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THE VIRTUAL TATE

Michael Batty
Ruth Conroy
Bill Hillier
Bin Jiang
Jake Desyllas
Chiron Mottram
Alan Penn
Andy Smith
Alasdair Turner

Centre for Advanced Spatial Analysis
University College London
1-19 Torrington Place
Gower Street
London WC1E 6BT

Tel: +44 (0) 171 391 1782
Fax: +44 (0) 171 813 2843
Email: casa@ucl.ac.uk
http://www.casa.ucl.ac.uk

http://www.casa.ucl.ac.uk/tate.pdf

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ABSTRACT

New methods for simulating the form of buildings using virtual reality (VR) have suddenly made it possible to link ways in which people use buildings to their geometric layout. VR opens up many different approaches to architectural simulation ranging from agent-based modelling of movement within a building to representing a building as a multi-user world. We demonstrate some of these possibilities using the Tate Gallery on London's Millbank where we predict the impact of detailed changes on the configuration of rooms and the display of pictures.

In an address to the *Architectural Association* in 1924, Winston Churchill[i] said: "There is no doubt whatsoever about the influence of architecture and structure on human character and action. We make our buildings and afterwards they make us. They regulate the course of our lives." The impact of this insight in architecture is enormous. Where it is possible, people continually adapt buildings to changing functions, but where the structure of a building is so inflexible as to permit little change, buildings fail. This is a hard lesson for designers to learn. It has not been helped by the appearance of computer-aided design (CAD) packages that enable designers to explore how major changes to the geometry of buildings affect appearance and economy but do little to show how patterns of building use affect their performance and suitability. Yet most changes in the environment involve ways in which space is manipulated locally. Users continually reposition furniture, rearrange objects d'art, and control microclimate while less frequently but nevertheless quite regularly, redecorate, occasionally modifying walls and windows as they learn what is affordable and best. In fact, in complex buildings whose function is production, exchange or entertainment, local arrangements can make an enormous difference to use and profitability as is evidenced in the importance that supermarkets, museums, hospitals, and schools give to layout. It is well-known for example that certain brands of good will sell better if they are positioned in a store to take account of the movements of shoppers and their buying habits.

Hitherto it has been difficult to embody such elements into formal architectural design. CAD has been largely concerned with representing buildings, not their users. Data on behaviour has been sparse, rarely linked to the design of prospective use although recently, much better information on use is beginning to appear from specialised questionnaires as well as passive sources such as closed circuit TV. However, it is virtual reality (VR) interfaces to digital representations of buildings that is changing this prospect most. In essence, VR allows both ordinary users as well as expert designers to enter building environments encoded in conventional CAD form, and to begin to react to what they see and feel. Such immersion enables us to by-pass the problem of simulating the behaviour of the user by enabling "real" users to explore an environment "virtually" although there is the obvious problem of knowing the extent to which behaviour in the virtual environment is directly transferable to the real. This real-virtual interaction is by no means the only new approach to building simulation. Ways of modelling “virtual” users based on micro-simulation in spatial environments are making substantially headway, drawing on new developments in complexity theory such as artificial life. Examples such as the Los Alamos Lab’s TRANSIMS traffic model based on modelling the motion of every vehicle in a city developed for US Federal Highways, and Chris Langton’s SWARM system developed at Santa Fe illustrate the potential for agent-based simulation in small-scale environments.

These possibilities can be defined by considering real versus virtual users against real versus virtual environments (Figure 1).

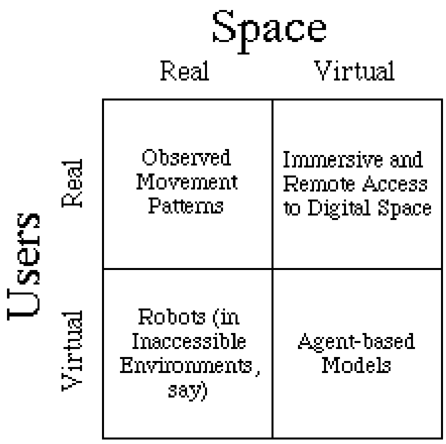

Figure 1: Concatenating the Real with the Virtual

Our starting point is real users in real environments and in the example of the Tate Gallery that we use to illustrate these ideas, a detailed survey of the spatial patterns of visitor use forms the raw data on which such simulations are built. At the opposite extreme, computer models of the way agents behave in simulated environments define methods for modelling the way virtual users behave in virtual environments. Real users in virtual environments define the heartland of VR where single or multiple users enter the virtual environment through various forms of immersion. Virtual users in real environments - real artificial life as some have called it - is something that we will not discuss here. These might be robots exploring real environments such as the creatures that inhabit Rodney Brookes’ Mobile Robot (Mobot) Lab at MIT.

There are other ways of classifying our examples for buildings can be simulated in 2 as well as 3 dimensions; in fact our agent-based models operate in 2-d space with an emphasis here on spatial behaviour that downplays the third dimension. The distinction between single and multiple users is also important. Traditional VR is focused around a total immersion in the virtual world, usually using some device such as a head-mounted display through which the user gains access to the world by navigating according to the visual cues prompted by the display. VR however is developing more remote forms of access. VR theatres and smaller scale equivalents such as CAVES in which many users can casually interact in conventional ways while being semi-immersed in a virtual environment, are broadening access. Configuring environments as multi-user worlds accessible over the net in which real users appear “virtually” as avatars are now being adapted to serious scientific uses.

These possibilities throw up a variety of opportunities for simulating how users behave in the spaces defined by buildings, and it is important to note that the ability to represent users in real or virtual forms changes the emphasis in computer-aided design from a concern for space *per se* to one in which the user becomes central. In CAD, users are either absent or remain passive - it is space that is active - while in VR and agent-based modelling, space has a more dormant role with the user being the focus of attention. Of course, comprehensive simulations will give equal emphasis to relationships between users and the space that they occupy, and the challenge in this kind of modelling is to simulate realistic behaviour which takes account of these interactions.
To illustrate these ideas, we will describe three related but very different approaches to building a virtual model of the Tate. Starting from the basic data, we will illustrate how the effect of geometry can be used to explain movement between the various spaces within the gallery by defining the viewsheds that visitors experience (Figure 1a: real users - real space). This data-driven model based on the ‘space syntax’ is contrasted with our second set of models based on the behaviour of agents in digital space (Figure 1d: virtual users - virtual space) where we develop both 2-d and 3-d versions. We then move to two models where real users can explore the Tate digitally (Figure 1b: real users - virtual space), first in single user mode where the Tate is encoded as a CAD model and the user navigates the space using a head-mounted display; and second where the same CAD model forms a multi-user world accessible by remote users across the net who appear to one another as avatars and who can communicate their experiences through text-based conversation. With this wide array of virtuality, we can access any of these versions (with the exception of the head-mounted display) in the more casual context of the VR theatre although we will not formally describe such experiences in the examples shown here.

Movements of visitors in the Tate were recorded over a 12 hour period in August 1995. Visitors were tracked for the first ten minutes after they entered the gallery with a sample of these shown in Figure 2 while counts such the average room occupancy over a one hour period shown in Figure 3, were also made. The comparative geo-metric symmetry of the Tate is clearly broken by visitors whose paths show a distinct left-handed orientation. This favours the western side of the gallery which houses the British collection since 1500, in contrast to contemporary art which is housed on the east. Room occupancy also indicates that the bookshop which is located on the right near the single entrance to the main gallery is the most frequently visited space. Good models of movement through the gallery should thus predict the relative asymmetry between the left and right sides, the dominance of the bookshop, and the lesser used rooms in the gallery's north east corner.

Our first model has been developed by the Space Syntax group at University College London, and this suggests that it is the configuration of the spaces and how they are connected that largely determines movement in complex buildings. This is in contrast to the relative attraction of the rooms themselves, in this case the art they exhibit.

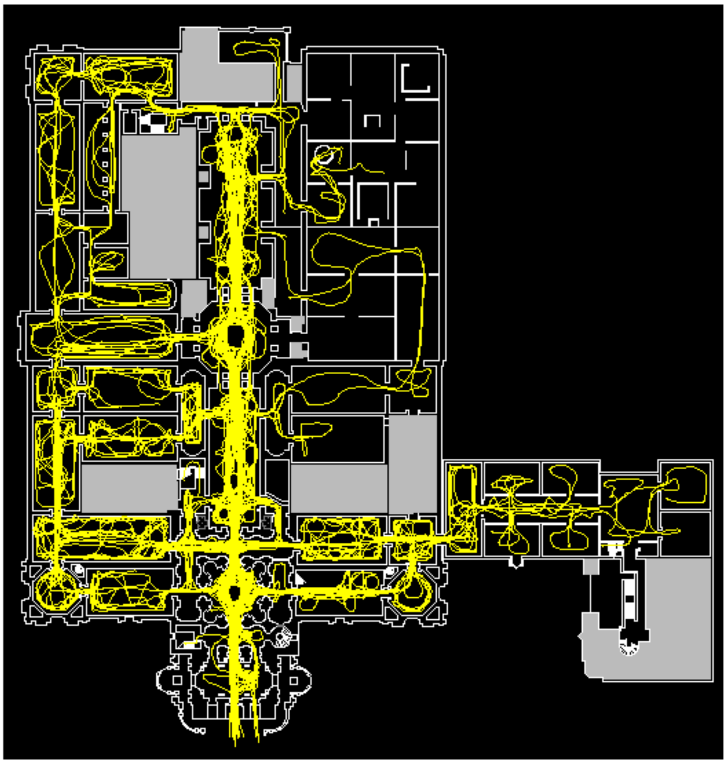

Figure 2: Walking through the Tate

The grey lines show the paths of visitors for the first 10 minutes after they enter the gallery

Much of our modelling is thus concerned with testing the balance in explaining movement and occupancy as a function of spatial configuration *per se* and other features that attract visitors. To measure such spatial relations, we have computed the geometric extent and area which can be seen from any point in the gallery, and the geometric links between these "isovists" have been used to build a measure of connectivity, accessibility, or integration as it is called in the theory of space syntax,[ii] for all points in the space to every other. Figure 4 shows the layout of the gallery coloured according to the degree of integration where it is immediately clear that the left-handed bias to the layout is revealed. Over 70 percent of room occupancy can be explained by these integration values and this provides a benchmark for all our subsequent modelling.

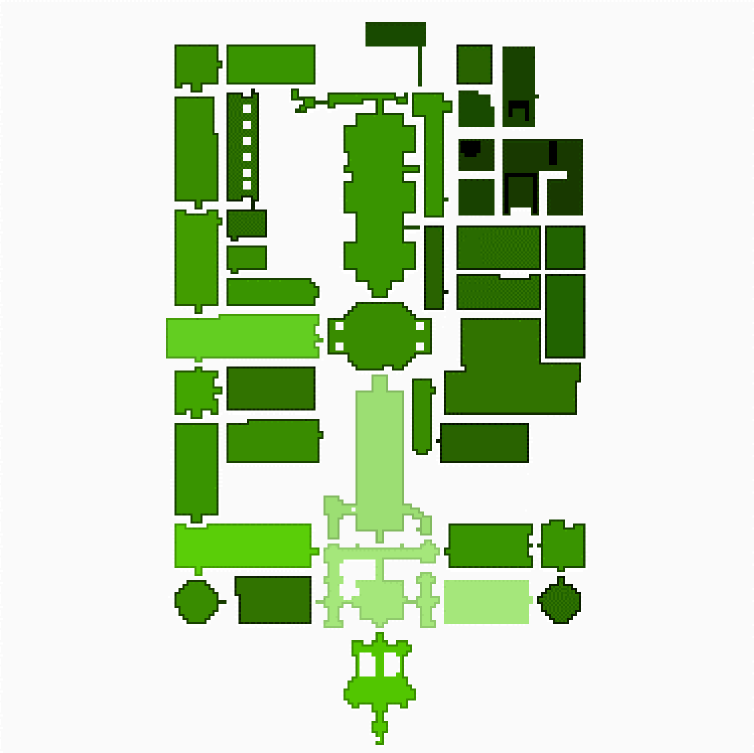

Figure 3: Visitors in the Tate

The scale from dark (low) to light (high) grey indicates the average number of visitors to different rooms in the gallery during a one hour period

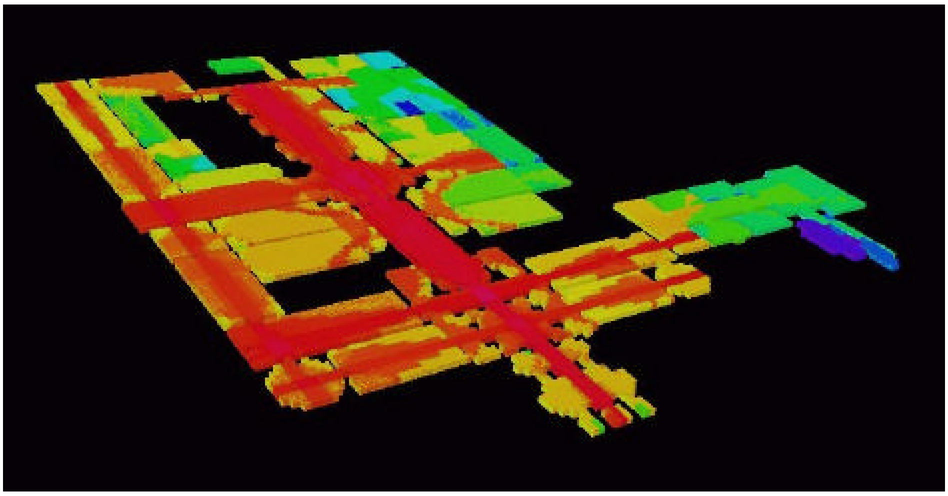

Figure 4: What Visitors Can See in the Gallery

Dark grey through light grey reflects the increasing number of areas within the gallery that can be seen from each point

The second set of models simulate virtual users in virtual space. The paths of visitors who enter the gallery through the main entrance are modelled as a function of local motion (where walkers avoid geometric obstacles and each other), and the perceived attraction of different spaces measured by frequency of visit. Agents thus trade-off their local navigation of space against their preferences to visit different areas, and the focus of explanation is on the way the geometry of the gallery combines with relative attractions of different spaces to generate observed movements[iii]. This model is heavily parameterised and has been calibrated both externally by ourselves and internally through agents learning about the spaces that they navigate through. It works in 2-d, predicting multiple paths through the gallery from which room occupancy is computed and tested against observed behaviour. In one sense, this model is the most well-developed for making predictions about changes to room attraction and local geometry. We show the kind of flow densities it generates in Figure 5. Once again we explain over 70 percent of the variance in observed movements from this model.

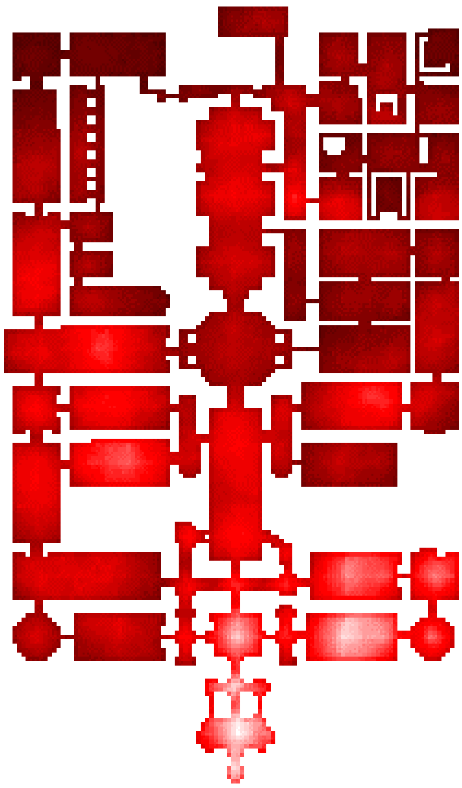

Figure 5: Predicting the Flow of Visitors

Dark grey (low) to white (high) shows the number of persons visiting each square metre in the gallery during a typical simulation of the agent-based model

This agent-based model is structured around software which embodies the principles of cellular automata (CA) using **StarLogo** from MIT's Media Lab. Its agents are geometrically blind although they make progress through finding clues to directions in under which to move within their local neighbourhood. The related model that we have under construction operates in 3-d where agents can be endowed with many more personal attributes and with the ability to see much longer distances. Agents make progress through the gallery by focusing on lines of sight and this connects their behaviour to properties of the geometry which are measured by isovists and the connectivity between spaces. The model consists of adding agents as objects (with their behaviour encoded through scripts) to the visualisation package **Iris Performer**. Agents have remarkable properties of self-avoidance in this model whose 3-d form can be viewed at many scales from entire motion in the gallery to the most local detail. Figure 6 shows the model in operation.

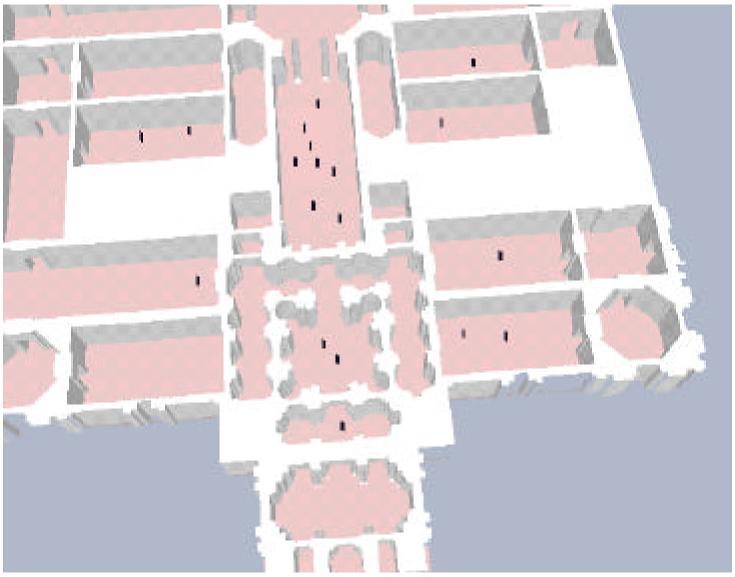

Figure 6: Agents Moving in the Gallery

Each dot represents an agent whose behaviour is encoded in a script and whose motion takes account of the 2-d and 3-d geometric qualities of the space

Our third set of models are based on the traditional ways of developing VR: enabling real users to enter, navigate and manipulate virtual space. Our first foray into the virtual Tate involved its encoding in **Microstation CAD** (used for all subsequent models), its translation into the **DVise** software, and its operation in immersive form using a head-mounted display. Individual users enter this world and are then left to navigate around the rooms stripped of any ornamentation and art. A snapshot of this virtual world through the headset alongside the real world is shown in Figure 7.

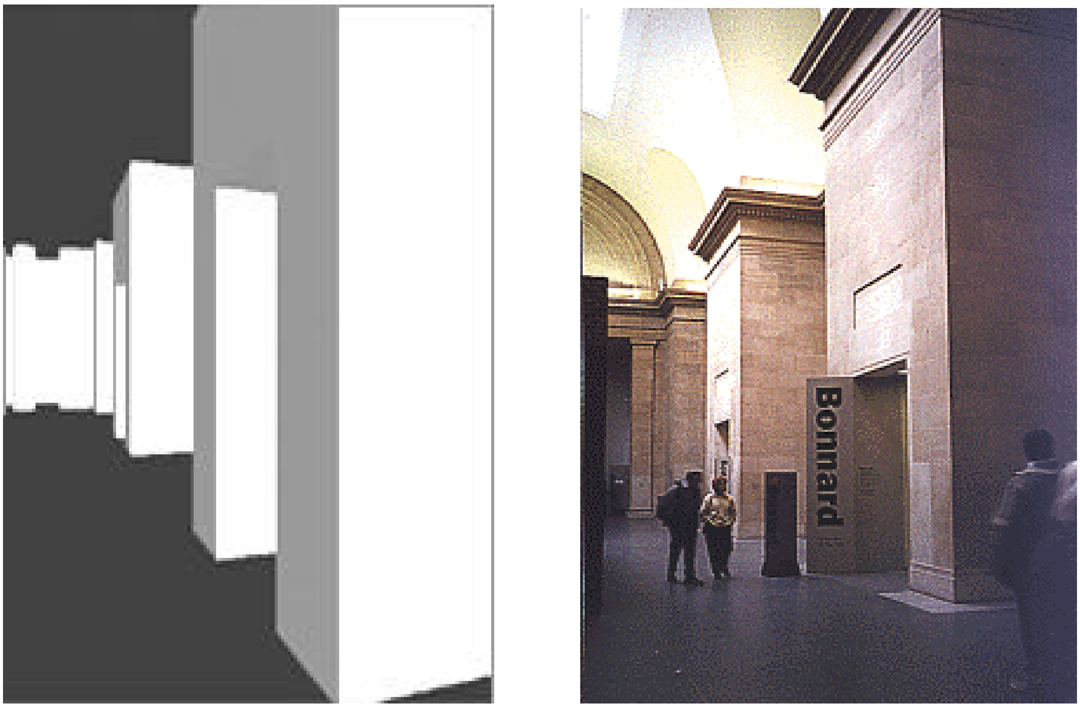

Figure 7: Inside the Virtual Tate

On the left is the virtual imagery of the Tate viewed through the headset alongside the real Tate

The essence of the experiments so far are to evaluate the extent to which the pure geometry of the space conditions movement. Individual tracks are recorded in the same manner as those recorded for real users in the real gallery, and those computed for the virtual users (agents) in the virtual gallery. The variation explained in this world through combining the paths of a dozen users who have 'walked' this virtual Tate is also consistent with observed data. The left-handedness of the walks and the broken symmetry of room visits observed in real life is once again replicated. A typical set of paths is shown in Figure 8.

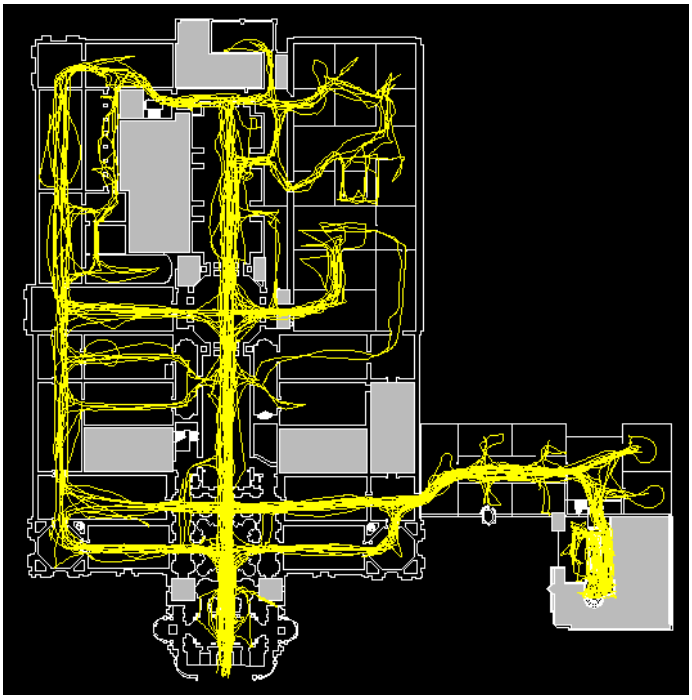

Figure 8: Paths of Visitors to the Virtual Tate

A series of paths through the gallery produced by visitors immersed in the virtual space

Just as we have a more elaborate agent-based model under construction, we have a more elaborate multi-user virtual Tate. The CAD layout has been used to form a virtual world (based on the **ActiveWorlds** software) which can be entered by users from remote sites over the Internet. Users enter this virtual Tate whose ground zero is the main entrance. They appear as avatars (in a variety of forms over which the user has control), and begin their walk in much the same manner as in the immersive example. However this multi-user world enables visitors to see one other and thus to generate paths which meet criteria for self-avoidance. Furthermore, users can communicate with one another through text, which provides opportunities for the evaluation of art objects, and any other kind of conversation for that matter. We are able to enrich this world in a much more elaborate fashion that any of our others in that it is easy to put pictures on the walls, record the paths of visitors, and the frequency of room visits, and even offer questionnaires to visitors so that their online experiences can be monitored. A birds-eye view of part of the gallery in which a number of visitors are viewing various exhibits is illustrated in Figure 9.

Figure 9: Avatars in the Networked Virtual World of the Tate
Here five visitors have logged on to the virtual Tate from remote locations, they appear as avatars, can "see" each other and "converse" through text as they view the art exhibited in the gallery

Although we have illustrated many different ways of exploring movement in a complex space, the question arises as to which, if any, of these approaches are preferable to any other. Each of our models characterises different features of the gallery through the ways in which users or agents respond to geometry, to the content of spaces, and to each other. These various worlds constitute a virtual laboratory in which we are designing a series of experiments to test the factors which determine movement at a local scale. The agent-based CA model is quite different in detail from the space syntax model which in turn is quite different from the immersive Tate, yet in these very different ways, all three account for about the same amount of variance in the observations. But the choice between them cannot be made on grounds of explanation in this narrow sense for each has particular characteristics useful for different kinds of prediction. Immersive and network-based virtual worlds enable the model-builder to get a much stronger handle on the effect of content in buildings, in this case on the effects of pictures and other art objects on the way people move through space. Space syntax models which are driven by the definition of isovists enable macro predictions of the effect of new geometry on movement patterns while agent-based models enable much more local scale movements to be predicted.

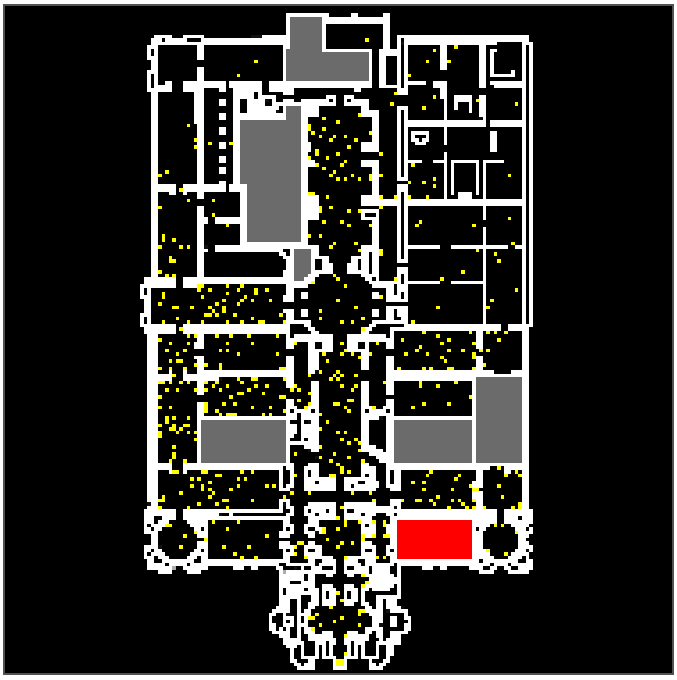

Figure 10: Closing the Bookshop

The white room with the cross hatch is the bookshop, the grey rooms are those closed to the public in August 1995, while the dots are the positions of 550 "virtual" visitors to the Tate, once they have reached a "steady state"

Predicting the effects of closing rooms and entrances, of constructing new additions to the gallery, of changing the use of rooms and exhibiting different types of pictures on the walls, these are some of the questions that can be asked of these models of the virtual Tate. For example, the impact of closing the bookshop would clearly shift people into other areas of the gallery but which ones ? Of course this might reduce the total number of visitors to the Tate too although these models cannot answer this type of question. We do however show the effect of closing the bookshop as predicted by the agent-based CA model in Figure 10 and this suggests that the asymmetry of the movement pattern would be lessened.

Yet there are much more radical changes in prospect at the Tate which these models might predict. When the New Tate Gallery opens on Bankside in the year 2000, the contemporary collection will be rehoused there freeing up Millbank to take a more extensive British collection. There are many questions that we might answer with our models when this happens but the key one is: will the asymmetry of the existing movement pattern (where the British collection is dominant) disappear altogether, and will movement through the gallery be substantially more different than it is at present? The success of this and other complex buildings depend on good answers to these questions as Winston Churchill presciently described so long ago when the debate over form and function was only just beginning.

[i] Quoted in Stewart Brand (1994) **How Buildings Learn: What Happens After They're Built**, Viking Penguin, New York, (footnote 2, page 3).

[ii] Integration is a normalised measure of the distance from each node to every other in a symmetric binary graph, where each link between every immediately adjacent isovist is coded as a node, arcs between these nodes being defined if these links intersect one another. A definition and elaboration is given in Bill Hillier (1996) **Space is the Machine: A Configurational Theory of Architecture**, Cambridge University Press, Cambridge, UK.

[iii] The attraction of each space or room in a building such as an art gallery is hard to measure where room function and what is displayed in each as well as the artistic preferences of the visitors are likely to be highly heterogeneous. We have used measures of actual room usage as a proxy, notwithstanding the circularity of calibrating the model to this same measure. Independent measures however are being developed in related contexts, see for example, Michael Batty (1997) Predicting Where We Walk, **Nature**, **388**, (3 July) 19-20.

Michael Batty, Bin Jiang and Andy Smith are with the Centre for Acvanced Spatial Analysis, Ruth Conroy, Bill Hillier, Jake Desyllas, and Alan Penn are with the Bartlett Graduate School, and Chiron Mottram and Alasdair Turner are with the VR Centre for the Built Environment, all at University College London.

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