MIXED REALITY ARCHITECTURE:
a dynamic architectural topology

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Abstract

Architecture can be shown to structure patterns of co-presence and in turn to be structured itself by the rules and norms of the society present within it. This two-way relationship exists in a surprisingly stable framework, as fundamental changes to buildings are slow and costly. At the same time, change within organisations is increasingly rapid and buildings are used to accommodate some of that change. This adaptation can be supported by the use of telecommunication technologies, overcoming the need for co-presence during social interaction. However, often this results in a loss of accountability or 'civic legibility', as the link between physical location and social activity is broken. In response to these considerations, Mixed Reality Architecture (MRA) was developed. MRA links multiple physical spaces across a shared 3D virtual world. We report on the design of MRA, including the key concept of the Mixed Reality Architectural Cell, a novel architectural interface between architectural spaces that are remote to each other. An in-depth study lasting one year and involving six office-based MRACells, used video recordings, the analysis of event logs, diaries and an interview survey. This produced a series of ethnographic vignettes describing social interaction within MRA in detail. In this paper we concentrate on the topological properties of MRA. It can be shown that the dynamic topology of MRA and social interaction taking place within it are fundamentally intertwined. We discuss how topological adjacencies across virtual space change the integration of the architectural spaces that MRA is installed in. We further reflect on how the placement of MRA technology in different parts of an office space (deep or shallow) impacts on the nature of that particular space. Both the above can be shown to influence movement through the building and social interaction taking place within it. These findings are directly relevant to new buildings that need to be designed to accommodate organisational change in future but also to existing building stock that might be very hard to adapt. We are currently expanding the system to new sites and are planning changes to the infrastructure of MRA as well as its interactional interface.

Introduction

Physical architecture traditionally functions as a social object through the way that it acts to structure patterns of co-presence. In doing so, it creates the potential for social interaction on which the reproduction of social forms, such as organisational or community structures, and the generation of new forms ultimately depends. In this way architecture acts not only to express, but also actively to shape and reproduce the norms and rules of social interaction of a particular society. Describing this process, Hillier and Hanson (1984) argue that architecture plays a much more active role in society than had been previously suggested. Mitchell (1995) points out that the architecture emerging from this process is available publicly in principle, which makes interaction within it legible. It is also very stable as any change to the spatial pattern of the built environment tends to be relatively slow, making the interactions structured by it relatively predictable.

However, physical architecture has come under the influence of a number of different technologies whose impact on our need to be co-present has been profound. Steadman traces the parallel development of telecommunication technologies and the spatial organisation of urban space (Steadman, 1999). He identifies dispersing and concentrating effects working in parallel. Telecommunication technologies allow certain activities to be pushed out to the periphery, while others are concentrated in the city centre, such as those benefiting most from face-to-face interaction. The new architectural form enabled by communication but also rapid transportation technologies then affords near instant access to non-adjacent parts and, as Virilio points out, the distinction between near and far becomes irrelevant here: the spaces 'travelled across' are lost and become invisible (Virilio, 1997); social interaction becomes effectively de-spatialised. This can result in the reduction of chance encounters which form an essential part of the economic function of physical architecture (Hillier and Penn, 1992) and of its capacity to foster innovation (Penn, Desyllas et al. 1999). In this sense, although new technologies have had an effect of a compression of space, there appears to be a concomitant elimination of chance interactions and their unpredictable outcomes.

In this context, it is of considerable interest to investigate how the more recent 'virtual' media can be used to support social interaction. Spatial approaches in the design of telecommunication technologies have been a long-standing interest in the field of Computer Supported Cooperative Work. For example, Media Spaces and Collaborative Virtual Environments both have spatial frameworks (Gaver, 1992; Greenhalgh, 1999). More recently, Mixed Reality provides perhaps the greatest potential to enable remote communication and interaction between people and groups in ways that are directly analogous to, and add to, those offered by physical architecture. Mixed Reality joins or overlays physical and virtual environments to varying degrees, using a number of different approaches, technologies and interaction paradigms (Milgram and Kishino, 1994).

Our approach to Mixed Reality then involves linking and overlaying multiple physical and virtual spaces that have three spatial dimensions and one temporal dimension (Benford, Greenhglgh et al. 1998). This is in an attempt to bring together the affordances of modern communication technologies, especially their flexibility, the affordances of physical architecture, as well as human competences in dealing with everyday physical reality as a framework for social interaction.

We are considering Mixed Reality from a distinctly architectural perspective and the remainder of the paper will describe the construction and evaluation of a prototype Mixed Reality Architecture. Our discussion briefly reflects on the Human Computer Interaction results as reported in more detail in (Scnadelbach, Penn et al. 2006), before concentrating on the topological properties of MRA. We conclude by illustrating the direct and immediate link between dynamic Mixed Reality architectural topology and social interaction taking place within it.

Mixed Reality Architecture

Our aim in the design of Mixed Reality Architecture is to explore how to make physical architecture more dynamic so that it could better respond to the requirements of today's very flexible organisations. In addition, we aimed to apply architectural design principles to the development of communication technologies. Within the chosen framework of Mixed Reality technology, we then had to consider how to link and structure physical and virtual environments in a dynamic way.

In this context, we took the elementary architectural cell as our starting point. It is a fundamental architectural concept and the smallest building block that architectural structures consist of. One of the functions of the cell is to establish the two categories of inhabitants and strangers. A cell is owned by its inhabitant who controls its boundary or link to the outside public space, which is the domain of strangers as well as the domain of encounters between strangers and inhabitants. Inhabitants can authorise the crossing of the link to their architectural cell, turning strangers into visitors (Hillier and Hanson, 1984). Another function of the cell is to establish co-presence between two or more people who are present within it at the same time. This is achieved by placing people within the boundaries of the same space. In this context, architectural cells can therefore be defined as spatial units within which people are regarded as co-present and have a symmetrical relationship to each other in terms of their potential for social interaction. Arguably, this can be applied to both physical and virtual architectural spaces, i.e. 3D spatial environments designed and set up on a computer.

Mixed Reality Architectural Cell

As an extension to the above considerations, the concept of Mixed Reality Architectural Cells (MRACells) was developed. MRACells are defined as spatial units, consisting of one physical and one virtual spatial cell, which are permanently joined together. MRACells form the basic building blocks for the creation of Mixed Reality Architecture. Based on the definition of architectural cells adopted here, they are also designed to support co-presence between inhabitants who are physically or virtually present within them. The aim is to maintain a symmetrical as possible relationship between people present within an MRACell.

For the construction of MRACells we used an established technology: the Mixed Reality Boundary (MRB) (Benford, Greenhalgh et al. 1998). In contrast to previous uses, the MRB has been made virtually mobile for Mixed Reality Architecture. A large screen projection provides a view from the physical part into the virtual part of the MRACell. A camera mounted on the screen captures events in physical space and maps them back onto the virtual representation of that same space. There is also a two-way audio connection between physical and virtual spaces making use of noise cancelling microphones. The virtual space has been implemented in MASSIVE3, a computer platform for Collaborative Virtual Environments (Greenhalgh, Purbrick et al. 2000). In physical space MRACells are represented by their actual physical cell (an office for example) with the attached virtual cell being projected on the screen of the MRB.

Within virtual space virtual and physical cells are both represented with 3D geometry as one element. Live video taken from the physical cell is mapped on to the front of the representation of that physical cell. Live audio captured from the physical microphone is mapped to its virtual position. The audio range is visualised as a circle around the MRACell.

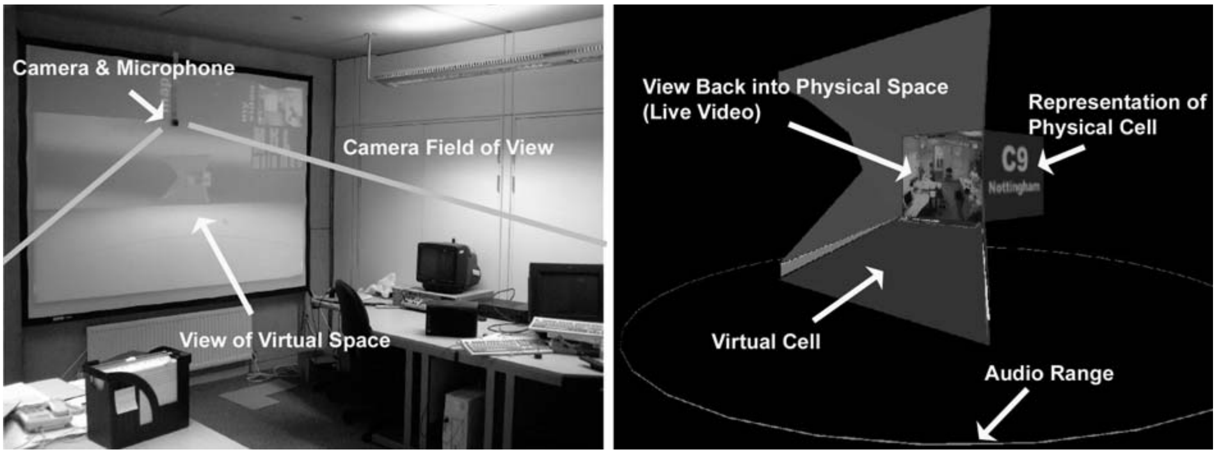


Figure 1:

MRACell in physical space (left) and in virtual space (right)

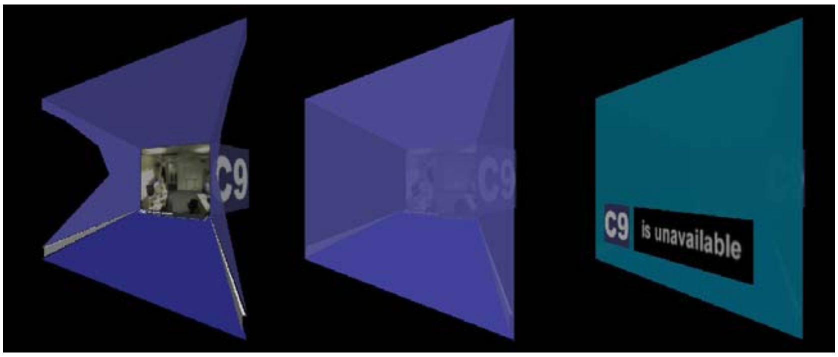
The shape of the virtual part of the MRACell derives from the field of view of the virtual camera that generates the view projected in physical space. It makes the affordances of the MRACell clear within virtual space, by indicating 'how much' inhabitants can see of the virtual environment and in which direction they are pointing. The design also enforces symmetry of visual awareness, i.e. when somebody looks into the physical part of an MRACell from virtual space, they can be seen by its inhabitants on their projection screen.

Control over access and virtual position

Owners of MRACells have the rights and tools to change the quality of access on two different boundaries. Firstly, there is the physical access to the physical space. This is usually controlled with a door in addition to windows controlling visual access only, just like in any typical room. Secondly, access to the virtual side of the MRACell is controllable through similar architectural elements, effectively creating a virtual door. For this reason the virtual part of the MRACells has been designed so it can be open, semi-closed or closed.

Figure 2:

MRACell: open, semi-closed and closed



The semi-closed state acts like a curtain, blurring the view into the physical cell unless one actually steps through, which would be very clearly visible to the inhabitants. The closed state blocks the view into the physical space and marks the MRACell as unavailable. Inhabitants toggle between the three states using the buttons on the joystick associated with each of the MRACells, the joystick also being used for navigation. Using spatialised audio, when two MRACells are virtually close to each other, a live audio connection is opened in an application of the spatial model of interaction (benford and Fahlén, 1993). Once the audio ranges (visualised by a circle as shown in Figure 2) of two or more MRACells overlap, audio is transmitted between them. The volume changes according to the distance between the MRACells involved in the interaction. In addition, the video becomes clearer when MRACells get virtually close; simply because it fills more of the available screen space (compare Figure 3 with Figure 4 (left)).

The interface

The onscreen interface includes a map at the centre top of the screen, which displays the live MRA including all its currently connected MRACells. The video to the right displays the view of the inhabitant's own camera. This was added to allow people to position themselves so they were in view and close enough to be seen properly by others. The main part of the interface displays a first person view into the virtual public space of the MRA.

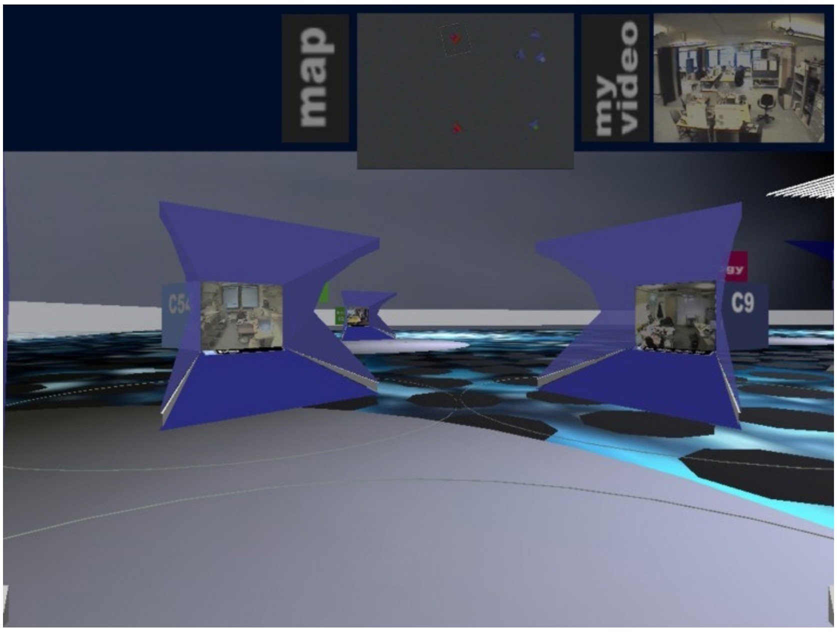


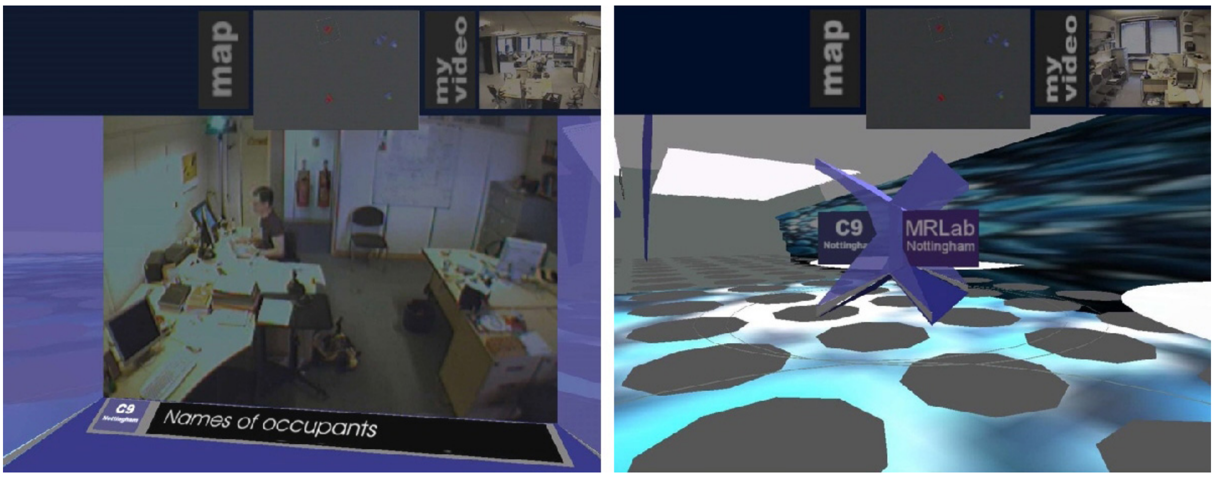
Figure 3:

Sarah's view 1

The 3D nature of MRA makes remote social interaction within it legible (Mitchell, 1995), as a direct result of drawing on principles grounded in architecture. Connections between inhabitants are clearly visible to everyone else, not only on the map but also in the 3D space. Figure 3, showing the view of Sarah into the MRA, can serve as starting point for an example scenario. To speak with Sam in C9 (on the right) Sarah needs to move her MRACell forward, using the joystick, until the two audio ranges (circles on the floor) overlap and the video becomes clear enough, filling a large proportion of the screen (see Figure 4 left). This movement can clearly be observed by Kate in C54 (see Figure 4 right).

Figure 4:

Sarah's view 2 into Sam's MRACell (left) and Kate's view (right)



Inhabiting Mixed Reality Architecture

The deployment of MRA then followed an iterative prototyping process, in which our goal was to feed back initial results quickly back into the development process (Floyd, 1984). Initially three MRACells were installed in our building on two different floors. A second prototyping stage lasting three months followed, for which a fourth MRACell was added on a different floor in our building. The study of the final situated prototype began in July 2004. The main data collection took place in the following four months with six MRACells, including three that are remote to Nottingham. Three were installed in Nottingham in one shared office, in one single office and in one foyer space, the entrance to the Mixed Reality Laboratory (MRL). The other MRACells were installed in a lab space at University College London (UCL), a single office at UCL and a single office at Bath University. The first three were located within the same building. The following two MRACells were located in different buildings belonging to the same organisation, which is itself approximately 140 miles from the first organisation The sixth MRACell was located in a third organisation, approximately 150 miles from the first and 120 miles from the second organisation. MRA has proven to be very reliable, interrupted only by holidays as well as technical issues, such as upgrades to the various networks. At the time of writing this amounted to about 30 months in total.

For the study of the final situated prototype, the main method of enquiry was an observational study. Video and audio were recorded via the infrastructure set up for MRA and the six streams were taped on two S-VHS recorders in parallel with the live map. 30 hours of material was indexed and labelled to be able to gain an overvie.. In addition, using the Record&Replay feature of MASSIVE3 (Greenhalgh, Purbrick et al. 2000), virtual movements, re-orientations and changes of privacy settings were being logged. The playback of these logs then allowed the study of virtual configurations in more detail and from any angle. From the combination of both sources of material, a series of interactional episodes was documented. These describe social interaction in detail, including people's actions in physical and virtual space and the talk between inhabitants across the MRA.

For brevity we cannot include a description of how people interacted within MRA but a full account of the findings of our observational study can be found in (Schnädelbach, Penn et al. 2006; Schnädelbach, 2007). In summary, MRA was successful in supporting spontaneous social interaction between the inhabitants of the six MRACells. They were able to make themselves aware of others and others' activities and the privacy mechanisms built into MRA worked well. In terms of social networks within MRA, it can be said that MRA supported the already existing social network over distance very well, helped to strengthen it and managed to extend it, although in a very limited way. MRA was used for interaction very much in an occasioned, purposeful way. Once there was a social connection with someone or there was a requirement to work together, MRA greatly facilitated the resulting interaction. In what follows we concentrate on the topological properties of MRA that made these interactions possible

A Dynamic Architectural Topology

Physical architecture has clear topological limitations as described by Steadman (1983). These result in certain limitations on the adjacency of physical spaces, where those might either be desired or need to be prevented. In turn, adjacency of physical architectural cells is the prerequisite for there to be visibility and accessibility between them. Hillier (1996) then shows how this translates into spatial configurations. Visibility and accessibility between spaces determine their integration in a spatial system, with integrated spaces playing a more central role, which in turn affects movement and encounter patterns. Of course the premise is that the configuration is fixed and is entirely physical. In what follows we discuss how this changes when architectural topologies are made dynamic and are extended into virtual space.

Topological Adjacency in MRA

Consider physical cells P^a, P^b, P^c, P^d. For the sake of the argument they are arranged in a line of four. P^a is adjacent to P^b which is adjacent to P^c which is adjacent to P^d. Clearly, this means that some physical cells cannot be adjacent to certain others. For example, in this arrangement P^a cannot be physically adjacent to P^c. The concept of MRACells is core to this research. Here a single virtual cell is permanently attached to each physical cell. They are V^a, V^b, V^c and V^d. Connections across public virtual space can now be made between two or more MRACells. These can be dynamically established as well as ended by inhabitants as described in previous sections.

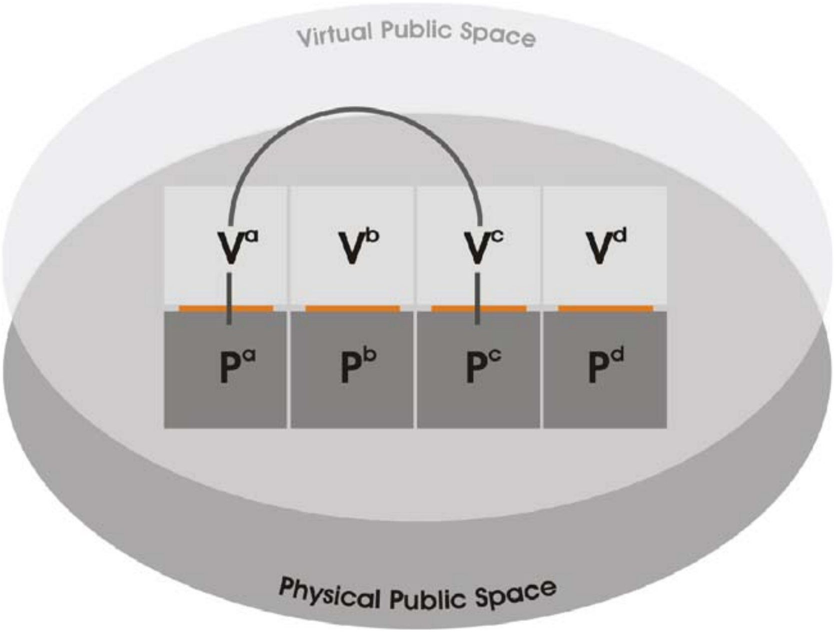


Figure 5:

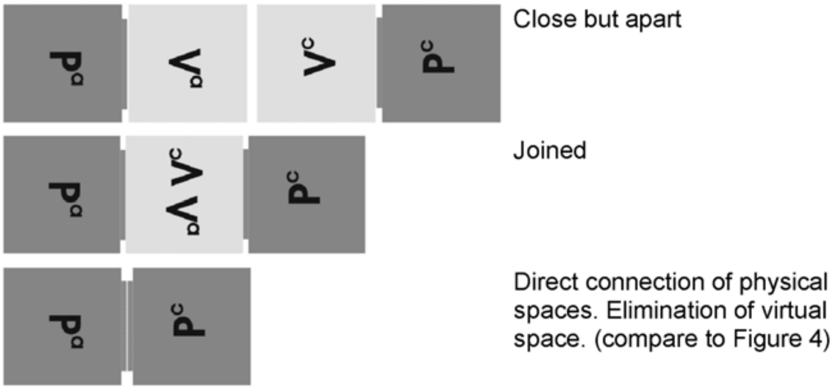
Connection between two MRACells

Through their connection across public virtual space P^a can now appear adjacent to P^c, overcoming the geometrical limitations imposed in physical space. Of course this does not change the actual physical arrangement of the two spaces as they both remain in their physical positions. Instead, the resulting configuration might be described as a meta-architectural cell consisting of two physical and two virtual architectural cells. The figure below depicts the same relationship between P^a and P^c, concentrating on just the two relevant MRACells. Initially they are close together but sill apart. They can also be moved closer together to join the two respective virtual cells. When these are brought even closer, virtual space can effectively be eliminated altogether as shown in Table 1.

This demonstrates how the spatiality within virtual space can be adjusted by inhabitants dynamically turning interaction in a 3D virtual spatial framework into interaction that is more similar to ordinary video conferencing. In all of the three cases above a new functional unit has been established dynamically by inhabitants. This allows inhabitants of the two MRACells to experience co-presence with people located physically at a distance.

Table 1:

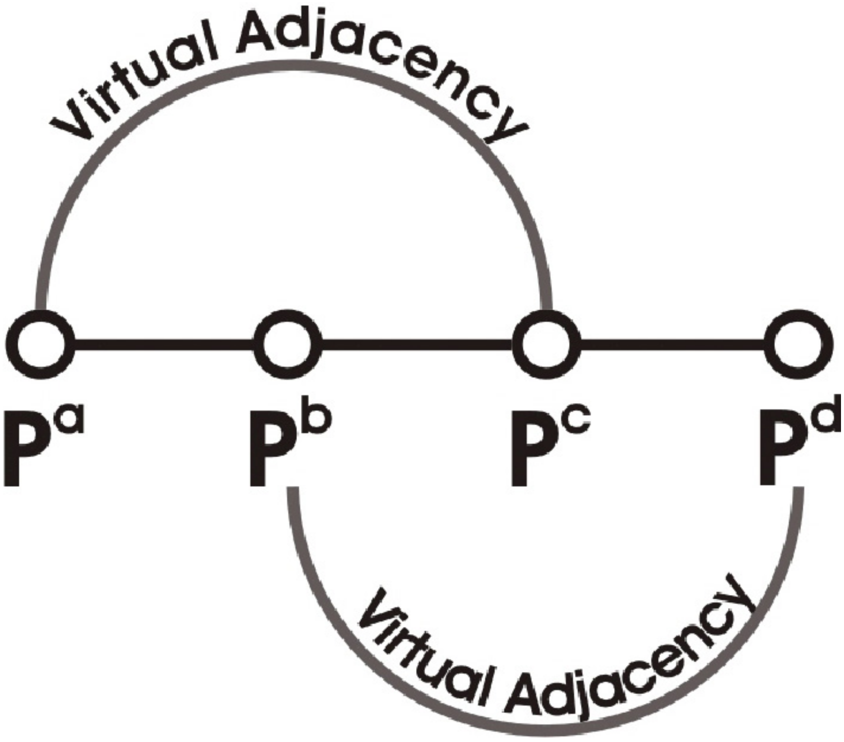
Meta-architectural cell



A second way of describing this relationship is through adjacency graphs. This type of representation makes very clear that virtual adjacencies can overcome limits on physical adjacencies. Physically, P^a and P^c remain non-adjacent, while virtually they now are. In addition, virtual parts of the adjacency graph can easily change as inhabitants move around with their MRACells and multiple adjacencies can also be established independently from each other, see Figure 6.

Figure 6:

MRACells – Multiple virtual adjacencies



Finally, these considerations also change the perspective on non-planar adjacency graphs. Non-planar graphs are those that cannot be drawn without some of their edges crossing and are impossible to build as physical architecture on a single plane, as illustrated in detail by March & Steadman (1971). Although MRA does of course not change the actual physical plan, it allows non-planar adjacency graphs to be 'built' across Mixed Reality space.

Spatial İntegration

Directly derived from the new possibilities in terms of spatial adjacencies are new types of spatial integration that are shown within the dynamic topology of MRA. As an example, consider the relative integration of C54 and the Mixed Reality Lab (MRL) foyer space both at the Computer Science department at the University of Nottingham. The lecturer's office C54 is near the end of a corridor on the second floor of the building. It is easily accessible for students and is well connected to the administrative areas. In relation to the MRL foyer however it is located on a different corridor from most other MRL offices and on a different floor from the MRL itself, making it deep in relation to those. In contrast, the MRL foyer is central to the MRL as a whole.

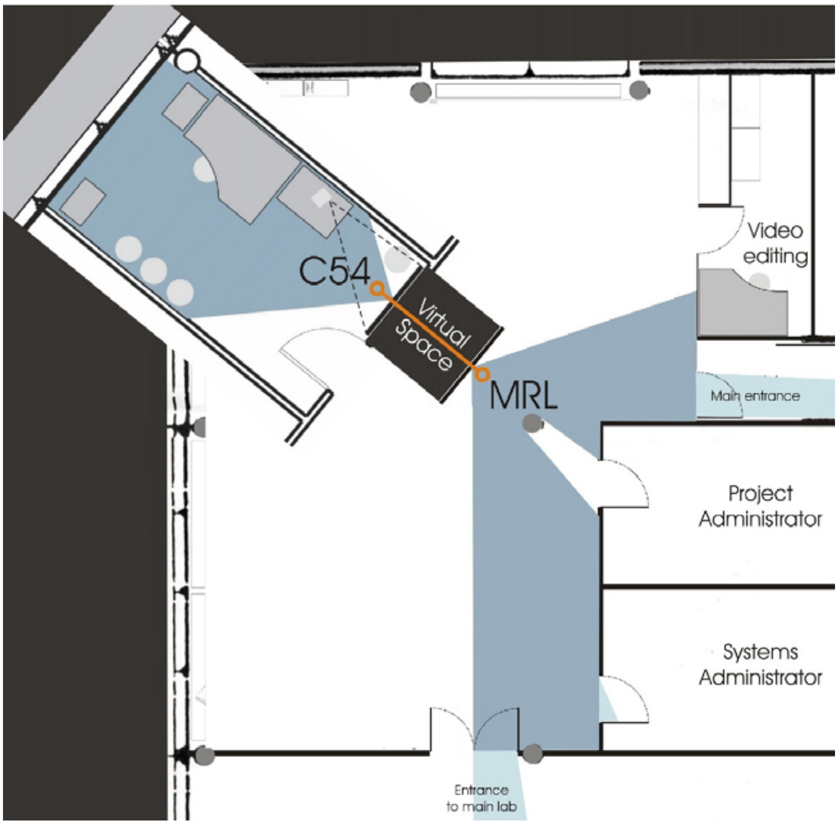


Figure 7:

C54 connected to MRL foyer across MRA

The MRL foyer itself controls access to the main MRL lab. There are two administrator office adjacent to it as well as a small library and the video editing suite. In relation to C54, it is also more integrated with the remainder of the building, being on the first floor and near the main vertical circulation. When the C54 MRACell is brought together with the MRL MRACell , its level of integration changes dramatically, as can be seen in Figure 7. MRA provides visual and verbal access between the two physically non-adjacent spaces, while not allowing actual permeability which could however be simulated (Koleva, Schnädelbach et al. 2000). However, in terms of visual and verbal access, C54 is now integrated with the core of the MRL lab. Our observational study has then shown how this integration changes patterns of social interaction, allowing awareness between the two spaces but also chance encounters, for example (Schnädelbach , Penn e al. 2006). The following two figures 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.

Figure 8:

Spatial integration for four physical cells (including total depth values)

One might then imagine a case where an identical spatial configuration existing in a place remote to the one above is linked across an MRLink. Figure 9 explores this scenario.

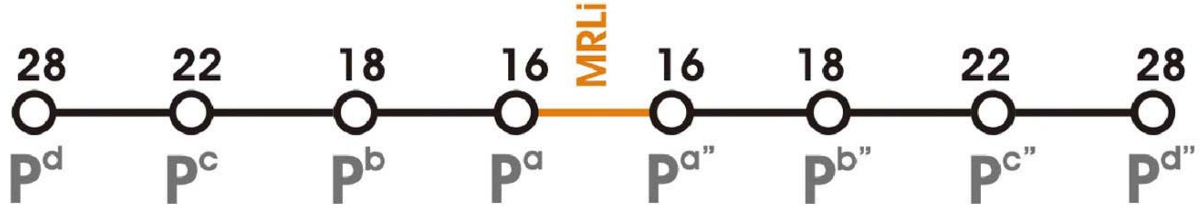


Figure 9:

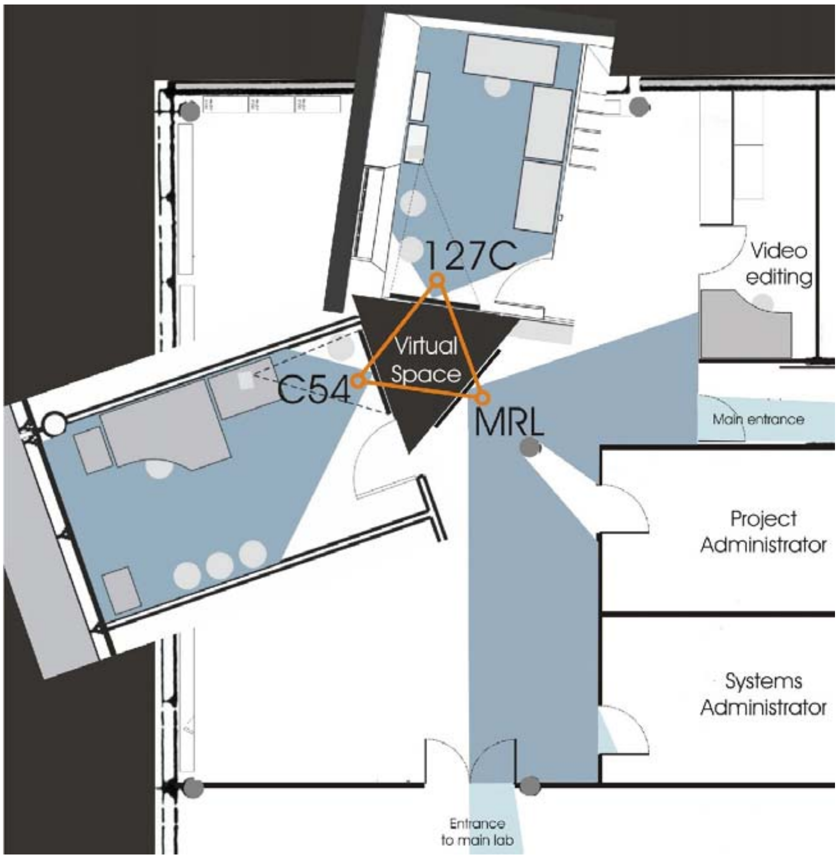
Spatial integration of two sets of four physical cells (including total depth values)

In contrast to the figure above, spaces P^a and $P^{a"}$ are now the most integrated spaces, if one takes the MRLink into account. So far the discussion has only considered one MRLink being made to a particular physical space. But of course the introduction of the virtual spatial framework allows the simultaneous establishment of multiple connections and these connections are publicly available to everyone close by in physical and virtual public space.

In addition to C54 already connecting to the MRL foyer, the 127C MRACell has joined the group. 127C is a lecturer's office at UCL and is located on the first floor of the Computer Science building. It is off the 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 10 then shows how C54 as well as 127C have both become shallower as a result of the re-configuration that inhabitants have made. In contrast to C54 though, and very importantly in this context, 127C has been made shallower in relation to a physical space whose integration would not normally be considered, as it is physically too far away.

Figure 10:

C54 and 127C connected to MRL foyer



There are three additional issues that are worth pointing out here. Firstly, the spatial integration discussed above also extends beyond the actual MRACells to other spaces near by. On the one hand this is simply the result of people moving into an MRACell and then having access to the connection. On the other hand it is the result of the MRA topology extending into other spaces to a certain extent through the placement of the interface technology within physical spaces. This will be discussed in the following section. Secondly, virtual adjacencies cannot reduce the existing level of integration of a particular physical space. Only its level of additional integration through MRA can be controlled through privacy settings and virtual positions by the inhabitants and others. At the same time the physical placement of MRA technology might well have a negative effect on integration when for example certain types of views and access are blocked as seen in the MRL foyer or certain individuals start avoiding spaces as seen in at a different MRACell. Finally, the integration of each separate MRACell is the result of the collective configuration of all MRACells. Although one inhabitant might decide to increase the integration of their MRACell with one or more others, this can easily be changed by other inhabitants moving their own MRACells elsewhere. This results in a dynamic set of integration values for the overall MRA, determined by the individual actions of members of its society.

Orientation of the Interface Technology

When considering the resulting integration of the physical parts of MRACells, a key issue is the physical placement of the interface technology in each of the MRACells. One of the early design choices was the central position of the MRB camera on the screen surface pointing away from the screen. When positioning the screen, inhabitants therefore also decided what others could see of their space. In none of the set-ups was the physical cell shown in its entirety, which was simply a result of placing the camera on one of its internal surfaces. However, the aim was to capture as much of the activities as possible. In terms of the orientation of the interface, three relative orientations needed to be considered: the orientation of the interface towards people, the orientation to other interface technologies and the orientation to the access to a particular space. For brevity, the following concentrates on the latter, which is directly relevant for the discussion of spatial integration in MRA. Each MRACell had one or more physical entrances, in the shallow parts of their respective physical cells and the interface technology can be discussed in terms of how it was oriented towards it.

Firstly, the location of the MRA interface itself could be deep, when it was away from the entrance(s) but the camera was pointing at it (them), the shallow part of a space. The observational study clearly showed how inhabitants coming virtually to these spaces used information from the camera pointing to the shallow end of a space as a resource for their decision making. For example, When Fred and Sarah explored MRA together from Bath and arrived at the C9 MRACell in Nottingham, they found the door to the physical cell open and deduced that Sam could not be very far. In another interaction, Sarah in the Bath MRACell comes over to the MRL MRACell to find the lights in Glenda's office turned off. She deduces that Glenda must be out, as the lights in this buildings are automatic (turning off after no movement has been detected for 20 minutes). The placement of the MRA interface in the deep part of a space also had a direct effect on people coming physically to these spaces as the screen was clearly visible from the shallow end of the physical cell. In the case of the C9 MRACell, the screen could be seen from just outside C9 on the corridor and the audio tended to project to this space as well. For example, this allowed Bill (Nottingham) to effortlessly join a conversation between Sam (Nottingham) and Sarah (Bath), since he had seen and heard it taking place when he walked past C9. As a result of the placement of the MRA interface technology the space itself was then also transformed, as a formerly deep part of a space was converted into a shallow part, from where other inhabitants of MRA would enter to interact socially. For the C9 MRACell for example this would therefore mean that it became more like a corridor, with control over the access to this corridor granted to the inhabitants of C9. The following provides an example. Gemma in the C9 MRACell (Nottingham) first interacted with Eric entering via the door, the physical shallow end of the room. Shortly afterwards she turned around to interact with Sarah (Bath), entering via MRA from the virtual shallow end of the room.

Secondly, the MRA interface could be shallow itself, when it was near the entrance, with the camera pointing towards the deep end of the space. People connecting to these spaces across MRA were provided with very little sense of the topological context of the MRACell in its physical surroundings. At the same time, people passing by physically were not provided with any sense of the state of the MRA as the screen was turned away from the entrance. On request, Kate confirmed that no interaction between a person physically passing by and person connected over MRA had occurred by chance at the C54 MRACell, where the interface was facing the deep end of the physical space. Furthermore, the effect on the space itself was much less dramatic than with the first category. The MRA installation merely re-enforced the 'shallowness' of the entrance area and did not affect the deep part of the space.

Finally, there were also installations where neither of the above was the case. Here the installation was located somewhere in between deep and shallow ends and pointed at neither of them. This was the case with the MRACell at Bath, where the size and shape of the room meant that the only available surfaces large enough to hold the projections were on the long sides of the spaces. Here no topological context was transmitted to people connecting over MRA, because this was not in camera view, while people passing by physically might have been able to see the MRA interface depending on its angle to the door. What the installations did do was create a second shallow area in a physical space at an angle to the physical shallow end.

What can be said in summary is that there were clear interactional consequences at least for the two main types of installation. Installing the MRA interface near the deep part of a physical space and pointing it at the shallow end encouraged chance encounters between people passing by and people connecting over MRA. It also turned this space into a corridor between physical topology and MRA topology and the access via two shallow ends now had to be controlled by inhabitants. Doing the opposite, installing the MRA interface in the shallow part and pointing it at the deep part had much less dramatic effects. Both access points to the physical part of the MRACell in question were then located at the same shallow end.

A Novel Type of Architectural Interface

MRA might be described as a very rapid and changeable manifestation of the processes that Hillier and Hanson (1984) outlined when discussing the agglomeration of physical architectural cells. Just as with physical architecture, in MRA this process is restricted by the rules and norms of the society inhabiting it, the community of MRA inhabitants. For MRA these rules were partly derived from experience in physical space but also emerged from long-term inhabitation. The following are a few examples of such unspoken rules. Lurking, staying in audio range without being seen, was not acceptable and no instance of this behaviour was recorded. Inhabitants also generally avoided each other's MRACells when navigating. There were no recorded instances where two or more MRACells occupied the same virtual space for any length of time. Also, breaking through somebody's closed 'front door' was deemed unacceptable. What appeared to be perfectly acceptable though was to stay in sight of others but out of audio range. This allowed inhabitants of that MRACell to be aware of other physical settings visually but not 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.

These rules then influenced the overall configuration of MRA. Taken together these behaviours frequently resulted in virtual architectural configurations that were widely spaced so that visual awareness could be maintained. The log data has clearly shown that the number of group formations increased with the distance of group members from each other. Although there were a number of recorded instances when close proximity was maintained between MRACells for longer periods, this was mostly for times when verbal social interaction was actually taking place and was between just two MRACells.

In this context, MRACells as developed for this research, can be described as entirely new architectural interface, where those are understood to be spatial manifestations of social relationships. The MRACell has extended this notion in three ways. Firstly, it is an architectural interface between local and remote spaces, which allows people from both of these spaces to interact socially. Secondly it is spatially mobile which allows spatial relations to be adapted by participants on the fly in a way that is legible by others. Finally, spatial relationships between the different MRACells in MRA are not determined from outside beyond their starting positions, while they are clearly limited in terms of geometry and ultimately social conventions.

In that sense MRA might be described as following the shortest social model possible for an architectural configuration. In a similar way to a party, MRA 'maximises 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.

Conclusions

In this paper we have described the design, construction and evaluation of Mixed Reality Architecture, a dynamic architectural topology linking local and remote physical spaces across a 3D virtual space. Its topological properties have been described. This has focussed on how virtual adjacencies allow for the spatial integration of physically non-adjacent spaces and how technology placement can change the nature of a space that MRA is installed in. In summary, it can be said that the MRACell is a novel architectural interface, as it integrates non-adjacent local and remote physical spaces, where inhabitants control the adjacencies in a dynamic way.

Beyond increasing MRA in size and functionality, this research opens a number of additional research questions. It might be worth exploring how space syntax techniques can be more systematically applied to virtual extensions of architecture, whether these are static or dynamic. Equally, it seems be that space syntax techniques should really take account of virtual extensions to architecture as part of its general framework, particularly with video conferencing becoming more widespread. In both of these cases, the potential dynamic nature of such virtual extensions might prove most challenging. Finally, it seems that architecture in general should take virtual space as extensions to the physical building fabric more seriously. This would have to go beyond merely installing technology, such as that installed for the intelligent home (Kidd, Orr et al. 1999), but would have to consider the topological and interactional effects of such extensions in a fundamental way.

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