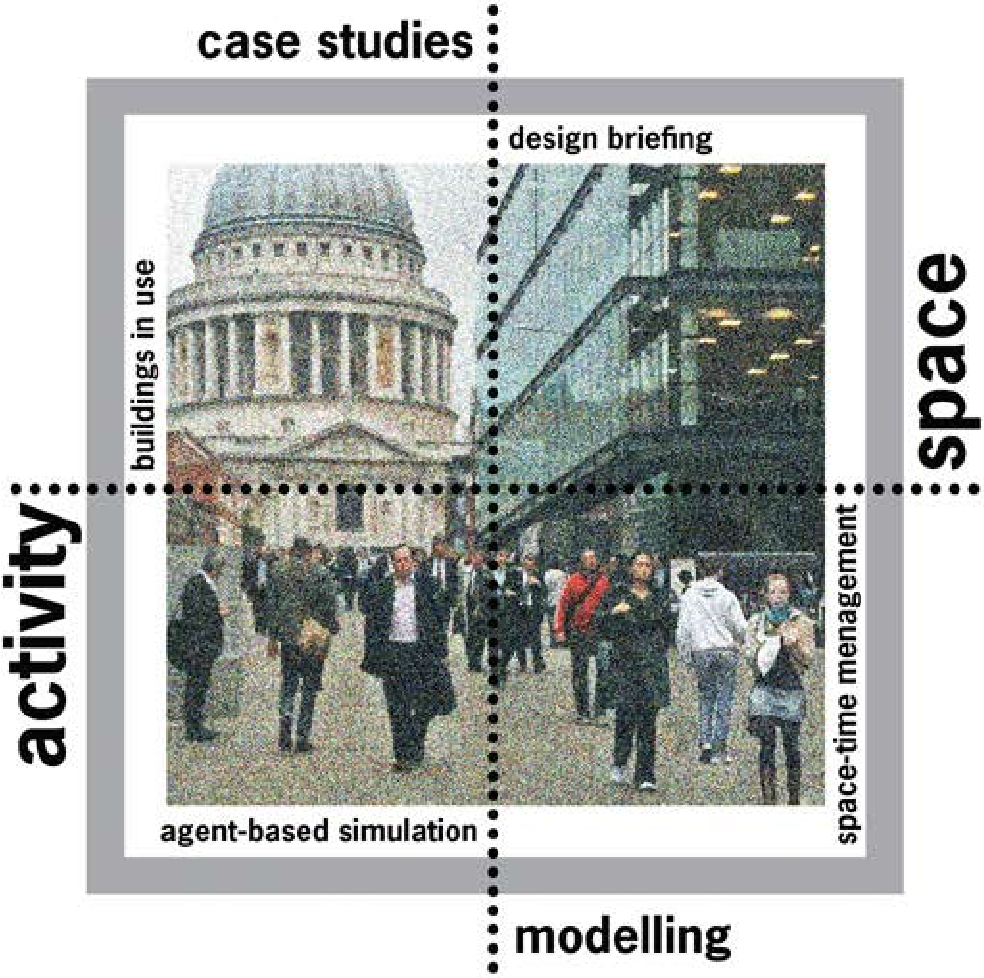
BUILT SPACE IN THE DIGITAL WORLD

the Activity-Space Research initiative



William Fawcett with John Worthington, Andrew Chadwick, Jeremy Myerson, Lionel March, Andrew Rabeneck, Ziona Strelitz
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FOREWORD

John Worthington

Andrew Chadwick's farsightedness and generosity in funding a five year Fellowship at Pembroke College, Cambridge has provided a unique platform to reflect on new ways of looking at the briefing of works of architecture, through the mathematical modelling of the use of space and time and the understanding of the needs of human behaviour.

William Fawcett, the Chadwick Fellow, following in the long tradition of the Martin Centre within Cambridge University Department of Architecture, is both an architect and mathematician. This combination has allowed for speculation through mathematical modelling tested against the insights of practice. This workbook draws together the outcome of fourteen half day workshops, hosted at Pembroke College, which brought together practitioners and academics from a range of disciplines but all with experience of briefing, designing and managing space for more effective utilization. The research model was to at each workshop present a proposition around a different theme described with a mathematical model and then tested in discussion and exercises by the participants drawing on their experience in practice.

The theme of the series, reflecting Andrew Chadwick's own significant pioneering work in practice, has been the changing ways of work and changing paradigms for the planning, design and management of space, time and activities. The sessions exposed new insights by exploring other disciplines and sectors. The models developed by the airline and hotel sectors for yield management had direct relevance to the facility manager, whilst the research on perceptions and behaviour recognised that individuals choices do not necessarily follow a logical pattern, resulting in uncertain demand.

I commend *Built Space in the Digital World* to both senior managers responsible for space management and consultants in briefing management and design. It broadens the perspective and highlights the symbiotic relationship between space, time, technology and usage. For organisations it identifies alternative approaches to defining, managing and using resources. For consultants and researchers each chapter has insights to allow the rethinking of perceived wisdom and the framing of sharper research questions to explore.

As we face the challenges of climate change and creating a more sustainable future, lean thinking, resulting in the more intensive and effective way we use resources, is becoming a central theme. The Chadwick Fellowship has provided a platform of insights for more in depth exploration through organisational case studies to identify ways through new models of the use of space, and time, supported by technology, organisations can rethink working processes to improve business performance, reduce energy usage and enhance lifestyles.

Professor John Worthington
Co-Founder, DEGW
Graham Willis Professorship, University of Sheffield
Visiting Scholar, Pembroke College, Cambridge

OVERVIEW:
BUILT SPACE IN THE DIGITAL WORLD – A NEW ROLE?

Andrew Chadwick

The old assumptions about the role of built space in the human world are all under threat with the inexorable advance of the digital world. It is not that long ago that we were debating whether office workers would share computers on a 3:1 or a 2:1 basis. It is, equally, not long ago that mobile phones were bulky, expensive and unreliable.

Today you can measure your blood pressure, watch the television, phone your friends and see people on the other side of the world in the blink of an eye – and it's only really just started.

This dynamic world we live in challenges our centuries old shelter driven built space assumptions. If we could organise ourselves nobody actually needs a physical office any more. We only need them as a convenient assembly point for our physical artefacts and a place to meet other humans. Even the 'nine to fivers' don't really need to do what they do in a specific place. It's only the apparent need for control and the inadequacy of managerial process that demands physical location.

It is against this historical backdrop and at a tipping point in the equilibrium of life that this work on Activity-Space Research should be considered.

In a world where individuals have increasing choice in their working locations the concept of a 'built to suit' building is becoming less and less relevant. However, if we have no physical shell to consider when looking at occupancy and environmental design we need a more abstract form of spatial control to be able to predict space provision in a meaningful way. Activity-Space Research is aimed at filling this void.

William Fawcett, the Chadwick Fellow at Pembroke College, Cambridge, has spent five years carrying out research and interactive studies with professionals in all major space categories to establish mathematical tools which can predict space need in the digital world. This work has also started the process of not just looking at the mathematical need for space but its nature and should be read by all those concerned with the design and management of the physical environment. It is an ongoing piece of work which will develop as corporations and individuals 'get the point' and start the journey themselves.

Andrew Chadwick MA RIBA MCSD
Principal, Chadwick International

Chapter 1

ACTIVITY-SPACE RESEARCH

THE ACTIVITY-SPACE RESEARCH MAP

Activity-Space Research is concerned with the quantified relationship between activities and the buildings they occupy – the amount, type and location of space that is used by given activities. This is not the whole of architecture, but it is a vital issue for the successful design and management of practically all buildings.

Three conditions of architecture

Well building hath three conditions: firmness, commodity, and delight.

This catchphrase is a picturesque 17th century translation from the Roman architect Vitruvius, expressing the diversity of topics making up the discipline of architecture. It hasn't lost relevance with the passage of time.

When architects design buildings they must take account of all three 'conditions' simultaneously – quite a challenge and not always achieved: think, for example, of a beautiful building with a leaky roof, achieving **delight** but not **firmness**.

In contrast to practice, architectural research advances by focusing in depth on particular parts of the discipline. In the case of Activity-Space Research the focus is on **commodity**: the ways that buildings serve human activities.

Activity-Space Research map

The map of activity-space research has a boundary that separates what is and isn't included in the territory for investigation.

The map has two axes, horizontal and vertical. The horizontal axis starts way out to the left with all the aspects of activities that are not directly affected by the spatial environment – the greater part of social science.

Off to the right are all the aspects of the spatial environment that do not directly affect activities, such as structures, building costs, and the whole of architectural history.

Many important issues fall outside the boundary, but that still leaves many fascinating and important topics for Activity-Space Research.

Styles of research

The vertical axis represents different methods of activity-space research.

At the top there is case study research – looking in detail at parts of the real world. Case studies are complex and always unique, but they have factual authority.

At the bottom is modelling – creating simplified versions of the real world, defined by a small number of key attributes but ignoring everything of secondary importance (the modeller decides what to include and exclude).

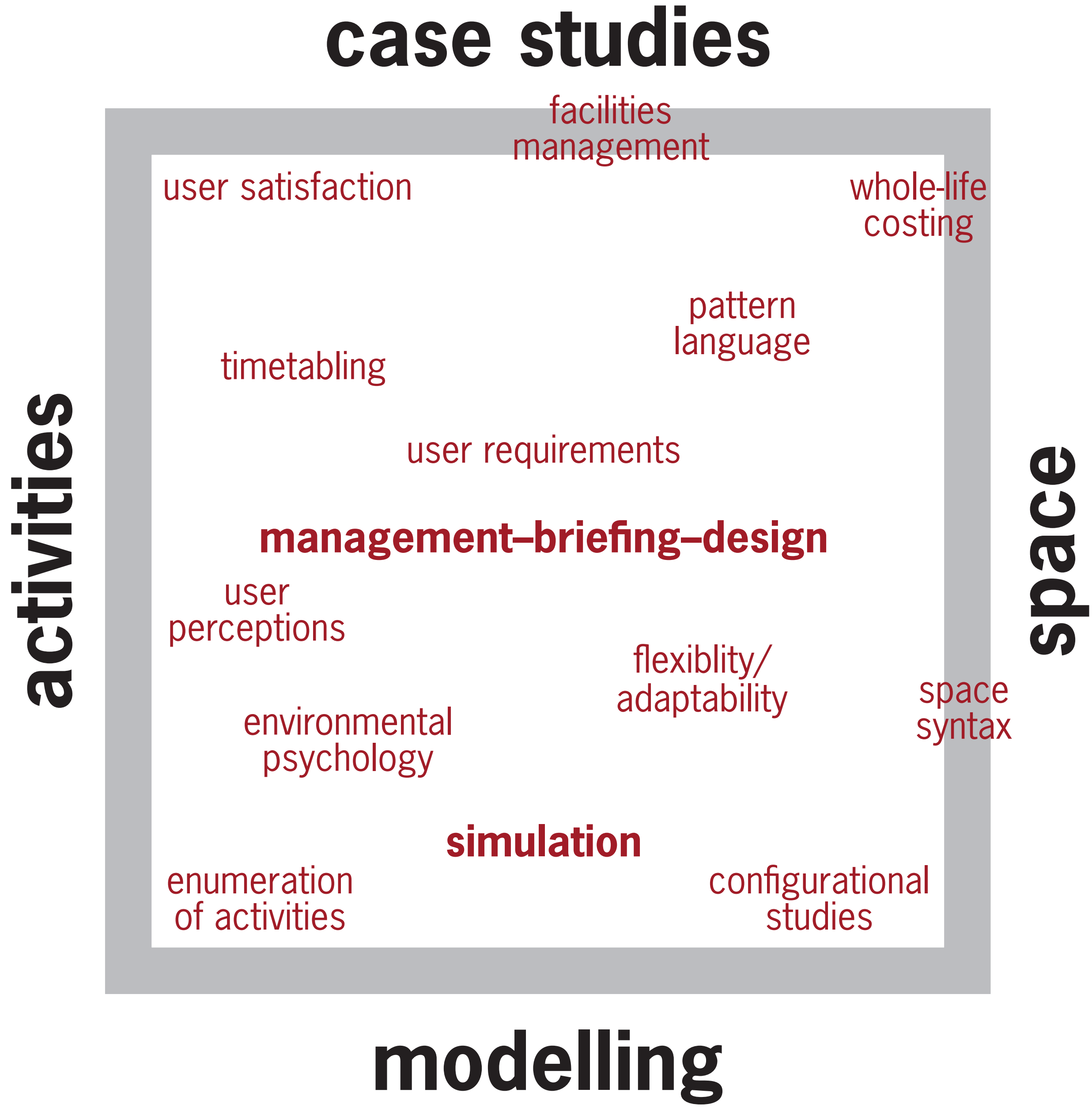
Both case studies and modelling are valid approaches, but up to now case studies have been dominant in architectural research, so we have chosen to prioritise modelling.

It is said that architecture has three components, 'firmness, commodity and delight'.

Firmness deals with construction and the technical performance of buildings (left).

Delight is evident in buildings that are designed with an artistic objective (right, the Senate House, Cambridge).

Finally, *commodity* is concerned with how well buildings meet users' needs. This is the focus of the Activity-Space Research initiative.



The map of the Activity-Space Research initiative draws a boundary around topics where activities and the built environment interact. The names of a far from exhaustive range of topics are placed within (or straddling) the boundary.

The map is structured in two dimensions.

Horizontally, aspects of activities that have little or no connection to the built environment are off to the left, and aspects of buildings that have little or nothing to do with activities are off to the right; Activity-Space Research is where they overlap.

The vertical axis separates different research styles – case studies at the top and modelling at the bottom. Both are important, but modelling is relatively neglected in architectural research. The Activity-Space Research initiative has concentrated on modelling.

MODELLING AS A RESEARCH METHOD

Modelling sacrifices vast amounts of real world data – why? There are three benefits: simplicity, control and experimentation.

Modelling

Most research into the use of buildings relies on data collection form real buildings in use. It is possible to collect large amounts of detailed data, describing real-world settings. Modelling studies, on the other hand, are highly simplified and artificial. Modelling sacrifices vast amounts of real world data in exchange for simplicity, control and experimentation.

Simplicity means reducing the number of variables in a model, so that their interactions can be studied and compared and understood. Three or four interacting variables is plenty; a model with more than five or six variables is too complex to understand and therefore self-defeating.

Control is a consequence of simplicity – the modeller can set the values of all the variables and observe the outcomes.

This means that the modeller can carry out **experiments** by changing attribute values in a systematic way, revealing trends and patterns in the outcomes.

Experiments

Experimentation is easy for a modeller, but problematic for a case study researcher.

It is highly unlikely that it would ever be possible to find case study examples representing all the interesting permutations of key attributes in a research study, and even of you could the data would be 'contaminated' by other, extraneous variables (from the point of view of the experiment). So it is rarely possible to conduct systematic comparison between precise features of interest using as-found case studies.

Researchers are seldom able to intervene and make experimental changes in real case study situations. 'Before' and 'after' observations, such as when an organisation moves or redesigns its premises, are about the closest a case study researcher can get to experimentation. They are great research opportunities, but infrequent.

Hypothetical scenarios

A crucial benefit of modelling over case studies is that you can only observe settings that already exist, but with modelling you can study all imaginable buildings and use patterns.

In particular, you can model future scenarios. This is not the same as trying to predict the future, which is impossible, but it allows the probable consequences of alternative courses of action to be compared – something that is of immense value to managers and policy-makers.

Managers study past data to help make decisions about the future. What they need is forward projections. Up to now these have to be made intuitively or using simple extrapolations. Systematic modelling provides a far more powerful way of testing future scenarios.

Relevance

A weakness of modelling is that you can construct artificial worlds that bear little or no relation to reality. This is why the case study and modelling research approaches must communicate with each other.

Model predictions must be compared with case study data from corresponding real-world situations, so that the model can be verified and calibrated. Only when a model has been shown to replicate a variety of real situations, can its findings for hypothetical situations have credibility.

Real environments, like 19th century industrial housing (Burnley, above) sometimes approximate to idealised built forms (opposite), but they represent only one instance, whereas a built form model can be used to explore an infinite number of variants of block height, length, spacing, etc.

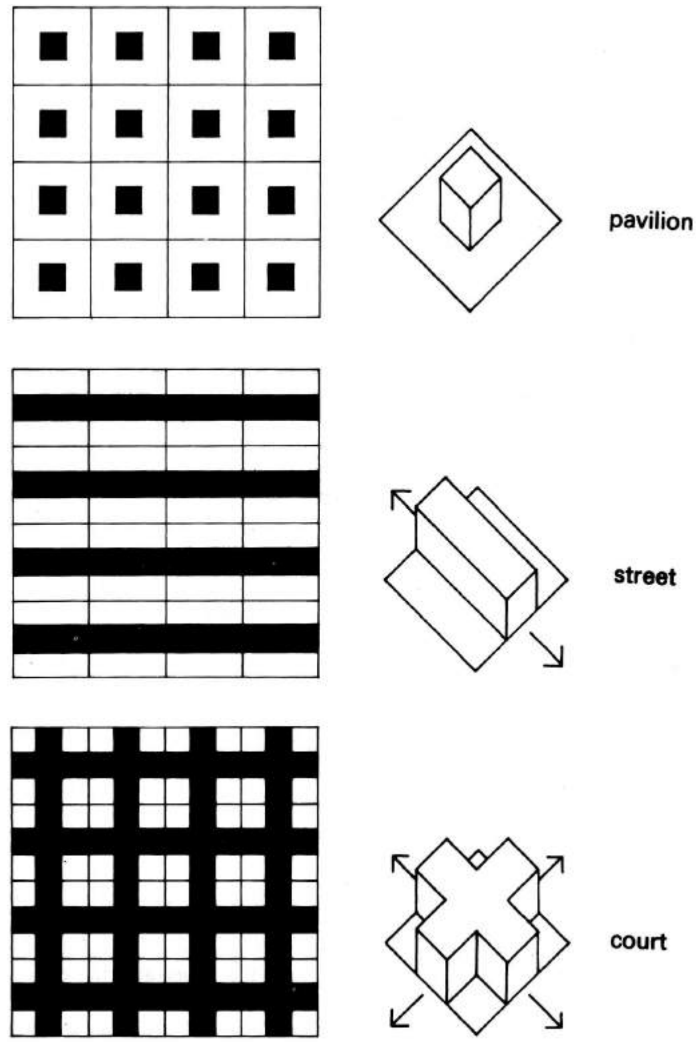
There is a clear difference between the design of individual buildings and the design of towns or cities; but there is also continuity because towns or cities are predominantly made up of many individual buildings. The interaction between the two scales is interesting and important: how are conventions about the design of individual buildings reflected in overall urban form?

This was described as the 'land use and built form' question in the early days of architectural research in the Department of Architecture in Cambridge University. The Department's new research centre, founded in 1967 by Sir Leslie Martin, the Professor of Architecture, was called the Centre for Land Use and Built Form Studies; it was renamed The Martin Centre in 1974 when its scope of activities had expanded to a wider range of architectural research questions.

The land use and built form question was investigated with simplified models of generic building forms: pavilions, streets and courts. Systematic variation of plan dimensions, building heights and street widths showed that these 'built forms' have widely varying urban consequences.

Assuming that some outcomes are more desirable than others, land use and built form understanding should allow architectural and urban planning policy-makers to guide urban systems towards desirable future states.

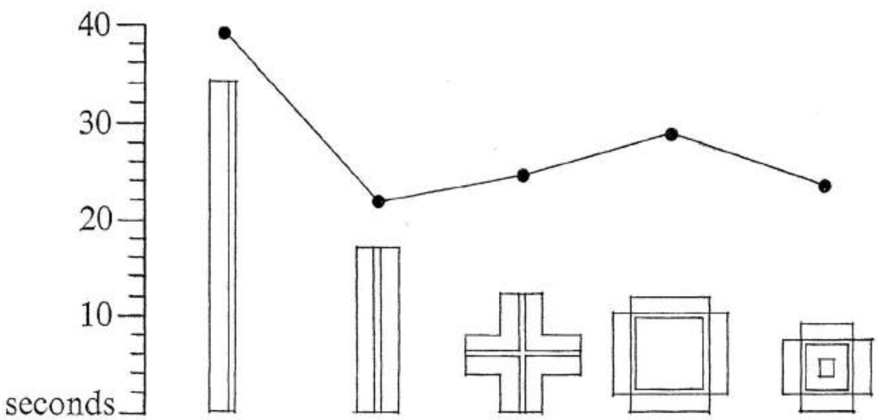
(Diagram from *Urban Space and Structures*, edited by Leslie Martin and Lionel March, 1972, p.36.)



A tremendous stimulus for architectural research in Cambridge in the 1960s and '70s was the power of then-new computers for investigating many architectural questions, using innovative mathematical models.

One study at building scale compared the circulation efficiency of alternative plan types. The diagram shows five different configurations for a building floor-plan with 32 rooms. There are 496 possible room-to-room trips (32 x 31 / 2), and the variations between the average times for these trips were calculated for the five configurations.

(Diagram of research studies by Philip Tabor, from *The Geometry of Environment*, by Lionel March and Philip Steadman, 1971, p.319.)



ASR RESEARCH WORKSHOPS

A key component of the Activity-Space Research initiative has been a series of fourteen Research Workshops. They are both a means of disseminating the new research, and a means for advancing the research through informed feedback and the sharing of ideas with participants who have complementary experience in research or practice.

Workshop format

The Research Workshops provide a forum for the exchange of ideas between researchers, design professionals, policy-makers and owners/managers of buildings in the commercial, higher education and healthcare sectors. In addition the Workshops are attended by academics and research students.

A high level and productive exchange of views and experience is achieved.

Each Workshop is on a specific theme in Activity-Space Research. Most include presentations of the latest work of the Activity-Space Research group in the Martin Centre, and presentations by other practitioners or academics working in the same field. These presentations provided much of the source material for this book.

Usually the participants take part in a prepared exercise to explore the theme of the Workshop: some of these Workshop exercises are also reported in this book. There is time for contributions from all participants, and discussion.

Over 100 people participated in the Workshops. The average attendance was 15-20, but 28 came to the eleventh Workshop on Flexibility – a clear signal of the importance attached to this topic.

The Workshop format is a half-day session held in Pembroke College, Cambridge, which is the base for the Chadwick Fellowship in Architecture.

The first Research Workshop included an exercise in which the participants noted down on cards the important issues that *are likely to have an impact on the way the buildings are managed and designed*. The participants explained their reasoning, and the cards were pinned on a board with related issues grouped together.

Then the participants were asked to stick green and red dots on the cards – green dots on the those they thought raised important issues, and red dots on the ones that they thought were secondary.

The number of dots attached to the most and least favoured of the 45 issues are shown in the table opposite.

The favoured issues demonstrated a conviction that rapid and continuing change is occurring.

The topmost issue showed a desire to rediscover how architecture and design in the built environment can be exploited – a topic that would be on the right-hand margin of the activity-space research map (*see* page 11).

THEMES

ASR-W1	The Activity-Space Research initiative
ASR-W2	Typology of space use and space management
ASR-W3	Space-time decision-making by building users
ASR-W4	Simulation of buildings in use: validation of research agenda
ASR-W5	The simplest possible model of buildings in use
ASR-W6	Micro-scale: modelling the individual building user
ASR-W7	Macro-scale: modelling the overall performance of the building
ASR-W8	Work-life harmonisation
ASR-W9	Promotion of informal contacts through design and management
ASR-W10	Space management for uncertain demand
ASR-W11	Flexibility: flexible workplaces and flexible activities
ASR-W12	Case studies and modelling for activity-space research
ASR-W13	How should activity-space modelling be applied?
ASR-W14	Scenario-building – preparing for the future

The Research Workshops are held in the Nihon Room in Pembroke College's Foundress Building (below), designed by Eric Parry and opened in 1995.

	Issue	Green dots	Red dots	Net score
1	Role of 'delight' and how do you define it	**8**		**+8**
2	Accelerating rate of change relative to the life of the building	**6**		**+6**
3	Multiple uses and flexible spaces	**5**		**+5**
4	The oil is running out	**5**		**+5**
5	Sustainability from using what we have already more intensively	**4**		**+4**
6	Environmental considerations – energy, noise, visual, thermal – affect the form of buildings	**4**		**+4**
7	Lifestyle choices affect the location and form of buildings	**4**		**+4**
8	Young people adopt new technologies more quickly and enthusiastically	**4**		**+4**
9	Designing for continuous change	**4**	**1**	**+3**
10	Organisational culture affects work/life balance	**4**	**1**	**+3**
11	Using the design/modelling process to make the best use of the building in use	**3**		**+3**
12	Increase in mobile communication & transport impacts on space requirements	**3**		**+3**
13	Technology supports a diversity of spaces	**3**		**+3**
14	Choices are possible by increased mobility and communication – 'personalised services'	**3**		**+3**
15	Society is atomising	**3**		**+3**
41	Buy a total service, don't just buy a building		**2**	**–2**
42	More autonomy at school		**2**	**–2**
43	Obsolescence of deep-plan buildings	**1**	**4**	**–3**
44	Specialist individuals need virtual tools		**3**	**–3**
45	School leavers more autonomous		**3**	**–3**

PARTICIPANTS in one or more of the ASR Workshops

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FUTURE DEVELOPMENTS IN ACTIVITY-SPACE RESEARCH

The value of modelling has been demonstrated by the Activity-Space Research initiative, but there is much more to be done before the full benefits of the modelling approach can contribute to the design and management of buildings.

Digital dislocation

Use patterns in buildings are determined by the interaction between the physical features of the accommodation and the behavioural characteristics of both users and managers.

It is much easier to observe and measure the physical environment than behavioural factors. A major advance of the ASR initiative has been to model behavioural and physical factors as a system.

Modelling is vital now that assumptions based on past experience are being invalidated by the digital revolution – with its rapid advances in mobility, flexible working and dispersed computing. A decisive force for change is that digitally-empowered individuals now have greatly increased freedom of choice in selecting the times and places for carrying out activities – work, education, shopping, leisure, and even healthcare.

Waste and opportunities

When building managers continue with pre-digital practices the penalties are high. The under-occupation of buildings is now commonplace, which is wasteful and unsustainable in resource terms. Buildings that fail to support their users effectively are an impediment to the objectives of organisations, the economy, and society.

Mangers are under intense pressure to innovate, but they lack quantitative understanding or tools that would enable them to act decisively and confidently.

Can the insights and tools provided by ASR modelling feed into improved practice in the management and design of buildings?

Applications and theory

The objective of the next stage of ASR research is to work with real-world partner organisations who know that current management is outdated – and that the future holds more far-reaching change.

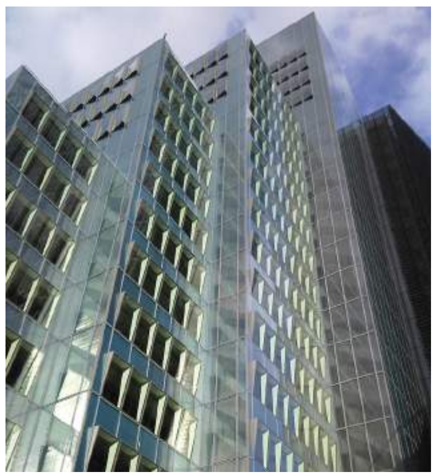
As well as helping the partners manage change, this collaboration will enrich the theoretical work on activity-space modelling.

The simulation models so far developed are highly simplified – deliberately so. Experience from the partners will guide model development in ways that maximise improved performance without getting drawn into the mire of *ad hoc* complexity.

There is continual investment in the building stock, despite boom-and-bust fluctuations; recent demolition and redevelopment in Dalston (left) and a gleaming new office building in the City of London (right – Arup Associates, architect, and British Land, developer).

Each investment cycle is driven by current perceptions, usually based on past experience, but buildings are durable and have to be useful in the future, not the present.

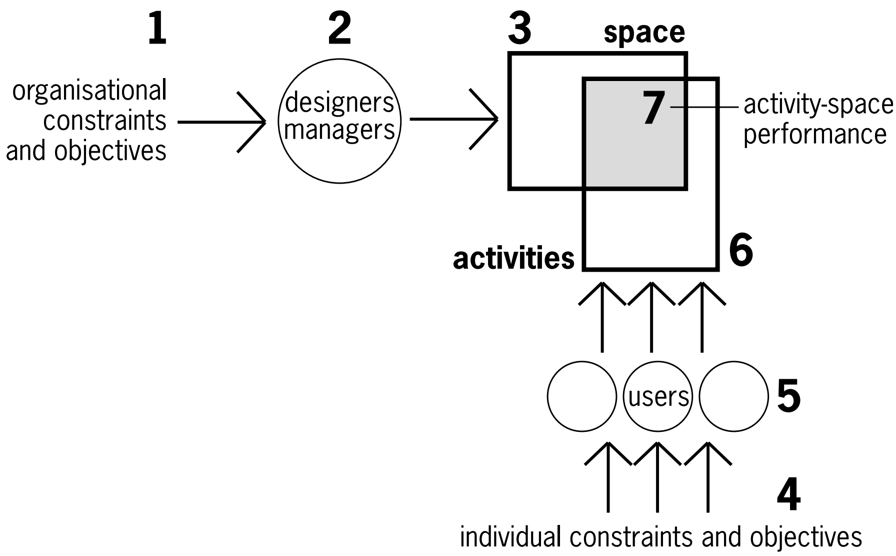
Simulation modelling of future scenarios is immensely valuable: it cannot predict the future, but it can remove much of the surprise attached to future change.



Applying the ASR simulation models to real-world organisations will reveal underlying structures to managers, and at the same time test and develop the simulation models.

The diagram shows the proposed approach to modelling the system of office premises and use, with components that interact in the following ways:

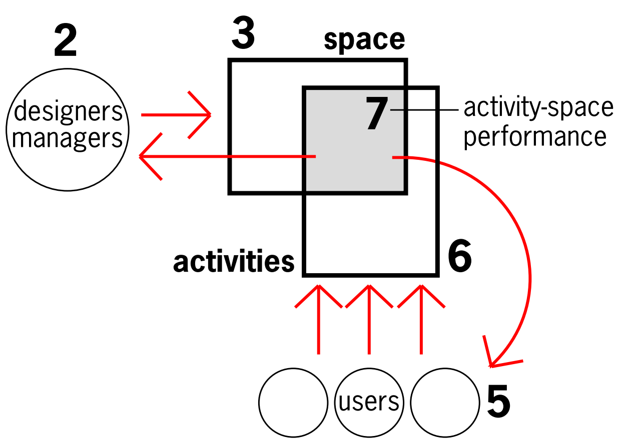
1. Organisational constraints and objectives – these are not changed by the model
2. The facilities management strategy; this responds to organisational constraints and objectives [1] and activity-space performance [7]
3. Space – the amount and type of workspaces at the employer's premises; this results from the facilities management strategy [2]
4. Individual employees' constraints and objectives – these are not changed by the model
5. The employees' decision-making between space-time alternatives; this responds to individual constraints and objectives [4] and activity-space performance [7]
6. Activities – the employees' work activities, at the employer's premises and elsewhere; this results from the employees' decision-making [5]
7. Activity-space performance – observed data about occupancy and utilisation resulting from the given activities [6] in the given space [3].



This way of modelling the system of office premises and use has dynamic feedback loops:

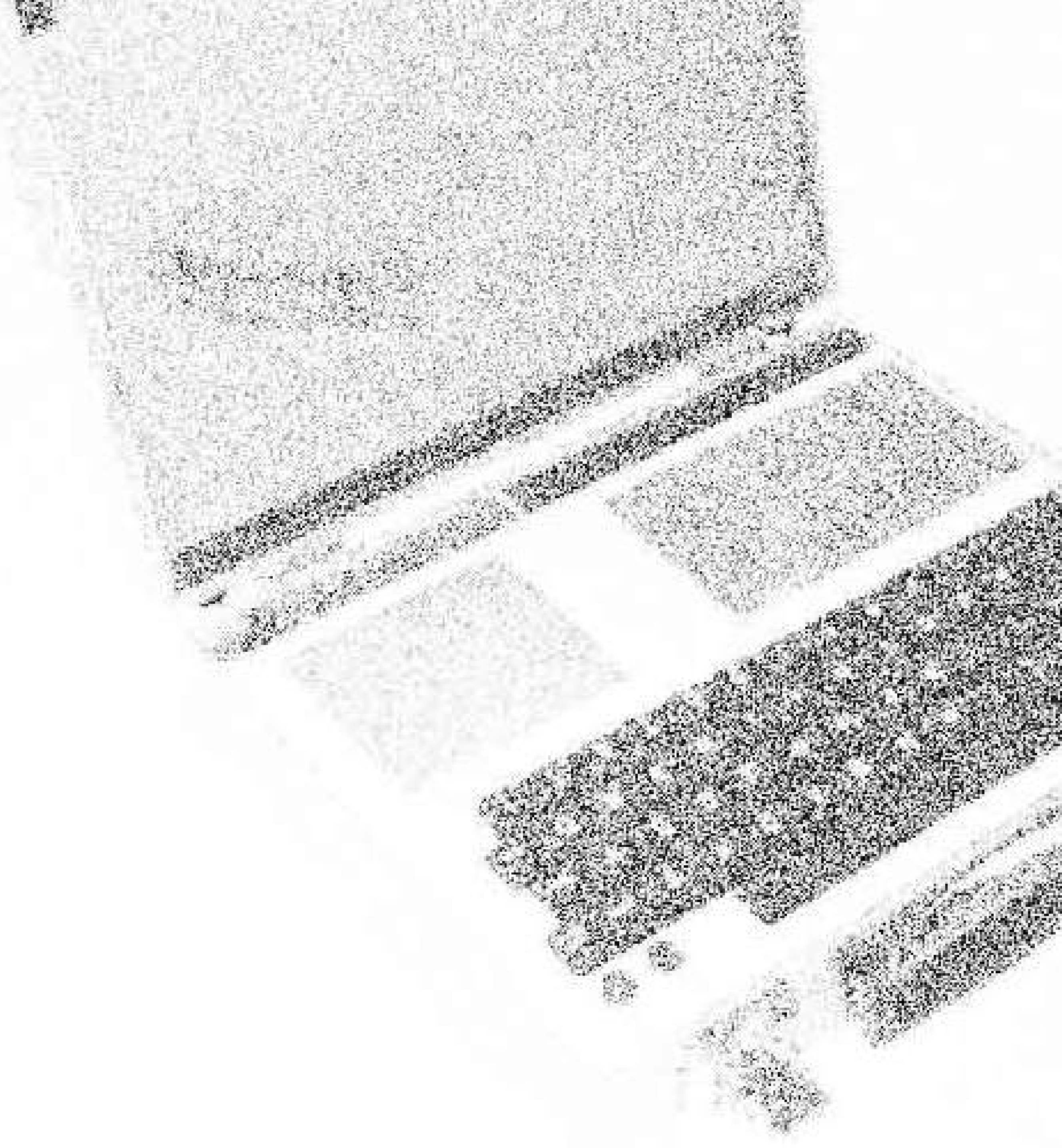
- a new initiative by the facilities manager or designer [2] causes change in the space [3], and therefore in activity-space performance [7]
- this causes change in the employees' decision-making [5] and hence a change in the activities [6] and activity-space performance [7]
- and this in turn causes change in the facilities manager's decision-making [2]
- and so on.

The feedback loops are a crucial feature of the facilities management process; without understanding of how it operates, there is a high risk that managers' or designers' initiatives will lead to unintended outcomes.



Chapter 2

TRANSFORMATIONAL CHANGES



ASR AND THE CHANGING WORKPLACE

Jeremy Myerson

Jeremy Myerson is Helen Hamlyn Professor of Design at the Royal College of Art, London. With Philip Ross, he wrote *Space to Work* (2006) on the changing workplace in the digital economy.

As a focused investigation into the changing workplace, the Activity-Space Research (ASR) initiative takes its place within a broader frame of enquiry driven by a host of factors – technological, social and demographic. Whatever the starting point for research, the signs are inescapable that new environments are required to meet changing patterns of work, whether the drivers are wireless networks and mobile computing or ageing workforces and portfolio careers.

My own work forms part of that broader landscape of new thinking in office design that acts as a kind of backdrop for ASR. My starting point has been historical – the emergence of the modern office in the early 20th century as a by-product of the bureaucratisation of industry and with a dominant design template based on the factory floor.

This industrial template has been surprisingly resistant to change, but today most people in offices no longer do the kind of repetitive, linear, process-driven work for which the efficiency mantra of mechanistic repeating floor plates makes sense. As the knowledge economy grows, my research has therefore been to look at alternative models of workplace design, based in part on historical precedents such as craft guilds, traditional colleges or ancient marketplaces.

New models

Why the search for new models? In place of process work, there is a growing emphasis on knowledge work. This depends less on formula and process and more on the application of knowledge and learning. Instead of individuals sitting in serried ranks to follow explicit instructions within a supervised hierarchy, new working practices are emerging based on collaboration, initiative and exploration.

As a term, knowledge work was first coined around 1960 by the American economist Peter Drucker. Doctors, lawyers, academics and scientists were among the first identified knowledge workers, but now the term extends to most executive, managerial and marketing roles within organisations. Drucker has also drawn attention to a class of worker he describes as 'knowledge technologists': computer technicians, software designers, analysts in clinical labs, paralegals and so on, who are swelling the ranks of knowledge workers worldwide.

Increasingly, in the early years of the 21st century, the world of work is becoming a world of knowledge work. Where once manual and process work fuelled economic growth, such activities are now increasingly outsourced to lower-cost economies. In the developed world, ways to build, share, exchange and retain knowledge have assumed the highest priority.

But how much do we know about how to design the workspaces that knowledge workers and knowledge-based organisations need to be effective? Clearly, we have a lot to learn. Forty years after his first pioneering research on knowledge work, Peter Drucker felt moved to comment on knowledge-worker productivity: 'We are in the year 2000 roughly where we were in the year 1900 in terms of the productivity of the manual worker.' Productivity of the manual worker increased roughly 50 times during the 20th century through changes in factory design, but can we be confident that knowledge-worker productivity will make similar advances in the 21st century through changes in office design?

Knowledge workers

Against this background, I worked with technologist Philip Ross to investigate office design that supports and enhances the performance of knowledge workers. For a book called *Space To Work* (Laurence King, London, 2006), we selected 40 case studies drawn from 16 countries around the world. Organisations included accountancy, law and insurance firms; technology, media and music companies; charities, car manufacturers and filmmakers; advertising agencies, scientific institutions and seats of government. Each scheme was completed after 2001.

What the body of work told us was that companies have made a start on office buildings, space plans and interior designs that support a more fluid, collaborative and cognitive style of work within the corporate campus. However knowledge workers supported by wireless technologies are also breaking free of the traditional office building and working in a new way across a continuum of different locations: corporate campus, city, home and settings for professional associations and networks.

Four realms

Space To Work identified four 'realms' for knowledge work:

- corporate realm (**Academy**)
- professional realm (**Guild**)
- public realm (**Agora**)
- domestic or private realm (**Lodge**).

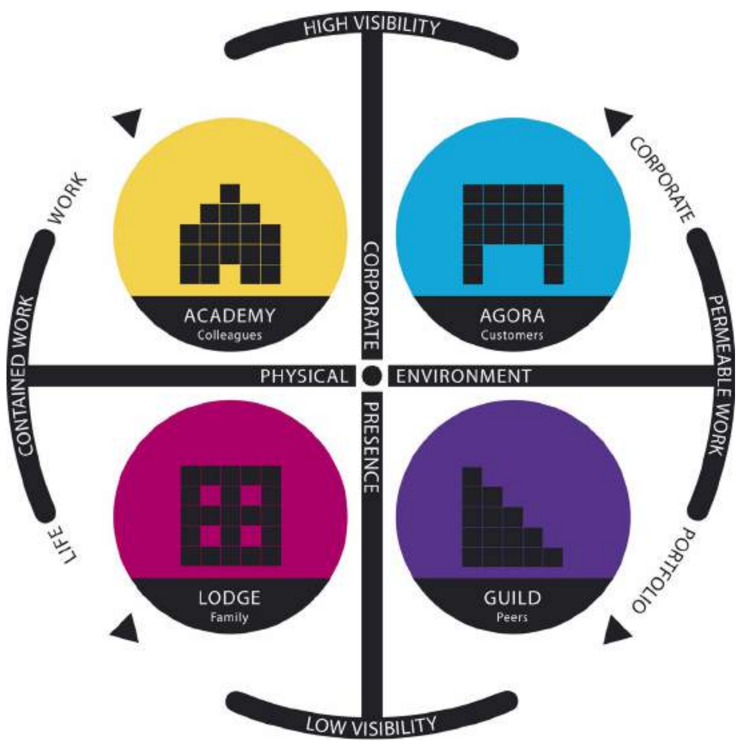
In the book we argued that knowledge workers must seek to achieve a balance or equilibrium between four conflicting sets of relationships: colleagues within the employing organisation; professional peers; customers in the marketplace; and friends and family in the home.

Academy describes a learning campus in which the employer is developing a more collegiate and collaborative approach to work; its historical precedent, in spirit if not in terms of precise architectural template, is the university courtyard or quadrangle.

Guild refers to a professional cluster of peers who share a skill or specialism; its historical precedent is the medieval guild or craft society.

Agora describes the public workplace in which the corporation is open to the city and the marketplace; its historical precedent is the commercial and social open space in the heart of ancient Athens.

Lodge describes the live-work setting, the home that doubles as an office: its historical precedent is the domestic setting, whether farmhouse or bourgeois residence, that is the hub of enterprise.



The diagram places all four types of knowledge workplace within a matrix. The vertical axis measures the level of corporate presence from low to high visibility. The horizontal axis shows physical environment from work contained within a specific setting to work that is permeable across locations.

The tension between living and working – between home and office life – is shown on the left hand side of the diagram. In the relationship between Academy and Lodge exists the challenge of achieving work-life balance, a recurring corporate preoccupation. The tension between corporate working and portfolio working – between allegiance to an employer and reliance on your own skill or knowledge – is shown on the right hand side of the diagram. This identifies the challenge of managing a career as work becomes permeable, distributed and virtual rather than an activity that takes place only within a corporate building.

Architecture

How the four realms for knowledge work are expressed in architectural terms can be see in any number of imaginative shared spaces, courtyards, atria and meeting rooms in Academy-style workplaces; in the design focus on dialogue and exchange in Guild spaces; in the strategies to engage with the city through public thoroughfares or landmark art and architecture in the Agora; and in the fusion of living and working in Lodge offices.

These models may be drawn from the past but they point towards to the future – towards new workplace environments as dynamic settings for new activities. To rely on stacking the same old repeat-pattern office floors is to stick to a status quo that will not survive the growth of the knowledge economy.

THE OFFICE OF THE ~~FUTURE~~ PRESENT

The transforming power of ICT (information and computing technology) has been predicted for decades, but seldom with the accuracy of the winning entry in the Philips' *Office of the Year 2000* competition of 1982. The judges were expecting snazzy office designs but got ... a laptop computer!

Looking ahead

Andrew Chadwick's winning entry for the 'Office of the Year 2000' competition was precise and tangible, but many other predictions about new technology have been perceptive but vague.

Arguing that ICT has transformational potential is perfectly true, but it can't compare with demonstrating that a briefcase could provide all the resources that used to be inseparable from a conventional office building – 'a mock-up is worth 10,000 words.'

A handful of predictions that have acquired a period charm:

1936: 'Careful study and observation of technological possibilities leads me to the inescapable conclusion that we can do an entirely adequate amount of routine work with an average labour expenditure for the common man of only a few hours per day, four at the most, and perhaps in some distant day, as few as two or three. ... To forestall misunderstandings, I had best explain that I do not believe that the leaders and professional men and women are ever going to be these short-period workers.' (C C Furnas, *The Next Hundred Years*, 1936).

Furnas was right about the decline of manpower in manufacturing industries, but he did not realise the limitless potential for growth in services industries, where almost everyone behaves like Furnas's 'leaders and professional men and women'.

Mass employment in manufacturing industry has disappeared in developed countries, but it has been replaced by mass employment in service industries, not by limitless leisure.

1973: '... the utility of the words 'house', 'school' and 'office' to denote separate concepts becomes increasingly suspect. It is important not to forget that the development of non-physical forms of communication is already having a drastic effect on our ideas of office location. ... [Changes brought by the industrial revolution are] eclipsed by the potential of cybernetics and audio-visual communication.' (*AJ Office Handbook*, 2 May 1973)

1974: 'In principle, if really adequate telecommunications were available it might not be necessary to construct office blocks at all since everybody could work from home and communicate by means of telephones, television, document facsimile transmission and so on. Although the technology exists to make this possible, it would not be economic. Further, where such visionary suggestions have been made they have not been greeted with any enthusiasm. This implies that although people may complain about the necessity for travelling to work, the social aspect of office work is much more important than is often realised.' (*AJ Office Handbook*, 13 February 1974)

A mainframe computer of the late 1950s, complete with a reader for punched paper tape. It was built about ten years after the very first commercial computer: the ICT revolution has been in progress for two generations.

‘With me everybody has an office, from schoolboy to Prime Minister ....
.... where you put me is another matter ....
.... in your car, in an aeroplane, on a train, in your meeting place – because that’s what the office of tomorrow, sorry I mean today, is all about ....’

Andrew Chadwick’s 1982 prediction for the ‘Office of the Year 2000’ was a mock-up of technologies that were still under development. One of the main differences from today’s laptop computers is its bulkiness – whereas in 1982 its compactness and portability were incredible – and the way that keyboards have moved backwards.

The mock-up included a tape-recorder (remember them?) with a prophetic script that has proved remarkably accurate.

THE DIGITAL ECONOMY

It has long been acknowledged that the transforming impact of the information revolution will be as great as that of the industrial revolution, but when the impact occurs it is still experienced as sudden and dramatic.

Anticipated but sudden

No-one could say that the digital revolution is a surprise. Norbert Wiener, in his immensely popular book of the 1950s *The Human Use of Human Beings: cybernetics and society*, wrote, 'Society can only be understood through a study of the messages and the communications facilities that belong to it; and in the future development of these messages and communications facilities, messages between man and machine, between machine and man, and between machine and machine, are destined to play an increasing part.'

Wiener discussed a multitude of speculative ideas over 50 years ago, some but not all of which have now become part of everyday life.

Struggling to adapt

Despite the long lead time, the way that established habits can evaporate in a few years is amazing. Electric typewriters, pagers, fax machines, video-tapes: they were new and exciting not so long ago, but they have gone.

Tremendous benefits can come with the take-up of new technologies, and there are penalties attached to continuing with pre-digital economy practices.

The rate of change isn't likely to slow down.

ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. Turing.

[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.

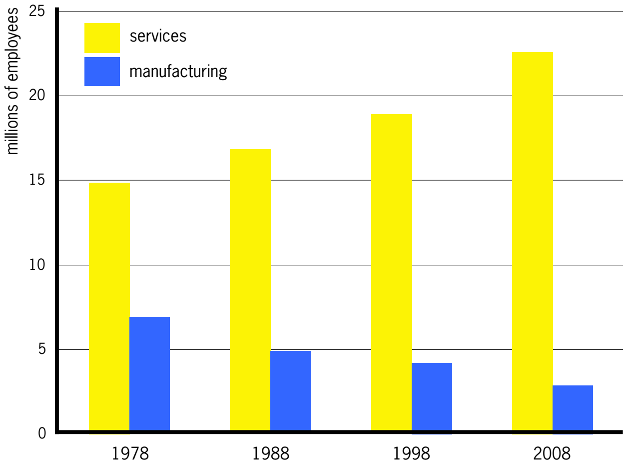
In §§ 9, 10 I give some arguments with the intention of showing that the

The digital revolution is the outcome of many enabling theories and technologies, including pure mathematics, where an important source was the paper of 1936 by the Cambridge mathematician Alan Turing (the first paragraph is reproduced on the right). The paper introduced the novel idea of a 'Turing machine', an imaginary computer that encapsulated the functionality that any real computer would share.

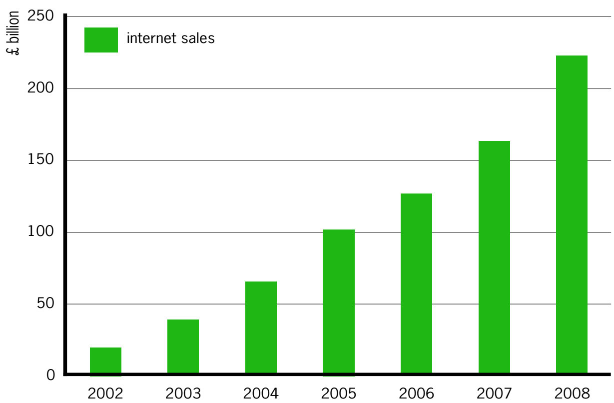
A few years later Turing was a key contributor to the team that built the first electronic computer in 1943, for the Allied code-breaking effort at Bletchley Park during World War II. It was top secret and destroyed at the end of the War.

Computer building re-started in the USA and UK in the late 1940s, little more than ten years after Turing's theoretical paper.

The balance of economic activity in developing countries has been moving from manufacturing to services for a long time, and has moved quickly in the last generation. Thirty years ago the services sector in the UK had just over twice the employment numbers of manufacturing, and now it is nearly eight times as large.



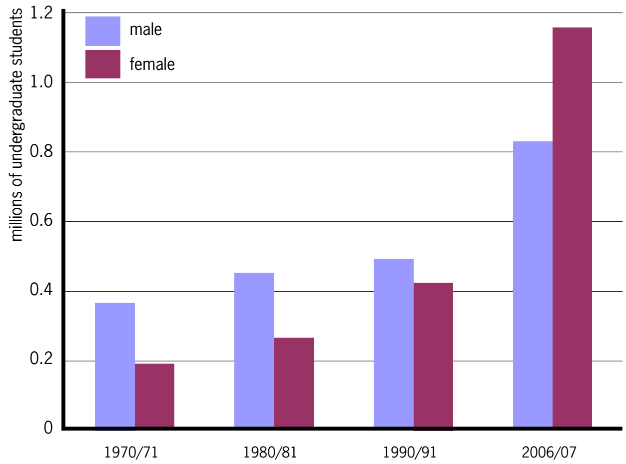
source: Social Trends 39 (ONS, 2009)



source: E-commerce and ICT Activity Statistical Bulletin (ONS, 2008)

Internet sales have grown rapidly during the last decade from a low starting point. There's plenty of scope for continuing growth. In 2008 the internet accounted for 9.8 per cent of the value of all sales of UK non-financial sector businesses.

The digital economy is built on ideas and creativity. The expansion of higher education is a symbiotic part of the transition to the digital economy. Thus the number of full- and part-time undergraduates in the UK has grown more than three times since 1970.



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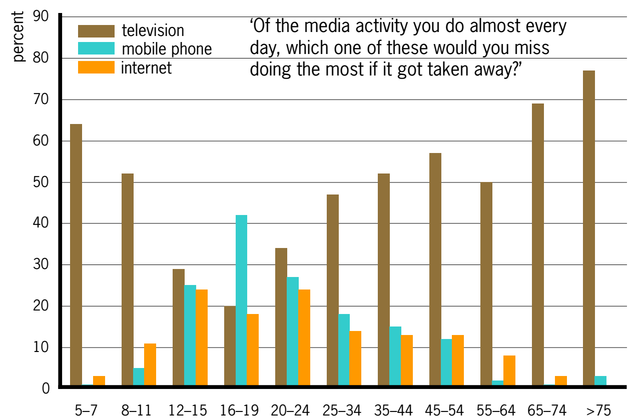


source: Social Trends 39 (ONS, 2009)

Media priorities vary greatly between generations – television dominating for young and old, with internet and especially mobile phones peaking in the 12–24 age groups. Is this a transient phenomenon or a permanent change? Will today's teenagers and young adults gradually become more like their parents, or will the new technologies gradually colonise the older age ranges?

TRANSFORMATIONAL POTENTIAL

The digital revolution effects the ways that all kinds of buildings are used. The Activity-Space Research initiative has focused on three particular building types: offices, higher education and healthcare. There are also points in common with many other building types.

Office buildings

The aggregate floor area of commercial offices in England and Wales is about 100 million m^2 (or 100 square kilometres), equating to rental costs of about £20bn per year.

Businesses generally find at least 30% saving in premises floor area and cost with activity-space innovation (Fawcett & Chadwick, 2007), so if businesses occupying 25% of office floor area adopted activity-space innovation a overall saving of 30% x 25% = 7.5% would be achieved, equating to about £1.5bn per year.

Government and public sector offices are additional to this. In 2008 central government occupies about 9.7 million m^2 of offices costing about £5bn per year, and aimed for 25% savings up to 2102-13 (DEGW, 2008). The efficiency gains would be reflected in lower costs to the taxpayer, or transfer of resources to front-line services.

Higher education

UK Higher education institutes occupy 24.9 million m^2 of buildings costing £1.5bn per year to keep operational (HEFCE). Observed levels of space utilisation are very low.

Even though most university buildings are used rent-free, intense pressure of running costs and student numbers, coupled with innovation in teaching and research, mean that established space-use practices have to be reassessed.

Healthcare

The NHS estate comprises about 27.5 million m^2 of occupied floor area, with recorded maintenance costs of £600m per year (NHS Information Centre). Utilities costs are additional to this.

Emerging activity-space use patterns are of vital concern, as rapid advances in clinical practices may conflict with long-term commitments to new PFI hospitals.

Responding to change

Attempts to improve efficiency are already given a high priority in all three sectors, but with limited success.

The sectors usually operate in near-complete isolation from each other, despite increasing convergence between their activities as they adapt to the digital revolution.

The constant cycle of renewal of office buildings: the former P&O building in the City of London being demolished in 2008 (left). The innovative design of the 1960s by Gollins Melvin Ward & Partners featured a suspended structure – so it had to be demolished from the bottom up.

The rebuilding programme at Barts and the London NHS Trust is budgeted to cost £1bn (right: new building at Barts, HOK architects). As with all hospital projects, the new buildings will be obsolete before they are finished – but hopefully less obsolete than the buildings being replaced.

It is easy to measure the floor area of a building, but much harder to measure its capacity. Capacity is a measure of the quantity of activities that can be accommodated. It is important, since organisations' demand for space is derived from the activities that they expect to take place.

Going back to first principles, the way buildings are used is a function of three factors:

- the space
- the activities
- activity-space management.

For a given building, if any of the factors change, the capacity changes as well. And all three factors do change – the building most slowly, for example by alterations or extensions.

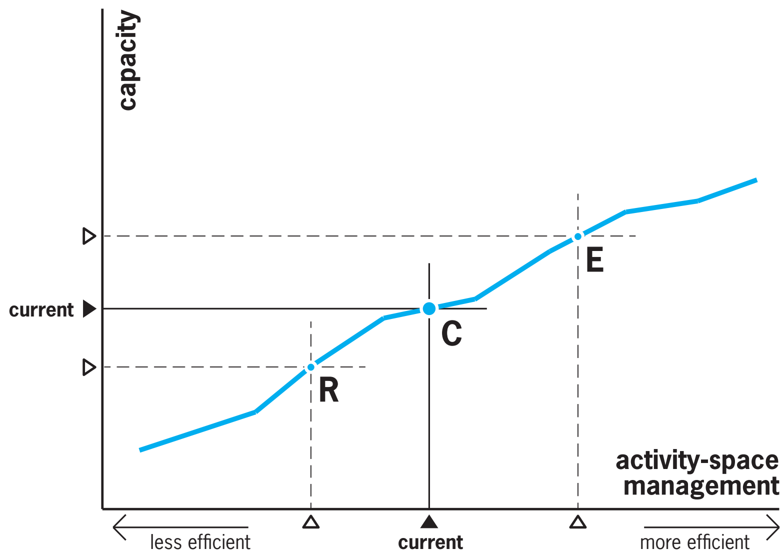
Activity-space management has the greatest opportunity for short-term change. It defines the ways that activities are able to use the space. Every time a potential activity-space-time usage is excluded, capacity is reduced. Such constraints typically result from:

- specialisation (or territory): activities can only take place in designated (or owned) spaces
- conflicts: certain activities cannot occur simultaneously
- time restrictions: activities can only take place at specified times.

It isn't desirable or feasible to eliminate all activity-space constraints, but they should be closely evaluated. In schools and universities timetablers talk about *hard* and *soft* constraints. Hard constraints have to be respected, for example, two activities involving the same person cannot be timetabled a the same time; but soft constraints are preferences and can be negotiated, for example, the preference for avoiding early lectures on Monday or late ones on Friday.

Unrealistically high targets for activity-space management are unhelpful. The size of educational buildings used to be governed by a formula saying that they must be designed to accommodate the number of full-time-equivalent pupils at a utilisation level of 64%, ie. for every 100 FTE students there should be space for 156 students (100 / 156 = 0.64). This was based on the activity-space assumption that on average rooms would be 80% full when used, and that they would be used during 80% of the teaching week: 80% x 80% = 64%. These assumptions were plucked out of the air and were hopelessly optimistic for many schools (Fawcett, 1976).

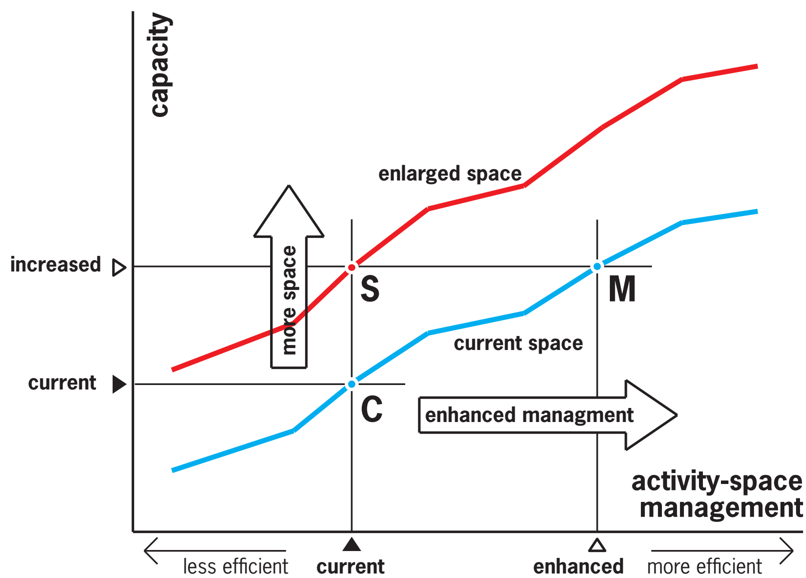
To increase capacity, first look closely at innovative approaches to activity-space management.



Whenever a single value is given for the capacity of a building, it is implicitly based on a current set of activity-space conventions.

A given building has a higher capacity when few activity-space-time restrictions apply, and a lower value when more restrictions are imposed. As shown in the diagram above, the current capacity [C] can be enlarged with more efficient activity-space management [E], and reduced with less efficient management [R]. The line connecting thee points is the **capacity profile** of the building.

Consequently there are two ways of increasing the capacity of a building, as shown in the diagram below: the current activity-space conventions can be maintained and more space added [S], or alternatively the existing quantity of space can be used with enhanced activity-space managment [M].



MICRO-SCALE: MODELLING THE INDIVIDUAL BUILDING USER

It is believed that the digital revolution will give individuals greater choice about when and where they carry out activities: given this increase in choice, what characteristics of individuals will determine how the choices are made?

Individual choice

The digital revolution has the potential to liberate people from what had been fixed constraints on how they run their lives. For example, liberation from fixed working hours, commuting at times of peak congestion … in fact, all aspects of grinding routine.

How much diversity?

Will every individual's activity pattern become completely different from everyone else's?

Unlikely. People are sociable and adapt their behaviour to fit in with others and with social/cultural conventions. And although different people are never identical, they can have many characteristics in common.

The participants at the sixth ASR Workshop took part in two exercises to explore ways of capturing information about activity styles.

Self-assessment of workstyles

The first exercise asked the participants to state their activity preferences. The exercise and the findings are sketched opposite.

The participants expressed confidence in their self-assessments.

What if …

The second exercise asked the participants to respond to imaginary situations, or micro-narratives, which were intended to reveal preferences. The micro-narratives are shown below.

The participants were less happy with this exercise, finding it difficult to identify with the micro-narratives.

Consistency of responses

The results of the stated and revealed preference exercises can be compared. For a few participants there was close agreement, and for most weak agreement. A small minority of cases showed divergence. Overall, this is encouraging.

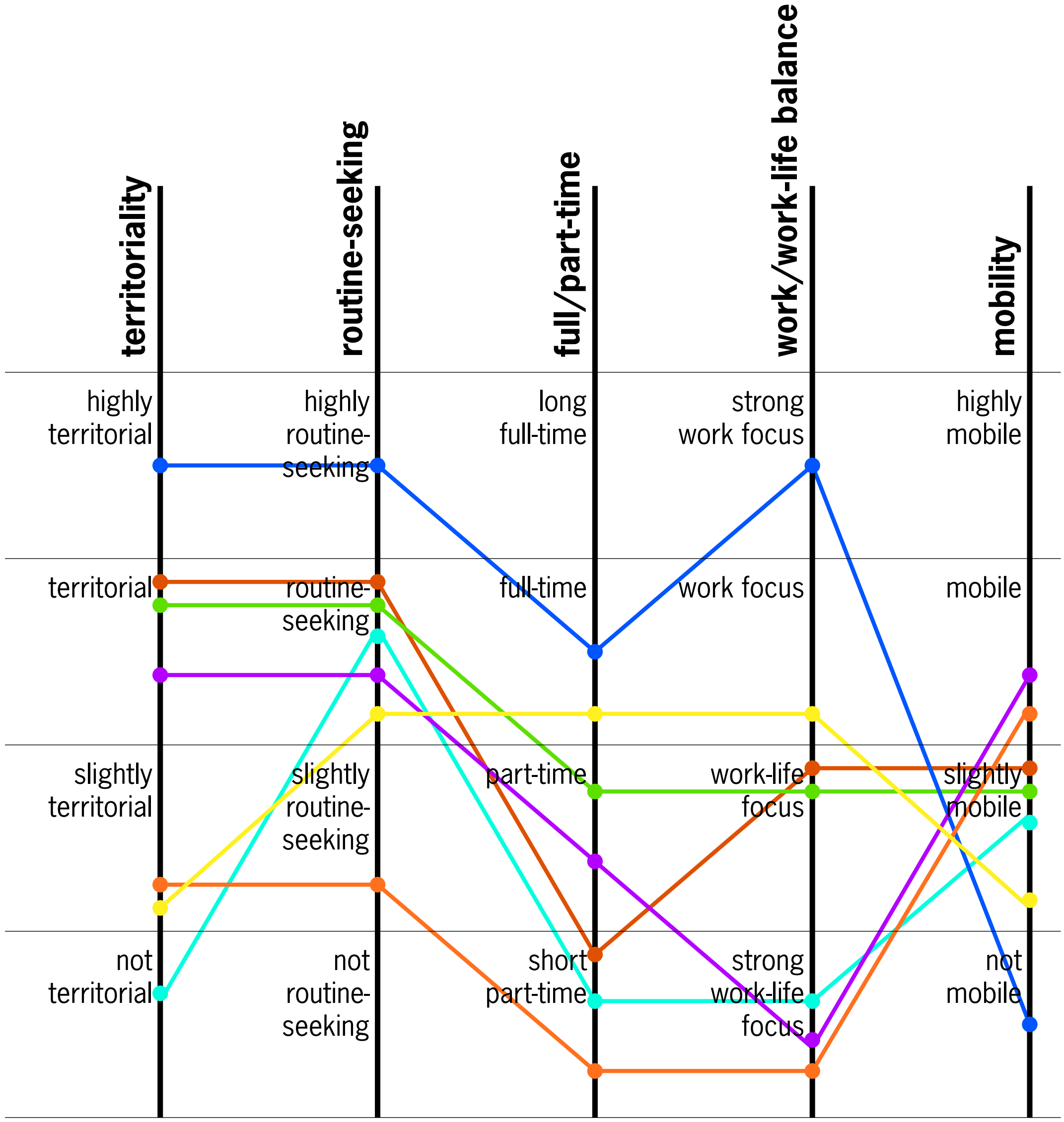
Surveys of this type could provide valuable information about the ways that people's activities are likely to change in the digital economy.

The Workshop participants were presented with pairs of statements, or micro-narratives, and asked to indicate which they agreed with more. The six pairs (right) were designed to reveal preferences for three attributes – territoriality, work/work-life balance, and mobility.

In the second pair, for example, the left-hand statement implies high mobility and a good work-life balance, whereas the right-hand statement implies non-mobility and work focus. Each pair contained mirror-image micro-narratives of this kind, dealing with two of the three attributes. It is a form of conjoint analysis.

Although the small Workshop exercise was not a great success, it is a potentially useful survey method and worth taking further.

Being able to work anywhere, anytime means you can put more into the job	You have to be in the office to work effectively, but luckily they make it easy to deal with non-work problems
A great advantage of working at home is that you can keep in touch with the children's activities	Working in the office means you can really focus and avoid distractions
Having my own desk means I don't waste time getting things done	I'd be happy with hot-desking if the office had a bank machine and somewhere for making private phone calls
I sometimes have to put work aside and deal with other problems, so it's helpful to know that everything will be where I left it when I get back to the job	I'm happy to work wherever there's a free desk so long as I can concentrate on the job
Because I never know when I'm going to be in the office or travelling, it's good to have a personal base which is available at any time	I spend a lot of time in the office so I enjoy being able to work in different areas when I feel like a change
My work keeps me in the office and I get used to working at a familiar workstation	I come and go so much that it would be crazy to keep a desk reserved for me



The Workshop participants were asked to describe their own typical workstyle by selecting the most appropriate values for five attributes:

territoriality – the preference for having a personal workplace

routine-seeking – following the same pattern from day to day

full/part-time work – from 'long' full-time to 'short' part-time

work/work-life balance – whether work dominates or is balanced with non-work priorities

mobility – whether work activities take place in many or few locations.

For each attribute the participants could select one of four values.

This method of description creates the possibility of 1024 distinct workstyles (4x4x4x4x4 possible selections), but perhaps a small number of 'typical' workstyles would occur frequently?

The Workshop participants were a small and probably unrepresentative sample, but their self-assessments showed a lot of diversity and little indication of emerging 'types'. It would be interesting to analyse data from a larger survey.

Seven individual profiles are shown above, giving a snapshot of the variety of participants' responses.

Analysis of the data showed moderate correlation between the responses on the territoriality and full/part-time work scales; and some negative correlation between routine-seeking and mobility.

Chapter 3

MODELLING AND MANAGING UNCERTAIN DEMAND

THE ROLE OF THEORY

Lionel March

Lionel March, with Sir Leslie Martin, founded the Centre for Land Use and Built Form Studies – later the Martin Centre – at Cambridge University's Department of Architecture. He later held posts at The Open University, the Royal College of Art and the University of California at Los Angeles.

What we have learnt in the past few years is that a class of architectural problems can, under suitable conditions, be transformed into a class of mathematical problems for the solving of which, very often, powerful methods already exist. Furthermore, because of its symbolic nature mathematical manipulation is more versatile than any verbal or graphic equivalent.

But perhaps more importantly, the mathematical model often gives us insight into the structure of the architectural situation we are investigating. Thus, the creative aspect of research requires recognition of an appropriate abstraction or idealisation of our subject by which we may represent it in order to reveal its essential structure.

Our task in architectural research is to understand and explain what goes on in the environments we build, how people and environments relate. But is this the only task? No – certainly to describe past and present situations, but also to design new situations.

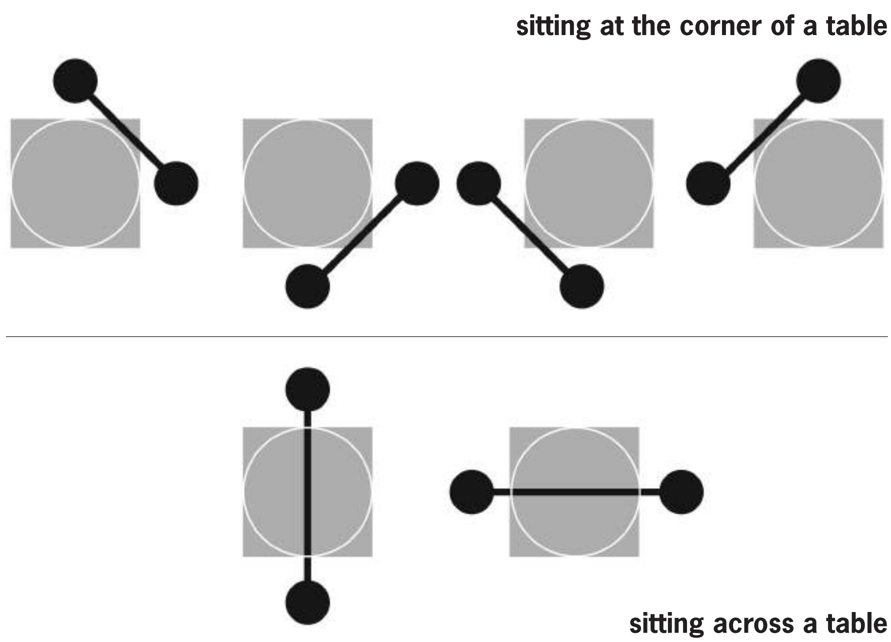
From *The Architecture of Form*, edited by Lionel March, 1976, pp.x-xii

Empirical versus theoretical investigation

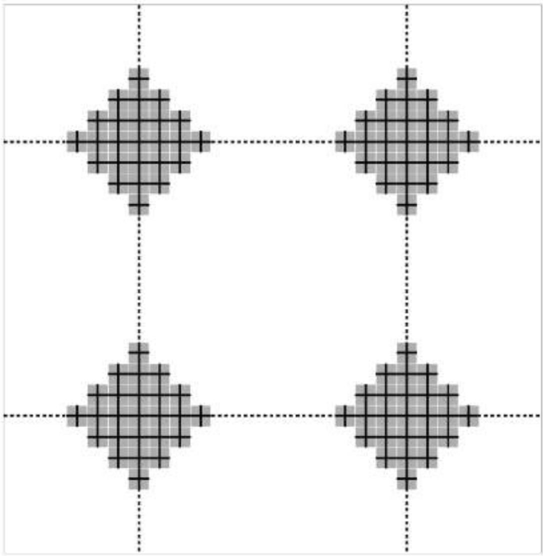
A professor of sociology used to send his class of undergraduates on campus trips to record human behaviour. His students were sent to the commons where others gathered for their coffee breaks. The commons had square tables for four customers. The question the professor posed was: when two students sit down at a table do they sit opposite one another or at adjacent seats across a corner. After several classes had made their observations, the conclusion was reached that two thirds of the couples sat at the corners and one third across the tables. The professor made the obvious empirical observations that 'couples clearly preferred to sit at corners rather than across from one another'.

But a study of the symmetry of a square shows that there are precisely six symmetry axes: four on the diagonal and two orthogonally – in the ratio, two thirds and one third. That is to say, a MODEL of the situation establishes the expected result without making any empirical observations. The observed behaviour was entirely random!

Now, if the students had observed that two thirds of the couples had sat opposite across the tables, then to suggest that the customers 'preferred' this position would be a legitimate behavioural observation since it counters the prior probabilities.

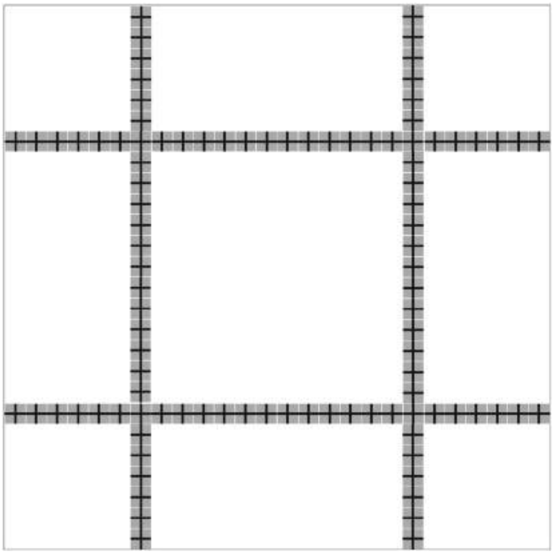


Conventional wisdom versus speculative reasoning



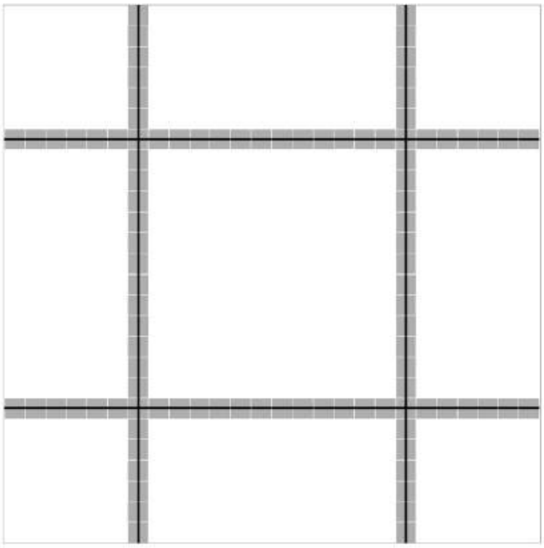
1

Consider an array of **compact** urban forms. Each one contains a gridiron of 25 blocks arranged as a 1 + 3 + 5 + 7 + 5 + 3 + 1 diamond. This arrangement ensures that the 'taxicab' distance from the urban edge is constant. The urban coverage is approximately 15% of the land. In each settlement there are 25 road intersections with implications for accidents and pollution. The total urban road length is 50 block lengths. Between the towns there is an additional 24 block lengths of unbuilt road associated with each settlement



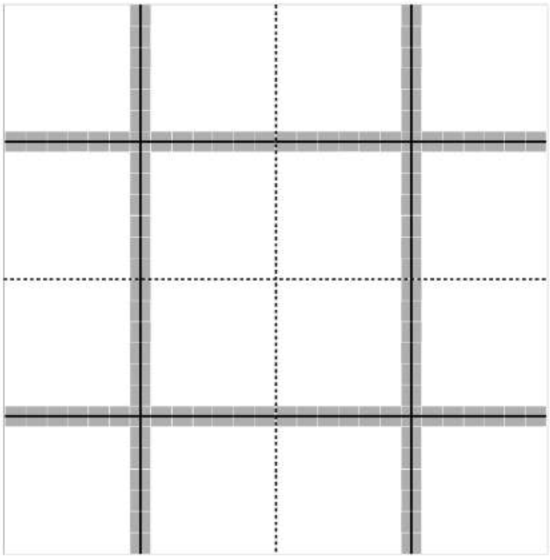
2

The urban configuration is rearranged as a **cruciform** with the same number of blocks. The urban coverage is still 15%. However, whereas in the compact arrangement 12 blocks in each settlement are in direct contact with the countryside, twice that number have this contact in the cruciform arrangement. The unbuilt roads between the compact towns are not required.



3

It will be observed that 24 crossroads are redundant in the cruciform arrangement. There are 24 fewer intersections. The blocks are served by just under half the length of road. This suggests that the service runs for electricity, gas, water, telephone are also halved. If the lanes in the road are doubled (preserving the total road area), the capacity of the road system will be more than doubled. The cruciform arrangement links up to create a linear network and an urban retiform over the countryside.



4

Alternatively, instead of doubling up the lanes in the urban roads, the additional road capacity could be separated from the urban development and relocated through the countryside as a parkway with no development.

ACTIVITY-SPACE SIMULATION

There is almost unlimited complexity in the ways that people use buildings – the behaviour of every individual, every day, is the response to a unique set of constraints and opportunities. But under this surface complexity there may be stable and repeating processes, which transform chaos into comprehensible patterns.

Puzzle and explanation

In his autobiographical notes (1876) Charles Darwin writes about climbing plants: 'I was fascinated and perplexed by the revolving movements of the tendrils and stems of a Cucurbitacean plant, which movements are really very simple, although appearing at first very complex. I was not satisfied with the explanation of Henslow, namely, that they had a natural tendency to grow up a spire. This explanation proved quite erroneous.' Darwin published his own explanation in 1865, in a book of 120 pages.

Darwin's investigations combined meticulous observation and the construction of explanatory hypotheses, which were derived from the observations and tested against them – until he arrived at an explanation that he believed was fully verified.

It's an inspiring example of the way that scientific analysis can reveal simple truths that are not self-evident when one views a complicated real-world situation.

Activity-space simulation

An axiom of the Activity-Space Research initiative is that the use of buildings is changing because individuals now have much greater freedom of choice about the times and places for carrying out activities. This decentralisation of decision-making brings apparent unpredictability and complexity.

Because individual decision-making is the critical factor, this is what the ASR simulation models concentrate on.

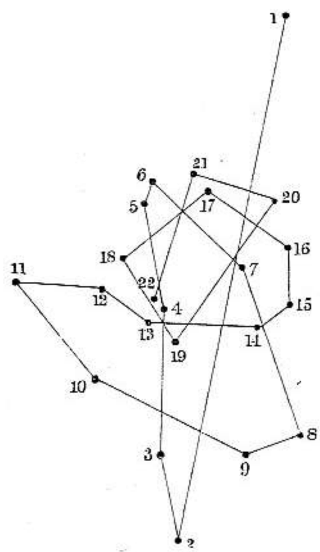
Agent-based models

Models that simulate individual members of a large population as a way of making inferences about the population as a whole are called agent-based models; the individuals are the agents. For large populations, agent-based models are computationally demanding, but that is no longer a problem with modern computers.

A classic example is the simulation of a shoal of fish. All agents are identical and use very simple decision rules to adjust their movement in response to their neighbours' movement. The outcome is the amazingly complex and beautiful movement of the shoal, which appears to have a life of its own but is wholly derived from the agents' simple decision rules.

A list of the main ASR simulation models is shown opposite. Many are under continuing development.

BRYÓNIA DIOÍCA (*White Bryony*).



White bryony, 'the only plant belonging to this tribe [Cucurbitacae] which is native to Britain', from *Flowers of the Field* by Rev C A Johns (c.1863). (left)

Darwin's 'Diagram showing the movement of the upper internodes of the common Pea, traced on a hemispherical glass and transferred to paper (Aug. 1st) ', from *Climbing Plants* (1865). (right)

AVERAGES ARE NOT ENOUGH – simulation ASR-S1

When a population of building users can decide individually whether and when to use the building, demand is variable. Suppose a building is used by 20 people, and on average there is a 50/50 chance that they decide to use the building.

The average demand is therefore 10 people. But this average ignores the behaviour of individual users. The table (below) shows each individual's chance of deciding to use the building in four alternative organisations.

All four organisations have the same average demand – 10 people – but the demand profiles vary widely, as shown in the charts.

	Organisation			
	1	2	3	4
1	100%	90%	70%	50%
2	100%	90%	70%	50%
3	100%	90%	70%	50%
4	100%	90%	70%	50%
5	100%	90%	70%	50%
6	100%	90%	60%	50%
7	100%	90%	60%	50%
8	100%	90%	60%	50%
9	100%	90%	60%	50%
10	100%	90%	60%	50%
11	0%	10%	40%	50%
12	0%	10%	40%	50%
13	0%	10%	40%	50%
14	0%	10%	40%	50%
15	0%	10%	40%	50%
16	0%	10%	30%	50%
17	0%	10%	30%	50%
18	0%	10%	30%	50%
19	0%	10%	30%	50%
20	0%	10%	30%	50%
Av.	50%	50%	50%	50%

Simulation results

The number of people in the building was simulated 250,000 times for each of the four organisations. The percentage of runs in which the number of people in the building was 1, 2, 3, 4 ... and so on is shown in the charts, which all have a peak at the average demand, 10 people.

In organisation 1, half the population of 20 always come to the building and half never do, so demand is always exactly 10 people.

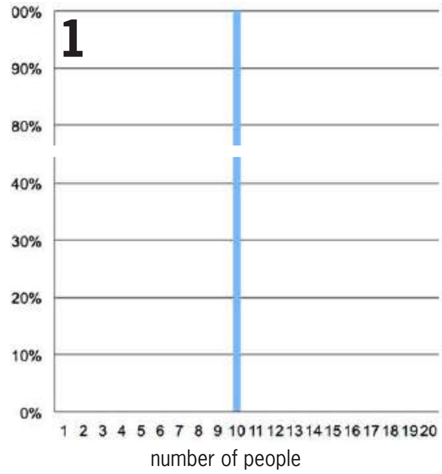
Looking at the data table, organisation 2 doesn't look so different from organisation 1, with half the population attending very frequently and half very infrequently. But the pattern of demand is dramatically different, varying between 7 and 14 people.

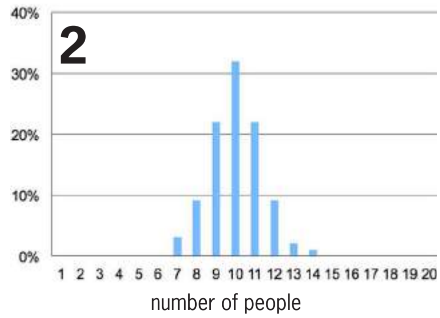
Organisations 3 and 4 look significantly different in the data table, but the charts show a marginal impact in demand, both varying between 5 and 15, apart from a very few extreme cases.

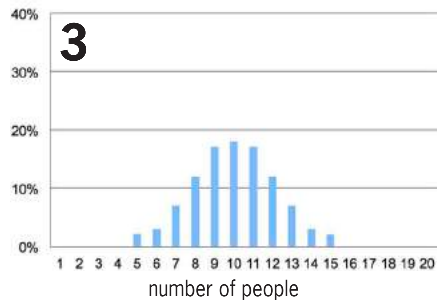
The change in demand from organisation 2 to organisation 4 shows a gradual transition, not a radical shift.

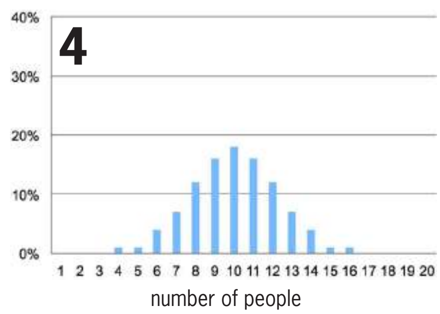
The impact on demand of a move – even a small move – from the certainty of organisation 1 is huge. But certainty is not replaced by chaos, but by orderly probability distributions that are relatively insensitive to detailed variation in the behaviour of individuals.

To model uncertain demand it is essential to have a reliable estimate of the decision-making of individuals, but there is no need for overwhelming detail.









SIMULATIONS

ASR-S1	The spatial demand of unpredictable activities
ASR-S2	The use pattern of a fixed spatial resource
ASR-S3	Activity-space decision-making by individuals
ASR-S4	Activity-space decision-making and the work-life balance
ASR-S5	Habitual decision-making
ASR-S6	Generic office organisations
ASR-S7	Informal workplace contacts
ASR-S8	Flexibility for variable demand

SIMULATION OF INTERACTING AGENTS

The foundation of agent-based modelling is the decision-making of individuals, but individuals are not always independent. When agents' decisions take account of the decisions of other agents the models and their outputs get more interesting.

Modelling

Activity-space decisions often take account of interaction with other people. Concern with privacy, for example, is about controlling the exposure of ourselves and our actions to other people.

A direct way in which one person's actions are affected by (and affect) others' is congestion. If everyone decides to do the same thing at the same time, they all experience congestion. People learn from experience, and those who can will often adjust their decision-making to avoid congestion.

Congestion is usually unwelcome, but so is total isolation; for example when choosing a restaurant a sea of empty tables is not attractive. Many environments work well when there is an equilibrium between under- and over-occupation.

Sometimes people are congestion-seeking. Charles Dickens observed that, 'it is a hopeless endeavour to attract people to a theatre unless they can be first brought to believe that they will never get into it' (*Nicholas Nickleby*, 1839, Chapter 30).

Perceptions and expectations

An individual's activity-space decisions are affected by what other people do, and also by perceptions and expectations about what they may do – even when they are unfounded.

For example, a large company had a site with three under-used buildings. Analysis showed that with a small amount of desk-sharing all the people could be accommodated in one building, releasing the other two. The change was announced and carried out over a summer close-down – and when the site reopened hardly anyone turned up. Because of fear of congestion they had found alternative places to work, at home or at other company sites.

The fear of congestion was irrational. If previous activity-space behaviour had continued, the probability that all users would independently decide to come to the site at the same time was inconceivably small.

Simulation modelling could dispel irrational fears – and irrational hopes.

Diversity and complexity

In principle, an agent-based simulation model can replicate any well-defined interaction mechanism. So there could be very many such models.

The temptation to develop complex models with many variables and decision rules should be resisted. 'Complexity kills. It sucks the life out of developers, it makes products difficult to plan, build and test ... and it causes end-user frustration ...' (Ray Ozzie of Microsoft, *New York Herald Tribune*, 27 March 2006).

Simulation experiment ASR-S2

This simple model simulates 12 people who make individual decisions about when to use a building, and generates the resulting use pattern in the building.

On average 6 people want to use the building, but demand is frequently lower or higher. However, suppose that the building is only large enough for 6 people. When the demand is for 6 people or fewer there is no problem, but when it is for 7 or more, some people are blocked.

Despite the average demand being equal to the capacity, there are periods with unused capacity and others with unsatisfied demand.

This model has only four variables, but it still allows multiple model runs with systematic variation of input values. See also ASR Paper 2 (page 76).

A six-person table for shared use (right). At the time the photo was taken only one person had decided to work at the table, but at other times there may be a queue of people waiting to use it.

agent		average epidose length	period 50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
1	on-site	4					2	1			4	3	2	1			3	2	1		X	
	away	1	4	3	2	1			2	1					2	1				1	3	2
2	on-site	4				3	2	1						X			3	2	1			
	away	5	3	2	1				5	4	3	2	1	3	2	1				5	4	3
3	on-site	5				5	4	3	2	1			6	5	4	3	2	1				2
	away	4	3	2	1						2	1							3	2	1	
4	on-site	2	2	1				X			3	2	1		X			2	1			
	away	2			3	2	1	3	2	1				1	3	2	1			3	2	1
5	on-site	4	3	2	1						5	4	3	2	1					5	4	3
	away	4				5	4	3	2	1						4	3	2	1			
6	on-site	5		2	1		X			6	5	4	3	2	1			6	5	4	3	2
	away	2	1			1	3	2	1							2	1					
7	on-site	3	1					X			X			4	3	2	1					
	away	4		4	3	2	1	3	2	1	3	2	1					6	5	4	3	2
8	on-site	3	1		4	3	2	1					1						4	3	2	1
	away	4		1					4	3	2	1		5	4	3	2	1				
9	on-site	2					4	3	2	1					4	3	2	1				
	away	5	4	3	2	1					4	3	2	1					4	3	2	1
10	on-site	2	2	1				4	3	2	1			X			X			6	5	4
	away	4			3	2	1					2	1	3	2	1	3	2	1			
11	on-site	2		1							2	1		4	3	2	1			4	3	2
	away	3	1		6	5	4	3	2	1			1					2	1			
12	on-site	2				2	1							X			X			2	1	
	away	2	3	2	1			6	5	4	3	2	1	3	2	1	3	2	1			6
average on-site demand		6																				
	number on-site		5	5	3	4	6	6	3	4	6	5	6	6	6	4	6	6	5	6	6	6
																		aveage number on-site				5.2

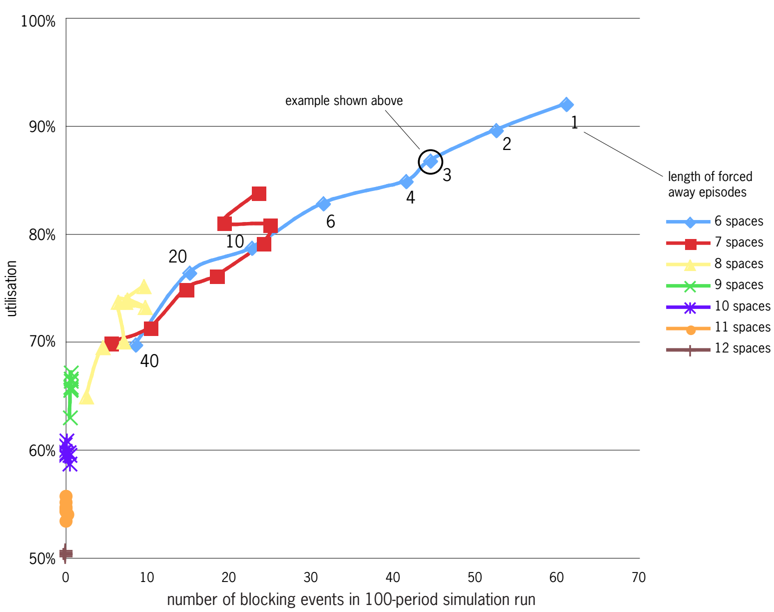
ASR-S2 simulation process

Each agent's behaviour alternates between on-site episodes when they decide to use their employer's building, and away episodes. The average length of each person's episodes are specified, but the simulated lengths vary randomly from the averages.

The model runs over 100 time periods; 20 typical periods are shown.

The length of episodes are in 'count-down' format, always ending with an entry of '1'. After the last period of an away episode, coloured orange, people want to start a new on-site episode, but if demand is too high they may be blocked – shown by the red cells marked 'X'. People who are blocked start additional away episodes; in this run all 'forced' away episodes last three time periods. At the end of a 'forced' away episode there is another attempt to start an on-site episode, but this may be blocked again – for example, agent 10 is blocked in time period 61 and again in time period 64.

Seven of the 12 agents experience blocking in this 20-period extract.



The graph summarises the results from 56 simulation runs with varying inputs. For all runs, the demand was the same as described above, with 12 employees and an average demand of 6 people.

Each point represents a combination of values for the number of places in the building, and the length of forced away periods after blocking events. The colours represent the number of places, and the blobs on the line the length of the away periods. The blobs are labelled on the blue line and occur in the same sequence on the other lines.

For each point, the lower axis of the graph gives the number of blocking events in a 100-period simulation run, and the vertical axis gives the overall utilisation in the building.

It can be seen that when the number of places is 9 or more there is no blocking, but utilisation is lower.

When the number of places is 6, 7 or 8 the levels of blocking and utilisation are determined by the input variables: increasing the length of the forced away period, or increasing the number of spaces, has the effect of reducing both aspects of performance.

SIMULATING A GENERIC ORGANISATION

Every organisation is different, but many have features in common. Universal statements that ignore the differences are unsatisfactory, but it is redundant to study each organisation as a totally special case. A generic but customisable model makes sense – this was the rationale for ASR-S6.

Basic attributes

Simulation model ASR-S6 attempts to balance simplicity and functionality.

It describes a generic office-based organisation in terms of basic attributes that should apply in practically all situations – like an application form that asks for an address and date of birth: people are all different, but everyone has an address and date of birth.

Activities and spaces

The model is implemented in Excel. The user sees two worksheets, for data input and output; the simulation program itself is hidden from the user.

On the input worksheet the user describes the organisation's employees and the workspaces at the employer's premises.

There are nine employee types, defined by time and workstyle. In time, employees can be **static**, spending 90% of their working time at the employer's premises; **flexible**, with 50% of their time on-site; or **mobile** with 20% of their time on-site (the numbers can be changed). In workstyle, employees an be **territorial**, always using an assigned workspace that they 'own'; or **task-focused** when they spend 75% of their time at the employer's premises in bookable workspaces for individual work and 25% of their time in informal spaces for interaction; or **interaction-focused** when 25% of their time is in bookable workspaces and 75% in informal spaces (again, the numbers can be changed).

There are three workspace types – assigned, shared and informal.

Cost data can also be entered, if desired.

It is undoubtedly a simple description compared to the incredible variety of the real world, but the purpose is to understand an organisation's use of space and time, and anticipate the changes that are coming with the digital revolution.

Simulation

When the simulation program is run, it allocates people to workspaces and calculates the utilisation achieved. It can also reports on 'displacement', and give costs if data is entered.

Displacement occurs when there are insufficient workspaces of the types that people wish to use. Displacement is the downside of space-saving – efficient facilities management has to balance space-saving against the risk (and cost) of displacement.

What-if explorations

The office organisation described by the input data can be real or hypothetical. The model is normally run with real data to validate its output, and then used to compare alternative scenarios, exploring trade-offs between capacity, workstyles, utilisation, queueing, etc.

Model ASR-S6 is still under development in partnership with case study office-based firms (Bartlett & Fawcett, 2013).

The same approach, using generic but customisable simulation models, should be equally applicable to other building types.

Employee Types		Number of Employees	Time On-site	Workspace proportions		
Time	Workstyle			Allocated	Bookable	Informal
Static	Territorial	10	90%	100%	0%	0%
	Task-focused	20	90%	0%	75%	25%
	Interaction-focused	20	90%	0%	25%	75%
Flexible	Territorial	10	50%	100%	0%	0%
	Task-focused	20	50%	0%	75%	25%
	Interaction-focused	20	50%	0%	25%	75%
Mobile	Territorial	10	20%	100%	0%	0%
	Task-focused	20	20%	0%	75%	25%
	Interaction-focused	20	20%	0%	25%	75%
	Total Employees	150	80	Average Employees on-site		

Extract form the data input sheet for ASR-S6, showing how an organisation's activities are described. The user enters the number of employees in each of nine types, which are defined by the use of time (% of time on-site) and workstyle. Workstyle is in turn defined by the % of on-site time spent in different types of workspace. All numbers can be over-written.

Components of ASR-S6

In the simulation model an organisation is described by input values specifying the number of employees and the proportion of time that they spend at the employer's premises, and also their preference for territorial, bookable and informal workspaces. The building is described by the number of territorial, bookable and informal workspaces. The diagram on the right shows an organisation with 36 employees and 32 workspaces, but many of the epmployess do not work full-time in the eomployer's premises

The simulation generates a series of snapshots, each with a specific number of people seeking territorial, bookable and informal workspaces. This varies in each snapshot; three snapshots are shown in the diagram.

With the snapshot demand, it may be possible to make a **successful** allocation with everyone in workspaces of the type desired; or some may be **displaced** to a different type of workplace; or if all available workspaces are occupied there may be an **overflow**.

For a given organisation, many snapshots are generated and the results aggregated to provide statistics for utilisation, displacement, overflow, etc.

It is easy to re-run the model many times with varying input values, to investigate the impact of organisational or premises changes.

Results from systematic runs of ASR-S6, for a population sharing 25 bookable workstations.

In successive runs the population of users was increased from 18 to 90 people. One-third of the people were static, one third flexible and one-third mobile; all were task-focused. For each run 50 snapshots were generated randomly – hence the slightly wobbly lines on the graph.

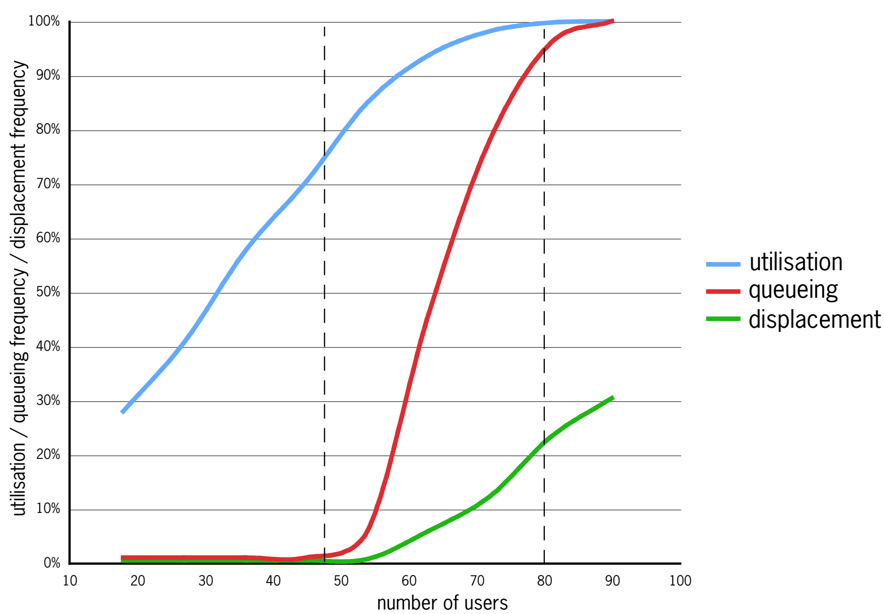
Utilisation (blue line) rises steadily to 90% with about 60 people, then more slowly to 100%.

Queueing (red line – the probability that at least one person will be displaced) never occurs for small populations, but from a threshold between 45 and 50 people, with utilisation at about 75%, it rises steeply.

Displacement (green line – the probability of displacement faced by each person) rises more gradually from the same threshold.

With more than about 80 people there is permanent congestion.

To avoid queueing and displacement, the upper limit on utilisation is about 75% – under the assumptions of this simulation: other input data would give different results.



YIELD MANAGEMENT AND THE SHARED WORKPLACE

When building use moves from the traditional certainties (or illusions) to the new world of decentralised decision-making, building managers' hard-won experience becomes irrelevant. Activity-space simulation can partially fill the vacuum.

Something has to be done

Many facilities managers are troubled by low levels of utilisation in buildings that are expensive to build and run. Utilisation is intuitively felt to be too low, but what target should be aimed for?

Setting a realistic target is different from saying, for example, that 'improving utilisation from 40% to 80% would halve premises costs, saving so many million pounds per year.' Arbitrary comparisons may be true, but they say nothing about whether it would be feasible or desirable to move to the higher utilisation level.

Shared use of space

In traditional office-based organisations employees expect their 'own' desks, but today many people spend time away from the employer's office during the working day. 'Owned' desks are left unoccupied and utilisation falls.

With decentralised decision-making, average demand at the employer's workplace falls, and is also more uncertain. Because of this uncertainty it is not easy to decide how much space-sharing can take place. It is logical that employees should share fewer desks – but how many?

Providing too many desks incurs a cost penalty due to unused space; but if there are not enough desks some employee requests will fail, with the penalty of employee dissatisfaction and perhaps loss of productivity. The facilities manager's task is to minimise the combined penalty from unused space or dissatisfied users.

Yield management

Industries like airlines or hotels have solved comparable problems using yield management techniques.

For example, when an airline takes reservations for a flight, some people usually fail to turn up. If seats are kept empty the flight has wasted capacity and lost income. To minimise wastage, airlines 'overbook' flights. But then there is a risk that too many people may turn up, when some have to be displaced or 'bumped' and paid compensation; the cost of compensation exceeding the cost of wastage from flying with an empty seat.

Yield management establishes the optimum level of overbooking, balancing the costs of wastage and of compensation for displacement.

Systematic analysis

To apply yield management to space sharing in an office is essential to know the demand probability and also the penalty costs of (i) unused space and (ii) displaced employees.

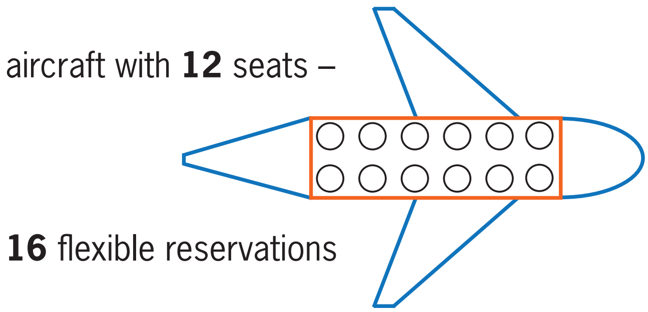
Most managers could provide the wastage cost but would hesitate over displacement. However, in any existing situation the implied penalty cost of displacement can be revealed by 'reversing' the yield management analysis. If excessively low utilisation is tolerated to eliminate the risk of displacement, the implied penalty cost of displacement is stratospheric.

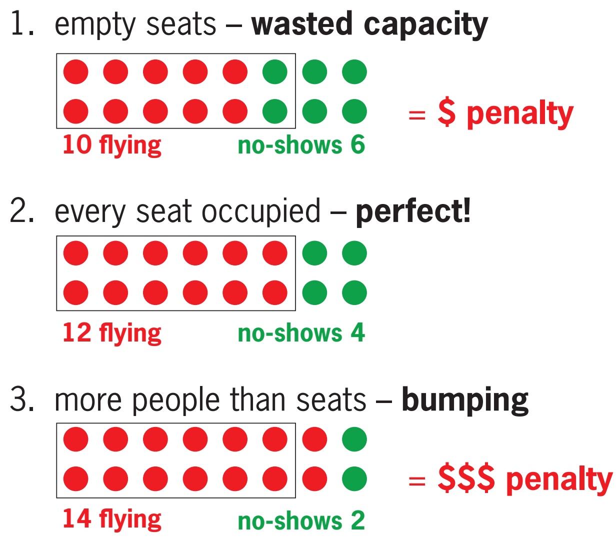
Whenever there is uncertain demand a margin of space above the average demand is needed. The size of this margin depends on the uncertainty of demand and the ratio between the wastage and displacement penalties.

To achieve efficiency, space-sharing must be taken to the point where there is a real, but small, risk of displacement. It's unwise to find out where this point is by trial and error. Much better to collect the data that's needed and do the yield management analysis.

There is more about yield management in ASR Paper 3 (page 78).

Facilities management is no longer like an economy run by central command; it operates as a market where efficiency depends on matching supply (space) and demand (activities).





Yield management in an airline

Suppose an airline flight has a capacity of 12 seats. The airline knows that on average one-quarter of people with flexible reservations do not show up, so it overbooks and sells 16 reservations (75% x 16 reservations = 12 seats).

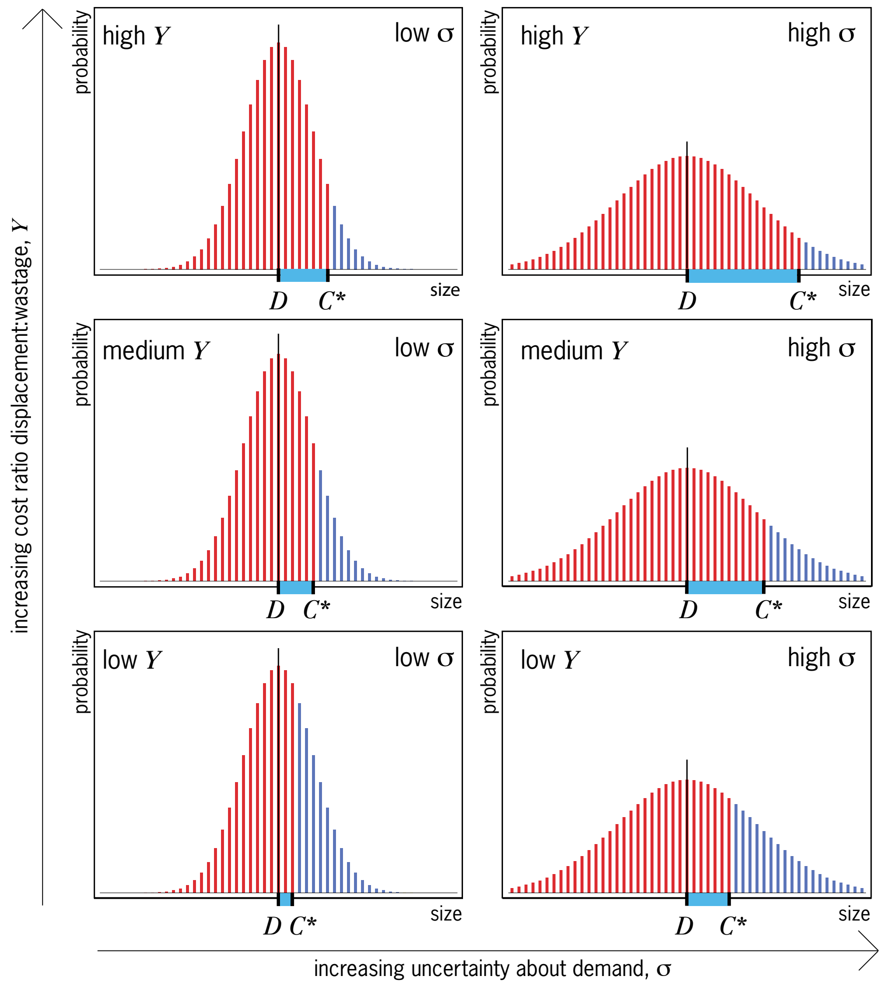
There are three possible outcomes:

1. Fewer than 12 people turn up, so the plane flies with empty seats, incurring a small wastage penalty (loss of passenger revenue)

2. Exactly 12 people turn up – perfect!

3. More than 12 people turn up, so some have to be bumped, incurring a high displacement penalty (compensation to passengers who cannot fly).

Airlines use yield management analysis to determine the level of overbooking that minimises the combined penalty cost from both wastage and overbooking.



Yield management in a shared workplace

Six graphs showing how yield management identifies the optimum margin between the average demand, D, and efficient capacity, C^*.

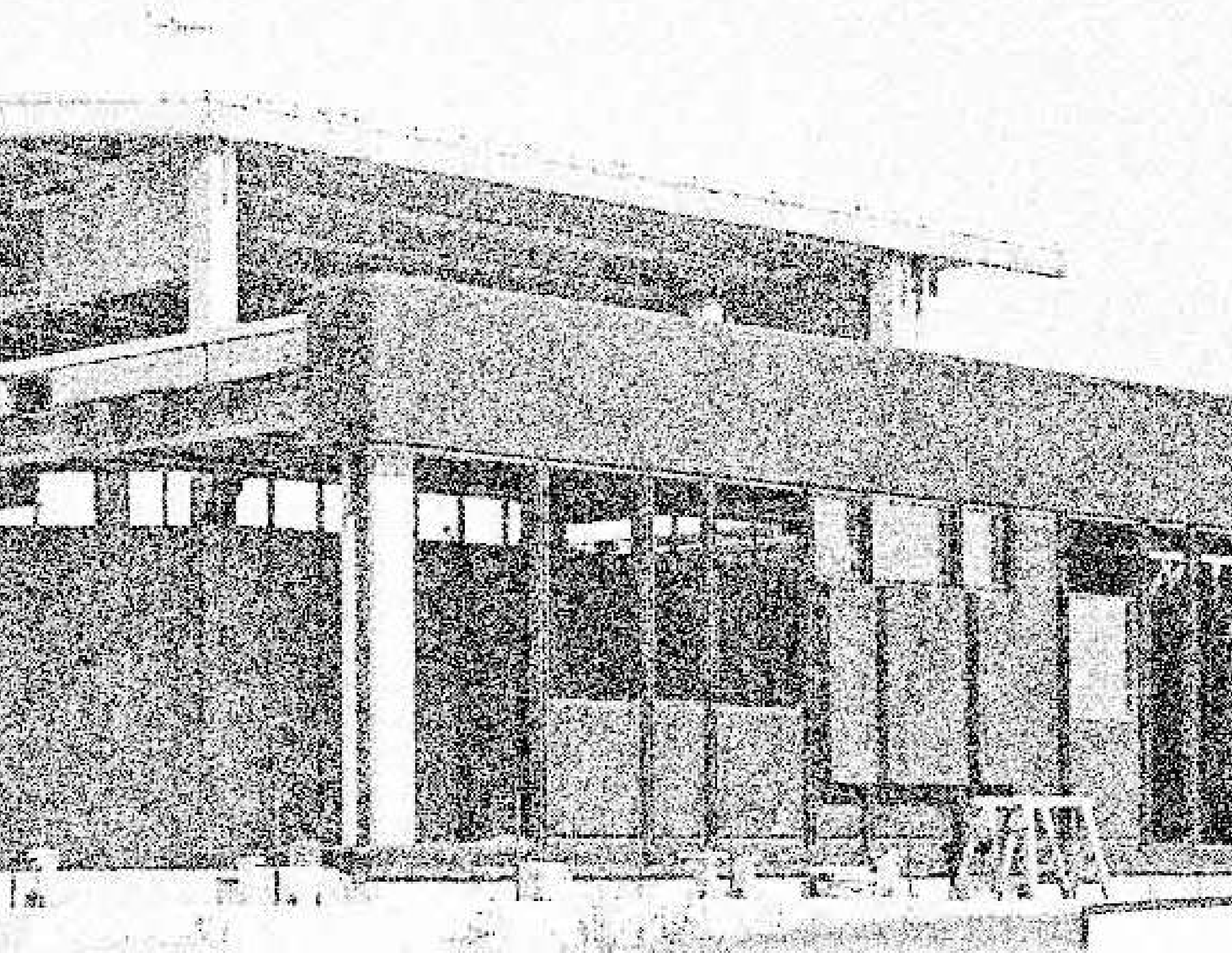
The cases vary in terms of the uncertainty about demand, σ [sigma] (as σ increases the graph gets flatter), and the ratio between the displacement and wastage penalty costs, Y (the ratio between the red and blue parts of the graph). Although the average demand is the same in all six cases, the margin between average demand and efficient capacity is very different, depending on the values of σ and Y.

In practice, the cost ratio would usually be high and the blue part of the graph correspondingly small.

The ratio between average demand and optimim capacity is an indication of the utilisation that can be achieved; it decreases as the values of σ and Y get higher.

Chapter 4

FLEXIBILITY FOR ACTIVITY CHANGE



FLEXIBILITY IN PRACTICE

Andrew Rabeneck

Andrew Rabeneck is an architect with extensive experience both in architectural practice and also as facilities manager for building users with major estate portfolios. These notes summarise his hard-won experience of success and failure in designing and building for flexibility.

Too much of a good thing?

Flexibility has been an architectural and planning enthusiasm since about 1960. It now pervades most areas of business. So how should designers of buildings today approach flexibility? Physical building flexibility takes the form of overprovision in relation to today's needs, built in at a cost. Most commonly this is the physical overprovision of space, services or gadgets such as moveable partitions.[1]

Flexibility is considered necessary because the future remains uncertain and design problems are endemically indeterminate or 'wicked', whether or not that is recognized by designers.[2] Designs are certain to be inadequate in some respects, yet buildings are assets that must be kept useful in order to maintain value, even when needs change: hence the urge to future-proof them. Hindsight over the last fifty years suggests some approaches to flexibility that might help, but there have been more dashd expectations than successes.

Design strategies that aim to increase flexibility

Despite its popularity, flexibility has not been much studied. Methods for measuring it or assessing its value are scant. There is no how-to-do-it guidance underpinned by theory – but perhaps Activity-Space Research can change that.

As a result assumptions made when flexible measures are considered often turn out to be mistaken. Typical problems include:

The probability and consequences of change are ignored or underestimated Tight fit between today's needs and resources are hard-wired into the design process, because there are easily grasped metrics of 'design quality'. Design management techniques are heavily geared to refining the fit between brief and design – cost prediction, 'knowledge management', 'value' engineering.

Expensive technological fixes are seductive A planning principle (eg. a module), a gadget, or a building sub-system is overvalued during design, frequently by architects or engineers, and treated as an insurance policy against unknown change, often at premium cost.

The wrong sort of change takes place The planned-in flexibility is defenceless against the unanticipated change that actually takes place. This is common, even when analysis might have highlighted the true areas of uncertainty.

The wrong sort of flexibility is built-in The kind of flexibility necessary to accommodate probable types of change is not properly evaluated by reference to cost histories.[3] There is inadequate or non-existent analysis of minimax regret criterion,[4] ie. the opportunity/risk appraisal between demand and supply.

So what does work, what is a sound investment?

When designing buildings it turns out that the most valuable precautions against unforeseen change are very old-fashioned: regularity of plan and section; adequate dimensions especially in public spaces and floor-to-floor height; good structural capacity; ample service risers and adequate plant rooms; services that are modular according to the state-of-the-art. Such attributes (with the exception of floor-to-floor height) are typically not expensive in relation to overall first cost, but are likely to buy a good measure of future-proofing.

We might call these attributes Vitruvian. They typically result in buildings that can ADAPT to the consequences of change at reasonable cost. This is an approach to future-proofing that is to be contrasted with the conscious advanced purchase of FLEXIBILITY, an investment made risky by its dependence on accurate forecasting about the type of change that will take place.

Experience of flexible/adaptable buildings in use

Greenwich District Hospital was completed in 1970 but has now been demolished – it saw one strategy for flexibility come full circle. The hospital used horizontal interstitial service floors with deep plans to maximize servicing flexibility.[5] But interstitial floors turned out to be an excessive response to the servicing needs of clinical space, where there was not actually that much change. The concept was technically exciting for the design team, but the zoning of services and their uncoupling from other building systems could achieve 80% of the benefits in a much simpler way. In the event the changes that condemned Greenwich after only 29 years were completely unanticipated by the design team: asbestos legislation and health service reorganization.

School Construction Systems Development (SCSD) was a set of subsystems for school building developed in the 1960s that addressed a pedagogic revolution in schools – child-centred learning. Variety of learning spaces and 'schools without walls' were the design creeds, and they resulted in deep-plan carpeted schools with great flexibility of partitioning, ceiling/lighting and air-conditioning. In reality the changes of configuration was less than anticipated. An irony of the SCSD story is that when teacher-centred classrooms returned in the 1990s (another unanticipated change), the schools were very economical to adapt physically, but the spaces in the deep-plan shells were generally unattractive.[6]

Victoria Plaza was a spec office building of 1984. This 200,000ft^2 four story building was a pioneer of American spec office construction standards in London, including the 5ft (1.5m) module, used for cladding panels and glazing, structure, ceiling grids, and even mechanical systems.[7] British buildings' dimensional discipline derived more from space-planning and the legacy of ill-founded ideas of modular coordination. Modules of 3ft 6ins, 4ft (1.2m), and 4ft 6ins (1.35m) jostled for adoption, promising a close fit between status and office size. The 13.5m^2 offices at Victoria Plaza, built as part of the American bank Salomon Brothers' fit out, were generous compared with the 9m^2 offices that were typical at the time in London. But the glass-fronted Salomon office could be used for a single senior manager, two junior managers sharing, three analysts and even four typists (with the glass front removed). It made a good meeting room for up to eight, and could be converted to a computer frame room. As a result, despite massive re-planning on a week-by-week basis, partitions and mechanical services rarely had to be disturbed.

Hard-won lessons

Four things we have learned about flexibility:

1. Things do not always turn out as you think they will.
2. To plan the right sort of flexibility you need to do the hard graft research.
3. Even with good research you may be caught out ('… events, dear boy, events' – Harold Macmillan).
4. Flexibility costs money – much is likely to be wasted.

1. Bev Nutt identifies ten dimensions of flexibility in his note 'Flexibility: Infrastructure, Property and Workplace' (2003). They are: Use; Operational; Spatial; Physical; Technological; Financial; Portfolio; Tenure; Market; Management.

2. Horst W.J. Rittel 'Wicked Problems' in *Management Science*, 1967, vol. 4, no. 4, pp.141-142. He spelled out the difficulties of practical reasoning in real world situations, e.g. architectural design.

3. For example, cumulative capitalization of investment over time for similar buildings, as a measure of adaptation to change.

4. In decision theory known as opportunity loss, a combination of actual monetary loss and unrealised potential profit.

5. The building was inspired by the work on flexibility of John Weeks of Llewellyn-Davies and of BSD in San Francisco, who had pioneered the interstitial service floor concept for bioscience Academic Buildings for the University of California and Veterans Hospitals, based on analysis of historic alteration costs and hierarchies of permanent and adaptable services. BSD's 750,000ft^2 Loma Linda veterans hospital still stands, as does John Weeks' Northwick Park, built on similar principles.

6. Chris Arnold and George Rand 'Evaluation: A Look back at the '60s' Sexiest System' in *American Institute of Architects Journal*, April 1979, pp. 52-57.

7. The building, an air-rights development above Victoria Station, was developed by Stuart Lipton while at Greycoat. Lipton had long been a student of American speculative office building practice, producing well-serviced adaptable office space that kept its investment value better than the more custom-built approach to offices common in Britain.

FLEXIBILITY: LOOSE-FIT

A building is flexible if it can cope with future activity change; because everyone accepts that change is constant, there is a strong demand for flexibility. But how does flexibility actually work? – and how can we predict whether today's buildings or designs will prove to be flexible? The idea of a 'loose-fit' building is a starting point.

Degrees of change

Buildings are durable and static; activities are ephemeral and changeable. Therefore, during the life of most buildings there will be a relatively large amount of activity change. New activities can often take place in the same accommodation that was previously used for different activies. But sometimes new activities need different accommodation, creating an activity-space mismatch.

To minimise the risk of mismatch, the idea of a loose-fit building suggests that designers should avoid too tight a match between activities and spaces, and create some 'slack' which may be valuable when activities change.

This was called a duffle coat strategy by John Weeks. Over a generation ago he proposed that, 'In order to get maximum flexibility ... it is necessary to provide rooms which fit around the activities which are to be carried out in them like a duffle coat. The duffle coat, provided by the Navy for its officers, was not a tailor-made garment. A few sizes were made and these were related to the known sizes of sailors so that it was usually possible to find one that would fit reasonably, and keep the sailor quite snug' (Weeks, 1960, p.20).

Measuring looseness of fit

The looseness of fit between a set of activities and a set of spaces can be measured by the number of ways that the activities can be arranged in the spaces. An example is shown in the diagram, where two alternative design are compared for the same set of activities. The design with more possible arrangements performs better in terms of loose-fit flexibility.

The activity-space match

Looseness of fit is particularly important for buildings that are timetabled.

Timetables have to satisfy 'hard' constraints like capacity – the space must be large enough for the assigned activity; there are also 'soft' constraints that can be violated if necessary, like locational or time preferences.

Greater interchangeability increases the likelihood of finding an assignment that satisfies all hard constraints – this is a *feasible* assignment; and also satisfies a high proportion of soft constraints – a *good* assignment.

Activity-space tolerance

The duffle coat theory argues that loose-fit flexibility is maximised in designs that have few distinct types of space, and many identical instances of these types.

This has become conventional wisdom in hospital design. A recent brief made the following statement: 'The intention is to generate a pool of beds capable of being utilised in a flexible manner according to the demands prevalent on any given day, or at any given hour. *This cannot be achieved without generic rooms*' [italics added]. This is anlaysed on pages 54-55 below.

The proposition is questionable. Loose-fit flexibility is enhanced when there is a high level of tolerance between the attributes of activities and spaces, so that small (or large) variations in the activity attributes do not cause a mismatch. But the same applies to spaces: small (or large) variations in the space attributes do not cause a mismatch. Therefore, if the spaces (or duffle costs) are not identical in size, it doesn't matter.

Standardisation of spaces may be desirable for design, construction and maintenance, but this is separate issue.

The important thing in designing for loose-fit adaptability is to maximise the tolerance between activities and spaces, not to get fixated on identical spaces.

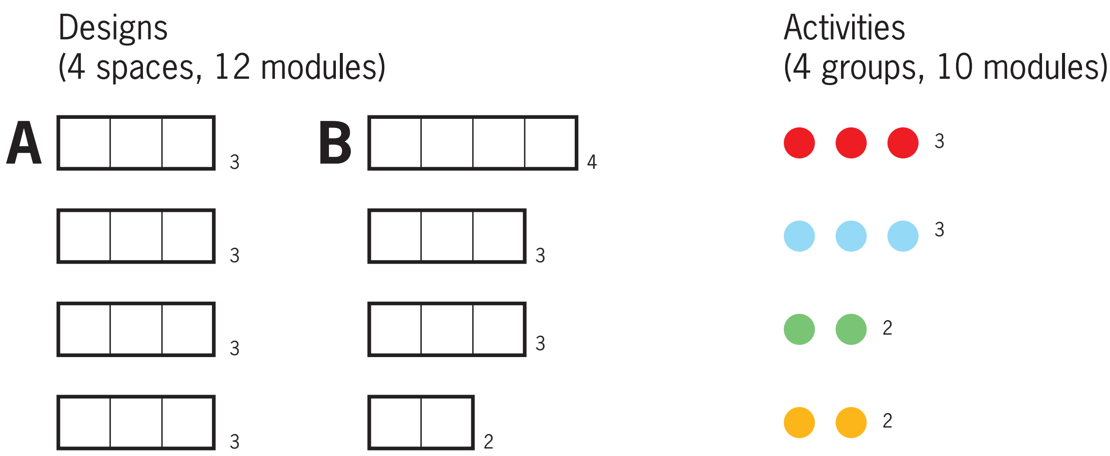
See also ASR Paper 6 (page 84).

Suppose that there are two alternative designs, A and B. Both have four spaces and a total floor area of 12 modules.

All the spaces in design A are the same size, 3 modules. In design B, one space is larger, with 4 modules; two have 3 modules; and one has 2 modules. Here we are only concerned with the set of spaces making up the alternative designs, not their layout.

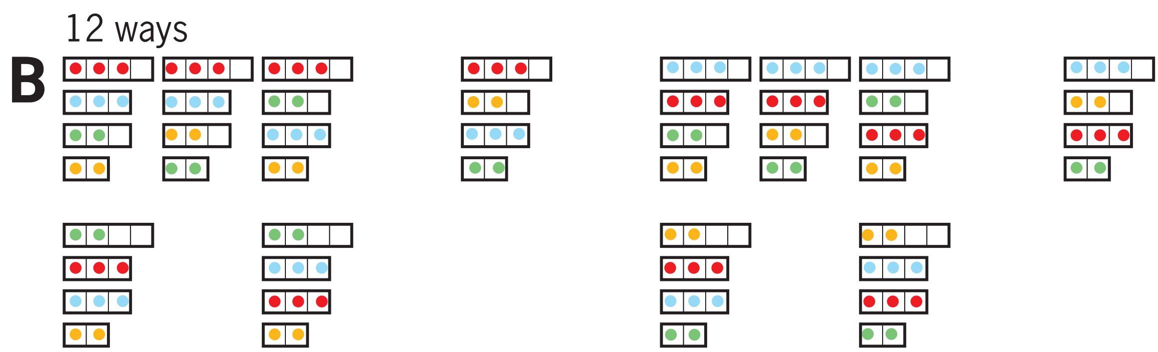
A set of four distinct activities must be assigned to the spaces – two activities require 3 modules of of floor area and two require 2 modules.

It is evident that both designs can accommodate the activities, because they can be assigned to the spaces in the order shown in the diagram (ie.the blobs on the right can fit in the boxes on the left).



There are many alternative ways of assigning the activities to the spaces. With design A the four activities can be assigned to the four spaces in 24 different ways, but with design B there are only 12 possible assignments.

Therefore design A performs better than design B in terms of **loose-fit flexibility**.



FLEXIBILITY: CHANGING ACTIVITIES

In a building with loose-fit flexibility a given set of activities can be arranged in a given set of spaces in many different ways. A different question about flexibility asks what happens when the set of activities changes: can it still be accommodated? This is flexibility for activity change.

Experimental comparison

It is hard to imagine a situation in which the activity-space match is so tight that even the slightest activity change would cause a mismatch. There is always some degree of tolerance between activities and spaces, and therefore there must always be some capacity for absorbing activity change. The greater the tolerance, the more activity change can be accommodated.

The challenge of design for changing activities might apply, for example, to the designer of a suite of meeting rooms who wants flexibility to accommodate a wide range of meeting sizes.

In this context a single feasible assignment of activities to spaces is sought. We are not concerned with activity-space interchageability.

In this activity change experiment we compare the same designs A and B as in the previous loose-fit experiment. We saw that A performed better than B in terms of loose-fit flexibility.

The design with many identical spaces (design A) performed well for loose-fit flexibility, whereas the design with a range of different spaces (design B) provided more flexibility for changing activities.

Design for flexibility

Designers often seek to extend the range of activities that a building can accommodate by making provision for alterations, for example by movable walls, relocatable services, or strategies for growth.

Physical change clearly extends (or more accurately, modifies) the range of activities that can be accommodated.

Design for physical change is fraught with pitfalls. Many buildings, such as Victorian terraced houses, are altered for changing activities even though physical flexibility was not an objective of the original designers. Conversely, design features for physical change, such as demountable partitions in offices, may be left untouched. And buildings that were designed to maximise flexibility are sometimes demolished after a short service life.

These experiences, coupled with the findings from the experiments reported here, show that flexibility is not a one-dimensional attribute, but must be carefully defined for different situations.

The site of Greenwich District Hospital in 2008. It was a complex and expensive hospital design of the early 1970s which aimed to maximise flexibility – but it closed in 2003 after barely 30 years of use and was demolished (*see* page 45).

Flexibility and adaptability

In this chapter the words 'flexibility' and 'adaptability' are taken to be synonyms, describing the ability to cope with change.

It is possible to use the words to identify distinct concepts. This was done by Andrew Rabeneck in the 1970s, when he proposed that flexibility meant the ability to change the physical configuration of a building, and adaptability meant the ability of a building to absorb a variety of use patterns without physical change (Rabeneck *et al*, 1973 & 1974). This terminology has been widely followed, for example in Schneider & Till's *Flexible Housing* (2007).

Unfortunately, the words are sometimes used in precisely the opposite sense, for example, in the UK government's guidance on school design (DFES *Building Bulletin 98*, undated, p.21).

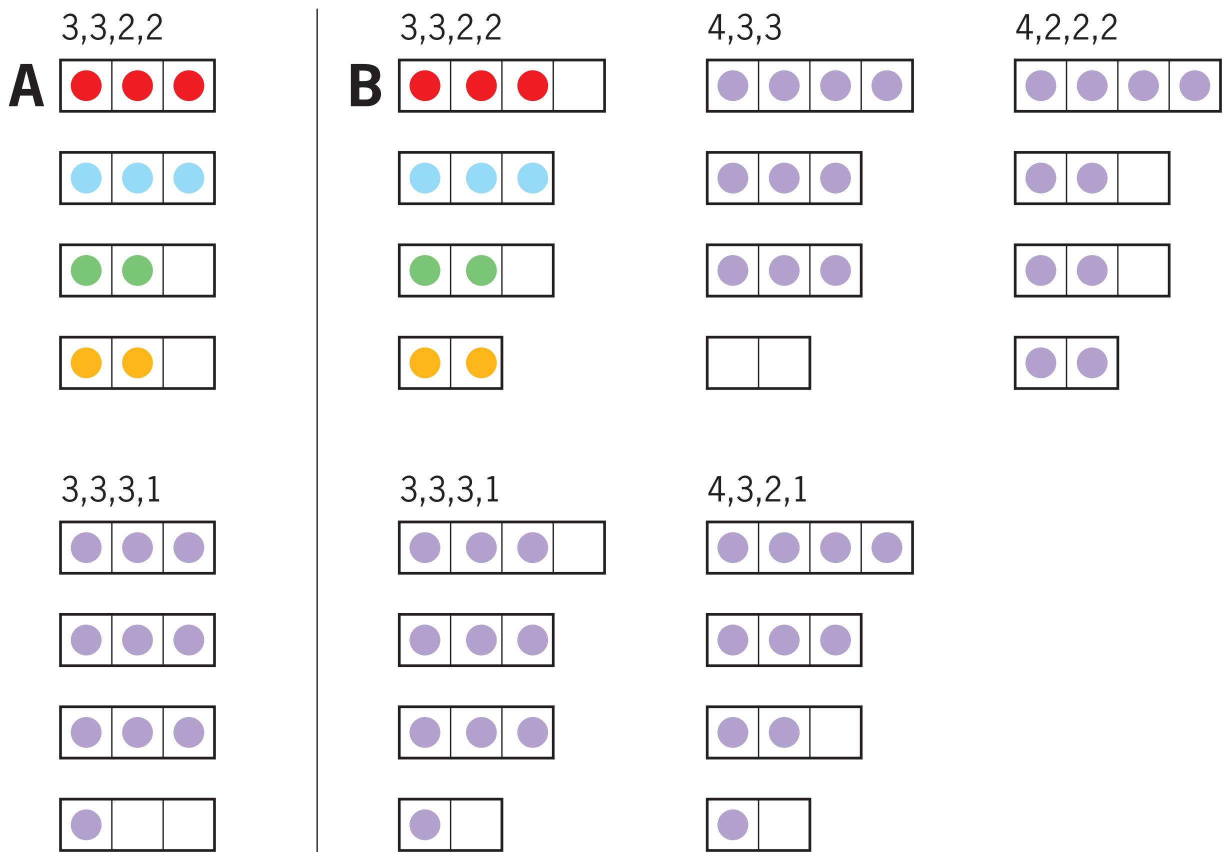
Using the two words to refer to different aspects of flexibility/ adaptability risks confusion, so here only one word 'flexibility' is used. When particular aspects of flexibility or adaptability are discussed they have to be defined explicitly.

ASR Paper 6 (*see* page 84) considers both loose-fit flexibility and flexibility for changing activities.

As in the previous experiment, suppose that there are two alternative designs, A and B. Both have four spaces and a total floor area of 12 modules. All the spaces in design A are the same size, 3 modules; in design B, one space is larger, with 4 modules, two have 3 modules, and one had 2 modules. We are only concerned with the set of spaces making up the alternative designs, not their layout.

As we saw in the previous experiment, both designs A and B can accommodate the 10 modules of activity when they are grouped in the schedule 3,3,2,2.

Suppose now that the ten activity modules can be rearranged into groups in different ways. How well do the two designs accommodate the activities with changing schedules of grouping?



Design A can accommodate the 10 modules of activity in grouping 3,3,2,2 and just one other grouping – 3,3,3,1. Thus design A can accommodate the 10 activity modules in **two** different groupings.

Design B can accommodate the groupings 3,3,2,2 and 3,3,3,1 and also three more – 4,3,3; 4,2,2,2; 4,3,2,1. Thus, design B can accommodate the 10 activity modules in **five** different groupings.

Therefore design B performs better than design A in terms of **flexibility for activity change**.

SCENARIO-BUILDING

Flexibility can only be designed for activity change that can be imagined – but what can be imagined when the future is uncertain? Defining possible activities in a systematic way involves a process of scenario-building.

Changing activities

Flexibility can only be designed for activity change that can be imagined. Planning for flexibility therefore requires that a range of possible activities is defined. Other changes may take place but then it is a matter of luck, not design, whether or not a building can accommodate them.

The range of possible activity states that might have to be accommodated can be defined *explicitly*, by providing an exhaustive list of every relevant activity state.

More often it is done *implicitly*, by specifying the extent to which activity attributes might change; then, by systematically varying these attributes, every relevant activity state could be generated.

Explicit enumeration

An example of explicit enumeration of all possible activities is the group-sizing analysis shown in the diagram.

It turns out that the most probable size distribution of groups in a population of individuals follows a positive poisson distribution (Fawcett, 1979). This applies in the absence of constraints that skew the distribution; for example, in schools there are many more class-size groups than in an unconstrained situation.

In a survey of room sizes in hospitals in the 1960s, Peter Cowan (1963) found that the size distribution followed a skew shape, which was similar to a positive poisson distribution.

Implicit enumeration

Implicit enumeration involves defining the critical activity attributes, together with the range of possible values that they could take. Trees of possible activity states can then be generated by systematic variation from the current attribute values, perhaps in proportion to past volatility.

When there are too many possibilities to list exhaustively, it is easy to generate a representative set of activity states by randon selection of the attribute values (a type of Monte Carlo simulation).

The sizing of the seminar rooms in the new Faculty of English building in the University of Cambridge (Allies and Morrison, architects) was chosen to approximate to the positive poisson distribution.

Evaluating flexibility

Having defined a set of activity states explicitly or implicitly, it can be used to test the flexibility of a building or design proposal. Taking each of the sates in turn, they be compared against a design: in principle, each activity state can be:

(i) accommodated,
(ii) accommodated after modification to the design, or
(iii) not accommodated.

Alternative designs can be compared against the same array of activity states, and will perform differently in terms of those than can or cannot be accommodated: the proportion that can be accommodated is a measure of flexibility.

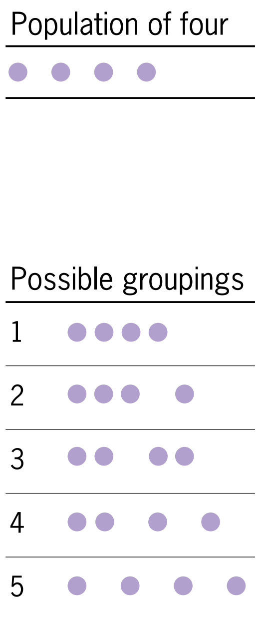
Designs that can accommodate more of the relevant set of activity states are more flexible.

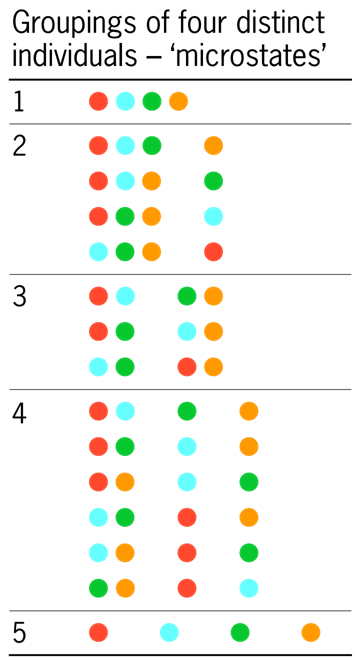
Note that a design's flexibility depends on the set of activity states used for the test. The same design will perform differently with different sets of activity states; and if alternative designs are being compared, the ranking may depend on the set of activity states used for evaluation.

In simplified cases *all possible scenarios* can be explicitly enumerated.

Suppose that we are only concerned with the way that a population divides into groups: there is a finite number of ways – for a population of four people there are precisely five groupings. If the members of the population are regarded as individuals we can also look at microstates. There are more microstates, and they are not evenly distributed across the groupings.

If a designer does not know how a building will be used, it is reasonable to provide for groupings with the largest number of microstates.





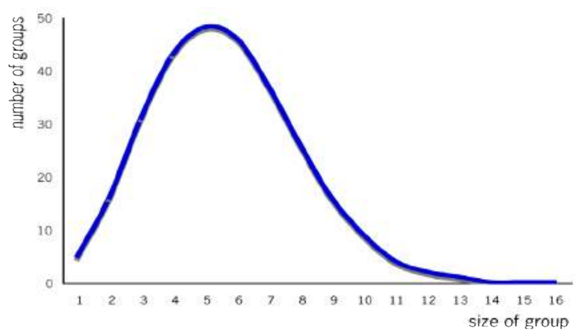
The number of microstates associated with a pattern of grouping can be found with a counting expression. This is cumbersome for large populations. However, the groupings with the highest number of microstates can be established with a hill-climbing search.

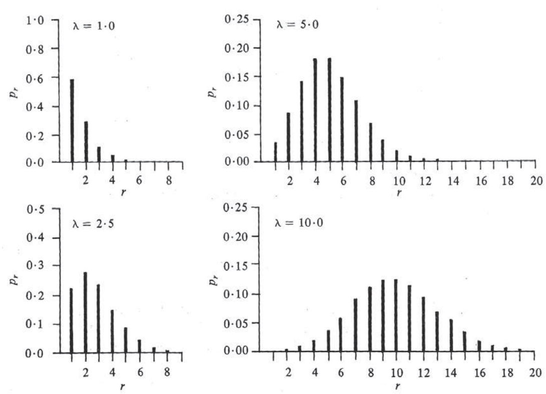
Mathematically, it turns out that the size and number of groups approximate to a positive poisson distribution. These distributions have few very small groups, many fairly small groups, and very few large groups.

$$W = \frac{N!}{\prod_{r=1}^{N} (r!)^{q_r} \prod_{r=1}^{N} q_r!}$$

SIZE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NUMBER	5	16	31	43	48	46	37	26	16	9	4	2	1	0	0

Counting expression (above); hill-climbing result for population = 1600 (above right); most probable poisson approximation for population = 1600 (below); typical positive poisson distributions (below right)





FLEXIBLE WORKPLACES AND FLEXIBLE ACTIVITIES

At the eleventh ASR Workshop on *Flexible workplaces and flexible activities*, the participants took part in a two-stage exercise, reported here.

Selected activity schedules

Before the Workshop on flexibility, the participants were e-mailed a form and asked to suggest a set of activity states for seminars in a university. They had to suggest a list of six schedules of seminar groups for a department with 80 students; the group sizes having to fall in multiples of 10.

84 schedules were received, six each from 14 people. There many repeats between the different participants' lists.

Now, this problem allows precisely 22 distinct schedules, so the 84 examples suggested by the participants can be mapped onto the 22 distinct schedules.

All possible activity schedules

The number of times that each of the possible schedules was suggested by the participants is shown in the table. Most popular was the schedule in which the 80 students are divided into eight small seminars, each of 10 students; 11 of the 14 participants suggested this schedule. The least popular schedules with no suggestions were {40,30,10} and {40,10,10,10,10}.

The number of microstates associated with each schedule of groupings can be calculated using the counting formula given on page 51, treating 10 students as one 'unit'. On this basis, by far the most probable schedule is {30,20,20,10} with three times as many microstates as the next, {30,20,10,10,10}. These two schedules were suggested by some participants, but less often than others with many fewer microstates.

It seems that the participants had a

Pre-Workshop exercise

A university department holds lectures/seminars every morning for 80 students. The students divide into lecture/seminar groups of various sizes; the sizes change from day to day. On the spreadsheet below please suggest six possible ways that the 80 students could divide into lecture/seminar groups, where the size of groups is rounded to the nearest 10. The number of groups can vary. An example is shown.

									TOTAL
ple	10	20	10	30	10				80
1	20	20	20	20					80
2	10	10	10	10	10	10	10	10	80
3	10	20	10	20	10	10			80
4	10	20	10	20	20				80
5	10	20	10	10	10	10	10		80
6	20	30	30						80

A specimen copy of the form that was filled in by 14 participants at the Workshop (left). Each one suggested 6 schedules of grouping for a population of 80 students.

The 22 possible schedules can be listed (right): the number of times each one was suggested by the participants is shown, labelled 'suggestions', together with the number of microstates calculated using the formula given on page 51 (right hand column).

The weighting given to the schedules by the participants' suggestions and by the microstates calculation are significantly different.

	schedule	suggestions	micro states
1	80	1	1
2	70 10	1	8
3	60 20	1	28
4	60 10 10	2	28
5	50 30	3	56
6	50 20 10	2	168
7	50 10 10 10	1	56
8	40 40	6	35
9	40 30 10	0	280
10	40 20 20	3	210
11	40 20 10 10	4	420
12	40 10 10 10 10	0	35
13	30 30 20	6	280
14	30 30 10 10	5	280
15	30 20 20 10	4	1680
16	30 20 10 10 10	5	560
17	30 10 10 10 10 10	3	56
18	20 20 20 20	9	105
19	20 20 20 10 10	6	420
20	20 20 10 10 10 10	6	210
21	20 10 10 10 10 10 10	4	28
22	10 10 10 10 10 10 10 10	11	1
	TOTAL	84	4945

‘modularity bias’, preferring schedules that divided the population into equal or near equal group sizes; whereas schedules with a variety of groups sizes have more microstates.

Seminar room plan

In the second stage of the exercise the participants at the Workshop were asked to select a building plan for the seminars, from five alternatives A to E shown below.

Plans A to D had eight ‘modules’ of space, each capable of accommodating a group of 10 students; and two fixed and four movable partitions. Plan E had no movable partitions, but it had one extra fixed partition and an extra module of space.

The participants made 27 selections. The most popular plans were C with 14 votes, and E with 10 votes.

The plans can be compared in terms of the number of schedules of grouping they can accommodate: plan C can accommodate 7, and plan E can accommodate 3.

Comparing the plans with the participants’ 84 suggested schedules, plan C can accommodate 39, and plan E can accommodate 15.

But comparing the plans with the calculated microstates, plan C can accommodate 1695, and plan E can accommodate 2660.

Plan E has a flexibility bonus: it provides the option of adding movable partitions in the future.

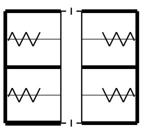
There are other possible plans, such as plan F, which was not offered at the Workshop; it can accommodate 22 suggested schedules and 3290 microstates.

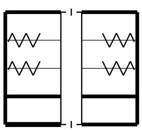
Which plan is most flexible?

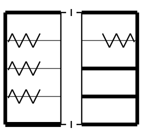
If the 84 suggested schedules are regarded as representative of the seminar demand, then plan C is a flexible selection (plan D is equally good but A, B, E and also F are worse). perhaps this indicates consistency by the participants.

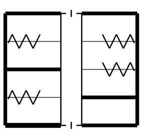
If, on the other hand, the microstates are regarded as a better indicator of probable seminar demand, then Plan E is the best of the five Workshop alternatives, and plan F is better still.

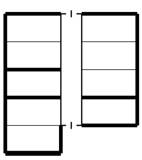
This exercise reinforces the message that flexibility can only be evaluated against a well-researched and credible statement of expected activities – flexibility is not an inherent attribute of plans.

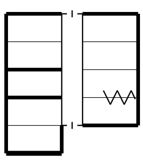
A


B


C


D


E


F


The participants at the Workshop were asked to make a selection from five alternative plans for accommodating the seminars; these were plans A to E (left). The votes were –
A: 1; B: 0; C: 14; D: 2; E: 10.

The performance of the preferred plans C and E are compared in the tables on the right, which show the schedules of grouping that can be accommodated, the number of times that each of these schedules was suggested by the participants in stage 1 of the exercise; and the number of microstates associated with the schedules.

Plan C performed well when compared to the suggested schedules, and plan E performed well when compared with the microstates.

Plan D, which was not popular, performed as well as C with respect to the suggested schedules (39) and better than C or E with respect to microstates (2955). Arguably, it was the best of the five plans offered to the participants.

There are many alternative plans, including plan F; it performed significantly better than E in terms of both suggestions and microstates.

C	schedule	suggestions	micro states
11	40 20 10 10	4	420
16	30 20 10 10 10	5	560
17	30 10 10 10 10 10	3	56
19	20 20 20 10 10	6	420
20	20 20 10 10 10 10	6	210
21	20 10 10 10 10 10 10	4	28
22	10 10 10 10 10 10 10 10	11	1
		TOTAL 39	1695

E	schedule	suggestions	micro states
15	30 20 20 10	4	1680
16	30 20 10 10 10	5	560
19	20 20 20 10 10	6	420
		TOTAL 15	2660

F	schedule	suggestions	micro states
10	40 20 20	3	210
11	40 20 10 10	4	420
15	30 20 20 10	4	1680
16	30 20 10 10 10	5	560
19	20 20 20 10 10	6	420
		TOTAL 22	3290

FLEXIBILITY AND EFFICIENCY

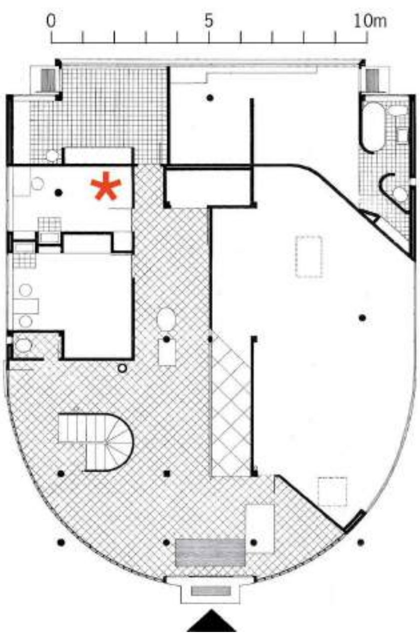
Flexibility aims to enhance the long-term efficiency of investment in buildings, but efficiency is also an issue in deciding how to provide flexibility.

Vitruvian attributes

There are some fairly obvious design strategies to enhance flexibility, particularly strategies of redundancy or over-capacity. These include long spans, tall ceilings, strong floors, deep service zones, etc, which Andrew Rabeneck refers to as old-fashioned or Vitruvian attributes (see page 44).

It is evident that cranking up these structural-spatial attributes will enhance a building's flexibility for future use by activities that require larger unobstructed spaces, greater clear height, heavier floor loadings or more intensive servicing.

But this adds to cost, and there is no certainty that activities will materialise to make use of the over-capacity. Indeed, scaling up the Vitruvian attributes does not necessarily increase flexibility.



The avoidance of columns as a strategy for flexibility should not be over-rated. In Le Corbusier's famous Villa Savoye (1929-31) there is a freestanding column in the maid's bedroom on the ground floor (room marked with an asterisk). It is a small room but even with the column it is satisfactory for a maid's bedroom, and for various other uses that might occur in a residential building (such as study, workroom, utility room, storage, etc). Little useful flexibility would have been gained by altering the building's structure to reposition the column.

Flexible offices

The typical post-Word War II offices built in the UK had naturally ventilated floor plans about 40 feet (about 13 m) deep between external walls, and modest ceiling heights. Then office users asked for bigger floors to accommodate more employees, larger service voids for more cabling, with air-conditioning to cope with greater heat gains and therefore sealed windows. The old buildings became less attractive for office users, but happily they had flexibility for adaptation to residential use – and many have been adapted in this way.

Despite, or in fact because of, their larger floor plans and greater depth between external walls the new office buildings have less flexibility for future adaptation to residential use.

What is flexibility for?

Defining the purpose of flexibility is a pre-condition for effective and efficient design for flexibility.

There is a lot of discussion about flexible offices, but it does not usually refer to change to residential use. Instead it refers to the changing day-to-day or year-to-year needs of office occupiers, or the needs of different occupiers in the case of speculative office space. This is what the designers of flexible offices focus on.

Universal flexibility is an illusion. Practical steps to increase flexibility rely on specifying the kind of change that is of concern. Otherwise measures that are vaguely intended to increase flexibility, like over-capacity, may be of no value or even counter-productive.

There is also windfall flexibility, when the use of buildings changes in ways that were not anticipated by the designers. The re-use of post-War offices as flats is an example of windfall flexibility. But designers cannot provide for windfall flexibility, by definition; if windfall changes can be anticipated, they fall into the scope of specified changes that can be designed for.

It is easier to define the purpose of flexibility for short-term cyclic activity change. A hypothetical example about flexibility for varying patient demand in a hospital is described opposite. When flexibility is well defined, its cost and effectiveness can be established, allowing it to be compared against other desirable project objectives.

Flexibility and efficiency in a hospital example

The design brief for a new hospital states the need for ‘a pool of beds capable of being utilised in a flexible manner according to the demands prevalent on any given day, or at any given hour.’

To explore this requirement in a worked example we first simulate the demand for beds. The demand model steps though regular time periods (perhaps an hour or a day) in accordance with the following rules:

1. Five patients arrive per time period
2. The length of stay varies with an average of 4 periods
3. Patients can be of four types with equal probabilities: S = ‘simple’, A = ‘type A’, B = ‘type B’, and C = ‘complex’.

Over a sequence of time periods, patients of the various types arrive seeking treatment, and they stay for varying lengths of time. At any point in the sequence the total number of patients currently requiring treatment and the number of each type can be counted. There is considerable variation, as shown in Table 1.

We turn to the provision of beds for treatment. Like the patients, the beds can be of four types, which have varying costs: S = ‘simple’ (4 cost units per bed), A = ‘type A’ (6 cost units), B = ‘type B’ (6 cost units), and C = ‘complex’ (8 cost units). Patients do not always need to be treated in a bed of matching type; the possibilities are shown in the feasibility matrix. Type C ‘complex’ beds are more expensive but suitable for all patients.

The design challenge, as set out in the brief, is to provide a set of beds of the four types (S, A, B, C) with flexibility to cope with the varying demand for treatment. There are many possibilities – a few are shown in Table 2.

The average number of patients requiring treatment in each of the four types is 5 (see averages in Table 1), so a design with 5 beds of each type would meet the average demand – this is Strategy 1 in Table 2, costing 120 units. However, demand virtually always varies from the average and Strategy 1 can only accommodate 27.5% of the test set of 1000 demand simulations.

At the other extreme, the maximum number of patients requiring treatment in the 1000 demand simulations is 26, so 26 type C rooms are certain to accommodate all cases – this is Strategy 3, costing 208 units. Have we solved the flexibility problem?

Strategy 3 has good flexibility (as defined in the design brief) but it is not efficient. A little experimentation shows that Strategy 4 with 26 beds of the four types can also accommodate all 1000 demand simulations, at a cost of 172 units – saving 17% compared to Strategy 3.

In 1000 demand simulations the extremes of high demand occur rarely, so a set of beds that can accommodate the extremes is under-used for most of the time. It is worth considering the trade-off between:
(i) the cost saving if the number of beds is beds is slightly reduced, and
(ii) the number of cases that would fail. Strategy 5 saves 12 units of cost compared to Strategy 4 (and 48 units (or 23%) compared to Strategy 3), while accommodating 98.2% of the 1000 demand simulations. It provides a slightly lower level of flexibility, but hospital managers may (or may not) feel that this is justified by the cost saving.

Flexibility should be subject to the same tests of efficiency as other design features, and it would be unreasonable for designers to assert that because Strategy 3 is most flexible it must therefore be selected.

This result is specific to the input data. Different results can be expected with revised data for demand, bed types, feasibility or cost. Efficient design for flexibility requires rigorous analysis, not broad generalisations.

Table 1 (right) is an extract of 20 demand simulations from 1000 that were used to test the design strategies. The high and low values are indicated with flashes, and the averages for these 20 cases are given.

TIME PERIOD	NUMBER OF PATIENTS BY TYPE S	A	B	C	TOTAL
100					
101	7	5	2	6	**20**
102	8	5	1	7	**21**
103	7	6	1	6	**20**
104	5	5	3	4	**17**
105	5	4	5	5	**19**
106	4	2	8	5	**19**
107	5	2	7	5	**19**
108	5	2	4	6	**17**
109	6	3	3	6	**18**
110	5	4	7	4	**20**
111	4	4	8	5	**21**
112	3	5	7	5	**20**
113	4	5	9	4	**22**
114	5	4	9	4	**22**
115	4	7	11	2	**24**
116	4	5	9	2	**20**
117	7	3	8	2	**20**
118	5	5	7	3	**20**
119	5	7	7	1	**20**
120	4	6	9	3	**22**
121					
AVERAGE	4.87	5.13	4.97	5.01	**19.99**

The feasibility matrix (below right) shows which bed type is suitable for treating which patient type. ‘1’ indicates that the bed is suitable, ‘0’ that it is not. The cost per bed for each bed type is shown below the matrix (in arbitrary cost units).

PATIENT TYPE	BED TYPE S	A	B	C
S	1	1	1	1
A	0	1	0	1
B	0	0	1	1
C	0	0	0	1
COST	**4**	**6**	**6**	**8**

Table 2 (below) shows a few alternative design strategies, described by the number of beds of the four types, with the flexibility performance when tested against 1000 demand simulations, and cost.

STRATEGY	NUMBER OF BEDS BY TYPE S	A	B	C	TOTAL BEDS	FAILURES	% OK	COST
1	5	5	5	5	**20**	625	27.5%	**120**
2	6	6	6	6	**24**	345	65.5%	**144**
3	0	0	0	26	**26**	0	100%	**208**
4	4	5	5	12	**26**	0	100%	**172**
5	3	5	5	11	**24**	18	98.2%	**160**
6	3	5	5	10	**23**	54	94.6%	**152**
7	3	5	5	9	**22**	114	88.6%	**144**

THE REAL OPTIONS SYNTHESIS

Flexibility is best understood as a particular type of lifecycle option. This perspective can accommodate all forms of flexibility in a uniform way, and it establishes the basis for calculating not only the degree of flexibility provided by a design but also its value. This is crucial for decision-making.

Enhancing flexibility

When flexibility is a project objective designers introduce features that they believe will enhance flexibility. This often leads to more highly specified designs that are more expensive. Are they a good investment? – only if the value that is gained from the investing in flexible features is greater than the investment. But how can the value be quantified when the future is uncertain?

Lifecycle options

The extra investment in flexible features can be seen as buying 'lifecycle options', which are exercised at nil or low cost if future conditions make it advantageous to do so (Ellingham & Fawcett, 2006). The extra cost can be regarded as a 'flexibility premium'.

It is possible to quantify the option value for alternative designs by comparing them against a representative set of future scenarios; and then this option value can be compared against the flexibility premium: only if the option value exceeds the flexibility premium is the design good value.

Movable partitions cost more than studwork, the extra cost buying the lifecycle option to rearrange the office layout economically and with minimum disruption.

Note that the greater the future uncertainty, the higher will be the option value of flexible designs, thus justifying higher flexibility premiums (ie. an inverse of the situation with no uncertainty, when there would be no need for flexibility and lifecycle options would have no value).

Robust design

Flexibility is best understood in terms of lifecycle options. Whenever a designer provides the opportunity for other people to make new decisions in the future in response to unfolding events, a lifecycle option is created. Typical lifecycle options include the options to extend, adapt, change use, refurbish, and so on. Many buildings also incorporate embedded options that do not require special input by the designer, for example, the option to make *ad hoc* alterations.

There are two ways of planning for the future:

The first is to make predictions, and design what is effectively a phased project to match the sequence of predicted future events.

The second is to accept that predictions are impossible and provide a design that can evolve in a variety of ways as future events unfold.

The two approaches can be characterised as aiming for **optimality** or **robustness** (Rosenhead *et al*, 1972).

The first approach is usually a lost cause; the later phases of multi-phase master-plans are practically never implemented as initially expected – new decisions are made in response to unfolding events.

There are two benefits of acknowledging uncertainty at the time of design. First, the early stages of a multi-phase plan can be designed to work well even if later phases are abandoned; and second, opportunities for the widest variety of long-term development paths can be built in.

Cost-effectiveness

Flexibility can be thought of as 'the probability that a building will not become functionally obsolete.' It is not determined by the ability to make physical changes – a static building may have all the flexibility you need, and a movable building may not. It is easy to over-design for flexibility – as in the case of Greenwich District Hospital (*see* pages 45 and 48).

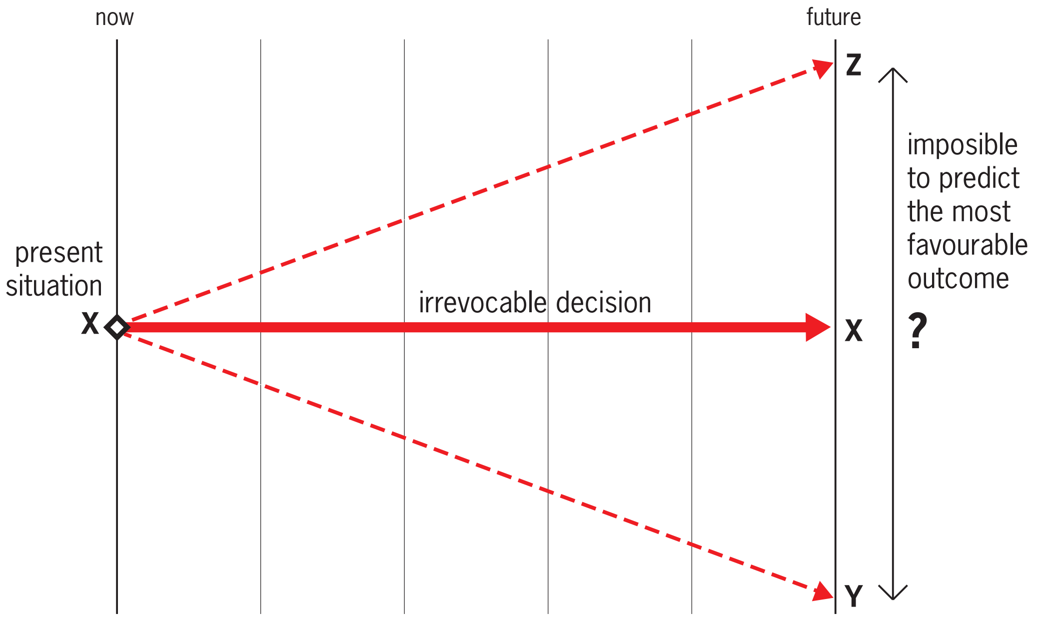
If the need for flexibility is defined by the extent of relevant activity change, then it is possible to evaluate the flexibility provided by alternative designs, and select the most cost-effective design.

See also ASR Paper 5 (page 82).

Design based on a precise prediction about the future:

A decision is made now, say decision X, in the belief that it will be the right decision many years in the future. It might be about the use of a building, or the types of material or technology, or fuel, and so on.

In the future, however, it may transpire that alternatives Y or Z would have been preferable – but there is no possibility of changing.

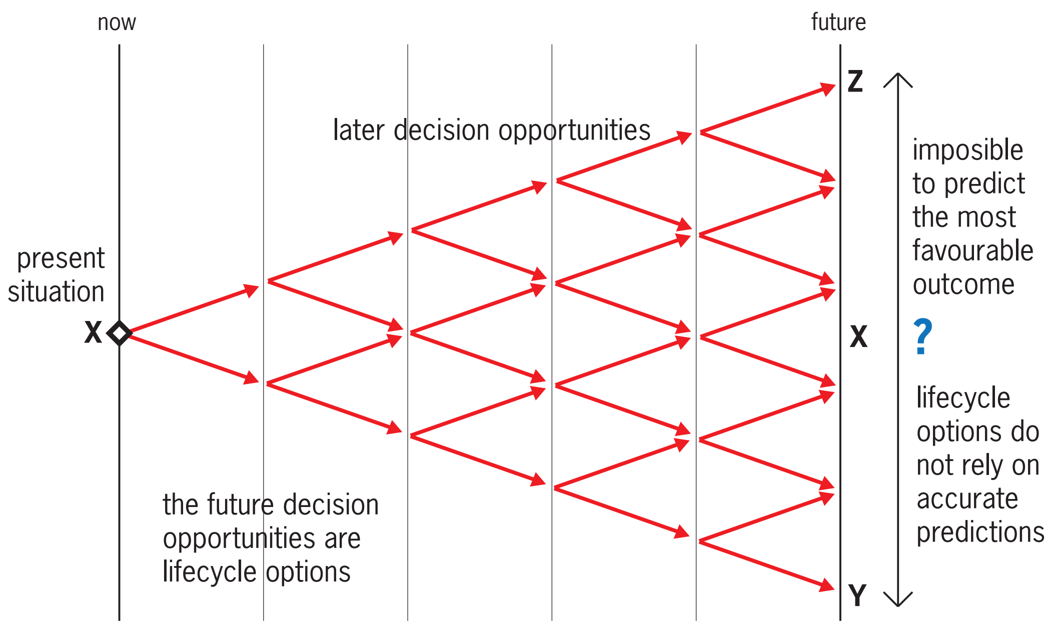


A design incorporating lifecycle options:

The present decision X can be modified during the service life by exercising lifecycle options, if it turns out that Y or Z are preferable.

Lifecycle option are valuable if there is uncertainty about the future; the more uncertainty there is, the higher the value of having lifecycle options.

Lifecycle options avoid the need for precise predictions about the future.



Chapter 5

Behavioural issues in ASR

Not just events, events ... also people, people!

Ziona Strelitz

Ziona Strelitz is a social scientist whose career has focused on how people use buildings. She founded the consultancy ZZA and wrote the book *Buildings that Feel Good* (2008), based on her experience of investigating office buildings in use.

Virtual ... but still real

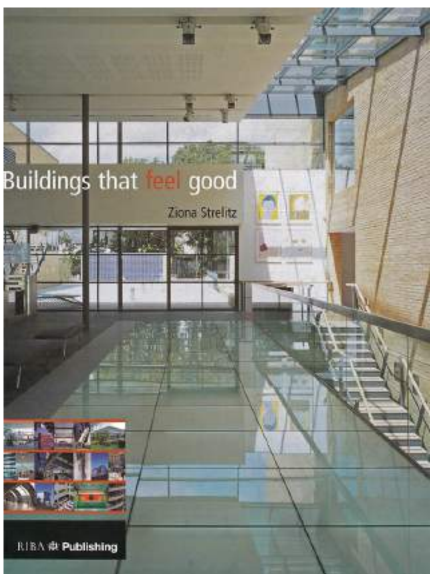
A decade into the 21st century, one is struck by two apparently contradictory phenomena.

The previously vaunted (or for real estate developers and investors dreaded) prospect of an entirely virtual world has not come to be, but Mel Webber's 'non-place urban realm'[1] or 'community without propinquity' is indeed with us, existing in parallel with the continued use of buildings as places of physical congregation. This includes buildings' continued elective use – much of the presence in buildings is by people who have a choice over whether to be there or not; their physical attendance in the space is not mandatory.

At the same time, building utilisation rates are frequently far below design capacity, with occupancy rates of 40% or so not uncommon. This involves many inefficiencies: for those providing the space, unnecessary rent; for those operating the space, wasted resources on building servicing; for those using the space, too little activity or buzz; from a societal perspective, undue environmental impact with an excess of buildings that thereby entail superfluous land use, embodied energy and energy in use.

If simulation can better predict demand for building use, it promises obvious benefits in terms of sizing the supply of built space. In addition, the thinking involved to inform effective modelling is itself instructive, nor just for more realistic assessment of demand, but also for relevant innovation in built environment concepts and products.

Effective prediction is about anticipation at scale. The choices that any specific individuals make in shaping how and where they spend their time are not pertinent, but they are relevant in aggregate. And the factors that underpin them are relevant to our understanding of what shapes demand for existing settings, as well as our potential to generate productive innovations in supply.



Behavioural factors

What do we know about the behavioural factors that influence people's decision-making regarding when and where they undertake activities over which they have temporal and/or locational discretion? What can we learn from empirical research to inform relevant model-building and calibration? And how can the thought required for effective modelling help shape useful approaches in evolving the built environment?

In support of both conceptual clarity and better base data, we need to widen the notion of 'convenience' that we define as central in activity-space decision-making. The vantage points of the corporate real estate supplier and theoretical modeller typically focus on a framework of utilitarian rationalism, prioritising factors like travel time and cost, and the availability and quality of support resources in this venue or that.

However, qualitative research on

people's choices expands the repertoire of identified factors that influence individuals' behaviour. Drawing from decisions regarding where to work as an index, significant **positive** forces are evidenced at play. These include sociability at the workplace, the image that a given workplace projects – and then confers on its users, the sense of privilege, endorsement and belonging that people associate with being there, the access to colleagues' skills and experience, the potential practical advantages of being present in a physical marketplace where one's visibility and encounters can trigger new opportunities, and the sheer contrast from home.

Other relevant factors represent **negatives**. Rather than home being presumed to be a venue of preference – typified as relaxed, physically close to personal and family involvements, and dispensing with the time and energy spent on travel, individuals might find it too constrained and constraining – physically and/or socially, and it might feel isolating, lonely, unstimulating, unmotivating and disassociated from the goals and nerve centre of work[2].

There is a whole raft of factors that shape who is available for work, at what stage of the life cycle, and with what associated pulls, counter-pulls and pressures in their lives[3]. These forces are both demographic and fiscal, and they change over time, generating new confluences and disjunctions. The point is easily made by reference to women's extensive involvement in the contemporary world of work relative to several decades ago, resulting in new pressures at the interface of people's work, family and personal lives.

The guts of life

Whilst technology has catalysed the significant potential for new ways of organising ourselves in work as well as other spheres of activity, it has also fuelled the new sense of autonomy that individuals feel – relative to their work choices, family choices, other salient interests and commitments, and the trade-offs and linkages they seek to make between these in holding their lives together. Thus the realm of people's interests, values and emotions have acquired increased importance in the way they shape their activities, through the specific decisions on how they invest their time and other resources in given spheres like work and family, and in optimising their fulfilment of interests and commitments across their range of involvements. This is the guts of life: writing a good report, playing a part in the work team, being in touch when your manager wants to connect, avoiding being made redundant, reaching your baby's nursery in time, being 'there' when your child comes back from school, buying food, running one's home, keeping fit, remaining culturally engaged, playing sport, attending to ageing parents, seeing friends, having time to read, and so on. This tiny sequence of examples indicates the substance and rich detail that a responsively expanded definition of 'convenience' will comprise.

Whilst individuals make their own choices with the cards and values that they hold, and the options and constraints that they perceive, there are consistencies across them, as evident in the existence of social patterns and trends, even though the range of patterns in work and life styles may be expanding. One strong current driver is the widespread interest in work-life alignment[4]. This influences many specific decisions about where and when to work, encompassing factors that activity-space research models can be scoped to incorporate.

Attention to a wider range of behavioural factors derived from research on living patterns and aspirations can also contribute to activity-space modelling for new supply strategies.

Choices

People's current choices are heavily influenced by existing patterns of urban development. In respect of the workplace, this frequently involves large buildings and campuses, delivered in support of real estate economics, with the focus on office consolidation. The solution forces a largely binary decision for many individuals – to go to the office or to work from home. A more distributed range of networked work venues may involve a more productive set of choices for individuals seeking to optimise their engagement in all spheres of life, including work. It also offers the promise to be more sustainable environmentally. On the supply side, it implies a different cost base.

Enriched activity-space modelling can help to inform, test and optimise these possibilities.

1. Melvin M Webber, 'The Urban Place and the Non-Place Urban Realm', in *Explorations into Urban Structure*, ed Webber *et al.*, Pennsylvania University Press, Philadelphia, 1964

2. Ziona Strelitz, *Liveable Lives, Office Push and Pull: Common Employee Predicaments*, Regus, London, 2010

3. Rhona and Robert N Rapoport and Ziona Strelitz, *Fathers, Mothers and Others,* Routledge & Kegan Paul, London and Henley, 1977

4. Ziona Strelitz and Michael Edwards, *Getting it Together: The Work-life Agenda and Offices*, British Council for Offices, London, 2006

INFORMAL CONTACTS

It has become a truism that in the digital future the primary role of buildings (other than homes) will be to provide places to meet, rather than places for individual activities. And not just places for planned meetings, but also, perhaps more importantly, for unplanned encounters – chance events that can trigger the unpredictable creative spark.

Dispersed activities

In the era of ubiquitous digital connectivity, there are fewer and fewer reasons for travelling to particular locations at particular times to carry out activities – as we used to go to shops for shopping, to libraries for journals, and so on. Now we can do these things by computer wherever we are, whenever we choose. There's a huge gain in convenience, but one penalty is that we don't meet other people.

To counter this trend, the encouragement of person-to-person encounters is increasingly put forward as a primary objective in the design and management of the built environment. It's an attractive idea, although the benefits are hard to quantify.

Chance encounters – design

How can opportunities for chance encounters be maximised? Here are two examples that depend on spatial layout – one occurring by chance and the other planned.

In a traditional Oxbridge college, to go from one part to another you walk in the open air – and, as well as getting wet on rainy days, you meet people. In contrast, buildings that are designed for 'efficiency' have related functions close to one another and connected by short circulation routes, minimising opportunities for encounter.

The Isaac Newton Institute in Cambridge (Annand & Mustoe, architects, 1992) is for three- to six-month workshops for visiting mathematicians. There are enclosed studies for the visitors' private work, all opening off galleries around a central atrium with the stairs and a generous coffee area. This was a deliberate design strategy, intended to maximise encounters and interaction, and it has proved very successful.

Chance encounters – management

Chance encounters depend on spatial layout and also on activity-space management.

In many organisations people mix in social or refreshment areas, so the provision of these areas is vital – this is a design issue. But that isn't the end of the story. There is an instructive comparison between what happens at lunchtime in two parts of the dining hall at Pembroke College, Cambridge.

People using the main part of the hall usually come in groups and choose a table with a clear area that is large enough for their group, preferably leaving a gap separating them from neighbouring groups. When the hall is full the groups have to join up, but the preferred arrangement is characterised by distinct clusters of people who already know each other.

At the high table quite a different convention applies. Each newcomer takes the next available seat, regardless of who is already seated. This means that there is a degree of randomness in neighbour-pairs. Assuming that there is conversation and exchange of ideas when people sit next to each other, the high table convention with random neighbours means that once in a while there will be an unplanned creative spark that would otherwise have been lost.

To maximise opportunities for unplanned encounters it is not enough to have people in the same space at the same time – the social conventions of behaviour and interaction are also crucial.

Open-air circulation in the traditional Oxbridge college creates many opportunities for informal encounters (Pembroke College, Cambridge, left).

The Isaac Newton Institute, Cambridge (right), was designed to maximise encounters between occupants, whose rooms all open onto a central atrium. One professor said that when he had work to do, he would use the lift rather than the stairs to get to his room unobserved.

Chance encounters – simulation

A small-scale simulation of Pembroke College hall shows the impact of seating conventions on cross-disciplinary encounters. The simulation is of a lunchtime when both the main part of the hall and the high table are a little over half full (*see* simplified diagram, right).

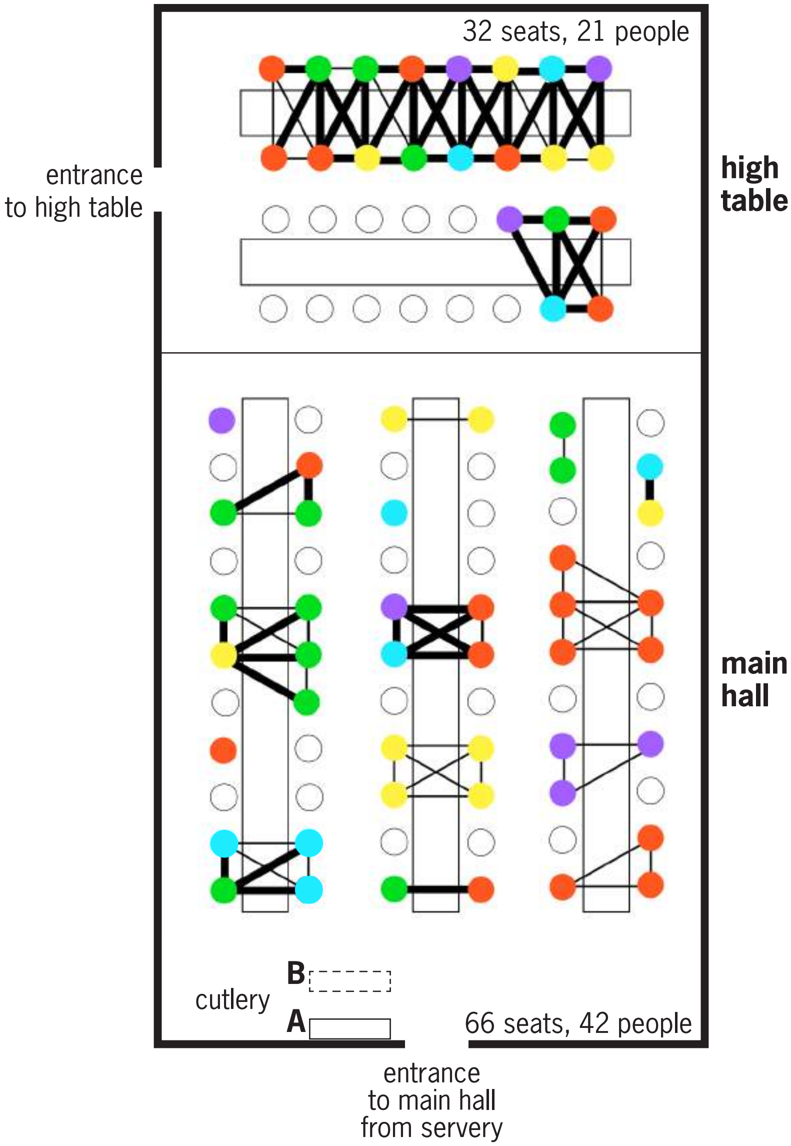
The people in both parts are from five disciplines of varying size, shown by colours. The numbers from each discipline in the two parts of the hall are generated using random numbers. The seating sequence on the high table is simulated; in the main part of the hall the clusters are placed manually.

Where neighbours are from the same discipline they are linked by a thin line; where they are from different disciplines a thick line is used.

In the simulation shown, each person in the main part of the hall, where most people sit in 'private' discipline clusters, has an average of 2.1 neighbours; of these 64% are from the same discipline and 36% are cross-disciplinary.

On high table, with sequential seating, each person has an average of 4.1 neighbours, 16% within-discipline and 84% cross-disciplinary.

In this simulation, people following the high table seating convention have **four times** the likelihood of a cross-disciplinary encounter.



Two first-year Architecture students were asked to observe how people entered the main hall in Pembroke College and chose where to sit.

The students noted that people get their meals in the servery, enter the hall carrying trays, collect cutlery from the trays on the left (position A on the diagram above), and then choose somewhere to sit. Most people enter and sit in groups. When a newcomer enters alone, he or she has to scan the hall to locate a group of friends to join. If no friends can be seen the newcomer does not join a group of 'strangers', but often gravitates to the outermost rows of seats below the windows, facing the the hall (the familar combination of prospect and refuge).

The students came up with an idea for improving this mechanism by modifying the spatial setting: if the cutlery trays faced into the hall (position B on the diagram), rather than being against the end wall, it would provide a vantage point for newcomers to pause and scan the hall for friends. Now they have to do this in a few frantic seconds as they walk from the cutlery trays to the tables, while attempting to maintain a nonchalant air – a tricky exercise, especially for people who have yet to establish a wide circle of friends and find a hall full of strangers intimidating.

GROUPING AND SOCIAL NETWORKS

There is a correspondence between the structuring of activities in a society and the building types it develops. This also applies at the scale of an organisation and its building: the nature of the activities calls for congruence in spatial provision.

Is behaviour predictable?

Building designers and managers sometimes express frustration at the perverse behaviour of users.

This shows a mismatch between designers' or managers' expectations and real users. Behaviour is of course very complex, but that should not be an excuse bad outcomes but a stimulus for more effective user research (Fawcett, 1995).

Sometimes behaviour appears to be complex but turns out to be surprisingly simple. For example, the number of journeys per day between two cities can be estimated from their populations and the distance between them – without having to know the reason for a single one of the journeys.

There is a valuable regularity in the way that a population divides itself into groups. Observational data on 'free forming' groups in the 1940s and '50s found regularities that followed the positive poisson distribution (Coleman & James, 1961) – the same result can be derived mathematically without observations (see page 52 above).

This regularity is valuable in predicting behaviour and ensuring a match between activity demand and spatial provision.

Defensive behaviour

People are naturally anxious about change to a familiar activity-space convention.

One change that is often regarded as a threat is space-sharing. It is a reasonable activity-space strategy in buildings where people are away from 'their' space for long periods, and utilisation is therefore low and wasteful. This is an increasing trend with the take-up of digital technology.

When a space-sharing scheme is introduced it is common for people to cling on to ownership of space. An environmental psychologist made observations of this phenomenon (Brown, 2009), and classified anti-sharing strategies into four types:

- identity-oriented marking
- control-oriented marking
- anticipatory defending
- reactive defending

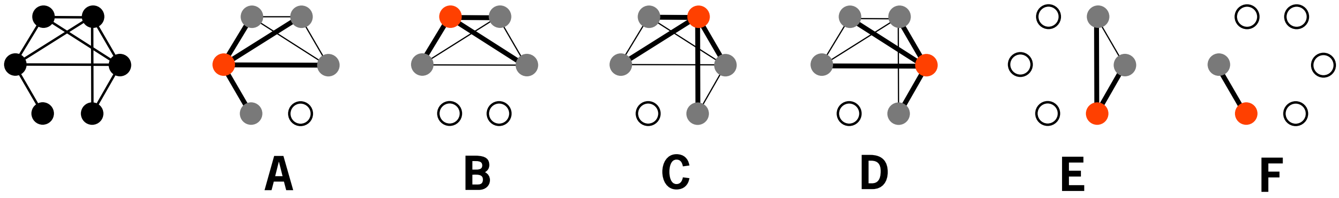
Within the four types he observed 32 distinct defensive actions and counted their frequency of occurrence.

He then interviewed the actors in this drama and applied personality tests.

One has a shock of recognition in seeing these all-too-familiar territorial strategies dissected. The implication is that they are negative behaviour patterns, but that is probably wrong – they reflect most people's desire to minimise the perceived risk of situations that impede the achievement of objectives, or that would be uncomfortable or embarrassing.

Activity-space planning must attempt to understand and to take account of behavioural realities.

There are innumerable reasons why visitors on the steps of the Metropolitan Museum, New York, at 4.29pm on 11 April 2008 (left), or people enjoying the sun in the City of London at 1.08pm on 7 May 2008 (right), happened to fall into groups of 1, 2, 3 ... or more people, but regardless of the reasons we can be confident that the group sizing followed the positive poisson distribution that is characteristic of free-forming groups.

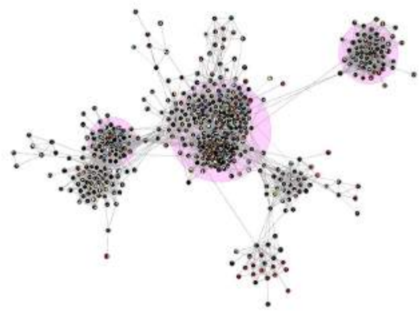


A social network can be represented by a graph.

The social network of six individuals is shown in the first graph in the diagram (above left). All the individuals are included in the whole-group network, but they have different individual networks, shown in the six sub-graphs (above right). The owner of the sub-graph is coloured red; a heavy line joins the owner and his/her acquaintances, coloured grey, and a light line shows whether the acquaintances also know each other; people not known by the owner of the sub-graph are shown in outline only.

Individuals C and D are the most fully integrated with the whole group, and share the same sub-graph connectivity. A has the same number of acquaintances, but their mutual connectivity is lower. B is ‘trapped’ in the A-B-C-D clique. E and F are connected to the group, but only weakly.

Real social networks are much larger. The sub-graph of a mid-20s knowledge worker in London (right) shows acquaintances in distinct clusters; people in separate clusters do not usually know each other. The size and density of these sub-graphs vary between individuals.



Strong activity-space patterns can emerge purely from people’s tendency towards habitual behaviour.

In this experiment twenty agents choose between five alternative rooms (right). Their initial choice on day 1 is completely random.

The agents are from three different groups, and they like to share the same room with others from their group. So whenever an agent encounters a member of the same group in a room, that room’s attractiveness score goes up by one point.

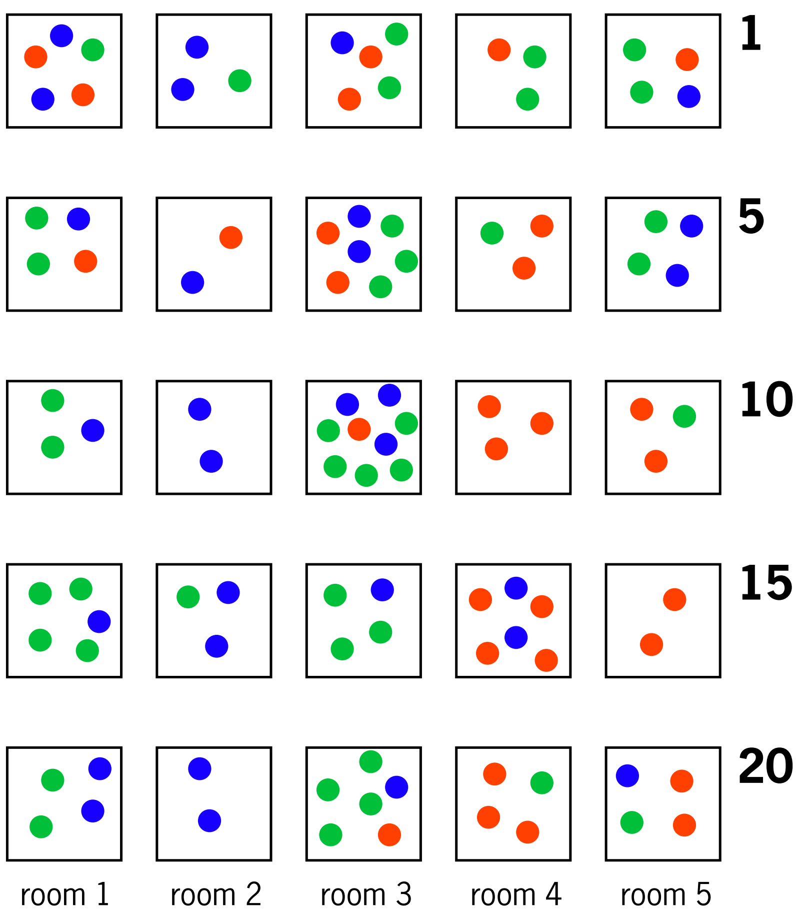
When choosing rooms on successive days, the agents’ choices are weighted by previous encounters; and their new encounters in turn modify the rooms’ attractiveness scores.

Over time some rooms become popular for one particular group, whereas other groups favour different rooms. This is from a random starting point; every time the simulation is run it produces a different, and therefore unpredictable, pattern of behaviour.

Twenty days were simulated – every fifth day is shown. By the end of this simulation the green group tended to favour rooms 1 and 3, and the red group rooms 4 and 5; the blue group’s preferences were less stable.

Even with emerging preferences, there is still an element of randomness in room choice that runs counter to the dominant pattern. This would diminish but not disappear in a longer model run.

Habitual behaviour is a powerful and not easily predictable force in activity-space planning.



WORK-LIFE HARMONISATION

For most people in the pre-digital world, the times and places for work were imposed by employers and non-negotiable. What happens when the boundaries become blurred?

Work is changing

The content and context of work is changing in the digital economy. This has not gone unnoticed. But studies of new ways of working do not provide many insights about knowledge workers' use of space and time, or how demand at employers' premises can be expected to change.

In the absence of survey data the Activity-Space Research initiative has addressed this question with an agent-based simulation model.

Performance and convenience

When they have a choice of times and places for work, people evaluate and rank the alternatives, and choose the one that is most favourable.

This attractiveness of alternative places is simulated by scoring two attributes:

- **performance**: effectiveness for performing work tasks
- **convenience**: effectiveness for dealing with non-work commitments.

With old-style conventions, offices have a high score for work-related performance and a low score for non-work convenience, whereas homes have a low score for performance and a high score for convenience. In the modern world, the convenience scores of offices are higher, and the performance scores of homes are also higher with distributed computing.

Each alternative place has two scores, one for performance and one for convenience.

Individual variation

The balance between the performance and convenience scores varies with time, so that different places are selected at different times. This is modelled with a time-varying work-life index.

There are strong social conventions about the hours of the day that are devoted to work or to personal life – this is reflected by a work-life index in which performance has a high weighting for weekday mornings and afternoons, and convenience a high weighting at other times.

People are not all the same and in the model each individual agent has a work-life index that varies from the average – the amount of variation reflecting the take-up of digital opportunities.

The simulation model evaluates and ranks the alternative places of work for each agent, creating a weekly diary. Analysis of the diaries of many agents is a way of studying the process of behavioural change, and the changing pattern of demand at employers' premises.

Emergence

An important feature of agent-based models is emergent behaviour that was not anticipated in the model design.

The changing pattern of home-based work was an emergent outcome in this model. In pre-digital scenarios there was no home-working, unsurprisingly. With moderate take-up of digital opportunities some daytime office work transferred to evening home-based work – this is familiar today. With a more complete digital take-up the model suggested that home-based work would increase further – but it would mostly take place during the daytime, not the evening.

This would be a significant reversal of the currently perceived trend towards a 24-hour working day.

Looking ahead

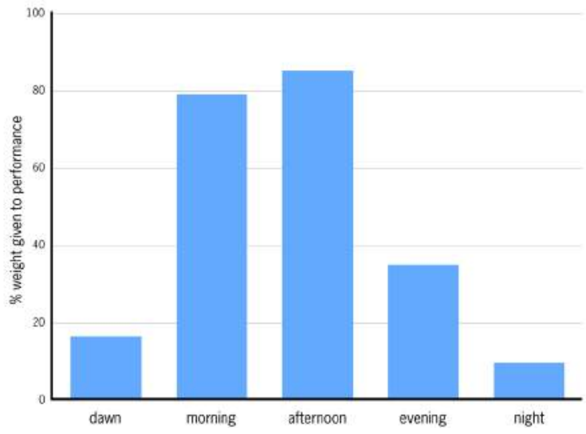
The findings from such a simple model are not definitive, but they should stimulate fresh thinking about trends in knowledge work – questioning the conventional wisdom.

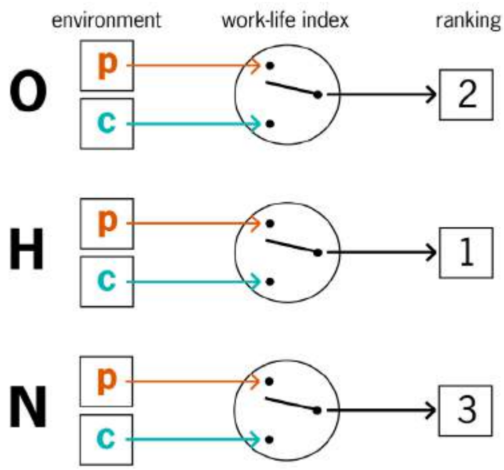
This model investigated the choice between working at home or in the employer's office, but for an employee in a modern service industry there are many more locational choices, including the array of alternative settings in modern offices.

There is plenty of scope for the development of more advanced simulation models and behaviourla choice.

For more information, see ASR Paper 4 (page 80).

	office	home work	non-work
traditional environment			
performance	3	1	0
convenience	0	2	5
modern environment			
performance	5	4.5	0
convenience	2	3.75	5





The three diagrams explain the components of the agent-based simulation model of work-life harmonisation.

Above: The alternative locations which the agents choose between are described by their performance and convenience scores, on the scale 0–5 (5 being most suitable). In this example there are three alternatives to choose from, and their scores are given at two levels of digital adaptation – **traditional** or pre-digital, and **modern** when digital opportunities are fully exploited (in the future).

Top right: The average or reference work-life index shows the weight given to performance at different time of the day. It is derived from census data. Performance dominates during the middle of the day, but is is given less weight at other times. Individual agents' work-life index values vary randomly from the reference, the amount of variation reflecting the level of adoption of digital opportunities.

Right: The performance and convenience scores are combined using the work-life index to produce a ranking of the alternatives. Because the work-life index varies though the day, the agents choose different alternatives at different times. Because the agents have unique work-life index values, they make different choices from each other.

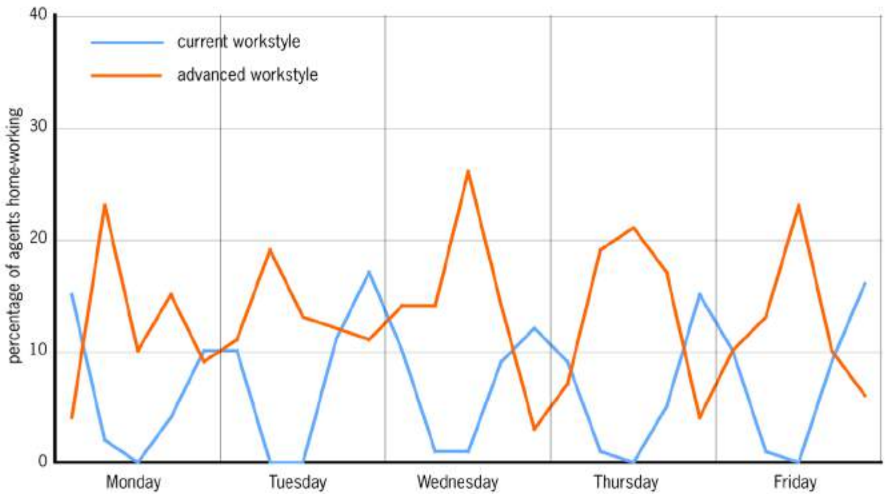
The aggregate of many agents' diaries gives an overall picture of behaviour for the given performance and convenience scores and work-life index. The imapct of changing the scores or the index can easily be compared by re-running the simulation model.

Graph showing an emergent finding from the simulation model of work-life harmonisation, relating to the timing of home-based work.

With a current workstyle (blue line) most home-based work takes place before and after the conventional working period which is in the middle of the day.

With an advanced workstyle (orange line) the pattern is inverted. There is more home-based working – but it is now concentrated in the middle of the day, with a reduction at early and late hours.

The graph lines are irregular because they are the average from 100 independent agents' diaries. If the simulation was re-run with 1,000 or 10,000 agents the graphs would be smoother, but with the same contrast between current and advanced workstyles.



BUILDINGS IN USE

The Activity-Space Research initiative has prioritised the use of simulation models. But simulation models must reflect real world situations, and require calibration with real world data. This section outlines a case study investigation of real buildings designed for knowledge work.

Environments for knowledge work

Many architects and interior designers have put forward ideas for the digital workplace (including Andrew Chadwick's radical proposal of 1982 that a portable computer would be the 'Office of the Year 2000' – *see* page 23). Many ideas have been acted on, so there is now a stock of buildings in existence that can be considered as full-scale experiments in design for knowledge work, funded on a scale that academic researchers could never dream of. These buildings, or experiments, are an immensely valuable research resource.

How can case study investigations extract knowledge from these full-scale experiments?

Case studies: selection

Data collection at case study sites requires a great deal of time and effort, so it is essential to choose only the most valuable sites for investigation.

In a case study project on recent buildings for research and development organisations, a very long list of candidate projects built was drawn up from publications and website queries. In total 180 buildings were identified, located in Europe and the USA.

A review of these projects led to a long list of 86 candidate projects where the building configuration was predominantly horizontal and interaction or flexibility were mentioned as an explicit design objective. The 86 designs were classified into seven types.

A shortlist of 20 buildings was then chosen – examples with a clear expression of the features of the respective types and an accessible location. The owners were contacted with a request to allow research access.

A minority were agreeable. The effort put into the selection process, which took several months, was ultimately rewarded by a set of recently built case studies in Germany and Britain.

Case studies: data collection

A full day visit was made to four case study buildings, and the following information assembled:

- personal impressions, observations and photographs
- architectural drawings
- information about the use of space and time in the buildings
- building managers' report of experience in use.

In addition a web-based questionnaire was circulated to users of the buildings. In this project it was not feasible to carry out monitoring.

Case studies: interpretation

Every building and building user is unique, so a great deal of case study data is site-specific. Comparison of features that vary between case studies is only worthwhile if the variations occur in a similar context.

The literature on research and development buildings suggested that four key factors should be considered:

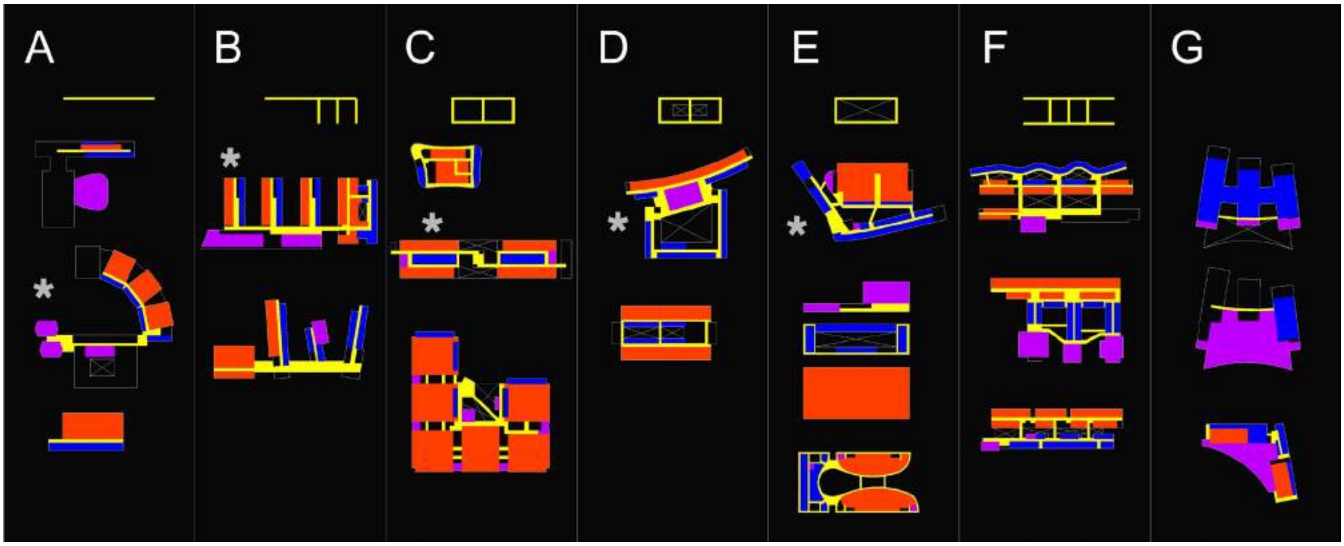
- interaction
- privacy
- flexibility
- perception of comfort.

These factors were analysed in the case studies, providing empirical evidence to support three findings.

1. There is a positive relationship between: a) physical provision for interaction and b) satisfaction with physical surroundings.
2. There is a positive relationship between: c) perception of comfort and d) satisfaction with physical surroundings.
3. There is a positive relationship between: e) physical conditions conducive to interaction and f) physical conditions providing privacy.

Despite the challenges of undertaking case study research, and the difficulty of deriving general principles from the individual cases, such studies are essential for validating the theories of activity-space research.

This case study research by Dr Erika Bataglia of the University of Sao Paolo, Brazil, was carried out when she was a visiting scholar at the Activity-Space Research initiative in Cambridge in 2008-09.

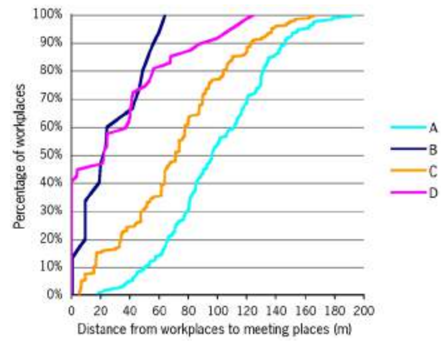


Configuration diagrams of the of the 20 shortlisted research and development buildings, classified by their basic plan arrangement. The case study set included one example each from types A to E, marked with asterisks.

laboratories
offices
meeting rooms
corridors

Cafeteria in Case A

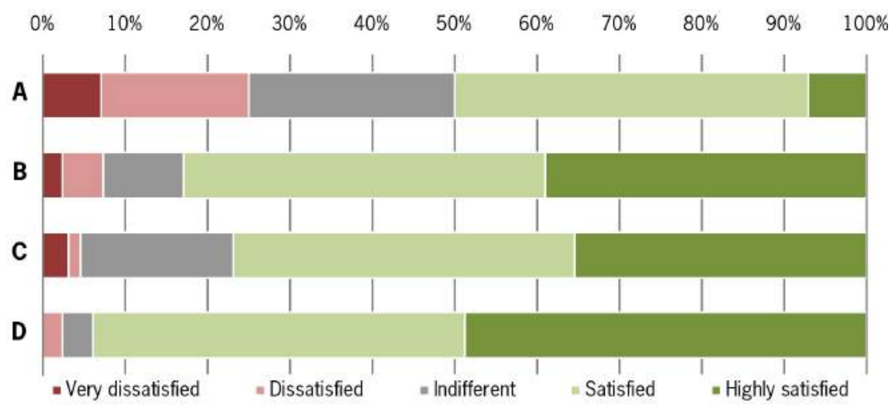
Cafeteria in Case C



In each case study, data was collected about the size, character and location of spaces for informal interaction (corridors, local areas, cafeteria), formal interaction (lecture halls, seminar and meeting rooms), and laboratories.

The spaces for informal interaction were compared. The graph (above right) shows the distance from the workpaces. The cafeteria in Case A is distant from the workplaces and rarely occupied, while the Case C cafeteria is more attractive, more central and better used.

This data about the spaces for informal interaction can be compared with the overall levels of satisfaction shown in theß histogram (right): Case A with an unattractive and distant cafeteria is the least well liked of the buildings; of the other three, Case C has the more distant cafeteria and a somewhat lower satisfaction level.



RESPONSES TO THE ASR PROPOSITION

Up to now the Activity-Space Research initiative has been university-based and has relied on the experience of the Workshop participants to ensure that the research engages with real world issues. This is a provisional position, until the ASR approach is applied directly to real world problems.

Access to real-world data

Most of the Activity-Space Research studies have taken the modelling approach that builds and testsa large number of abstract and simplified models, in contrast to the case study approach that investigates a small number of real buildings in detail. However, the ASR models have to be based on real situations.

The participants at the ASR Research Workshops (*see* page 14) have acted as external critics of the modelling studies, and by taking part in Workshop exercises they have provided valuable datasets. The participants were self-selecting and interested in architectural research, but even so they brought a wide variety of real world experience.

This section presents the results of some of the Workshop exercises that have not been reported earlier in the book.

How much theoretical knowledge do people in the real world need? In 1936 J M Keynes remarked that, ‘our basis of knowledge for estimating the yield ten years hence of ... a building in the City of London amounts to very little and sometimes nothing’, yet new projects are built (left British Land’s 165m high Broadgate Tower, SOM architects, completed 2009). This is risk-taking on an epic scale, but investors could manage risk with ASR modelling studies.

Workshop 10

This Workshop was about ‘Space management for uncertain demand’. It included a presentation of the yield management model for the optimal capacity of shared accommodation (*see* page 40 and ASR Paper 3, page 78).

The optimum number of workstations given by the yield management model depends on two factors – first, the importance attached to avoiding congestion, when more people turn up than can be accommodated; and second, the level of unpredictability of demand for accommodation.

To investigate these factors the participants at the Workshop were asked to imagine themselves in the position of the facilities manager in their organisation, and indicate how strongly they agreed or disagreed with six statements covering these issues.

The result are shown opposite. They seem to indicate a mixture of confidence and caution – downplaying the problem of potential congestion but accepting fairly extreme measures to ensure that it never occurs.

It will be important to explain to facilities managers that yield management requires trade-offs – it can bring tremendous benefits, but only in exchange for a calculated risk of congestion: no risk, no benfit.

Workshop 14

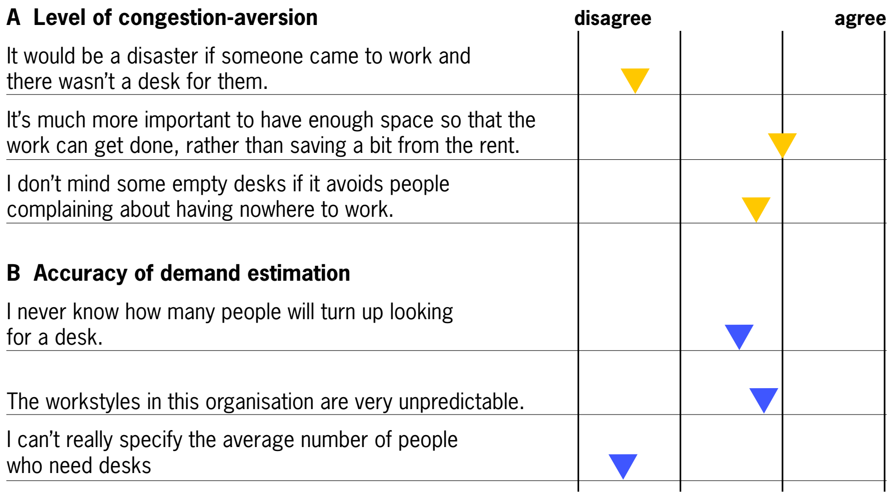
This Workshop was about ‘Scenario-building – preparing for the future’. The basic argument for scenario-building is that you can only prepare for future events that you can identify; everything else has to be left to chance.

In the Workshop exercise the participants were asked to mark their level of agreement with twelve propositions about scenario-building – six of them optimistic and six pessimistic.

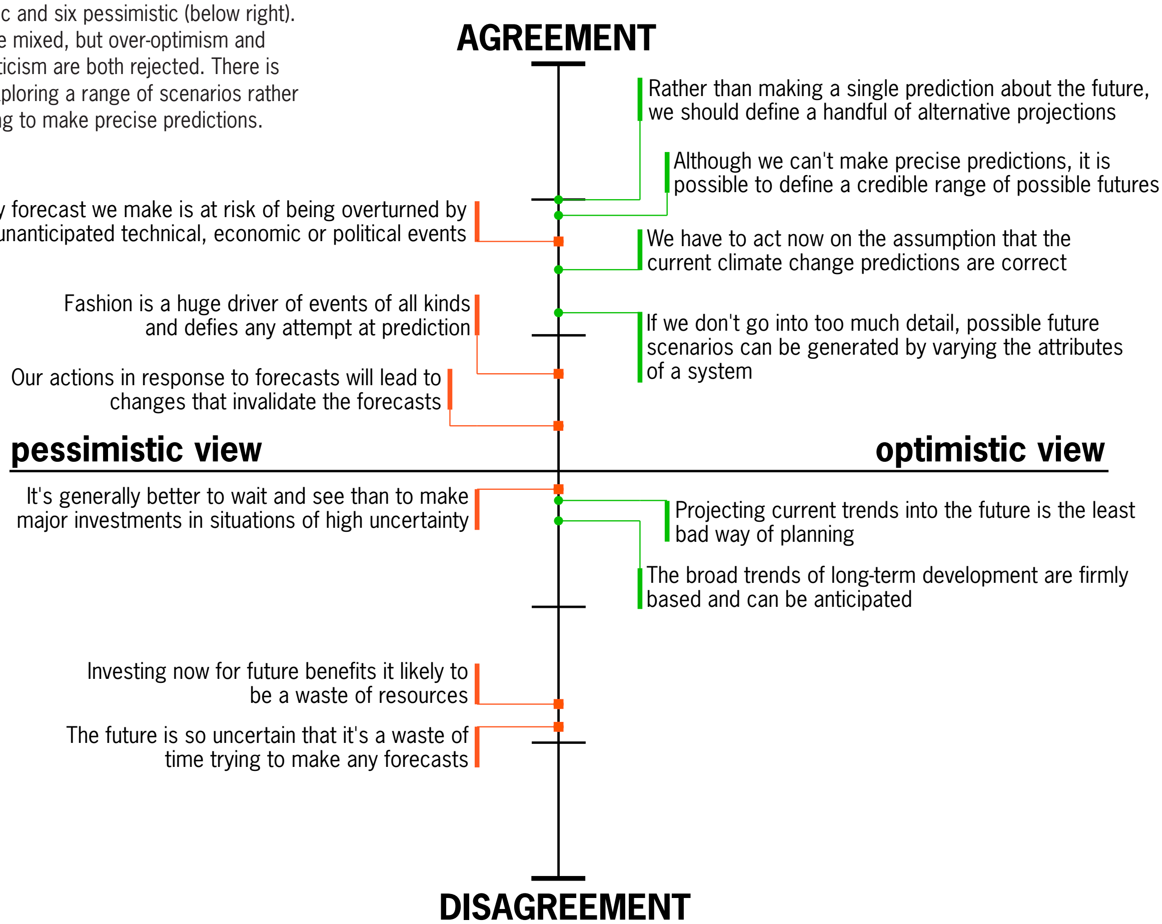
Overall there was more agreement with the optimistic than the pessimistic statements, but the participants did not display over-confidence.

The responses may reinforce a key point about scenario-building – that it is very different from prediction. To be useful, scenarios should broad in scope and not over-detailed.

The participants at Workshop 10 were asked about the risk of congestion when shared workstations are used. They indicated agreement or disagreement with six propositions, three about congestion-aversion and three about estimation of demand (right); these are critical for the yield management model. The results show a mixture of confidence and caution. This may indicate inconsistency, or more likely that the issues have not yet been fully thought through. This is a challenge for applying the yield management model in real situations.



At Workshop 14 the participants were asked about their attitudes to prediction and scenario-building, by indicating agreement or disagreement with twelve propositions, six of them optimistic and six pessimistic (below right). The results are mixed, but over-optimism and extreme scepticism are both rejected. There is support for exploring a range of scenarios rather than attempting to make precise predictions.



Chapter 6

SUMMARIES OF ASR RESEARCH PAPERS

ASR PAPERS – 1

Publication: *Journal of Corporate Real Estate*, vol.9, no.1, pp.5-24, 2007

Space-time management and office floorspace demand: applied experience and mathematical simulations

William Fawcett and Andrew Chadwick

This paper presents two approaches to analysing an organisation's spatial demand, one developed in real-world consultancy and the other as part of the Activity-Space Research initiative.

The real-world approach called Organisational Modelling was developed by Chadwick International and has been applied in several large office-based organisations. In every case the results have shown a high degree of inefficiency, with far more workstations and floorspace than necessary. The organisations operate with low *utilisation* to use a familiar measure of workplace performance.

Organisational Modelling begins with a survey of the organisation's existing premises – the Real Estate – and an observational 'clipboard' survey of the actual use of workstations.

Starting with a blank sheet of paper, an efficient spatial arrangement for the organisation's current personnel and activities is envisaged. Experience indicates that a 10% 'fit factor' should be added to this efficient arrangement to allow for layouts in actual office buildings. This gives the Virtual Estate (type 1), measured in square metres. In real cases the Virtual Estate (1) has shown floor area savings of between 25% and 73% compared to the Real Estate.

The Virtual Estate (1) uses *space* more efficiently, but it is also possible to use *time* more efficiently. Observational surveys in the Real Estate show that workstations have periods of non-use, sometimes long periods. The number of workstations that are in fact simultaneously occupied can be established. This number is the basis of the Virtual Estate (type 2), again measured in square metres.

In actual cases the Virtual Estate (2) has shown additional floor area saving of between 20% and 25% compared to the Virtual Estate (1). The Virtual Estate (2) is only viable with new space-time management, because the same number of employees share a smaller number of workspaces. In contrast, the Virtual Estate (1) requires no change in operating practices.

Organisation Modelling

The Organisational Modelling method uses three important measures:

- **static occupancy ratio** (SOR): an organisation or department's floor area divided by the number of workstations (measured in m^2)
- **dynamic occupancy ratio** (DOR): the floor area divided by the number of people reporting to the organisation or department (m^2)
- **space-time multiplier** (STM): the ratio of static (SOR) to dynamic (DOR) occupancy ratios. When STM is 1 there is a workstation for everyone reporting – higher numbers indicate more efficient management.

In actual cases the STM values for the Real Estate varied between 0.8 and 2.6; for the Virtual Estate (2) it varied between 1.4 and 3.8. The STM is equivalent to the desk-sharing ratio, which compares the number of people reporting in an organisation with the number of desks.

Simulation

Organisational Modelling focuses on the move from a stable one-desk-per-employee approach to office management, to a dynamic approach that involves desk-sharing. It is more efficient but also potentially riskier, because the number of employees wanting a workstation at any particular time is uncertain. Organisations moving to dynamic management cannot run observational surveys before making the change, so there is a obvious role for simulation modelling.

When demand is uncertain the one statistic that is often relied on is the average demand. It can be derived from observational studies of an organisation in its existing premises.

Knowing the average demand, how many workstations are needed? If the number of workstations is equal to the average demand it is obvious that there will be problems, because demand exceeds the average for half the time.

Two mathematical simulations in the paper explore uncertain demand when the average demand is known. They both use hypothetical data.

The first experiment (outlined on page 35) simulates 250,000 'snapshots' of demand for 20 employees whose average demand is 10 workstations. It's just possible that all 20 employees might decide to come to the office at the same time, but this is highly improbable. 12 or 13 workstations would be sufficient for 95% of the snapshots, and 14 or 15 for 99% of the snapshots. Increasing the margin between the average demand and the number of workstations reduces the risk of congestion – but it also lowers workstation utilisation.

The second experiment simulates 'episodes' of demand for 12 employees in an organisation with flexible working (*see* specimen output on page 37). Each employee has a sequence of 'on-site' and 'away' episodes. The average demand is 6 workstations and just 6 workstations are provided. During a simulation of 100 time periods there are inevitably occasions when an employee finishes an 'away' episode and comes to the office wanting to start an 'on-site' episode, but finds that all the workstations are already taken. The employee takes an extra 'away' episode and then tries again.

Despite the employees' average demand being sufficient to fill all the workstations all the time, the extra away episodes in the simulation means that workstation utilisation is 85%, not 100%.

For the hypothetical organisation in this highly simplified experiment, it seems that about 85% workstation utilisation may the highest that could reasonably be aimed for. An upper limit probably exists in all organisations, but its value will vary from case to case. Simulation with organisation-specific input data would give an indication of the realistic upper limit of utilisation.

Diagram showing that the floor space of an organisation – its Real Estate – can be reduced to the smaller Virtual Estate (type 1) by increasing space efficiency, and further reduced to the Virtual Estate (type 2) by increasing time efficiency.

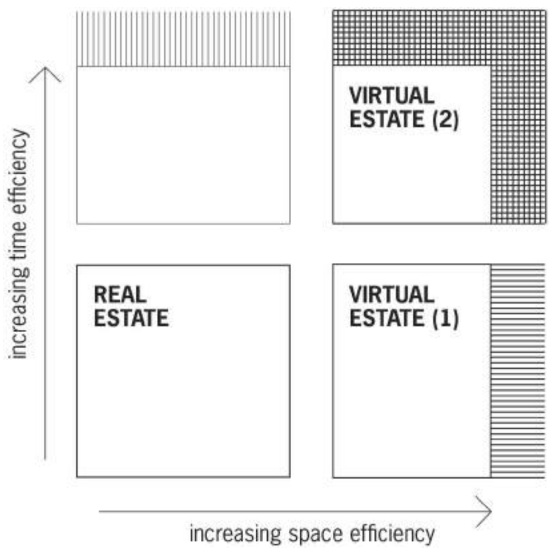
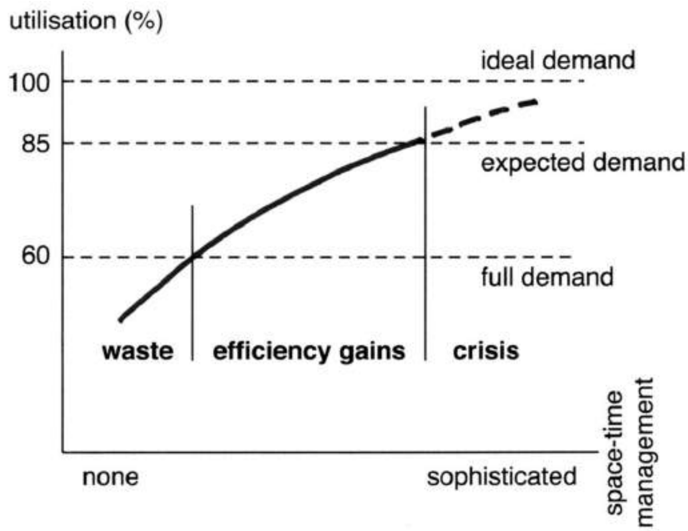


Diagram showing that in the experiment workstation utilisation could be rise to about 60% by eliminating waste without any change to space-time management, and further increased to about 85% by introducing efficient space-time management. Higher utilisation may be unachievable.



ASR PAPERS – 2

Publication: *Journal of Corporate Real Estate*, vol.11, no.1, pp.38-51, 2009

The interaction of activity, space and cost variables in office workstation sharing

William Fawcett and Danny Rigby

The second paper describes an extension to one of the mathematical simulations in the first paper, concerned with the sequence of 'in-office' and 'away' episodes for the employees in an organisation.

As before, an organisation with twelve employees is modelled. The individual employees' preferred sequence of episodes vary considerably, but as before their *average* demand equates to six simultaneous 'in-office' episodes.

The average duration of both 'in-office' and 'away' episodes is 3.5 time-periods (the length of a time-period is not defined – it might be hours, half-days or days).

In contrast with the first paper, this paper introduces two new variables:

- the **number of workstations** (it was fixed at the average demand in the first paper)
- the **employees' response** to being blocked (ie. wanting to start an 'in-office' episode but finding all workstations already occupied).

The employees' response is represented by the number of 'away' periods taken before trying again to start the blocked 'in-office' episode. If it is set to the value 1, the employees simply wait until a workstation becomes available – effectively, forming a queue. This implies a highly docile workforce. At the opposite extreme the employees might wait 40 time periods before returning – an extremely negative response that would be highly damaging for the employer.

The employees' response is something that organisations rightly worry about when considering the move from one-desk-per-employee management to desk-sharing. There are two potential problems: the employees' dissatisfaction with losing personal 'territory', and the loss of productive time if employees are blocked.

Systematic variation

With systematic variation of the new variables, the simulation produces the outputs shown in the 3-D chart. The column heights represent the average number of blocking events in simulations over 100 time periods.

The highest value is more than 60 blocking events. It occurs when there are just 6 workstations (the average demand) and only 1 extra away period after a blocking event. There is a queue for workstations in most time periods, but workstation utilisation reaches 92% – a very high value.

With more workstations the number of blocking events declines steeply. With 10 workstations blocking is rare but a necessary consequence is a drop in utilisation, to about 60%.

The chart also shows that the number of blocking events declines if employees take more away periods after blocking; this is simply because the extra away periods lower the workstation demand. The lower demand reduces utilisation.

Cost

In this paper the simulation experiments also considered cost, which can be incurred in three ways:

- cost of unoccupied workstations
- cost of blocking events
- cost of extra 'away' periods.

The first is incurred when there are more workstations than demand (oversupply of space), and the second and third when there is more demand than workstations (undersupply of space).

The table shows an extract from the

results of the experiment.

The data shows that if the cost of providing workstations is high compared to the cost penalty associated with blocking (case A), the organisation's priority will be high workstation utilisation, even though it leads to a high level of blocking.

If, on the other hand, the cost penalty associated with blocking is high compared to the cost of providing workstations (case B), the organisation's priority will be to minimise blocking, even though it leads to low workstation utilisation.

Optimal strategies

This simulation model of the workstation-sharing problem shows the intimate connection between activity, space and cost. The variety of outcomes that result from the combinations of a relatively small number of variables shows the importance of carrying out a systematic studies of a wide range of scenarios.

A preoccupation with high workstation utilisation, which can sometimes dominate the facilities manager's perspective, is an incomplete view of the workspace-sharing problem. The simulation runs show that in many cases, optimal strategies have relatively low workstation utilisation – but the relationship between overall efficiency and utilisation should always be tested with case-specific data.

The approach piloted by this model provides a basis for developing workstation-sharing strategies that balance the desire for space-efficiency on one hand, and human resources concerns on the other – objectives that sometimes seem to be in conflict but are different aspects of a single problem.

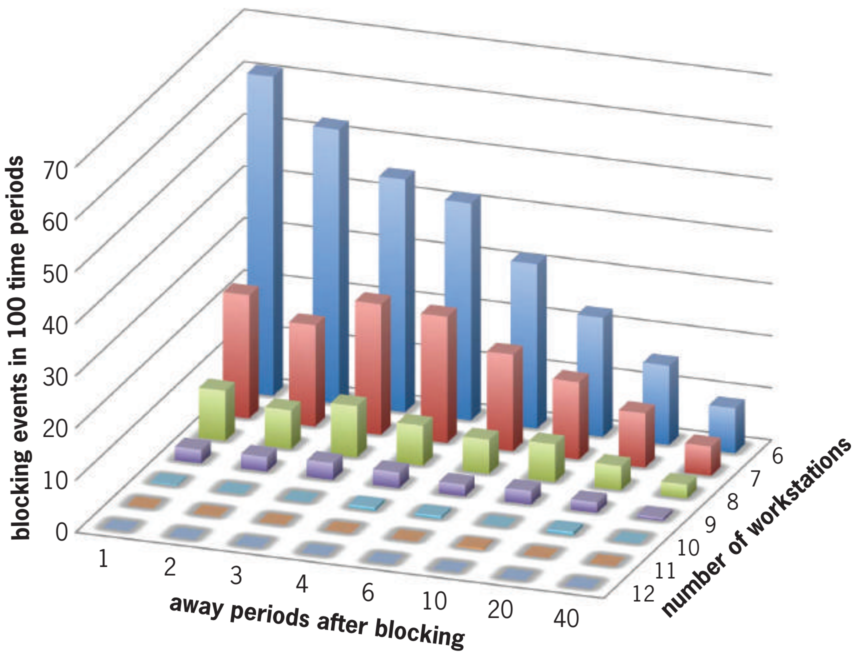


Chart showing the interaction of space and time variables. The height of the 3-D columns represents the average number of blocking events (more employees seeking workstations than workstations available) in simulations over 100 time periods, for different combinations of values for the number of workstations and the number of away period taken by employees after experiencing a blocking event. The highest columns occur when there are low values for both variables.

Table showing the interaction of space, cost and utilisation. It shows the average cost penalty per simulation run for different numbers of workstations, if employees take 3 away periods after experiencing a blocking event. The cost penalty is based on either (A) high premises cost and low blocking and displacement costs, or (B) low premises cost and high blocking and displacement costs.

For case (A) the lowest penalty cost occurs with 7 workstations (leading to high utilisation), but for case (B) the lowest penalty cost occurs with 11 workstations (leading to lower utilisation). It is evident that the pursuit of maximum utilisation is unlikely to be a cost-effective strategy.

	total of premises and blocking costs		
number of workstations	A. high premises cost, low blocking cost	B. low premises cost, high blocking cost	utilisation
6	73	528	87%
7	**62**	288	81%
8	65	118	73%
9	79	43	66%
10	102	15	60%
11	125	**12**	55%
12	149	15	50%

ASR PAPERS – 3

Publication: *Facilities*, vol.27, no.9/10, pp.339-356, 2009

Optimum capacity of shared accommodation: yield management analysis

William Fawcett

The first two papers demonstrated that when the demand for workspaces is uncertain (or varying), it is not a good strategy to make the provision of workspaces equal to the average demand. This is because half the time the demand will exceed the average, resulting in queueing. To reduce queueing, the number of workplaces must be greater than the average demand – but by how much?

The third paper shows how this question can be answered using the operations research approach, in which '... the scientific method is used to investigate the problem of concern. In particular, the process begins by carefully observing and formulating the problem. ... The next step is to construct a scientific (typically mathematical) model that attempts to abstract the essence of the real problem. It is then hypothesised that this model is a sufficiently precise representation of the essential features of the situation, so that the conclusions (solutions) from the model are valid for the real problem' (Hillier & Lieberman, 2005, p.2).

This operations research approach is the foundation for all the ASR studies.

The operation research method used in this paper is yield management, which is encapsulated in the 'newsvendor problem'. Each day a newsvendor buys a stock of papers from a wholesaler and sells them to the public at a profit. To maximise profit the newsvendor has to trade-off two competing objectives: he wishes to avoid ending the day with unsold papers that cannot be sold on the following day, favouring a smaller stock; but he does not want to lose sales by running out of papers when there are still customers willing to buy, favouring a larger stock. The optimum number of copies depends on the buying price and the selling price, which are known, and the expected number of customers, which varies from day to day.

There is a close analogy with the facilities manager who has to decide how many shared workspaces to provide when day-to-day employee demand is uncertain. Providing too many workspaces incurs a wastage penalty due to unused space (equivalent to the newsvendor's unsold papers); and if there are not enough workspaces some employees will be forced to queue (equivalent to customers who come to the newsvendor after all the papers have been sold). The newsvendor aims to maximise profit, but the facilities manger's task is to minimise the cost penalty from wastage or queueing.

Balancing supply and demand

Newsvendors may be unlikely to apply mathematical analysis but airlines do, to work out the optimum level of overbooking on flights. They know that some people with reservations will not turn up, so overbooking reduces the wastage from flying with empty seats. But more people may arrive than can fit on the plane, with the bumped passengers requiring substantial compensation.

Yield management balances the cost penalty of wastage if there is too little overbooking, and the cost penalty of compensation if there is too much overbooking.

Experiments and reality

Systematic yield management experiments were carried out and reported in the paper, partly summarised above (*see* pages 40-41). A number of 'principles of optimal capacity' were derived from these experiments and are reproduced here.

Reality

It would be extremely interesting to compare actual performance in shared workplaces with the results of the optimisation studies described in the paper. Lower levels of space-sharing than the optimum would be anticipated. The following hypotheses could be tested:

- If a facilities manager's overriding objective is to minimise the probability of displacement, there would be a high imputed displacement penalty cost, reflected in high cost ratio, high capacity and low utilisation.
- If a facilities manager is anxious about displacement and also uncertain about demand, risk aversion would cause an even higher imputed displacement penalty cost, leading to higher capacity and lower utilisation.
- Decisions about premises are long-lasting, making it hard to correct errors, again contributing to facilities managers' risk aversion, reinforcing the tendency to increase capacity and reduce utilisation.

These are valid considerations, but excessive caution is not justifiable. Management that cannot accept any risk of displacement is condemned to inefficient space utilisation.

Actual displacement costs should be quantified so that optimum capacity can be identified and used as a management target. Contingency plans for dealing with displacement events should be prepared.

If a move to higher levels of space-sharing is implemented, it is important to note that the facilities managers must also take action to mitigate social and practical problems of change management.

Theoretical basis

The well-established mathematical principles of yield management provide a basis for determining the optimum capacity of shared accommodation. The model involves simplification, but in yield management it has been found that, 'The justification for working with simplified representations of the underlying problem is that it works. Real-world applications have shown that this approach can lead to pricing decisions that generate additional profitability. By capturing 75% or so of the real-world complexity, mathematical analysis often does better than either human judgment or other [traditional] approaches to pricing' (Phillips, 2005, p.35).

The paper presents a mathematical foundation for the analysis of space-sharing. It requires further work, but it is hoped that the yield management approach will stimulate practical improvements in the design and management of shared accommodation.

Principles of optimal capacity

Definitions

The probability of the workplace operating with surplus workstations (lower demand than available workstations) = P_S.

The probability of the workplace operating with displacements (higher demand than available workstations) = P_D. (Note: $P_S + P_D = 100\%$)

Ratio between the cost of a displacement and the cost of a surplus workstation = Y (displacement cost is usually higher than surplus workstation cost, so Y is usually greater than 1).

First principle of optimal capacity for a given population

At optimum capacity, the probability of surplus capacity is equal to the probability of displacement times the cost ratio; that is, $P_S = Y \times P_D$.

Second principle of optimal capacity for a given population

As cost ratio Y between the surplus capacity cost and the displacement cost increases, the optimum capacity increases.

Third principle of optimal capacity for a given population

As the uncertainty about demand increases, the optimum capacity increases.

First principle of optimal loading for a given capacity

For the optimum population sharing a workplace of given capacity, the probability of surplus capacity is equal to the probability of displacement times the cost ratio; that is, $P_S = Y \times P_D$.

Second principle of optimal loading for a given capacity

As cost ratio Y between the surplus capacity cost and the displacement cost increases, the optimum size of the population sharing a given capacity decreases.

Third principle of optimal loading for a given capacity

As the uncertainty about demand increases, the optimum size of the population sharing a given capacity decreases.

ASR PAPERS – 4

Publication: *Building Research and Information*, vol.37, no.3, pp.312-324, May/June 2009

Modelling the use of space and time in the knowledge economy

William Fawcett and Ji-Young Song

It is widely accepted that working patterns are changing in the emerging 'knowledge economy'. Crucial drivers are:

- mobile telecomms and distributed computing
- educated, self-motivating and highly-valued employees.

This results in a considerable expansion of individual choice about how, when and where work activities take place.

Work activities by employees used to be concentrated in the employers' premises during specified working hours, but are becoming dispersed: many people can now work in their employer's premises, at home, at client sites, in fact more or less anywhere, at any time of the day or night.

Commentators have been discussing these changes for some time; for example, in 1992 Duffy wrote, 'The key to the new office interior is the freedom in use of time which information technology beings. The nine-to-five office day is anachronistic. The office is likely to become a meeting place rather than a place for so many desks' (Duffy, 1992, p.235).

There is a consensus that workstyles are changing, but there is little information about the quantified impact of change, creating uncertainty for those involved in the briefing, design and management of buildings for organisations in the knowledge economy. The preliminary study reported here addressed this problem by investigating possible activity patterns using an agent-based simulation model.

The study was developed in the context of office-based organisations, but the principles should be relevant to any building type in which individual users have freedom of choice about when and where they carry out activities; for example, in buildings for higher education and retailing.

Simulation model

For employees with choice about the times and places for carrying out work activities, it is proposed that activity patterns result from decision-making in response to individual constraints and opportunities and are likley to vary between individuals. A simulation model of this process was developed with an element of randomness in the decision-making of individual employees. By assiging numerical values to some of the factors that characterise new working practices, the model generates a quantified picture of activity patterns.

An important advantage of modelling compared to case study investigations is that it is not limited to present-day situations, but allows the exploration of hypothetical scenarios of change.

The model is based on the proposition that employees choose between alternative places and times for activities with a decision-making process in which the alternatives are evaluated and ranked – and the most favourable alternative is selected.

The evaluation of alternative places takes account of two attributes:

- **performance**: how good each place is for performing work tasks, and
- **convenience**: how convenient each place is for dealing with non-work commitments.

Thus each alternative place has a performance score and a convenience score. Traditionally, the office would be given a high score for work-related performance and a low score for non-work convenience, whereas the home would be given a low score for performance and a high score for convenience. In more modern conditions, the convenience scores of offices would be higher with greater provision for employees' non-work commitments; and the performance scores of homes would also be higher with distributed computing.

How do individuals use the two scores to rank alternatives? The model uses weighted averages of the performance and convenience scores, and select the place with the highest weighted average score. The weighting is specified in a **work-life index** which varies over time, in contrast to the performance and convenience scores that are fixed. The time-varying work-life index causes different places to be selected at different times.

Simulation experiment

The simulation model was run for scenarios with systematic variation of environmental and behavioural input data. There were three different environments, 'traditional', 'intermediate' and 'modern' (T,I,M), defined by the performance and convenience scores (*see* table); and two types of employee behaviour, 'unreformed' and 'flexible' (U,F), with different work-life index values.

As might be expected, the unreformed behaviour/traditional environment combination (U-T) leads to typical pre-knowledge economy pattern, with all work being carried out in the employer's office on weekday mornings and afternoons, and no home-based work. With unreformed employees the move to intermediate environment (U-I) brings virtually no change, and in the modern environment (U-M) there is only a small amount of home-based work in the morning time periods. The simulation suggests that if employees are strongly rooted in traditional working patterns, changing the environment has little impact on their decision-making.

With flexible employees in the traditional (F-T) and internediate (F-I) environments, the model shows most work is in the employer's office at peak times with some non-peak office work in the intermediate environment. There is a considerable change in home-based work: the favoured times change form non-peak to peak times. Home-based work at non-peak times is greatly reduced.

For flexible employees in the modern environment (F-M) the amount of office-based work at peak times falls, and office-based work at non-peak times also falls. Virtually all this work transfers to home-based work at peak times; home-based work at non-peak times remains low.

These simulations suggest that environmental change has much more impact on the activities of flexible employees than those of unreformed employees.

Regarding the demand at the employer's office, moving from the unreformed/traditional (U-T) scenario leads to longer periods of occupation and lower numbers of occupants. Even flexible/modern (F-M) scenario more work still takes place in the employer's premises than in employees' homes. (Further results are shown on pages 66-67 above.)

Hypothetical scenarios

This preliminary study shows the value of agent-based simulation for the investigation of hypothetical scenarios – something that cannot be done by observing current situations. However, simulation model must be developed and calibrated in parallel with empirical studies of current situations, to give credibility to model findings for hypothetical scenarios.

Simulation models are always simplified compared to reality, and it is vital that the model captures the key aspects of the system being studied, eliminating only secondary or peripheral factors. The choice of model structure is an implicit proposal regarding the aspects that are believed to be significant.

This model is part of an on-going programme of research into the architectural implications of the transition to the knowledge economy.

The performance and convenience scores of alternative locations for traditional, intermediate and modern environments, as used in the systematic model runs described in the paper.

	TRADITIONAL		**INTERMEDIATE**		**MODERN**	
	performance	convenience	performance	convenience	performance	convenience
Office	3	0	4	1	5	2
Home-work	1	2	3	2.75	4.5	3.75
Non-work	0	5	0	5	0	5

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Investing in flexibility: the lifecycle options synthesis

William Fawcett

Because of uncertainty about the future, environmental flexibility is widely desired – but it is poorly understood and there is a risk of either under- or over-providing for flexibility.

- **Under-provision** for flexibility leads to future problems that could have been avoided if there had been better provision for growth and change.
- **Over-provision** for flexibility makes provision for anticipated future growth and change, but it is not actually used.

To identify efficient strategies for environmental flexibility, avoiding the problems of under- and over-provision, a more rigorous approach is needed.

This is offered by the concept of **lifecycle options**. It unifies all aspects of environmental flexibility and allows the value of flexibility to be quantified.

A lifecycle option is a feature of the environment that makes it possible for new decisions to be made in the future, depending on the outcome of events that are presently uncertain. A simple example: if the future size of a hospital, university or factory is uncertain, build for current requirements and retain open space into which the buildings could be expanded. The retention of open space creates the lifecycle option to expand, which has flexibility value even though it is not known when, if ever, the expansion will be carried out.

Lifecycle options transfer decision-making power from people in the present, who are uncertain about the future, to people in the future who will know the new state of the world. By making decisions later, the risk of decisions that have bad outcomes is reduced.

If the future could be predicted lifecycle options would not be needed, because all decisions could be made in the present with no risk of under- or over-provision for growth and change. But in real situations lifecycle options become more and more valuable with increasing uncertainty about the future.

Lifecycle options always give value to the option-holder because they are only exercised if it is advantageous to so, but option value varies dramatically from case to case.

Flexibility for what?

Universal flexibility is impossible and whenever flexibility is sought it is necessary to specify what the flexibility is for. It is specified by a set of scenarios that reflect the decision-makers' state of knowledge about possible futures that might occur.

Is there a paradox? – flexible strategies are sought because it is impossible to predict the future, but the evaluation of flexibility requires that possible futures are specified.

It is not a paradox, but it demonstrates something about flexibility that is not always acknowledged. It is not a commodity that can be added in ever-increasing quantities until eventually a universally flexible environment is achieved – one that could accommodate all possible future demands of any kind. This is fantasy: there is no such thing as a universally flexibility environment.

Every environment can accommodate a range of activity states. Some environments are tightly adapted for a narrow range of activities, for example, a nuclear power station site, and others can be used in many different ways, for example, a gridded city like Manhattan. Environments with a wider range of possible uses are certainly more flexible, but each environment is flexible in a specific way. Manhattan is much more flexible than a nuclear power station site, but it cannot accommodate a nuclear power station.

The question 'what is the flexibility for?' is answered by defining by a set of possible activity states. Not states of configuration of the physical environment – a static environment may accommodate all relevant activity states without physical change.

In some cases the set of possible activity states can be listed; for example, a family house might require flexibility to accommodate the successive stages of a family with young children, older children, and then elderly parents.

More generally the ranges of activity states can be specified by defining possible attribute values; for example, a hospital accident and emergency centre might require flexibility to cope with demand between 100 and 200 patients per day and a male-female ratio between 60% and 40%. From the defined ranges of attribute values, many future activity scenarios can be simulated.

This is getting close to what Norbert Wiener termed the Gibbsian approach, after the Yale physicist J W Gibbs (1839-1903): 'Gibbs's innovation was to consider not one world, but all the worlds that are possible answers to a limited set of questions concerning our environment.' The answers are termed the ensemble of states of the system.

Specifying the ensemble of all possible activity states may seem over-ambitious, but the level of description can exclude unnecessary detail. This is appropriate when the objective is a generic type of flexibility, such as flexibility to accommodate people in a range of group sizes in a university department or conference centre.

A classic case of over-investment in flexibility: the Free University of Berlin by Candilis Josic Woods, built in 1967-74 (photo 1970), made the common mistake of confusing the objective of flexibility in use with the provision of elaborate and expensive hardware for physical change.

The architects said that, 'The need for the building to be adaptable to different work programmes has been dealt with through a flexible system "in the four dimensions". … So a totally industrialized flexible constructional system has been adopted as the standard for this building. … Entire blocks of the building can be dismantled and put up again elsewhere'.

The building was a disaster, suffering physical disintegration, institutional collapse and vandalism. A major refurbishment was required in the 1990s. Comparison of before and after plans shows that the building envelope did not move and the main internal alteration was the division of larger spaces into smaller offices – something that could be done in studwork without the 'totally industrialized flexible constructional system'.

Lifecycle options

This paper argues that environmental flexibility for future growth and change is derived from lifecycle options, and that flexible strategies must be evaluated by comparison with an ensemble of relevant activity states. It is a pragmatic approach that attempts to make the concept of flexibility precise, quantifiable and useful.

The history of flexibility as a design objective has been far from precise, quantifiable and useful. It has sometimes been used to justify crushing banality or irrational extravagance. The Free University, Berlin, falls into the first category; the Centre Pompidou, Paris (Piano & Rogers, architects, 1972) falls into the second, where flexibility 'seems to have led to an overschematic solution … It is difficult to envisage any function which would require an unimpeded fifty-metre span with a height limitation of seven metres' (Alan Colquohoun). Neither tendency would be supported by a rational understanding of flexibility.

Even when flexibility has been pursued soberly, it has been unfocused. For example, John Weeks's proposals of the 1960s and '70s offer a fairly comprehensive overview of what can be done by architects to create flexible environments, but he lacked a method for deciding when and where and to what extent the ideas should be used. Today this is possible through the lifecycle options approach.

By demystifying environmental flexibility the lifecycle options approach may strip the topic of some of its fascination, but if it can increase the long-term value of construction investment this will be a fair exchange.

ASR PAPERS – 6

Publication: Chapter 12 in S.Th. Rassia and P.M. Pardalos (eds): *Sustainable Environmental Design in Architecture: Impacts on Health* (Springer), 2011

The Sustainable Schedule of Hospital Spaces: investigating the 'duffle coat' theory of flexibility

William Fawcett

Hospitals are large and complex buildings presenting many challenges for design and management, amongst them problems of growth and change. What can be done to ensure that hospitals will continue to work effectively despite activity change? – that is, how can they be designed for flexibility?

One idea that has gained significant acceptance is the 'duffle coat' theory of flexibility proposed by John Weeks in 1960.

It was based on systematic surveys of new hospitals which found that the room size distributions were highly skewed: 'Between one-half and two-thirds of the rooms in most hospital buildings are under 200ft^2 [19m^2] in area. The largest single group of rooms almost always occur in a very narrow size range, between 100 and 150ft^2 [9.5 to 14m^2]' (Cowan, 1963, p.57). Cowan also observed that, '… the majority of human activities occur in spaces under 200ft^2 [19m^2]. In addition it is quite reasonable to suppose that rooms of 150ft^2 [14m^2] will serve a very large proportion of human needs' (p.59).

Weeks continued the argument: 'His [Cowan's] research therefore suggested that if the number of room sizes used in a building could be reduced, by compromising the functions slightly – some functions would take place in areas slightly too small, whole others would have a little too much space – then the interchangeability of functions between rooms would be increased' (Llewelyn-Davies *et al*, 1973, p.19).

The duffle coat design has proved to be flexible and long-lasting, still in use three generations after being worn by John Weeks when he served in the Royal Navy in World War II. However, the investigation reported in this paper suggests that Weeks's 'duffle coat' theory of hospital flexibility, which was formulated in the 1960s and has been widely accepted, is false. It should be set aside in favour of better-researched strategies for flexible hospital design.

Weeks proposed that flexibility in hospitals increases when there is greater interchangeability between activities and spaces, and that designs with a small number of distinct room sizes increase interchangeability – and hence flexibility. (This is called loose-fit flexiblity on pages 46-47 above.)

Weeks made an analogy with Royal Navy duffle coats that were loosely tailored and supplied a limited variety of sizes, so his proposal is called the 'duffle coat' theory of flexibility. It is attractive and plausible, but is it correct?

Well-defined model

The paper reports on an investigation of the duffle coat theory of flexibility which used an activity-space model based on activities' floor area needs.

Suppose that each activity or event

has a space 'demand', and would ideally take place in a room with a floor area exactly equal to its space demand. However, most activities are tolerant of some deviation from this ideal area, and the amount of reduction or surplus that is acceptable can be defined as the floor area tolerance of the activity-space match.

Moving on from individual activities and rooms, consider a set of activities and the schedule of rooms in which they are accommodated. The schedule must contain at least as many rooms as there are activities; and for each activity there must be a room with a floor area within the activity's tolerance range.

The fit between the activities and rooms can be represented by the feasibility matrix (*see* diagram below). From the feasibility matrix it is possible to work out the number of different ways of allocating the activities to the rooms. This provides a quantified measure of interchageability, or flexibility in Weeks's terms.

Comparative experiment

A schedule of spaces in which every activity has a room that is equal to its demand can be called the 'tracking' schedule; it contrasts with a duffle coat schedule that has fewer room sizes. The duffle coat schedule relies on activity-space tolerance, and with greater tolerance more granular duffle coat schedules are possible.

The experiment took a specimen set of twenty activities and generated feasibility matrices for the tracking schedule and also for duffle coat schedules of varying granularity. The number of feasible allocations was calculated for each of these feasibility matrices.

The duffle coat theory would lead us to expect increasing interchageability, ie. increasing number of feasible allocations, with duffle coat schedules.

However, the results of the experiment gave no evidence that the duffle coat schedules gave greater interchageability. A duffle coat schedule is no more flexible, in Weeks's terms, than a tracking schedule.

Interchangeability and change

Interchageability between a set of activities and a schedule of spaces is only one aspect of flexibility. Another is the ability to accommodate variations in activities' floor area demand (*see* pages 46-49 above).

A second experiment showed that the duffle coat schedules were less successful than the tracking schedule in accommodating adjusted activity sets, and therefore less flexible in activity change terms.

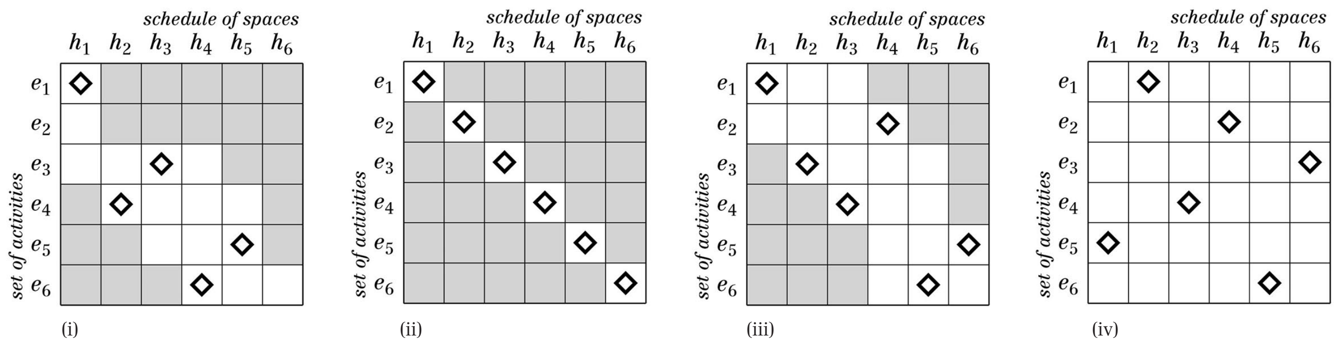
New directions needed

The experiments indicated that the duffle coat theory of flexibility has no validity.

The experiments also showed that activity-space tolerance has a great impact on flexibility and should be prioritised in future research.

Although there is no evidence that modular room sizing contributes to flexibility, modular design may be valuable for other, practical reasons in the design and construction of hospitals.

Flexibility is rightly seen as a high priority for the long-term value and sustainability in hospital buildings, but it is poorly understood. Weeks's duffle coat theory was an inspired but intuitive response to a complex problem, and should now be set aside in favour of better-researched strategies for flexible hospital design.



The feasibility matrix for a set of activities and a set of spaces. An activity can be allocated to any space for which there is a corresponding white cell in the matrix, but not to a space with a tinted cell. An allocation of activities to spaces is indicted by placing the diamond symbols in the relevant cells. In a feasible allocated all symbols are on white cells, and no row or column contains more than one symbol. The four cases illustrate:

(i) A 'failing' feasibility matrix in which there is no feasible allocation of all the activities to the spaces.

(ii) A 'tight fit' feasibility matrix in which there is only one feasible allocation of the activities to the spaces.

(iii) An intermediate feasibility matrix, allowing some interchangeability; there are 26 feasible allocations with this feasibility matrix.

(iv) The feasibility matrix allowing most interchangeability – any activity can use any space; there are 720 feasible allocations with this feasibility matrix.

Chapter 7

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This section includes the sources referred to in this book, plus some additional sources of direct relevance to Activity-Space Research, taken from the published papers summarised in Chapter 6.

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BUILT SPACE IN THE DIGITAL WORLD
the Activity-Space Research initiative

Theme

Built Space in the Digital World records the first phase of work in the Activity-Space Research initiative.

The investigations focused on the changing ways that buildings are used in a digitally connected world, where many activities can be carried out practically anywhere at any time. Buildings are still needed, but what patterns of use can be expected?

The use of buildings increasingly reflects individual choice between alternative activities, places and times: decision-making is decentralised and building use becomes an emergent property of activity-space-time systems. The Activity-Space Research initiative explored a variety simulation models of digitally-empowered users' decision-making. Simulation is the key to understanding the new digital world, where past experience is obsolete.

Context

Activity-Space Research is work in progress. This book explains the motivation and importance of the initiative.

The Activity-Space Research initiative was made possible by the support of Chadwick International, management architects, who established the Chadwick Fellowship in Architecture at Pembroke College, Cambridge. Dr William Fawcett was appointed as the Chadwick Fellow in 2005. The initiative was based in the Martin Centre for Architectural and Urban Studies, the research division of Cambridge University Department of Architecture.

The book

Built Space in the Digital World presents an accessible overview of research investigations by William Fawcett and PhD students in the Martin Centre, as well as the many participants in fourteen Research Workshops held in Pembroke College.

A wide variety of Activity-Space Research studies are presented with extensive use of diagrams and images. There are also summaries of the papers that have been published in academic journals, which describe particular Activity-Space Research studies in greater depth.

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