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Hybrid spatial topologies are those spatial configurations that dynamically span multiple local and remote physical spaces, at times across a mediating virtual 3D space. They are constructed through always-on, multi-user and shared video-mediated communication links. When such technologies become embedded into places, through large screens that are always on, architecture can be visually and interactionally extended. In this way, the space that can be acted upon or interacted within becomes enlarged beyond local physical space, which for a long time has been the exclusive frame for social interaction. Video communication technologies have become a core part of our lives. They are technically and economically available and are now used in workspaces, homes and urban environments. This general availability of video communication technologies to be deployed in a variety of spatial situations broadens the architect's palette. This paper systematically investigates the effects of introducing video communication into architecture. It demonstrates how architectural topology becomes extended into remote space, how it becomes fractured and how it becomes dynamic. Such topological opportunities can be employed to increase the spatial integration of connected spaces and it is shown how the placement of screen and camera directly impacts on the opportunities for social interaction. The concept of the spatio-technological isovist is introduced to capture how dynamic camera properties shape architectural visibility into connected spaces. The paper concludes with demonstrating how video communication embedded into architecture provides an entirely new architectural interface, where those interfaces are understood as spatial manifestations of social relationships. In hybrid spatial topologies it is social life that dynamically drives topologies in an immediate and observable way, with topology in turn having a demonstrable effect on social life.

1. Introduction

In recent years, video communication technologies have become a core part of our lives. They are technically and economically available and are now used in workspaces, homes and urban environments for a variety of purposes. This general availability of video communication technologies to be deployed in a variety of spatial situations broadens the architect's palette. This paper systematically investigates the impact of introducing video communication technologies into architecture: the impact on topology, spatial integration, visibility and social life enabled through this novel architectural interface. The discussion begins with a brief overview of the necessary background to this research.

It is well understood that architectural spatial configurations give rise to movement and encounter patterns, which in turn have a direct impact on social life (Hillier, 1996): architecture establishes and frames the co-presence of inhabitants to enable them to socially interact. The background to this understanding is the premise that visibility and permeability in architectural configurations tend to correlate, i.e. what you can see is generally also what you can access. Even in the case of spatial voids or windows, both of which visually connect spaces without offering a direct link to them, the linked spaces remain accessible. Via a different route, one tends to be able to reach those spaces...
physically with minimal travel involved. For a very long time, architecture has also been visually extended without extensions to what is physically accessible. For example, wall murals depicting imaginary worlds, such as the geometrically aligned ‘Last Supper’ by da Vinci, give the impression that the physical space continues into a virtual (albeit static) world (Gullström, 2010).

Over the last four decades, video communication technologies have started to provide entirely new forms of visual extensions to architecture. Video communication technologies are deployed to provide visual and auditory access from one physical space into another. Whether the physical spaces under consideration are relatively local (e.g. on different floors of the same building) or further afield (e.g. in buildings located in different countries), the visual access remains principally the same. A wide variety of such technologies have been developed, ranging from the 1970’s videophone to today’s Skype (Fish et al., 1993; Reynard, 1998; Dourish et al., 1996; Sellen et al., 1992; Benford et al., 1998; Skype Limited, 2008; Hewlett-Packard Development Company, 2007; Luft et al., 2011). These technologies are widely used today in the home (Kirk et al., 2010), in urban spaces and in the arts (Galloway and Rabinowitz, 1980).

However, the main driver for the development of video communication has been to support work. With the aim of improving organisational flexibility and allowing geographically distributed workplaces, including outsourcing activities and teleworking, organisations are making use of these technologies in the boardroom, ordinary offices and on the desktop. Some of the most interesting research in this area has emerged from the work in media spaces, placing always-on audio-visual connections within ordinary office environments (Mantei et al., 1991; Dourish and Bly, 1992; Adler and Henderson, 1994). When they are installed in such a way and are widely available, they permit spontaneous social interaction, and the connected spaces can become an integral part of social life and the work processes of a given organisation (Dourish et al., 1996). Although relatively small screens were used, it appeared that the technology infrastructure spatially and organisationally integrated with the various settings in which they were deployed. Of particular interest in the context here, movement patterns through buildings can be altered through the introduction of such technologies. This occurs when people divert from their route, enter certain places and stop to make use of existing connections to remote physical spaces in the media space research outlined above, but also depends on the availability of digital displays in architectural space per se (Scupelli et al., 2007).

1.1. Architecturally relevant additions to video communication

The original work into media spaces has seen two spatial additions that are directly relevant here: the first being concerned with extensions into 3D virtual spaces and the second being concerned with integrating audio-visual links into physical architecture.

The concept of the Mixed Reality Boundary and related developments (Koleva et al., 2000) have allowed for the extension into virtual spaces through the inclusion of collaborative virtual environments (CVEs). CVEs establish a 3D virtual interaction space that can be augmented with digital resources (documents, visualisations, 3D models). CVEs typically use a spatial model of interaction, directly inspired from physical space, to mediate between multiple people who are represented as avatars in the shared virtual space (Benford and Fahlén, 1993). The inclusion of streaming live video into CVEs allows the representation of individuals and places in the same manner that video conferencing allows (Nakanishi et al., 1996; Reynard et al., 1998). This technological innovation gave rise to the concept of Mixed Reality Architecture (MRA), applying...
media spaces implemented through collaborative environments to physical place. MRA establishes a hybrid architectural topology by mediating always-on audiovisual communication through a shared virtual 3D environment. Just like media spaces, it involves the installation of a screen and speakers in conjunction with a microphone and a camera. The mediating virtual space in MRA contains representations for each of the connected spaces. Those representations can be virtually moved by end-users, for example through a computer keyboard or mouse. When two or more representations are close together, the video into the connected physical places becomes clear and an audio connection is established. This allows configurable virtual office-shares across physical places and serves as an awareness, information and communication tool for everyday social interaction. Very importantly, as the connections are established across the mediating collaborative environments, connections become legible. Inhabitants of such systems can see at a glance who is connected to whom (Schnädelbach et al., 2006).

The other core addition has included developments to better integrate video into physical architecture, extending out from the monitor to include physical place and resources. Taking into account furniture design, room design and lighting has allowed the creation of set-ups that really begin to integrate distributed architectural spaces - not just interactionally, but visually too. This is in parallel to a substantial step up in the available audio-visual fidelity of the video communication systems furthered by developments in camera, streaming and display technology. Examples include set-ups where the room at one location appears to continue into a room at another location, and those that use furniture to allow people to place themselves in the most suitable location in front of the camera (Gullström, 2010; Hewlett-Packard Development Company, 2007; Cisco Systems Inc., 2008).

2. Hybrid Spatial Topologies
The type of spatial and social embedding of visual communication technologies into architecture described above leads to hybrid spatial topologies, where those are spatial configurations that dynamically span multiple local and remote physical spaces, at times across a mediating virtual 3D space. They are constructed through always-on, multi-user and shared video-mediated communication links that are publicly available in a variety of circumstances. From reported experiences in the media space literature, it is clear that the types of environment described here can appear to inhabitants as part of the wider environment to which they have access. The technologies become organisationally and spatially embedded into their host organisations and associated environments, an issue recently explored across a diverse set of mixed reality examples (Schnädelbach et al., 2010).

Critically in the context of this paper, the extension of the environment is a result of the spatial extensions made possible through audio-visual communication technologies. In this way, the space that can be acted upon or interacted within becomes enlarged beyond local physical space, which for a long time has been the exclusive frame for social interaction. Extensions can then take two (spatial) forms: extensions into remote physical spaces and extensions into virtual spaces. More common of the two are those that extend the environment into remote physical spaces, i.e. those spaces that cannot (quickly) be reached by physical traversal of the architectural configuration under consideration. The example of Mixed Reality Architecture (MRA) then highlights the second possibility, as it extends the spatial environment that is perceived and navigated within into virtual space. This virtual space is designed to mediate communication between a number of physical spaces, but also provides a spatial framework for remote social interaction. Architecturally, it also provides a way of making
architectural configuration topologically dynamic across the entire ‘inhabitable’ environment. In what follows, this paper will draw on the previously mentioned literature and direct experience with MRA to discuss the types of topologies that emerge in hybrid spatial topologies, the way in which they impact on spatial integration and how visibility and permeability are affected, before setting out hybrid spatial topologies as introducing an entirely novel architectural interface.

2.1. Topology

Physical architecture has clear topological limitations (Steadman, 1983). These result in certain limitations on the adjacency of physical spaces, where those might either be desired or need to be prevented. For example, it seems reasonable to want the kitchen next to the dining room, while avoiding the plant room being next to an auditorium. Such constraints can be expressed through adjacency graphs. Planarity of those graphs, i.e. the condition that no edges are crossing each other, is a prerequisite for physical ‘buildability’ on a single plane, as illustrated in detail by March and Steadman (1971). Furthermore, adjacency of physical architectural cells is the prerequisite for there to be accessibility and visibility between them, where architectural cells are abstractions for the constituent parts of architectural topologies. Finally, apart from in Adaptive Architecture (Schnädelbach, 2010), where topological adaptations have specifically been considered, the adjacency of physical cells in architectural configuration is relatively fixed. Although possible, it is not straightforward to move an architectural cell (not just the context of the cell) to the other side of another cell.

Through the introduction of embedded video communication media, the limitations on adjacencies introduced above are transformed. Consider Figure 1 where physical cells $P^a$, $P^b$, $P^c$ and $P^d$ are aligned next to each other. $P^a$ is adjacent to $P^b$, which in turn is adjacent to $P^c$. Clearly this means that some cells cannot be physically adjacent to certain others.

A video communication link that is always on (i.e. continuously available) then enables what we have come to call ‘virtual adjacencies’. Connecting to another place to communicate or disconnecting for privacy, for example, manipulated virtual adjacencies to suit the current social situation. In Figure 1, $P^a$ and $P^c$ remain physically non-adjacent, while now being virtually adjacent. The figure also clearly shows that multiple, independent concurrent virtual adjacencies can be forged independently from each other: a second video connection has been opened to also connect $P^b$ and $P^d$. As many existing video systems permit multiple connections, it is also clearly possible to connect to multiple other locations from a single physical place, here shown as $P^c$ connecting to somewhere outside this physical arrangement of spaces. Any limits on connections in this case are not topological, but merely technological, limited for example by available bandwidth, processor speed or display space and resolution.
In addition, multi-camera set-ups principally introduce a second type of topological flexibility by fracturing the view from one space into another (Luff et al., 2003), i.e. allowing multiple concurrent views between two individual spaces. Originally, this was achieved through connecting two rooms with multiple cameras, the rationale being that different views support different tasks (Gaver et al., 1993). This work has triggered a number of approaches to integrate multiple views with the aim to improve interaction. A more recent example, developed as a response to the problems that the fractured ecologies work highlighted, addresses this from a different angle. The CamBlend system provides a number of ‘lenses’ into a connected space that can flexibly be moved across a panoramic video of the connected place (Norris et al., 2012).

With this availability of multiple video views between two physical locations, topological adjacency becomes more fine-grained than that at the level of an architectural cell. Areas of rooms become connected. They become connected for specific purposes. For example, when connecting two design studios, views directly onto the tables holding physical models might be combined with views onto sketches pinned up on the wall, which are combined in turn with an overview to provide the context. This is illustrated in Figure 2 with multiple audio-visual links between P and P, connecting to regions P1 – P3. Interestingly, the topological relationships between areas in a particular cell are not necessarily maintained (in a similar fashion to connections on the level of cells). This is illustrated in Figure 2, which shows how it is technically feasible to move the display of a particular area of interest next to a physically non-adjacent area of interest. For example, P and P are physically non-adjacent in P. Remotely, they get displayed at P3 and P2, respectively, which are physically adjacent in P.

### 2.2. Spatial Integration

Virtual adjacencies then impact on visual spatial integration, which in turn directly impacts upon social interaction and the movement patterns through architectural space. This can best be explored graphically through the following example taken from a typical work environment. The space labelled ‘Single office’ in the Figure 3 is a lecturer’s office near the end of a corridor on the second floor of this particular building.

The office is easily accessible for students and well connected to the administrative areas, but is deep within the building. The space labelled ‘Foyer’ is the foyer to a laboratory space, located in the same building as ‘Single office’. There are adjacent administrator offices, a small library and the video-editing suite. In comparison to ‘Single office’, ‘Foyer’ is more integrated with the remainder of the building, being on the first floor and near the main vertical circulation. Organisationally, these two spaces are linked. The person working from ‘Single office’ is a core member of the laboratory, while the office is on a different floor from ‘Foyer’. The two are relatively distant from each other in the architectural configuration and the foyer is the space...
that is highly central to the function of the laboratory space. When creating a virtual adjacency between these two spaces through a video link, the level of integration of ‘Single office’ changes dramatically. The audio-visual link provides visual and verbal access between the two physically non-adjacent spaces, while not allowing actual permeability which could however be simulated (Koleva et al., 2000). The following two figures (4 and 5) express the possibilities in a more general form. This returns to the very simple spatial relationship of the four physical cells $P^a$, $P^b$, $P^c$, $P^d$. It is clear that the two central spaces, $P^b$ and $P^c$, are more integrated, their total depth values as shown at the top of the diagram being lower than those for $P^a$ and $P^d$.

With a virtual adjacency the situation changes. In contrast to the Figure 4, spaces $P^a$ and $P^{a''}$ are the most integrated if one takes the video link into account (see Figure 5).

So far the discussion of spatial integration has only considered one audio-visual link being made to a particular physical space. With multi-point video communication widely available, additional configurational possibilities emerge.
The following example considers these additional possibilities when multi-point video is enabled across a mediating virtual space. In addition to ‘Single Office – Local to Foyer’ already connecting to ‘Foyer’, the room labelled ‘Single office – Remote to Foyer’ has joined the group. ‘Single office – Remote to Foyer’ is an office at a different organisation in a different city. Within its building, this is off a main open plan office which provides desks for researchers and graduate students. In relation to the remainder of the building, it is the deepest space in this part of the building, being located as far as possible away from the entrance. Figure 6 then shows how ‘Single office – Local to Foyer’ as well as ‘Single office – Remote to Foyer’ have both become shallower as a result of the re-configuration that the inhabitants have made. In contrast to ‘Single office – Local to Foyer’ however, and very importantly in this context, ‘Single office – Remote to Foyer’ has been made shallower in relation to two physical spaces – the integration of which it would not normally be considered, as they are physically too far away.

With regards to spatial integration within hybrid spatial topologies, there are three additional issues that need to be considered. Firstly, the spatial integration discussed above also extends beyond the actual connected cell to other nearby spaces. This is mainly the result of the exact placement and orientation of interface technology in such spaces, discussed in more detail below. Secondly, virtual adjacencies cannot reduce the existing level of integration of a particular physical space. Only its level of additional integration through a video connection can be controlled. This second point comes with the caveat that there are, however, placements of technology that can have a negative effect on integration by impacting on physical movement. An example would be the installation of a digital screen as an audio-visual link which itself blocks visual and/or physical access to a region in that space. Finally, the integration of each separate cell in a hybrid spatial configuration is the result of the collective configuration of all cells in that configuration. Although inhabitants might decide to increase the integration of their cell with one or more others, this could easily be changed by other inhabitants moving their own cells elsewhere. This results in a dynamic set of integration values for the overall hybrid spatial topology, determined by the individual actions of members of its inhabiting society.

2.3. Camera Placement: Physically Deep – Technologically Shallow

Having considered the overall effects of the introduction of audio-visual links into architectural topologies, the following will discuss the relationship between interface placement and orientation.

It is generally assumed here that to embed audio-visual technologies into buildings and the organisations that inhabit them, large display screen sizes are essential and that screens can indeed be
Screens that are large proportionally to the space in which they are embedded have architectural presence, whereas a screen that is too small could easily be overlooked. Larger screens have also been demonstrated to have a positive effect on immersion, leading to better performance in mental map formation and 3D navigation – both being relevant for spatial extensions to physical architecture (Tan et al., 2006).

To enable interaction with the screen (looking at it and being seen at the same time), cameras are placed as close as possible to the centre of the screen, facing orthogonally away from it and towards the interacting inhabitant(s). Most commonly, cameras are placed in the plane of the screen surface at the top of the screen, so as not to obstruct the view of the images displayed. There are also technical approaches that would allow placement of cameras behind the screen, enabling true eye contact and preventing people trying to interact without being in camera shot (Ishii et al., 1992; G+B Pronova, 2008; Uy, 2006). However, these approaches are either not widely available or are somewhat impractical (e.g. they require a large space behind the display screen or a complicated set-up). They will therefore not be considered in this analysis.

With the constraints on camera placement on screens established above, it is clear that placing the screen for an audio-visual link also means placing the camera. Taken together, technology placement therefore incorporates a decision on what is visible (on-screen) from where, and what can be seen by people connecting from a remote place (the camera view); i.e. the two are inseparable. Previously, three relative orientations have been considered in the study of a deployed hybrid spatial topology: the orientation of the interface towards people; the orientation to other interface technologies; and the orientation to the access to a particular space (Schnädelbach, 2007). As it is most relevant here, the following concentrates on the latter, drawing on the long-term study of Mixed Reality Architecture (MRA) (Schnädelbach et al., 2006). Each architectural space that is connected with an audio-visual link has one or more physical entrances in their respective shallow area(s), and the interface technology can be discussed in terms of how it becomes oriented towards those areas.
Firstly, the location of the audio-visual link itself can be deep within a space, when it is away from the entrance(s) but the camera is pointing at it (them), i.e. the shallow part of a space (compare Figure 8 left). This placement provides people connecting remotely with a wealth of information about the status of the connected space and its inhabitants. For example, in an office environment, an open door (now visible in the camera view) would indicate that inhabitants have not gone far, even if they are not visible in the camera shot. The placement of the audio-visual link in the deep part of a space also has a direct effect on people coming physically to these spaces, as the screen is clearly visible through the entrance. In use, this affords people passing in the corridor the opportunity to smoothly join a conversation between the inhabitants of a space and the people connecting to that space. In hybrid spatial topologies this is the main source of chance encounters: through a chance encounter with a connected audio-visual link, a chance encounter with a remote inhabitant becomes possible. Anyone visible on the other side can be engaged in conversation. Effectively, the introduction of the audio-visual link results in this space having an additional technologically shallow region, having become shallow because of its integration with a variety of remote spaces.

The second possible arrangement places the audio-visual link physically shallow itself, when it is near the entrance, with the camera pointing towards the deep end of the physical space (compare Figure 8 right). People connecting to these spaces across MRA are provided with very little sense of the topological context of the physical space to which they are connecting. At the same time, people passing by physically are not provided with any sense of the state of the hybrid spatial topology, as the screen is turned away from the entrance. Such an arrangement more or less prevents chance en-

Figure 8:
Impact of the orientation of the interface technology. The dark blue shaded areas in the three plans indicate the camera field of view. The light blue shaded area highlights the case where parts of the corridor become visible.
counters, unless they are triggered entirely through the audio channel. In this case, the audio-visual link re-enforces the physical shallowness of through a technologically shallow region. Finally, there are also installations where neither of the above is the case. Here the link is located somewhere in between deep and shallow ends and points at neither of them (see Figure 8 middle). Such an arrangement tends to be dictated by the physical layout of the space being connected. No topological context is being transmitted to people connecting over the audio-visual link because this is not in camera view, while people passing by physically might be able to see the link depending on its angle to the door. Installations in this form result in an additional technologically shallow area that is at an angle to the physically shallow part.

In summary, each separate introduction of an audio-visual link into another space creates a separate technologically shallow region in that space. Just like physically shallow regions, technologically shallow regions are frequently the location for social interaction between two spaces. In contrast to physically shallow regions, their effect can easily be removed by turning the interface technology off.

2.4. Visibility

Any impact on spatial integration described above is fundamentally driven by extensions to what is visible when audio-visual links are introduced to architecture (extensions to the auditory space are not considered here for now). The analysis of visibility in architectural configurations is an important tool for the understanding of the relationship between those configurations and human behaviour, and visibility graph analysis is one basis for the analysis of spatial integration in architectural space (Benedikt, 1979; Turner and Penn, 1999).

Although the currently available version of the standard tool for evaluated visibility (Depthmap) does not permit the analysis of virtual adjacencies, they can be simulated. The following simple experiment offers another view of the possibilities that emerge. To illustrate these, a visibility graph analysis for each has been performed on the gallery layout shown below (included with the Depthmap distribution) and on the original layout extended through a mirrored copy of itself, respectively. Figure 9 shows visual integration in the original gallery, with highly integrated spaces located in the main central corridors.

The spatial configuration has then been changed to include a mirrored version of the gallery, attached at one of the more segregated spaces in the bottom right of the original layout.

Running a second visibility graph analysis on the hypothetical configuration (using the same parameters) then demonstrates how spatial integration is modified with visually highly integrated spaces shifting to the former periphery of the original single gallery configuration. As one might expect, it is also interesting to see that the most segregated spaces in the original configuration (e.g. the top left corner in the original plan – Figure 9), remain most segregated in the hypothetical configuration (e.g. the top left and top right corners in the merged plan – Figure 10).

Figure 9:

Single gallery: Visual Integration [HH] (Depthmap 8).
So far the discussion of visibility has remained on the level of cell-to-cell links, making links between multiple places. It is now worth looking more closely at the level of individual cells and some of the details that emerge. In hybrid spatial topologies, it is cameras and displays (together with microphones and speakers) that are the building blocks which allow architecture to be spatially extended, as they extend what is visible from different physical locations. To expose visibility in hybrid spatial topologies, the relevant properties of cameras and displays must be considered. This discussion forms the basis for the graphical analysis of visibility in hybrid spatial topologies on the level of individual cells, demonstrating the limitations that video introduces with regards to field of view and lines of sight.

2.5. Cameras and camera placement
To understand visibility in hybrid spatial topologies it is essential to consider the properties of the technologies that become deployed. For the sake of the argument presented here, the properties of the resulting auditory space generated by hybrid spatial topologies are not considered in this article.

Camera properties
There is a range of camera properties that is important. Firstly there are core properties. The maximum capture resolution determines the detail that can be seen in a connected space. The field of view of the lens determines the area that can be covered, and this can be fixed or dynamic through a manual or motorised zoom. In standard video applications, field of view tends to be fixed at between 50-70 degrees horizontal, which is quite narrow. In addition, the aperture of the lens impacts on the area of observed space that is actually in focus. Secondly, the potential dynamics of the camera set-up need to be considered. Most commonly, cameras are in fixed locations and are set up with a particular orientation to a room and its occupants. Therefore, people who are looking at a camera feed remotely will not be in control of any aspect of that camera in most cases, although there have been developments in that direction in media spaces using steerable cameras (Gaver et al., 1995) and virtual reality CAVEs through head-tracked view points (Cruz-Neira et al., 1993).

Sharing displays
Another important aspect of display screens and cameras concerns their shareability amongst multiple people physically close by. Ordinarily, everyone located around a display screen making a digital connection between two spaces will have the same access to it. In contrast to a physical doorway between two spaces, the viewpoint into the other space remains the same for everyone present.
around the interface. Even if the perspective of a single person can be accounted for as highlighted in the examples above, displaying multiple perspectives at the same time is currently technically cumbersome. If cameras are indeed placed with individuals as the work by Mann highlights (1997), shareability of perspective is entirely lost.

**Physical – virtual camera**

An additional level of complexity is introduced when a mediating spatial environment is introduced, as is the case with any approach that embeds video communication into a collaborative virtual environment, such as in MRA (Schnädelbach et al., 2006). The view generated into the 3D virtual environment in MRA is based on the view from a virtual camera that has been set up with a series of certain properties, equivalent to those of physical cameras. Therefore understanding this view into another physical space at least involves understanding the view of one virtual camera and that of one physical one. This complexity is further increased through the fact that virtual cameras are more easily rendered dynamic, i.e. their properties can change during use.

### 2.6. Spatio-technological isovists

Having described these key properties, it now remains to have a much more detailed look at the way in which environments become extended through audio-visual communication media. This will focus exclusively on the aspect of visibility as relevant for architectural configurations in contrast to, but also in the context of, previous work on the overall affordances of media spaces (Gaver, 1992).

**The extended space**

The following figure (Figure 11) illustrates two physical spaces (A and B) linked via a media connection. As suggested earlier, one entire wall in each space acts as the display surface, in an attempt to simulate an actual connection as closely as possible via a physical opening. Both of these display surfaces

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**Figure 11:**

*Physical and spatio-technological isovists.*
have a camera which points away from the screen and into the associated room. In this example case, each camera directly feeds the screen in the respective other space, establishing a two-way link.

On the left, spaces A and B are physically joined via a room-width and ceiling-height opening for comparison. To illustrate the spatial properties of this configuration, a single isovist is drawn from viewpoint A1, reaching out into both parts of the joined space. The centre and right hand side of the graphic then illustrates the environment extended through the video link described above. Audio-visual links are represented with orange lines in place of the physical joint between A and B. Cameras are indicated through their field of view and a connecting line in black for the video transmission.

Isovists across the space are drawn as before, and these are now linked through the media connection. In this context, it is important to understand them as one isovist – a spatio-technological isovist – although they appear separate in the illustrations. In the centre of Figure 11, the view from viewpoint A1 into B shows no change in the part of the isovist located in A compared to the physically joined version, while the part of the isovist located in B is now shaped by camera placement, orientation and field of view. Looking back from viewpoint B1 into A has the same effect, with an isovist shaped by the physical environment in both spaces (local and remote) as well as by the camera technology. It is clear that the effect is quite dramatic, removing from view two triangular areas directly around the screen area, whilst also providing a view slightly deeper into the remote space around the corner.

To illustrate a second effect of the embedded camera technology, lines of sight have been added to the illustrations in red. The view from A1 into B results in a view of the centre of the camera feed captured from B (centre of Figure 11 ‘View from A to B’). Focusing on an off-centre location results in a view which is proportionally off-set in the associated camera feed (Figure 11 right ‘View from B to A’). In the example here, a view straight at the screen is illustrated and this results in an ‘angled’ view in B. This allows a view through the gap between objects O1 and O2, which would normally be blocked (illustrated through the red dotted line), clearly shifting the perspective into the other a room in a very unintuitive way.

**Viewing position**

There is another effect of the audio-visual link between the two physical spaces A and B. Unlike the situation where A and B are connected physically, the isovist in B does not change with different viewer locations in A (compare VA1 to VA2 in the Figure 12), while the viewable area in A does indeed change as one would expect. Changes are to be expected both in terms of line of site and the proportion of local to connected spaces.

![Figure 12: Different viewing positions in A.](image-url)
Again, this feels counter-intuitive. In the comparatively much more controlled environment of virtual reality CAVE displays (Cruz-Neira et al., 1993), head tracking is frequently used to provide at least one observer with the correct perspective into a virtual environment. At present this is too unwieldy for more general applications, but it remains a technological option that might see extensions to multiple concurrent users in the future.

**Camera properties**

However, the isovist in B does change with a dynamic change of camera properties which include field of view, orientation, location, and in particular its relationship to other surfaces.

The left hand side of Figure 13 shows an isovist across the media connection that has a very narrow field of view in B due to the camera being zoomed in, while the centre shows a camera being rotated slightly towards the right. The most extreme change is shown on the right of Figure 13, where the camera is mobile and enabled to roam around in B. All three adaptive cameras placed in B are here assumed to be controllable in some way by a person located in A.

**Embedded in virtual environments**

For those architectural topologies that have been extended across shared collaborative virtual environments (e.g. MRA), the analysis of visibility across different spatial units becomes more complex again. Figure 14 illustrates the connection between the same two rooms A and B discussed previously, across a shared virtual 3D environment. This environment is displayed on a room-height and width display, similar to the direct audio-visual connections discussed above.

As A and B are embedded in a shared virtual environment, their positions relative to each other are flexible and can be controlled by their inhabitants. Here, B is shown at an angle towards A, but still in view of A’s virtual camera, VC-A (this refers to...
to the camera generating the view into the virtual environment from and for space A). To consider visibility across the two spaces, the starting point is the examination of the view from VA1 back into B. From VA1, the virtual environment appears visible full screen, i.e. it covers the entire wall. Within that virtual environment, a representation of B is visible that has live video from B attached to one of its surfaces. Via this live texture, the parts of B that the camera can see become visible in A.

Visibility between A and B therefore depends on a whole host of factors: the viewing position (VA1) in front of the display of the 3D virtual environment; the position and field of view of the virtual camera of space A; the virtual position and orientation of B in relation to A across the shared virtual space; and finally the position and field of view of the physical camera located in B. This complexity is then reflected in the complexity of the isovist that can be drawn between the two spaces, consisting of multiple parts: a local physical part which is generated in the usual way; a virtual part extending into the 3D shared environment (represented in darker grey in Figure 14), which is determined by the properties of the virtual camera associated with the representation of A; and finally a remote physical part, determined by the properties of the physical camera in B.

Very importantly, these relationships are not fixed. They can adapt in at least two different ways. The location and field of view of the virtual and physical cameras can change, as previously highlighted. Perhaps more interestingly, the geometrical relationship between A and B can change within the 3D world, which is driven by the social interaction taking place in the extended physical-virtual architectural topology (Schnädelbach et al., 2007).

Figure 14:
Spatio-technological isovist across local, virtual and remote space.
Audio-visual connections offer social interaction ‘across’ the screen surface, across the interface technologies that are in place to create hybrid spatial topologies. One might compare this to interaction at the threshold of a space, an open window into the front garden, for example, especially when such a threshold cannot be crossed. By providing an architectural interface for social interaction, locations of audio-visual links attain special significance in the architectural configuration, for example through the association of the location of a link with the linked person. The way that this significance influences movement through architectural spaces has been amply demonstrated (Adler and Henderson, 1994; Dourish et al., 1996; Schnädelbach et al., 2006). The discussion presented above has outlined how technologically shallow regions augmenting physically shallow regions in an architectural space can result in an increase in chance encounters. More recently, the mere availability of a view with specific properties has also been shown to influence movement patterns independently of encounters (Varoudis, 2011).

One key difference to fully physical architectural configurations is that virtual adjacencies are dynamic both on the level of connecting architectural cells and on the level of connecting areas within cells. Architects together with technology providers can design, construct and implement the technological capability to create virtual spatial adjacencies. However, it is up to the inhabitants of a place to make connections and make use of them. In this way, in hybrid spatial topologies, the critical ‘spatial privilege’ to decide what is next to what and who is next to whom is much more democratically distributed, rather than being left to architects and the people they are developing the brief with to pre-decide. In this context, the configuration of hybrid spatial topologies by inhabitants during occupation might be described as a very rapid and changeable manifestation of the processes that Hillier and Hanson outlined when discussing the agglomeration of physical architectural cells (Hillier and Hanson, 1984). Just as with physical architecture, the process is restricted by the rules and norms of the society inhabiting it, the community of inhabitants of hybrid spatial topologies in the discussion here.

The study of Mixed Reality Architecture (MRA) provides some illustrative examples of such behaviours (Schnädelbach et al., 2006; Schnädelbach, 2007). In MRA, rules were partly derived from experience in physical space but also emerged from long-term inhabitation. Lurking, staying in audio range without being seen, was not deemed acceptable and no instance of this behaviour was recorded. Inhabitants also generally avoided each other’s embodiments when navigating. There were no recorded instances where two or more nodes occupied the same virtual space for any length of time. Breaking through somebody’s closed ‘front door’ was deemed unacceptable, as that would have meant contravening their chosen privacy settings. Finally, instances of people making contact with strangers were rarely observed. Interaction attained a certain formality until inhabitants had been introduced to each other, similar to interaction in physical public places. What appeared to be perfectly acceptable though was to stay in sight of others but out of audio range. This allowed inhabitants of one space to be aware of other physical settings visually, whilst not being able to listen in on them. Indeed, this separation between visual and aural awareness in MRA and the communal legibility of the state of the two was a very important feature. The configurations were also the result of the particular preferences of its inhabitants. For instance, when colleagues knew each other well, they often remained within audio range, being able to generally hear what was going on without being able to pick out any details.
As with other media space technologies, the affordances of the technology, the preferences of inhabitants and the social rules and norms had a direct impact on architectural topology in response to social interaction. Once set up in a particular way, hybrid spatial topologies encourage or prevent certain types of encounters. In this way, the established topology has a direct impact on social life.

In this context, audio-visual links in hybrid spatial topologies can be described as entirely new architectural interfaces, where those are understood to be spatial manifestations of social relationships. They are novel because they concern an architectural interface between topologically local and remote spaces, which allows people from both of these spaces to interact socially. More importantly, they are novel because they are dynamic. They are not pre-determined from the outside beyond a base starting position, although they are limited by the particular technology used. Instead, audio-visual links are configured by independent actors in the course of action and during inhabitation. When embedded in a 3D virtual space, as in MRA, they remain legible to others in the overall configuration; this legibility supports social interaction through awareness. In that sense, hybrid spatial topologies might be described as following the shortest social model possible for an architectural configuration. In a similar way to a party, they ‘maximise(s) the randomness of encounters through spatial proximity and movement’ (Hillier, 1996), although this spatial proximity is now virtual. Such an interface is not possible in entirely physical architecture as its constituent parts are too inflexible.

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