glass façade through which a building can communicate its contents. Depending on the daylight and the degree of transparency, opaqueness, and compactness of the material, these connections are one-way or reciprocal. The skin acts as a *transformation layer*. The Lerner Hall Student Centers at Columbia University (Bernard Tschumi) has a ‘living glass wall’ whose modulating surface, in combination with light interventions, filters people’s view of the building’s content: “It begins in the static form of pure architecture, light and engineering details. Then people start invade it. First quietly – in slow motion – and then faster and faster, their movement appropriates, animates and alters the space” (La Biennale di Venezia, 2000).

Many objects can be looked at and used as *transformation layers*. Crucial is the idea of providing (spatial) connections of variable quality that mediate between people and the places they inhabit. This allows people to flexibly create regions and temporarily open them up again. This might, e.g., be used in support of boundary crossings between the technical production of images and their reading for a diagnosis. Other examples are moveable walls, or partitions whose transparency can be modified, or the possibility to configure the computer systems used for accessing the shared digital workspace, e.g., to grant particular rights for clinicians to have access to radiographic images.

We made use of the language of space, regions, and boundaries for identifying some key CSCW issues that may be addressed in spatial terms. We in particular asked ourselves, how to use systems such as PACS, RIS and HIS for enabling more fluent transitions and boundary crossings within a highly regionalised physical space. In our conclusions we point at architecture as an inspirational resource for thinking about spatial qualities and cooperative work. Designing *visual relations* and *flexible zoning* into physical spaces are just two examples of this cross-disciplinary thinking.

Notes

[1] While first generation PACS can communicate and archive only image data, PACS of second generation enables integration of different data types, like patient data from HIS or reporting and administration data from RIS. A hospital can introduce PACS in different scales. The first scale PACS consists of a conventional image production module with a digital archive unit without any network. PACS of second scale, also called ‘mini-PACS’, includes a local network connecting image production modules, the archive, the hard copy machine, diagnosis and reporting workstations and the digitiser to create digital images.

[2] This paper is based on a project (“Das digitale Krankenhaus”) of the Austrian Academy of Sciences’ Institute of Technology Assessment which was funded by the Austrian Ministry of Research and Transport and the Wiener Krankenanstaltenverbund (Peissl et al., 1996). We gratefully acknowledge the contributions of Walter Peissl and Claudia Wild to this research.

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