SPECIAL EDITION: DESIGN FOR HUMAN PERFORMANCE 1/2010

The Arup Journal

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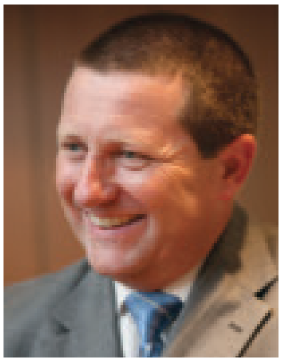
Foreword



At Arup, we are fond of using terms like “holistic”, “integrated”, “total architecture”, and “systems thinking” to express our interest in the totality of design. With good design, the whole can rise above the sum of the parts if we employ such thinking from the outset, and we have sought to achieve this from the day the firm was first established.

Until now, these intentions have been described almost exclusively in terms of our conventional technical disciplines. The drive to establish Arup Associates in the 1960s, and Building Engineering in the 1970s, was based firmly on the professional cornerstones of structural, mechanical, electrical, and public health (plumbing) engineering, architecture, and quantity surveying. More recent desires to embrace a wider range of disciplines (eg economics, the social sciences, and finance) illustrate a continuing commitment to an ever-broader multidisciplinary concept.

Strange, then, that one of the primary elements of design performance – how the product functions in the hands of its human end-users – should have been rather neglected. The psychology and sociology of human behaviour has not, in general, been a significant driver within our historic design thinking.

Humans interacting with buildings or products form systems that can have entirely different characteristics from those intended for the building or product alone. If humans behave in unexpected ways, the intentions of even the best designs can be thwarted. We might think of crowd behaviour in emergency situations, where the usual provisions for entry and exit suddenly become inadequate, or of workers who become more productive because their environment is more pleasant. Behavioural patterns influence the experience and performance of the end-user, and this can be positive or negative.

This edition of *The Arup Journal* concentrates on this hitherto neglected area of “human performance”. Here we present some explorations of different aspects of the subject, with some insight into the state of this developing art within our design lexicon. This discipline will grow more important to us as we strive to maintain our search for design excellence. We hope the seeds being sown now by the work reported in this issue will bear much fruit.

John Miles Arup Group Board Director

The new desk system for Arup’s London campus incorporates ergonomics, practicality, sustainability, and aesthetics in its design philosophy.

Are buildings getting better?

Adrian Leaman

It seems to be a straightforward question, but in fact there is no simple answer.

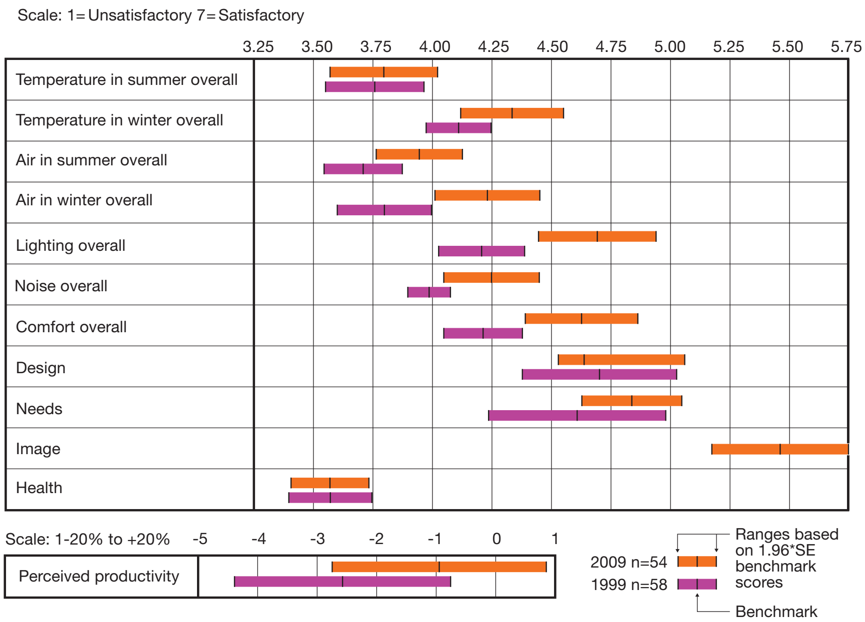
Introduction: study methodology

Are buildings getting better? The best estimate, based on comparative surveys of building users in the United Kingdom in the 1990s and 2000s, is a guarded "yes, they are", but it needs to be carefully qualified. For instance:

- Comparisons come from buildings surveyed by Building Use Studies (BUS) and its clients, using the standard BUS occupant survey (now known as Arup Appraise, see pp20-21)*. Samples of 54 and 57 UK buildings were drawn from studies carried out respectively in 1990-1999 and 2000-2008, but these were not random samples. Their inclusion depended on which buildings the licensees were interested in studying**.
- Buildings included in the samples were mainly offices, but there were also several other types including schools (primary and secondary), university buildings including libraries, courthouses, warehouses, and medical centres.
- In the 1990s sample only 10% of building designs explicitly claimed to be "green". Now, almost all make that claim, so there is an obvious change of emphasis.
- So is there a change for the better because of the greater proportion of "green" buildings in the sample? This is difficult to answer, because users tend to prefer features that are included in "green" buildings anyway[1,2]. So it is not necessarily their "greenness" – their supposedly lower carbon footprint*** – but their critical, context-sensitive features (like views out and openable windows) that matter more.
- Although buildings may be "green" in intent, they are not necessarily so in reality. It is difficult to test this properly, partly because thorough studies of occupants' views and in-use energy studies are

1. The Arup Campus, Solihull, West Midlands (see p8).

2. Summary variables.



* The BUS survey, now known as BUS methodology, was developed by Building Use Studies from 1985 to 2008. In 2008 Arup adopted the method in house, and it is now offered by Arup as a new service called Arup Appraise.

** By making the survey free to postgraduate students, we widen and randomise the sampling base, so that we avoid looking solely at buildings perceived to be "premium".

*** Arup's experience in measuring the actual performance of buildings in use showed that energy consumption can often be three times higher than predicted at design stage, and that it is relatively rare to find buildings performing better than UK Best Practice benchmarks for CO^2 emissions.

only rarely carried out on the same building, so we cannot look at the associations between them*. These findings should not, therefore, be used to argue that "green" buildings make the difference; this is not proven.

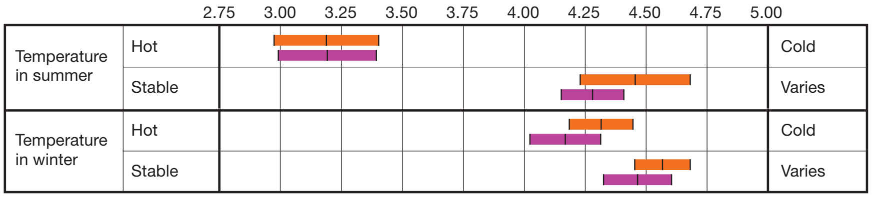
- Also, it depends on what is meant by "better". In the present context, "better" is a statistically significant change for the better (an improvement) between the sample results for the 1990s and 2000s on the range of variables used in the BUS survey.

First cut of results

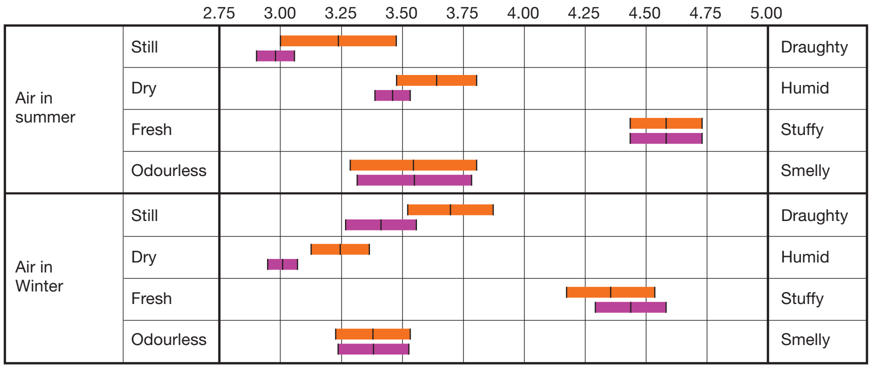
Arup Appraise includes what were treated as the 12 top-level indicator variables** (Fig 2). The use of the word "overall" in any particular variable highlights that the responses summarise a further sub-group, eg *temperature* or *lighting*. These are dealt with in more detail in the subsequent discussion of Fig 3.

In Fig 2, variable by variable, the 2000 results are shown first (orange/top), and the 1990 results next (mauve/bottom). In each case, the range is based on the standard errors of the study buildings as shown in the key. The centre tick in each result is the mean for the dataset – the benchmark mean. A significant difference is where the benchmark mean (centre tick) for one dataset falls outside the range of the other, for example *temperature in winter overall*, and a very significant difference is where the ranges do not overlap at all, as in *air in winter overall*.

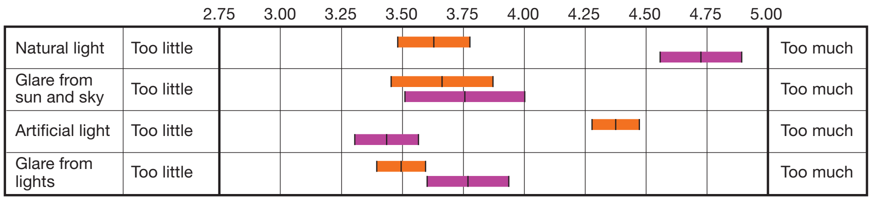
3. Temperature variables.



4. Ventilation/Air variables.

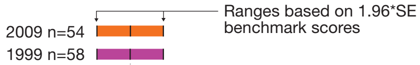


5. Lighting variables.



Key for Figs 2-4

Scale: 1=Unsatisfactory 7=Satisfactory



All variables are higher in some respect***, though for some, eg *temperature in summer overall* and *health*, the differences are tiny and fall within the bounds of normal sampling variation. *Design*, *needs*, and *perceived productivity* – with *temperature in summer overall* and *health* – are the other variables that are not significantly better. Six out of 11 are significantly better: *temperature in winter*, *air in summer*, *air in winter*, *lighting*, *noise*, and *comfort overall*.

There are several surprises, among them the improvement in *noise* perceptions. But *noise* has come from a low base, and features as a major, and growing, problem. The variation of the *noise* response has also widened, and so the difference between the best and worse instances is now more pronounced.

There is virtually no change in the means or variation in the *temperature in summer* and *health* variables. The lack of change in *overall summer temperatures* is a surprise, given the improvements in, for instance, the *comfort overall* variable and average winter conditions. However, this may be where the effect of the new generation of "green" buildings could be seen: they are performing less well in summer. The common claim that "green" buildings are "healthier" does not seem to be borne out here. A quirk of the sample, perhaps? Or maybe health perception is now less "building-dependent" than it used to be; in other words, the effect disappears outside the building. If so, some of the "sick building" research from the 1980s, including Arup's own, may have to be revisited.

In more detail

Figs 3-5 show more detail for some of the overall variables shown in Fig 2 (*temperature*, *air/ventilation*, and *lighting*). *Noise* cannot be treated in the same way because in the 1990s' BUS questionnaire, noise was not split into sub-variables. In fact, in 1985 when the questionnaire was first developed, there was lively debate about whether any questions on *noise* should be included at all! Such has been the change in internal environmental conditions since then, driven first by the consequences of predominantly open plan layouts, but now also by "green" design criteria. For example, there are more hard surfaces that can make unwanted noise much more intrusive.

The cluster of *noise* variables is now one of the most prominent in survey results, and one of the trickiest to control and manage+.

For *temperature* comparisons, Fig 3 shows that buildings in summertime seem now to be perceived as being just as hot they were in the 1990s, though with more variation between the extreme cases.

* The Probe series of post-occupancy studies (see next page) pioneered this approach in the 1990s.

** The "Image" variable was not included in the 1990s surveys.

*** Their means are higher in the 2000 dataset.

+ From 2002 questions were included about journeys to work, and in 2005 a new "safety" variable were introduced, which asked people how safe they felt in and around the building.

Two case studies:

The Rivergreen Centre and the Charities Aid Foundation headquarters

These buildings are not well-known, but they are important because:

- they have been thoroughly studied, using the Probe approach (now Arup Appraise)*,
- the results have been made available to a wider audience, and
- they exhibit clear lessons for the future, positive and negative.

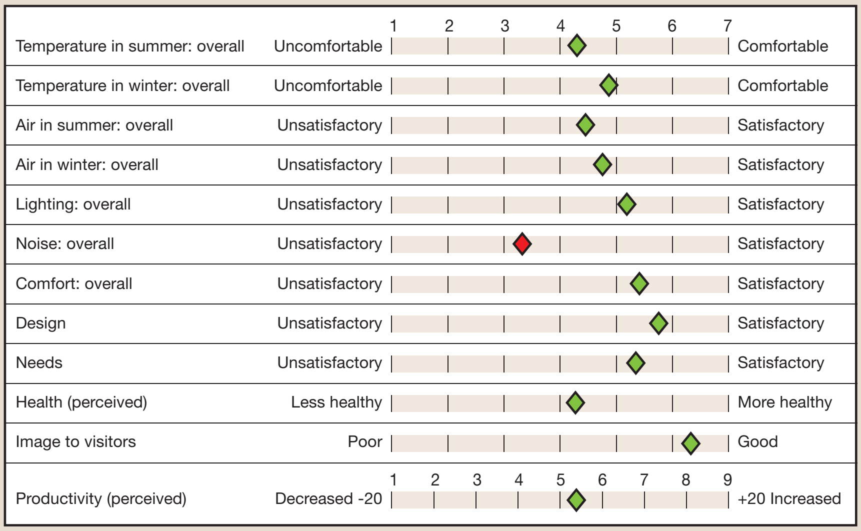
These are typical of many recent office buildings, the kind that should routinely work well for their occupants and investors, and with reduced environmental impacts. As they have been written up elsewhere[3, 4], the present article concentrates only on some of the salient lessons. Both buildings have explicit "green" targets, but both are also relatively modest in their aspirations. They try to do things simply and well, and respect their contexts.

The Rivergreen Centre, at Aykley Heads, Durham, England, is naturally ventilated throughout with no air-conditioning, including its 200-seat conference hall (reduced to 80 in the summer months). Features include an extensive sedum roof, and an internal rammed earth wall that induces a thermal flywheel. It has some ventilation pathways separated from the windows in side panels. These (and other) features were extensively researched beforehand so that they were considered to be appropriate for both the functions intended and the location. The building was monitored by Arup using Probe (now Arup Appraise) (Figs 6, 7).

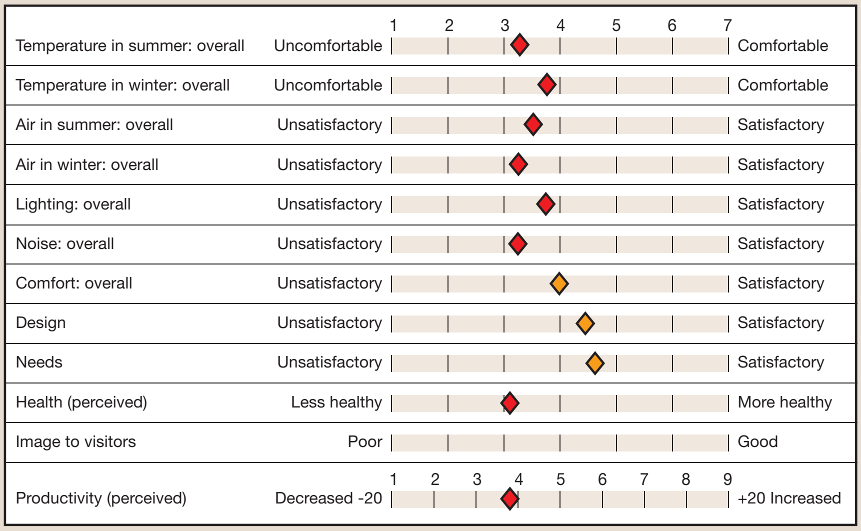
Rivergreen has some of the best results yet encountered in the UK both on occupant and energy criteria. That said, there are two obvious downsides: noise, and the performance of the biomass boilers. The developer, Peter Candler, is incorporating the findings into his next generation building, thereby "closing the feedback loop", and learning from the experience.

The Charities Aid Foundation HQ, on the former West Malling aerodrome in Kent, England, is also naturally ventilated. Some "advanced" features were incorporated in the original design, but for cost reasons, some were removed from the new building, so that it began operation in the mid-1990s without all the features the design team intended. Results for the mid-1990s are shown in Fig 8. In 2005, the design team was able to revisit the ventilation strategy and introduce some of the removed features (results are in Fig 9). At the time of the 2008 survey, the density of occupation was two-and-a-half times the 1997 survey. There was no major change in energy performance over the two study periods.

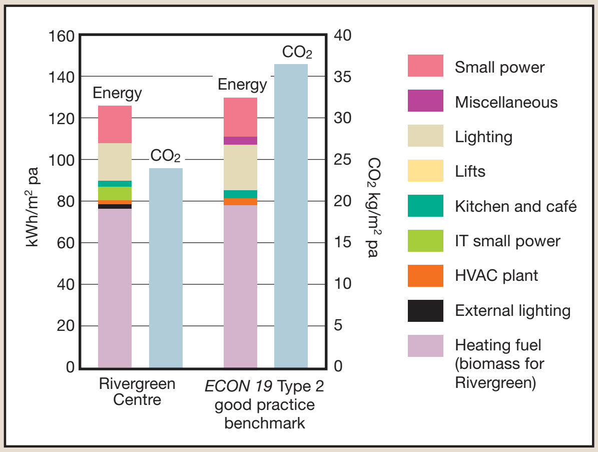
The major lesson from the Charities Aid Foundation surveys is the likely effect of occupant densities on performance. Too high will mean "own goals", for example in perceived productivity and occupant satisfaction; too low will mean wasted resources. Density of occupation is likely to be an important variable in the future.



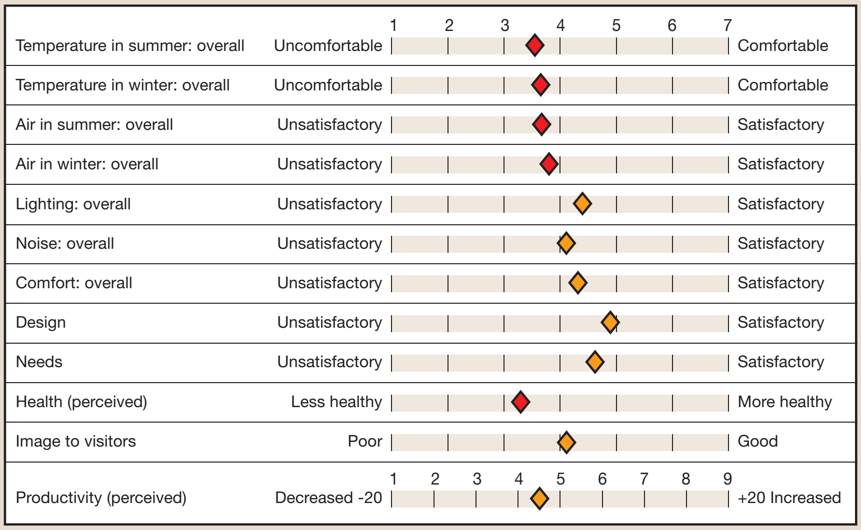
7. Rivergreen Centre 2007 survey results.



8. Charities Aid Foundation 1997 survey results.



6. Rivergreen Centre kWh/m² per annum and CO_2 kg/m² per annum.



9. Charities Aid Foundation 2008 survey results.

* In which detailed studies of occupant satisfaction and technical/energy performance are carried out within the context of a thorough diagnostic review. Then the results are written up and made available to a wider audience. Information relating to both cases can be provided by the author (adrian.leaman@arup.com), or for more information about this and Arup Appraise contact Barry Austin (barry.austin@arup.com).

In winter, they are perceived as colder and more varied. It seems, therefore, that buildings overall do not appear to improving their thermal comfort.

For *air and ventilation* (Fig 4), buildings are perceived as less still and less dry in both summer and winter, less stuffy in winter, and almost the same for "smelliness" – at the odour-free end of the scale. So ventilation shows improvement.

Lighting (Fig 5), has the most surprising result. The positions of the scores on the *natural light* and *artificial light* variables have almost completely changed places between the 1990s and 2000s study periods. This seemed so extraordinary that the results were double-checked to ensure they were correct. Now, perceptions seem to be showing too little *natural light* on average and too much *artificial light* – a common mantra among occupants. But the 1990s' picture is the reverse: too much *natural light* and too little *artificial*!

Perceptions of glare from both the sun/sky and from lights seem to be improving (that is, there is less of it), so this is evidence that lighting environments are changing, and seemingly for the better. However, it is dangerous to make leaps of faith on the back of generalised evidence. With buildings it is always better to look at cases, and examine specifics.

Summary

- All the main study "summary" variables show improvements, although five out of the 12 are not statistically significant.
- Comfort conditions overall seem to be better, but thermal comfort by itself still seems problematical. The gain in comfort seems to be coming from ventilation and lighting.
- Even perceptions of noise are improving, but these come from a low base, so there is still plenty of scope. Noise is a common "downside" of "green" buildings.
- Lighting perception shows a remarkable turnaround, but people are now saying "too much artificial light".
- Density of occupation is likely to be a critical variable in the future. Exceeding density thresholds carries performance penalties.
- The way forward is not to over-elaborate buildings with unnecessary features, and to make them much more demand- and user-responsive.

References

(1) LEAMAN, A *and* BORDASS, W. Are users more tolerant of green buildings? *Building Research and Information*, *35*(6), pp662–673, 2007.

(2) LEAMAN, A, *et al*. "Green" buildings: what Australian users are saying. *EcoLibrium*, pp22-30. November 2007.

(3) Contact adrian.leaman@arup.com or barry.austin@arup.com for more information.

(4) Contact adrian.leaman@arup.com or barry.austin@arup.com for more information.

Institute for Manufacturing, University of Cambridge

10.

11.

The Institute for Manufacturing building in Cambridge, designed by Arup Associates, was recently studied using the Arup Appraise methodology. Results look very promising, although they will need to be further verified after another year of occupation.

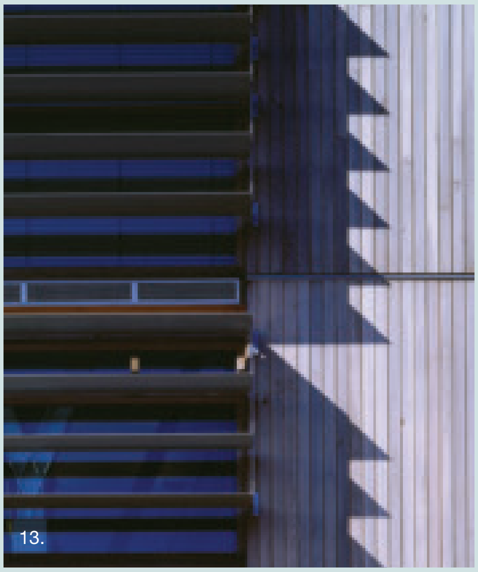
Completed in 2009, the IfM is a new Dept of Engineering at Cambridge University, sited within the new Cambridge West masterplan. It consists of laboratory, teaching and office space organised around two distinct social areas, an external courtyard that provides protected exterior amenity space, and a naturally lit atrium and stair that link all levels. The entrance and reception intersect these two spaces at the heart of the building.

As with the Arup Campus, a sloping site allowed the IfM design to follow the contours of the land with a stepped section, the levels of which are revealed within the atrium space where physical and visual connections across the department are made and from which all key teaching and meeting spaces are directly accessed. A third key organising space is the generous common room located a half level from reception. Most journeys around the building necessitate passing through it, promoting it as a hub of activity within the institute. The common room benefits from a glass curtain wall to the south façade that separates the inside space from a large south-facing terrace and onwards to views of fenland farming landscape beyond.

In line with the University's sustainable aspirations, the IfM achieved a BREEAM (BRE Environmental Assessment Method) "Excellent" rating. Where possible, spaces are naturally ventilated through the use of opening rooflights and wall vents controlled by a building management system. Much of the concrete structure remains exposed to provide thermal mass to regulate the building's temperature across the seasons. Extensive natural light is available throughout, with devices to control solar gain as required.

All material choices were environmentally considerate, such as FSC (Forest Stewardship Council) certified timber from a renewable source to clad the façades.

12.



13.

Arup Campus, Solihull

The Arup Campus is a series of naturally-ventilated pavilions in a business park near Solihull, West Midlands, UK. Designed by Arup Associates, it was developed in two phases between 1997 and 2003, consolidating design staff from several offices into a bespoke facility aimed to enhance these teams' operational efficiency within a flexible environment that promotes collaboration and new ways of working. A central reception and cafeteria space form the social hub that links into three two-storey pavilions containing a mix of office, meeting, and recreational space, plus a 150-seat auditorium.

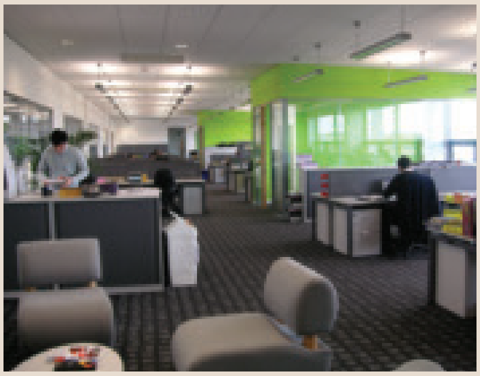
The pavilions were sited to relate to the sloping land contours, which both enabled a reduction in on-site cut-and-fill and enhances the relationship between the workplace and the external landscape, as well as allowing the creation of internal half-levels and atria that ensure fluid connectivity between workspaces. Boundaries are minimised – while still allowing for security and private space – with visual openness for visiting clients and shared work and amenity space for occupants.

The appearance of the Arup Campus building reflects a "radical traditionalism" – a rational approach to the surrounding rural vernacular. The weathering of the timber cladding melds the building into its landscape. Giant roof pods are prominently expressed, towering above the eaves. These distinctive elements define the ethos of an environmentally responsible and responsive space – a gentle, sustainable office building, designed for people.

The structure has an unusually wide plan, though the building was designed for natural ventilation and maximum daylight penetration. The roof pods provide the solution. Through a chimney-like stack effect they drive the ventilation naturally and bring controlled daylight deep into the heart of the building. This low-energy strategy is supported by the thermal mass of the exposed concrete floor and roof soffits. Exposed hard surfaces could cause unpleasant reverberation, but specially designed dampers integrated into the light fittings absorb the sound. Externally, timber louvres control solar gain and glare, and provide human-scale detail to the façade. Moreover, the louvres and opening windows can be manually operated, giving back environmental control to the people in the building.

Designing and managing a "factory of the future"

**Rose Challenger Chris Clegg
Matthew Davis Jamie McGourlay
Keith Ridgway**



1. Open plan office, including individual workstreams, break-out areas, and meeting rooms.

2. The shop-floor, with gallery and bridges above.

3. A bridge links the shop-floor gallery and the two sides of the first floor factory.

Introduction

The new research and development facility now known as the Rolls-Royce Factory of the Future was created for the Advanced Manufacturing Research Centre (AMRC), a partnership between Boeing and the University of Sheffield's Faculty of Engineering in the UK. Employees moved from the previous AMRC building to the £15M new facility, built at a business park near Rotherham, South Yorkshire, in February 2008. It was officially opened in October 2008 by HRH Duke of York.

The AMRC was originally formed as an environment in which research, design and manufacturing can interact, to showcase best practice methods, and to produce meaningful knowledge transfer. Essentially, the output is knowledge; the factory does not conduct full-scale production, though it does need to simulate the disciplines, standards, and attributes associated with modern precision production manufacturing on full-scale demonstrator and one-off prototype components.

The AMRC's success necessitated expansion, and the design and construction of this state-of-the-art new building designed by Sheffield architects Bond Bryan to BREEAM excellence standards. At 4654m², it is four times the size of the existing AMRC premises. Its remit has been to not only extend workspace facilities, but to symbolise and increase the AMRC's ability to innovate.

Design of the new workplace

From the outset, a multidisciplinary approach was adopted, to ensure the availability of the greatest possible skill-set. Organisational psychologists worked with AMRC staff and management, as well as industrial partner representatives, architects, and engineers, to help identify the human and organisational issues that are often overlooked in the design of new systems. A driving theme for the new factory's design was sustainability and the use of cutting edge technologies to achieve a building that could be considered truly green in its operation.

- Employing a socio-technical approach emphasised the early consideration and inclusion of human and social factors in the design. This included establishing a clear vision for the AMRC and its future objectives, which then formed the initial brief for the tendering architects. There was also a drive to identify design features or where changes to the proposed designs would impact upon how work would be performed, how the IT and other technologies could be best incorporated, and how the building could support the social aspects of the workplace, ie a flat hierarchy and easy interaction.
- There was an emphasis on participation during the initial brief and subsequent design stage. The psychologists facilitated several events to gain insight into both stakeholder and staff requirements for the new building, to help determine how it could best support these needs, and to explore user acceptance of proposed design choices.
- A rich and diverse workspace was designed to cater for the diverse range of tasks that the AMRC staff undertake – from CAD work to informal meetings, seminars, board meetings with external clients, to using heavy machinery and laboratory equipment. For all these, the workspaces were designed to help facilitate and support social interaction and knowledge sharing.

Added value

In a rigorous post-occupancy evaluation, the findings indicated that the building does provide a bright, modern, and flexible workspace, a true "factory of the future". It has been praised by staff, management, and industrial partners as being supportive of their work, an environment that allows innovation and collaboration to flourish. It has been showcased by Boeing and Rolls-Royce as an example of design excellence.

The AMRC's industrial partners have highlighted the new facility's role in emphasising the size, scale, and complexity associated with production manufacture, whilst keeping the clean, controlled but accessible laboratory or show-room environment that makes it unique from an industrial engineering perspective. The Factory of the Future now acts as a "shop window" for the AMRC, providing a balance between the familiarity of the traditional shopfloor and a degree of futuristic or "white coat" impact on visitors and potential partners. This balance helps create the right impression of the advanced work conducted in the centre, without alienating people by being too unfamiliar an environment. The factory itself provides the space necessary not only to foster the vital theoretical advances needed to solve practical problems, but also to test these using full-scale production equipment – a truly unusual accomplishment.

Many of the successes have been attributed to the joined-up thinking and multiple perspectives resulting from a socio-technical and participative design approach. The management feels that the high involvement of staff in securing the design and build funding has helped to strengthen and develop a strong sense of identity and commitment to the AMRC. Inevitably there are certain compromises in some aspects of the design and aesthetics. The management suggest that these may in part have arisen from decisions taken in isolation without the involvement of stakeholders or other professionals; they believe this highlights the key role that participation plays in successful design.

Sustainability

The Rolls-Royce Factory of the Future features over 20 environmentally sustainable features including:

- carbon neutrality
- high-performance translucent building systems to improve thermal performance/light
- dual-blade wind turbines (500kW of power)
- proprietary natural ventilation systems and windows
- workshop with displacement ventilation ±2°C
- ETFE roof lights
- 98% of floor space naturally lit
- ground source heat pumps
- renewable energy systems
- BREEAM "Excellent" rating
- sophisticated energy metering
- zero ozone depleting insulation materials and refrigerants
- rainwater collection from the roof and sustainable drainage for surface water run-off and landscaping using local wildflower meadow.

1.

Using design factors to improve human productivity

Michael Beaven Ann Marie Aguilar Francesca Galeazzi

Arup Associates and Arup have developed the integrated workplace concept as an organising structure for categorising and assessing the various factors that influence productivity and performance.

Background

Much work has been done on the subject of productivity in the workplace, for example as summarised in the British Council for Offices' *Guide to post occupancy evaluation*[1]. However, this work has generally been characterised by a necessarily broad understanding and presentation.

A knowledge gap analysis previously undertaken by Arup Associates, relating to the psychological response to space, encouraged the practice to extend research into this area. This was carried out through the production of social/mental maps of organisations, to better understand how people in those organisations work and relate to their environment, and specifically how the development of the design brief can contribute.

The starting point was the knowledge that the results of these exercises could influence design factors to create environments that drive business results. The research strategy was conducted in three phases, the latter two with external collaborators, expert in the field of workplace behaviour analysis.

* David V Canter is a psychologist. He is currently the Director of the Centre for Investigative Psychology, which is based at the University of Liverpool, where he also maintains the MSc programme in investigative psychology.

The first phase was to develop a design framework for workplace, to give the brief a development context and focus. The second phase applied the work done by Professor David Canter* with Arup's client, BSkyB, in relation to the brief development of its future UK campus.

In the third phase Arup Associates partnered with Arup's organisational behaviour consulting team to assist in the development of a brief for Lancaster Grammar School, also in the UK.

Both project teams applied exercises that experimented with different approaches, each resulting in unique reactions from respective clients, and in associated brief development.

Use of integrated workplace performance tool, Network Rail

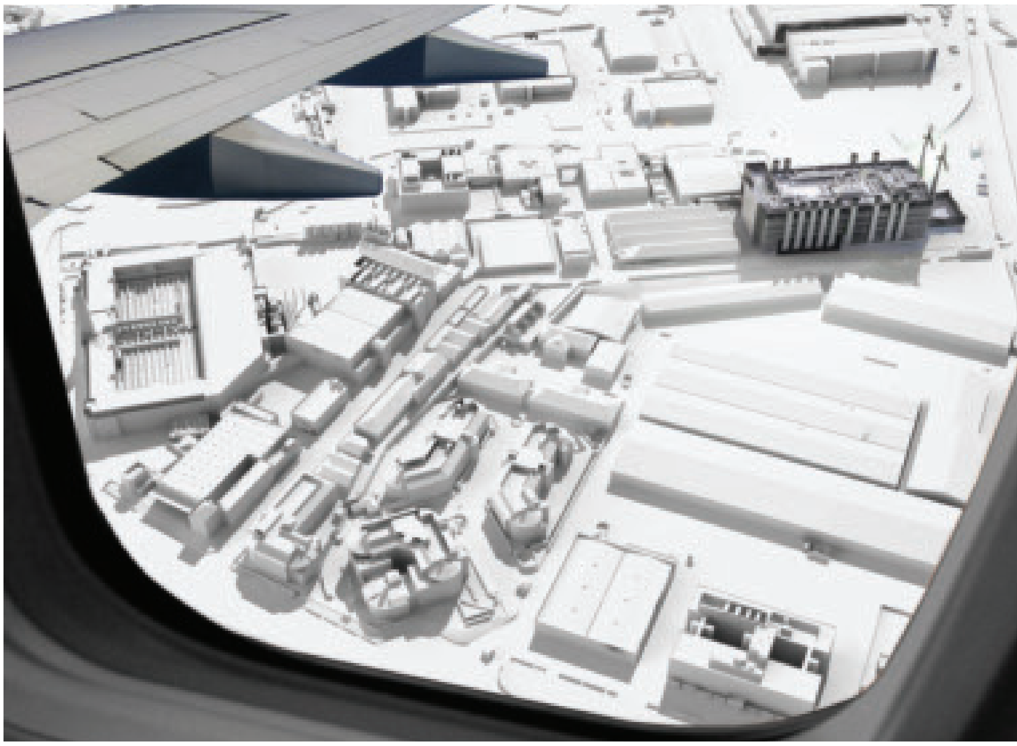
The integrated workplace performance (IWP) concept was developed in 2004 by Arup Associates and Arup's Foresight and Innovation team as an organising structure to consider workplace and productivity issues (Fig 2).

The nine sectors represent different factors that affect performance in some way and can be split into soft aspects (left side) and physical aspects (right side). They can also be divided into those that can be assessed (outcomes) and those that can be both assessed and changed (enablers). The IWP framework allows the workplace to be considered as individual aspects in context or in a holistic manner.

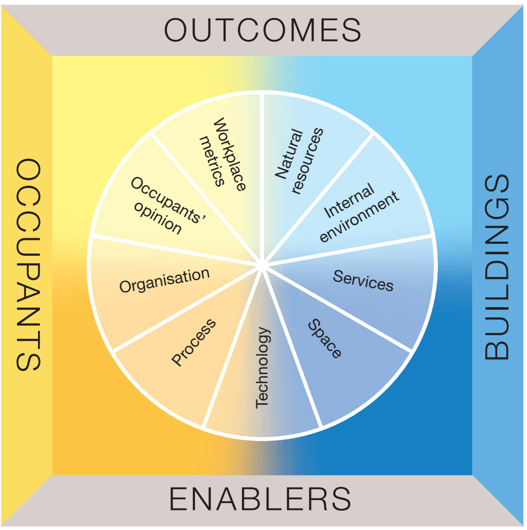
Strategy and outcome

Applying this tool to the consideration of workplace and business outcomes, Arup Associates and Arup's consulting team was engaged by Network Rail* to define the working brief for its next generation of training facilities (two example facilities were evaluated at Watford and Woking by interviewing trainers and trainees). IWP was used as the structuring tool to gather a clear understanding of the client requirements, and to develop guidelines for the design of effective and flexible training facilities that support the productivity and well-being of their occupants, while reflecting Network Rail's organisational culture.

The IWP methodology proved valuable not only in structuring the data collection process and analysing the information gathered, but also in communicating ideas within the final document issued to the Network Rail teams.



3. Model of BSkyB campus, Osterley, West London.



2. Integrated workplace performance (IWP) tool.

Psychological study, BSkyB

As part of its work on the development of the BSkyB campus in Osterley, West London (Figs 3, 4), Arup Associates wanted to build upon previous qualitative interviews by exploring what lay behind the high-level responses to questions that the team had received from directors and executives of BSkyB. This next exercise used a less direct approach, to reveal insights into how BSkyB operates in the non-physical realm, by producing a mental or social map of the organisation.

As noted above, this exercise was derived from the work of Professor David Canter[2, 3], to support architects in developing design briefs for various types of project. It consisted of asking a small sample of people across the organisation, in a particular and structured way, to:

- indicate their understanding and experience of the various departments and sections that make up the whole organisation (exploring the atmosphere and style of those departments and sections in ways that relate to the social and physical arrangements that enable them to be effective), and
- reveal the adjacencies and relationships of the various directorates, departments, and sections for the BSkyB campus; this would indicate the significance of the spatial relationships that characterise BSkyB at various levels of detail.

* The not-for-profit company that owns and operates Britain's rail infrastructure.

4. Harlequin 1 building at BSkyB campus.

Strategy and outcome

The BSkyB exercise was intended to deliver general schematic representations of the overall psychophysical structure of the organisation, as perceived by individual respondents and various sub-groups of respondents.

These schematic representations appear similar to the “bubble-diagrams” that feed directly into many architectural briefs. But unlike those hypothetical frameworks for selecting building form and environmental characteristics, these were derived directly from those who have day-to-day experience of the organisation.

As tools to support the design process, these diagrams proved valuable to the design team and to the client in understanding perceptions of the business and its functionality, and consequently the spatial relationships within the architecture that directly respond to these business and functional needs. Importantly, from the early stages the client was willing to collaborate, the sensitivity of which became clear when implementing the investigative part of the exercise.

Specifically for the BSkyB project, the Q&A exercises in which the directors and executives participated, alongside a strictly academic approach, proved that the designer’s role in mediating between these different worlds was critical. It became clear during this process that a more dynamic and inclusive approach would glean more useful results in terms of social and organisational mapping exercises.

Sociotechnical systems study, Royal Lancaster Grammar School

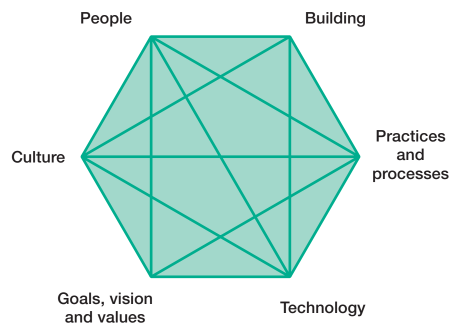
Developing this theme, Arup Associates then partnered with Arup’s organisational behaviour consulting team to build on its existing knowledge and work previously conducted in the field of user-centred workplace design, and new tools such as the socio-technical systems (STS) model (Fig 5).

The Lancaster School brief development exercise allowed this evaluation to provide a deeper analysis and understanding of the psychological and social representations individuals hold regarding their environment, and enable this to be translated into recommendations for that environment’s design. An iterative workshop was carried out to develop the design and layout of the environment from the users’ perspective.

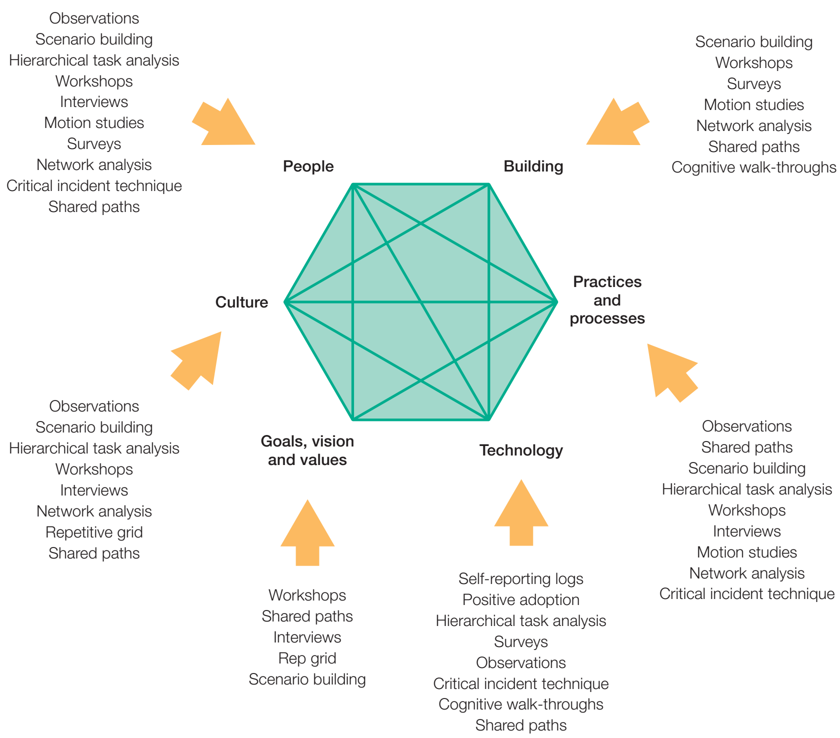
Strategy and outcome

A half-day focus group workshop was held with a small yet representative sample of users of the school – two School Governors, a House Master (who is also the School’s Head of Technology), one fifth year boarding student, and one sixth form non-boarding student – meeting with one representative of Arup Associates, two from Arup, and Prof Chris Clegg of University of Leeds Business School. The STS model was used, providing a structured approach to elicit the users’ personal views, needs, and perspectives on six fundamental characteristics of the built environment (people, processes, technology, vision and goals, culture, and the building itself), to effectively and reliably inform the design (Fig 6).

This workshop provided a means of piloting the approach and also served to highlight where additional focus may be required in terms of ensuring that all important and relevant information continues to be drawn out and considered in the design.

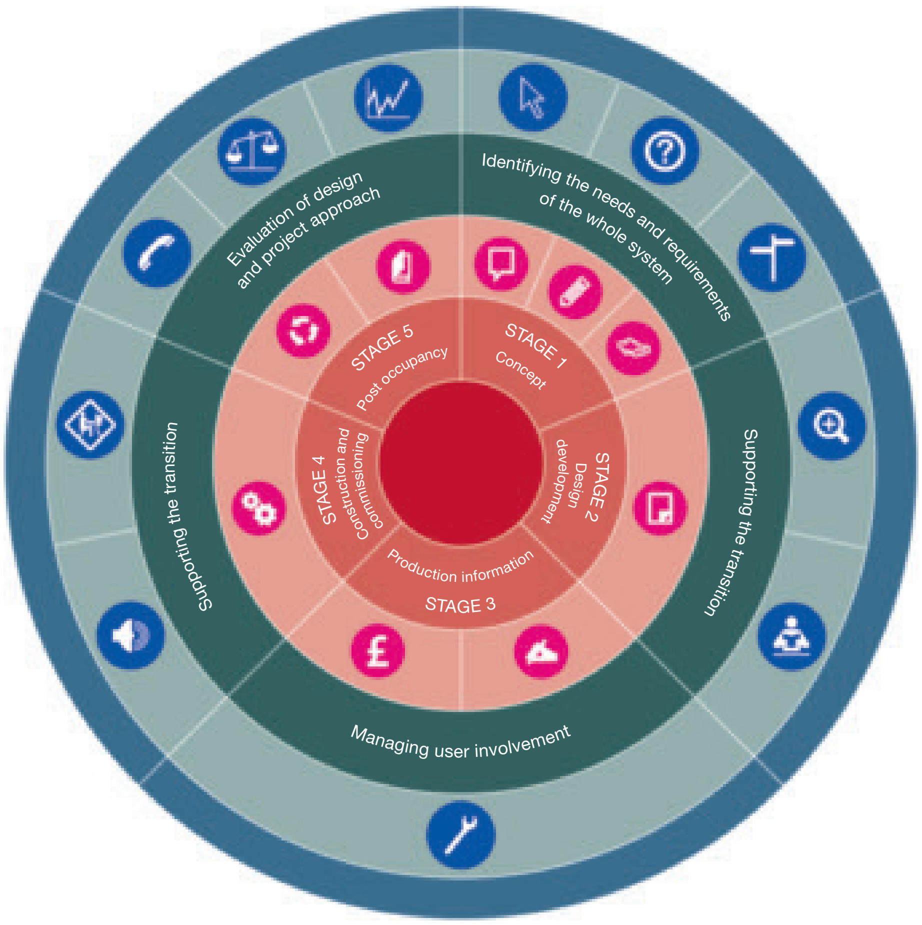


5. A sociotechnical systems (STS) approach to workplace design. This model considers the workplace as a system of inter-related elements, and not only includes all of the factors to consider when designing a new workplace, but also shows the links that exist between the various parts of the system (developed by Prof Chris Clegg, 2008).



6. The STS approach to workplace design, indicating the tools available to bring forward emphasis on the six specific areas of focus.

7. Framework diagram combining the Arup Associates plan of work – unified design – with the added benefit of social mapping tools.



8. Royal Lancaster Grammar School.

The process of engagement was comprehensive and demonstrated to both the client and design teams that, whilst with integrated design teams these topics would usually be engaged with a client body, the rigour of the tool gives structure for the mediated collaboration between occupational psychologists and perhaps less expert client and design teams.

Conclusion and ways forward

In their desire to push the boundaries of design methodology and outcome, Arup and Arup Associates continue to engage with and try to understand clients' needs better, interpret briefs and expectations, support change in management or process, understand better a specific organisational culture, conduct post-occupancy evaluation, etc. The relevance of these issues in developing the design brief has been made particularly clear by applying cutting edge tools in real projects with real clients, albeit so far with enthusiastic and expert clients.

As pilot schemes, the methodologies here show that this holistic approach is an effective way to develop new and key user information to feed into the design. Considerable care and sensitivity is required in implementing these pioneering tools, as important and penetrating questions are asked of clients and their teams. Arup Associates is further developing these tools in close collaboration with clients (Fig 7).

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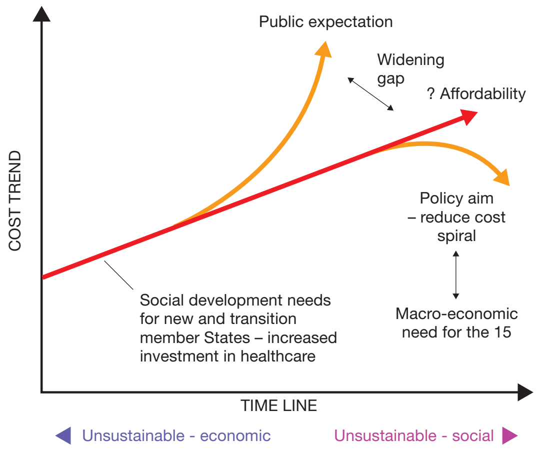
1. Front elevation of Medicover Hospital, Wilanów, Poland.

Design of the hospital environment to promote staff and patient wellbeing

Phil Nedin

Creating hospital environments that are truly therapeutic requires a fine balance between the sometimes conflicting demands of a number of "Cs": clinical care, cost control, local community needs, user comfort, and a low environmental carbon footprint.



2. The discrepancy between demand and affordability: European gradation in health and health facilities (data reproduced by courtesy of Barrie Dowdeswell, European Healthcare Property Network).

Background

The provision of healthcare has become far more complex than it was when the UK's National Health Service was created in 1948. Currently, around 1.3M people are employed by the NHS, with 1M patient visits every 36 hours and a budget of approximately £100bn per annum. The ultimate aim of the service is to care for all patients of any age, from all socio-economic groups, driven by the moral dimension that promotes healthcare for all at the point of need irrespective of the ability to pay[1].

Very often, however, patients are placed in environments that are alien to them at the same time as their anxiety levels are being heightened. With the burden of unaffordability alongside increasing patient expectations (Fig 2), healthcare is indeed a complex sector and value needs to be leveraged at every opportunity.

Learning from other sectors

Historically and for largely financial reasons, the benefits of a quality environment seem to have been ignored in the clinical setting, following the mantra "form follows function". However, many designers have learnt in other construction sectors that environment can have a positive impact on occupants.

Transferring this approach to the health sector is not easy. The initial task is to assess the area of greatest impact that the built environment can play in the acute healthcare environment. This assessment must be made with four groups in mind: the staff who work there, the carers who visit, the local community who engage, and the patients who are treated.

Each group's interaction with the environment is different, and a realistic understanding of what can be achieved is necessary to understand how each of those groups can benefit.

The aim is to create an environment that supports wellbeing, and this in turn is consistent with the sustainable design approach that Arup attempts to develop with all its clients. The creation of this type of environment also presents designers with some commonalities that relate to each group.

Potential benefits of the built environment

The following elements support a therapeutic environment, and each has particular primary beneficiaries:

- *Sufficient car parking:* local community, visitors, and staff
- *Clear way-finding:* visitors and staff
- *Privacy and dignity:* patients and carers
- *Responsive acoustics:* patients, staff, and visitors
- *Natural daylight:* patients, carers, and staff
- *Interesting/relaxing views:* patients and staff
- *Low risk of hospital-acquired infection:* patients and staff
- *Environmental control:* patients and staff
- *Artificial lighting:* patients and staff
- *Art:* local community, patients and staff
- *Music:* patients
- *Thermal comfort:* patients and staff.

It is vital to consider metrics that can be measured, and hence costs. Without this approach, return on investment (ROI) is impossible to calculate, and the chances of securing funds to make the necessary improvements to align with environmental needs will be lost. It is important to note that generally any investment made in the built environment is often considered as secondary to the main function of treating patients – the economic imperative of the NHS is, after all, to treat patients.

3. Florence Nightingale.

4. Reception area at Altnagelvin Hospital, Londonderry. "Variety of form and brilliancy of colour in the objects presented to patients is the actual means of recovery." (Florence Nightingale).

The perceived benefits form a complicated set, embracing patient satisfaction, patient stress/anxiety, pain, hospital-acquired infections, sleep quality, slips, trips and falls, length of stay, medical errors, patient communication, patient confidentiality, staff satisfaction/morale, and staff turnover. Some of these can be measured easily, others not so easily, but they are all considered to be valid outcomes to the design of the therapeutic environment.

Changing technologies

Probably the easiest metric to understand in the acute healthcare environment is length of stay (LOS). Patients need to walk away from hospitals in improved health in as short a time as possible. This LOS is a key driver in bringing down patient waiting lists, and forms the political imperative of the NHS. Of course, practical and operational factors affect the LOS.

For example, differences in time taken to perform the same surgical procedure and subsequent post-operative treatment and discharge strategies are well defined. But designers need to appreciate how the delivery of healthcare has moved forward over the years, and will continue to do so in the future.

The environments that are created now may not be appropriate in five years' time, such is the speed of change. Flexibility in design is therefore essential, but comes at a cost.

An ongoing debate

Some elements of the therapeutic environment are not new. For example, there is the intuition of one celebrated person, Florence Nightingale, who famously wrote in 1859 that "the first requirement of a hospital should be that it should do the sick no harm."[2] In her *Notes on Nursing* she added:

"Little as we know about the way in which we are affected by form, colour, by light, we do know this, that they have a physical effect. Variety of form and brilliancy of colour in the objects presented to patients is the actual means of recovery."[3]

Pembury Hospital, Maidstone West Kent, England


5.


6.

This, the UK's first large public acute hospital with 100% single in-patient rooms, will open in 2011. Built for the Maidstone & Tunbridge Wells Hospital Trust by the consortium Equion (John Laing, Laing O'Rourke & Interserve FM), Pembury Hospital provides Arup with many challenges in its multiple roles on the project: technical adviser to the Trust; site masterplanner; project manager; cost planner; civil, SMEP, façades, fire and security, and transportation engineering designer; life-cycle and facility manager; site surveyor, and landscape and ecology designer. Architectural subconsultant: Nightingale Associates.

A further example is the document *A scandalous impromptu*[4]. This 1976 business case by Evan Burrough, relating to the provision of single-bed hospital accommodation, was reprinted by Arup in 2008 to commemorate the 60th anniversary of the NHS as well as the first 100% single-bed hospital to be commissioned in England. Arup was client technical advisor for this project at Pembury, Maidstone, Kent (left).

The views of Nightingale and Burrough continue to be as relevant today as they were in their original eras.

The modern-day perspective

Bringing the argument up to date, a further characteristic to be considered is natural daylight, research into which has been carried out by Keith Scott Jamieson of Imperial College, London.

Ultraviolet light can destroy pathogens, and hence support reduction in hospital-acquired infection (HAI). In addition, infra-red can stimulate serotonin, which has a positive effect on the immune system. Both can thus directly affect the patient outcome and hence the LOS. Designers should, therefore, take seriously the impact of the glazing system. It is justifiable to go further and suggest that for reasons of views, daylight, natural ventilation, safety, and user control, the "window" is probably the current most important environmental system in hospital design.

Hypotheses can thus be developed from intuition, but in order to convince finance directors and policy-makers, there is still a need to create an evidence base through academic research.

Difficulties arise when researchers attempt to understand the effects of a challenging environment on the complexities of human health variables. Professor Roger Ulrich of Texas A&M University carried out a research programme in which it was shown that a patient who, following surgery, was sited in a room with good views out, had a shorter LOS than a similar patient who had the same surgery but was sited in a room that faced a brick wall. Among the many variables to patient outcomes are the level of acuity, the patient's state of mind, whether positive or negative, the nursing care, the role of the carer (if any), pre-operative treatment, etc.

There are thus many variables associated with this type of research, so much so that a repeat of an experiment may not deliver the same outcome. The resulting uncertainty will increase the chances of a design proposal failing at the hands of the facility's financial manager.

7. Optimum design for a single-patient room.


a)


b)

The way ahead

Does this mean that, because research evidence may not support measures that designers intuitively believe aid the therapeutic environment, progress cannot be made? Not necessarily, and for two main reasons, the first of which concerns the views of nursing staff.

A survey by the Commission for Architecture and the Built Environment (CABE) in the UK found that 90% of nurses felt that a well-designed environment improved patient well-being, and even more – 91% – said that a well-designed environment reduced their own stress levels. Given the difficulty of attracting and retaining staff in the UK healthcare environment, this is an important driver in the quest to justify designing high quality environments.

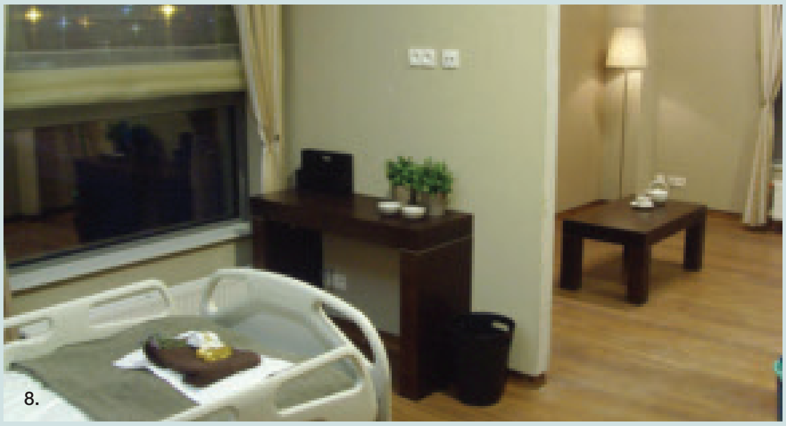
The second reason is that the NHS's recent reorientation towards patient choice and payment by result means that patients may in the future migrate to those hospitals that are perceived to have a better environment; indeed, hospitals with an improved environment may market this to increase their patient numbers. There is a further justification, but this requires a more holistic approach; when taken individually, design measures can easily be criticised on financial grounds, but when they are grouped together value is leveraged.

For example, the introduction of single bedrooms satisfies privacy and dignity issues, improves acoustics, allows music or other forms of entertainment, gives patients control of their environment, introduces opportunities for energy savings, eliminates problems with mobile phone use, lets families and visitors spend more time with patients, reduces the spread of infection, guarantees natural daylight, and will allow future clinical procedures to be developed and carried out without the need for the provision of specialist spaces.

When all these measures are grouped, the benefits to all parties are enormous. It is this subject that potentially offers the NHS probably one of its greatest modern-day challenges. There are currently three 100% single-bedroom hospitals being constructed in the UK: one in England and two in Wales, with another now being designed for Scotland. Once fully operational, all benefits of the single room concept can be evaluated. If/when it is found to be positive, it could render the multi-bed environment obsolete almost overnight!

To sum up, justifying the provision of a therapeutic environment in healthcare facilities through a scientific evidence base is extremely difficult. However, Arup is committed to pursuing this evidence as the firm believes that it benefits staff, patients, visitors, the community, and ultimately the financial performance of the client's healthcare business. Arup will continue to learn from other sectors, engage in research, and offer our findings to our clients.

Medicover Hospital, Warsaw, Poland



8.

The new 15,000m² Medicover Hospital at Wilanów, Poland, with 160 beds, clinical treatment spaces, imaging and operating theatres, and restaurant facilities, is designed to set new standards for a patient-centred therapeutric environment. Arup was lead consultant responsible for project management, cost management, architectural design, civil, SMEP engineering design and site supervision. The design includes infrastructure, 250 parking spaces, and landscaping. Architectural sub-consultants: Atelier 7; Nightingale Associates.

Altnagelvin Hospital, Londonderry, Northern Ireland

9.

This new five-level clinical building, of approximately 23 500m², is a southern extension to Altnagelvin Hospital, part of a multi-phase redevelopment of the entire hospital. It has 140 beds – of which 50% are in single patient en-suite bedrooms – across departments including adult acute, haemotology/oncology, maternity, obstetrics, coronary care, stroke services, and adult medical. There is also a physiotherapy outpatients department with a hydrotherapy pool. The building design emphasises good lighting, space, break-out areas, provision of artworks throughout, and external views to the Sperrin Mountains. Arup's role comprises M&E engineering design and cost control. Client: Northern Ireland Health Estates Agency. Architect: Hall Black Douglas.

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Redevelopment of Mersey Care NHS Trust facilities

Mary-Clare Race
Malcolm Gilmore

Interviews with staff, focus groups and observations at five hospitals run by Mersey Care NHS Trust informed this case study by Arup, aimed at achieving optimal working environments in the Trust's planned new buildings.

Introduction

Mersey Care is one of only three NHS Trusts in the UK that deliver the full range (community, outpatient, and high security) of adult mental health services. It is in the early stages of redeveloping these services across Liverpool, Sefton, and Kirkby, a process that will include new buildings.

The goal is exemplary designs that will become templates for future mental healthcare facilities. The Trust recognised the benefit of an empowered workforce, and this belief in the staff led it to engage the range of consulting and analytical skills offered by Arup.

This recognition, properly supported to deliver all the required service improvements, was a key challenge and early on Mersey Care's senior team realised that physical work environment is an important operational tool that can enable and catalyse people in the way they do their work.

Although much research has been done on the therapeutic aspects of mental health facilities, the Mersey Care redevelopment offered a unique opportunity to consider staff needs in terms of workplace processes, ergonomic design, and the built environment. This approach not only offered the chance to enhance staff wellbeing, but through a positive relationship between staff satisfaction and service provision, a service improvement opportunity as well.

To identify the optimal working environment, thorough understanding of how current workspace is used and the demands placed on it by different staff groups is essential. The aim of this consultative research was therefore to determine what elements of the current environment could be improved in relation to the proposed new-build facilities in order to enhance job satisfaction, wellbeing, productivity, and efficiency.

Methodology

As well as reviewing the Trust's business plan and objectives, the Arup team obtained information from staff at five different hospital sites. Studies were carried out at 18 wards to understand the core activities of all staff groups, how the physical working environment currently enables delivery of core processes, how the environment supports the needs of the staff and the objectives of Mersey Care, and finally how the current environment could be improved upon to enhance business outcomes.

Results

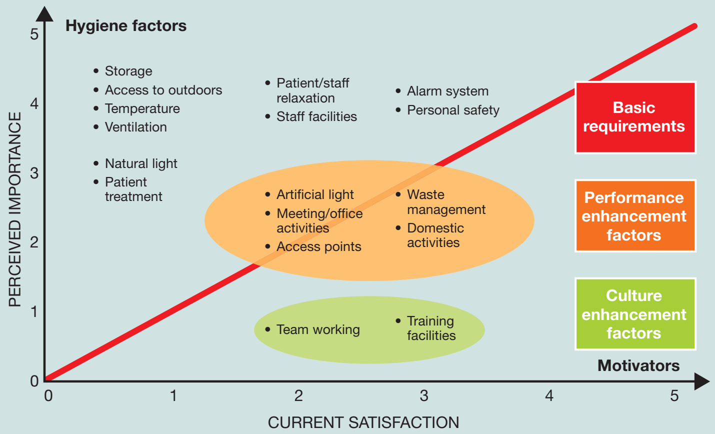
To provide greater context, the factors identified in Arup's interactions with staff were weighted according to the following dimensions:

- *How critical is the inclusion of the factor in the new design?*
- *How satisfied are staff members with the current state of each factor?*

Scores were allocated across each dimension by the volume of staff comment against each factor. Weighting the scores allowed the identified factors to be separated and prioritised (Fig 1). Most staff reported that the new building would be an exemplar facility if it improved their basic comfort. The focus is primarily on support for core tasks so, for example, having good storage is weighted as more important than how far the design reflects and supports the values of the Trust.

These basic needs above, to the left of, and on the red line (Fig 1) reflect the hygiene factors that cause employee dissatisfaction if not aligned with expectation. The items (in green) below and to the right of the red line, such as the Trust's culture and values, were not given particularly high importance when considering the new design, as demonstrated by the low weighting.

1. Balance of issues reflecting importance and satisfaction.



2. Conclusions and recommendations.

Once the hygiene factors have been addressed, these are the motivators that will enhance individual job satisfaction and lead to improved performance. In Arup's experience, it is important that hygiene factors are satisfactorily addressed so that the longer-term benefits of enhanced cultural/values alignment and other behavioural factors can be realised.

Several themes emerged from the data analysis and for each, a number of recommendations were made to address all the factors that came out of the consultation process; these will inform the new design. The issues identified can be summarised under four broad categories.

Comfort

Staff reported a lack of adequate lighting, heating and ventilation. Also, access to outdoor space was limited to a few wards. Addressing these issues in the new facility will enhance staff energy levels and there should be notable improvements in staff wellbeing, absenteeism, and performance.

Working processes

In many current facilities the environment does not allow appropriate waste management practices or meet personnel requirements. In addition, primary activities such as patient treatment, storing files and materials, and holding meetings are made difficult by environmental constraints.

The new facility's design should reflect the needs of all staff groups and involve relevant personnel when deciding on materials and interior details.

Organisational aims and objectives

Some features of the current environment were perceived to inhibit effective team working and the absence of dedicated learning and training facilities did not promote the image of the Trust as an organisation committed to developing its people. Furthermore, staff were generally critical of the "discretionary" facilities provided for them and felt that an improvement would encourage continued employment, improve attitudes to work, and attract more people into the Trust.

Opportunities for facility improvement included improved canteen services, recreational amenities, and support services such as a crèche. While these features are not critical to the functioning of the business, they are directly linked to staff wellbeing and performance, and hence the ability of the service to meet its business objectives.

Safety

Safety-related concerns included the effectiveness of the current alarm system and access points, and the personal safety of employees coming to and from work. The new facility should aim to provide safety systems that maximise staff and patient safety without impinging on the ability of staff to do their job. For example, entry systems should provide maximum security but not entail staff having to remember numerous codes or carry large bunches of keys.

Value added

Mersey Care's exemplar facility is still being planned and will not be occupied for several years. This work by Arup in 2006 identified actions that are needed in readiness for the new build, not least by showing that: (1) the voices of different staff groups will be listened to; (2) operating processes which currently inhibit effective working can be addressed now in expectation that other inhibitors to best practice related to the environment will be "designed out" in the new facilities; and (3) early engagement in the design approach itself has motivational effects.

The results will lead to improvements in culture, process, training, communication, organisational structure, and design.

Understanding and promoting "green behaviour" in the use of existing buildings

Rose Challenger
Chris Clegg Matthew Davis
Chris Jofeh

Introduction

Encouraging individuals to engage in pro-environmental (green) behaviours is attracting increasing levels of media, public, policy, and research interest. Despite this, understanding of the most effective ways to change (or "green") individuals' behaviour towards energy, water and waste use, and participation in recycling, is limited; this is especially true of the workplace, which is relatively unstudied. The authors' research sought to bring together the most robust studies and knowledge from across a range of literatures and subject domains – in particular those studies that have attempted to achieve changes in people's actual behaviour towards these matters – in an attempt to draw up a set of techniques and approaches that can be used to help change the way occupants act in existing buildings.

Research method

The team undertook cross-disciplinary literature searches in several academic databases. 8595 potential articles were returned, and of these, 165 articles, book chapters or reports, were reviewed in detail, together with other relevant references and theories. Interviews were conducted with some experts in the field.

Lessons learned

One of the most striking findings of the review was the lack of good quality studies of attempts to "green" individuals' actual behaviour. Much of the psychological research in particular has looked at how to change people's attitudes and values, but it is increasingly clear that there is often a weak relationship between a person's attitude and how they actually choose to behave. The team therefore compiled a list of the techniques that, based on their success as described in the literature, interviewees' opinions, and experience of changing behaviours in other contexts, are likely to prove effective in both the home and work environments.

Techniques

Feedback

Feedback can help to increase awareness of the value and use of resources (or the generation of waste), and feedback interventions have been successfully implemented in domestic settings and in organisational contexts. Feedback should, however, be tailored to the context, be continuous, and be provided as close to the consuming or generating device as possible. Within existing buildings, retrofitting feedback devices on or near machines and technology may be an effective way to connect individuals with their consumption. Domestic feedback devices are already available (Fig 1), providing domestic consumers with data on real-time electrical usage.

Information and procedural knowledge

Providing individuals with information can help to both strengthen the argument for changing their behaviours and show how they can go about doing this (procedural knowledge). The information should be tailored to the context, come from a credible source, and be specific, personalised and vivid. Information on how to use devices and appliances efficiently, together with the impact of their use, should be placed near the appliances.

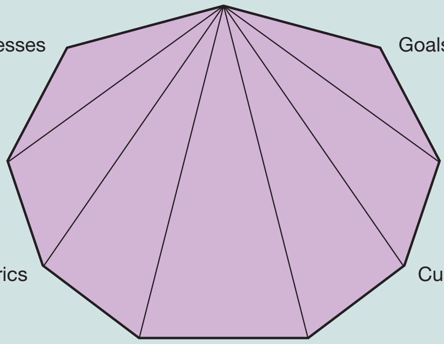
Social pressure

Group or social pressure should be harnessed to help support behavioural change. In a work context this may involve the use of group goals or competitions between departments, while domestically they may take the form of techniques that engage the whole family or neighbourhood contests. Worker (or resident) participation is important in designing interventions and policies, and representatives should be consulted as to the specific barriers to change that they believe they will encounter. They will also be able to identify the issues that are of greatest importance to them in their work.

Table 1: Techniques and approaches to help change the way occupants act in existing buildings.

Leadership	Strong, clear, and consistent leadership (business, community or political) is required to communicate the need to change and prevent "green" actions from being marginalised.
Ownership	Involve workers (or home users) in the design and implementation of new technologies or change programmes, so as to maximise acceptance.
Information	Provide occupants with procedural "how to" information, clearly explaining how to use technologies efficiently and avoid operational error.
Feedback	Provide feedback on resource use or consumption, close to consuming devices, and thus connect users to their physical usage and raise awareness of consumptive behaviours.
Competition	Use the power of social pressure between groups of employees or households, thus giving a competitive edge to changing behaviour.
Reward	Offer rewards or incentives to help incentivise individuals or groups to change their actions or usage initially and break ingrained habits.
Make it easy	Convenience is key to enticing people to change their behaviours in the first instance and to increase the likelihood of sustaining these changes over time.
Integration	Consider the problem in socio-technical terms: technology may be part of the solution, but changes to social structures (work processes or domestic patterns) may be needed to support effective usage.

2. The interconnected nature of building design and other aspects of system.



1. Example of a commercially available feedback device, the *Wattson* (http://www.diykyoto.com/uk/wattson/).

The need for a socio-technical solution

Large differences in energy consumption between comparable households demonstrates the role of individual behaviour in energy consumption. The need to target behaviours is also highlighted by the sometimes counterproductive use of more efficient devices and technologies – the so-called "take back factor".

We argue that a socio-technical approach is needed, integrating technological efficiency with changes in behaviours.

Well-designed technology in itself can be used as a tool to drive behavioural change, through providing the types of feedback detailed above. It can also incorporate features to help support changes to the social environment, eg providing information for new metrics, feedback on green performance targets and so forth. These advances, coupled with changes such as creating new job descriptions that explicitly include environmental objectives, community representatives responsible for leading green initiatives, etc, will help drive the uptake and maintenance of green behaviours.

Building performance feedback to promote behavioural change

Barry Austin Darren Wright

Understanding how buildings perform in practice is an essential part of designing for the future. Arup's post-occupancy building performance evaluation service relates operation, energy, and carbon use with occupant satisfaction ratings to give a comprehensive view of how a building is working from all aspects.

Optimising building performance

Design predictions for a building's performance are often not fully realised in practice and so, in the context of rising energy costs, climate change legislation, and dwindling resources, there is a pressing need for both new buildings and the existing building stock to deliver good performance in practice.

Employers want better levels of productivity; space is at a premium and there is a growing awareness of the real value of high quality accommodation. In the UK, government Energy Performance Certificates are now revealing underlying energy-related asset values, and thus changing the way in which properties are perceived and selected.

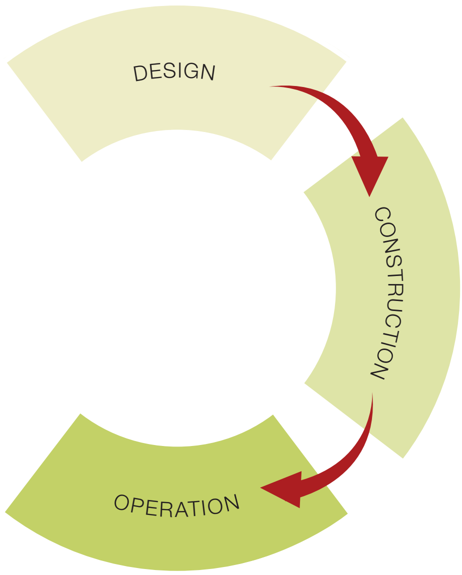
For buildings to perform well, three elements usually need to be in place:
(1) good design, with the design intent followed through with
(2) good quality construction, and then the full potential of the building realised with
(3) good operation (Fig 1).

A building can fail at any one of these stages, but most commonly it is the third. The key to success is feedback – a quantitative measure of what the building is doing and benchmarks to compare it with, to say whether this is good or bad. This must be coupled with procedures so that corrective actions can be applied and underpinned by continued monitoring and targeting.

In this process, feedback flows in two principal streams:

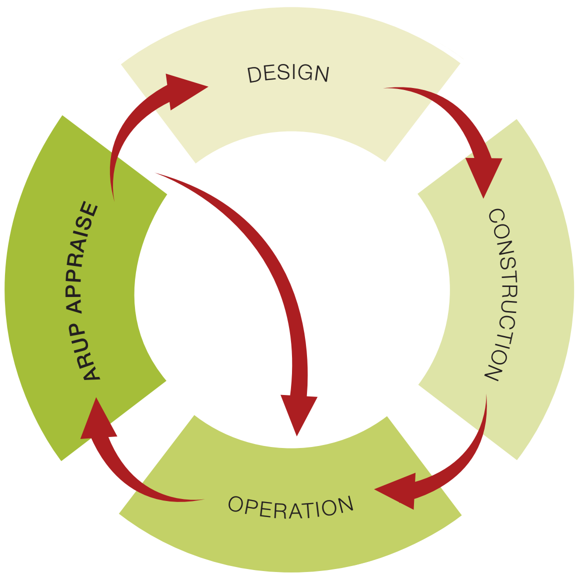
- *Briefing:*
  energy consumption, carbon emissions, thermal, visual, and aural comfort, occupant satisfaction
- *Operation:*
  plant operation, energy consumption, comfort, and occupant satisfaction.

Arup Appraise is a new post-occupancy building performance evaluation service that provides an assessment of energy and water consumption, carbon emissions, and occupant feedback, benchmarking these against published performance indicators. It has been designed to "close the loop", providing owners, operators and occupants with essential feedback (Fig 2).



1. Elements of good building performance.

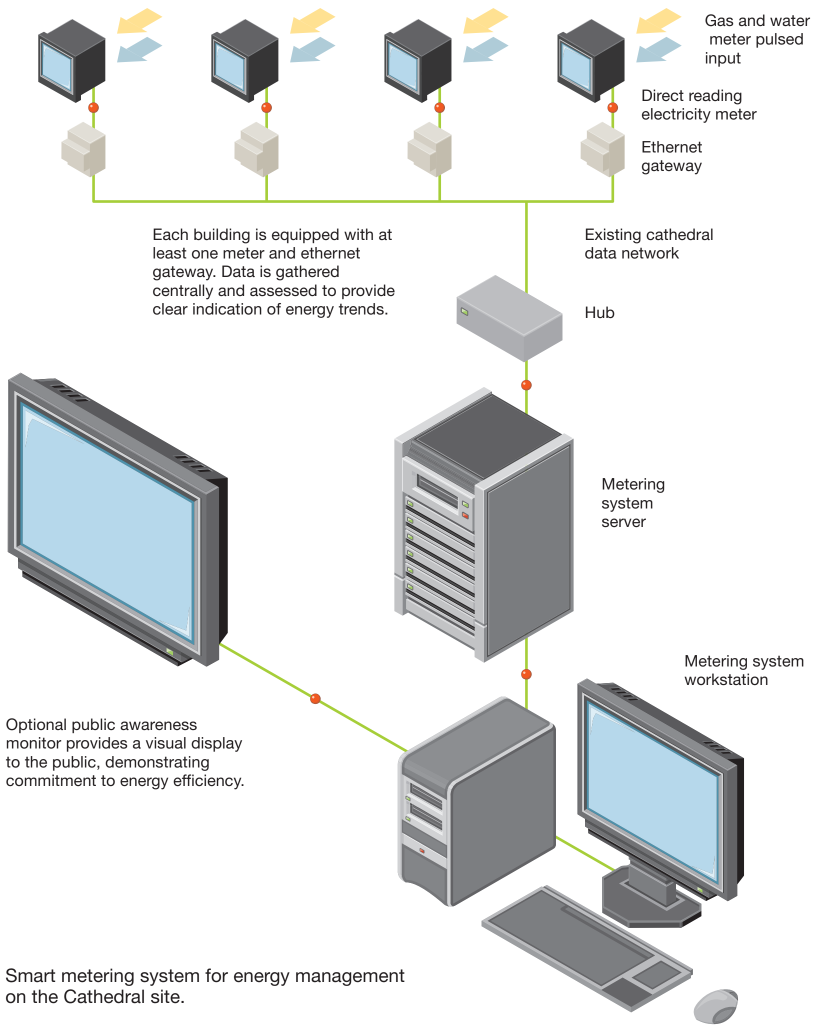
2. How Arup Appraise closes the loop for good building performance.



Arup Appraise can be tailored into a service that meets the client's requirements, but it may typically include any of the following areas:

- regulatory impact review
- building fabric performance
- indoor environmental performance
- HVAC system and plant performance
- building management system and control system performance
- metering and monitoring system performance
- power quality testing
- retro-commissioning
- maintenance strategy
- brief development.

3. Canterbury Cathedral.



4. Smart metering system for energy management on the Cathedral site.

Feedback for the brief for new buildings

The flow of information back to the design team and client about how previous designs actually worked in practice is vital in buildings that will be brought to the bar of their actual performance, eg operation ratings in energy certification.

The standards that future buildings will need to operate to will be increasingly stringent, eg in the UK to meet government and European commitments to reductions in CO_2 emissions. Using feedback to inform the brief will be the normal way of approaching a building design.

Arup Appraise is concerned with going back into buildings to obtain feedback on how the design has worked. This allows the performance to be optimised, benefiting the owner/occupier and also ensuring that lessons can be fed back to the briefing for future buildings. An example of how this feedback has been used to help the next generation inform the briefing process is the Rivergreen Centre in Durham. Arup worked with the developers on monitoring their first building, which demonstrated several energy-efficient and low-carbon features: a high level of insulation, high thermal mass, biomass boilers, solar water heating, rainwater recovery.

Arup's monitoring examined how these passive design features and technologies work in practice and how occupants perceive their environment. This showed the building to have a very low CO_2 emission level at 24.5kg of CO_2/m^2, and occupant satisfaction in the top 18% of buildings in the Building Use Studies (now part of Arup Appraise) national database (see also pp4-7).

Lessons learnt from the performance feedback are now being used in the development of the next Rivergreen building in Stannington, which has even more ambitious performance targets.

Feedback for sustainable operation

Feedback on how a building is operating is crucial for existing buildings to be correctly managed and realise the optimum energy use and quality of the internal environment. Arup is extensively involved with the evaluation of existing buildings and helping their clients set them to work in the most efficient and productive manner, optimizing current systems or helping with the implementation of intelligent management systems for continuous monitoring and improvement. A good example of this is the energy survey work Arup carried out with the Dean & Chapter of Canterbury on the Cathedral and Precincts building (Fig 3).

This work established the energy use, how it broke down into end use, and what the buildings should be using given their special characteristics and patterns of use. The Dean and Chapter are now implementing Arup's recommendations. New smart metering systems are being specified to ensure that a close check is kept on energy use, with any overuse being reported through a sub-metering system so that remedial steps can be quickly taken before it becomes a major issue (Fig 4).

Buildings in the future will be faced with increasingly stringent statutory requirements on energy use, emissions, and the quality of the internal environment - building performance feedback utlising tools and methods such as Arup Appraise are essential to meet these constraints. Equally, in order to deliver new buildings that have very low emissions, meet new legislation and maximize asset value, performance feedback to the briefing process will become a necessity for the future.

Creating healthy, sustainable communities

Paul Johnson

Introduction

A population's health and wellbeing are fundamental to its survival, and underpinning the development of any new settlement, or regeneration of existing rundown urban areas, is the need to provide an environment within which the community can thrive. Arup's experience in developing integrated planning and design solutions for socially responsible, sustainable development includes understanding the part played by the quality of the natural environment, landscape, and ecological diversity in promoting health and wellbeing.

Health Impact Assessment (HIA) techniques are used during design and planning to draw together these environmental factors with other social and economic variables to help improve health outcomes for urban communities. But what are the implications for delivery on the ground? Can good design provide all the answers? What other delivery mechanisms may be needed?

Planning the new/regenerating the existing

In many countries there is discussion about the developing structure of societies, especially in urban areas. Amongst many concerns are the environmental and social impacts of cyclical economic growth and decline, especially on community cohesion, health and wellbeing. Such issues form the core of policies by governments and agencies charged with implementing more sustainable urban development. Many complex interactions play their part in defining how sustainable and healthy a community is or will be in the future, but a key driver must be that improving the health of a community helps to make it sustainable.


1.

Developing new sustainable urban settlements, often termed eco-villages, eco-towns or eco-cities, is high on the agenda of many governments. Authorities worldwide face increasing pace of population growth, urbanisation, and the need to combat climate change and the spectres of food and energy poverty. Health Impact Assessment is one tool in this fight.

Neither the planning and design of new settlements nor the regeneration of old, run-down urban and industrial areas can be achieved by single-discipline working – they all need a high degree of integrated thinking, and the bringing together of varied disciplines. Arup is increasingly engaged in design activities that bring together expertise in structural landscape frameworks, biodiversity planning, and provision of community green space, water, play areas, and well-designed streets and public realm generally, specifically with the aim of providing an environment for healthy living.

This forms part of the firm's overall sustainable community design process which draws in many other areas of connected interest, such as the urban form, mobility, security, energy, education, sports, leisure, commercial, and other community amenities.

To help teams understand whether what is being designed has beneficial effects, many tools can be used. On recent projects in the UK the developing technique of HIA has been employed to determine their potential effect on the health of existing and incoming populations.

Greenspace, health and wellbeing

Much research has been undertaken in recent years on the relationship between human health and wellbeing and the external environment. In this context, wellbeing is defined as a positive physical, social, and mental state. For some it will seem like common sense confirmed, but academic research does show a strong positive relationship between better health and increased exposure to greenspace and natural space. The more "natural" the space, the better the health effects and feelings of wellbeing.

A restorative function is also seen with exposure to natural space – this has been recorded in relation to mental health and obesity. Conversely, there is also evidence of a "nature deficit disorder" where lack of access to natural greenspace has a deleterious effect on health and wellbeing.

Creating and designing environments that respect limits and promote strong communities with social cohesion and physical activity are perceived to create more opportunities for people to live healthier lives than they would otherwise.

Good design and creation of a sense of place creates feelings of security by reducing opportunities for crime and anti-social activity such as graffiti and littering, which repeatedly top surveys of things people dislike about their neighbourhood.

Health inequalities between rich and poor can also be significantly reduced by providing access to and an opportunity to exercise in greenspace – especially undeveloped land with "natural" vegetation as in parks, woods and forests. It has been found that

Northstowe New Town HIA, Cambridgeshire, UK

2. Illustrative masterplan, July 2008

3. Artist's impression, July 2008.

Arup undertook an HIA for the proposed New Town of Northstowe in Cambridgeshire, planned to include 9500 new homes and associated employment, retail, leisure, transport and infrastructure facilities (Figs 2, 3). The work was undertaken as part of the overall planning and environmental service to the clients – the Homes and Communities Agency and the urban developer, Gallagher.

Arup held initial meetings with the local Primary Care Trust (responsible for healthcare provision in the area) and early in the assessment established and chaired an HIA steering group with members of the local health bodies, planning authorities, and other interest groups. Public consultation involved developing an HIA questionnaire and discussions with local residents at project consultation events. Arup then took the HIA findings to the masterplan topic group so as to inform the new town design process.

Impacts were mainly associated with environmental noise and traffic and construction issues, with positive effects identified in terms of housing, greenspace and employment. The HIA recommendations focused on project delivery and construction issues, and were submitted as part of the suite of supporting documents in the project's planning consent application.

people living close to high levels of greenery are many times more likely to be physically active and much less likely to be overweight than those living with low levels of greenery.

HIA and urban design

Recognizing the value of greenspace is a driver of healthy sustainable development, and to assess the broader impacts of project designs, the processes and outcomes of HIA techniques are of value to the design team, stakeholders, community interest groups, and decision-makers, and help define more sustainable settlements.

In a Health Impact Assessment, numerous determinants are examined including those derived from socioeconomic, environmental, and lifestyle factors, the availability of services such as healthcare, education, transport and construction, and operational activities. The health status of the affected populations is examined at a detailed level and the significance of health effects from the designed development are assessed.

The assessment techniques examine the nature of the impact (positive or negative), its measurability, the degree of certainty, and limitations to drawing conclusions because of the lack of an evidence base backed by scientific data. Community engagement is an essential part of HIA, as feedback is critical to help the designers overcome issues.

In the UK Arup has undertaken HIA on both new settlement and urban regeneration projects, and found the process extremely effective at engaging community concerns and ensuring that health and wellbeing become central to the urban and environmental design process.

Working together with client project teams, Primary Care Trust health professionals, local authority planning and environmental health officers, and environmental and transport agencies has helped ensure the best possible delivery of sustainable communities. The ultimate value is in better health for people, better community cohesion, and overall achievement of better design, lower cost, and more sustainable development.

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(2) SUSTAINABLE DEVELOPMENT COMMISSION. Health, place and nature: How outdoor environments influence health and well-being: a knowledge base. The Commission, March 2008.

King's Cross Central Opportunity Area HIA, London, UK

Arup undertook a Health Impact Assessment for the redevelopment of the King's Cross Central Opportunity Area. The proposals included housing, employment and training, health and other community facilities on one of the largest plots of derelict land in Central London (Fig 4).

The study area is characterised by poor health and the existing communities there are amongst the most deprived in the UK. Issues include significant levels of long-term unemployment, overcrowded housing lacking basic facilities, high crime rates, and a shortage of community centres and other social capital. Additionally, exceedances of health-based air quality standards gave rise to poor environmental health conditions. The HIA determined the predicted effects of the redevelopment of the area on health determinants and health services.

4.

Anfield/Breckfield housing renewal HIA, Liverpool, UK

This scheme under the UK government's 2003 Housing Market Renewal Initiative (HMRI) comprises the regeneration of 1800 run-down houses in North Liverpool (Fig 5) through a combination of demolition, new build, and refurbishment. The proposals also included retail, employment and community facilities, and public open space.

The study area is characterised by high levels of deprivation and poor health, and to help foster stakeholder engagement Arup interviewed representatives from local community groups prior to submission of the HIA to Liverpool City Council. Recommendations were made in the HIA to improve health outcomes by ensuring that the benefits reach those most in need, and reducing the adverse effects of the phased construction and rehousing process.

5.

Developing a ticket office design for King's Cross St Pancras Underground station, London

Ian Rowe

Introduction

This project concerned the integration of human factors into design development for new ticket offices at King's Cross St Pancras Underground station[1]. It involved the examination of issues associated with compliance to many published standards, the engagement of a wide range of stakeholder groups, and the operational and commercial needs of the client. Developing the ticket office design also included addressing issues associated with creating an "inclusive" design that would both enable accessibility for both operators and customers, and provide a highly efficient and effective environment to allow fast customer throughput – and all while maintaining operator safety and comfort.

Integrating these human factors included primary research into the usability of various ticket counter heights for different profiles of users (operators and customers, including those in wheelchairs) and optimisation to enable a single counter height to be installed that could be used by all profiles.

Background

Guidance from the UK Strategic Rail Authority (SRA) specified that at least one "low" counter should be installed in all ticket offices to make them accessible to wheelchair users. This directive, however, seemed to contravene the "Inclusive" principles currently being adopted by Transport for London (TfL), whereby the provision of a dedicated facility does, by its nature,create an "exclusive" environment.

Utilising a "good practice" human factors approach, the Arup team conducted a short study of one of the "low counter" designs at a Network Rail mainline station. This, however, was found to be generally disliked by wheelchair users, as it drew attention to their impairment and made the queuing process awkward for them. As a result, the low counter was generally not used and remained closed for most of the time.

These findings were presented to London Underground and, in line with that organisation's commitment to integrate human factors into design, resulted in a new ticket office design being commissioned.

Approach

The approach adopted had two stages, firstly to understand the requirements, and then develop the design. To understand the requirements, the following activities were undertaken:

Process mapping

Front line staff were engaged in a series of workshops to capture the processes that take place in the ticket office. These range from those that face the customer, such as selling tickets and providing information, to "back office" functions such as cash counting and administration. All processes were drawn up and then verified by operational staff members.

Hierarchical task analysis

For each process identified, a detailed task analysis was conducted, including both video capture of operatives undertaking tasks and live observations of staff. These were then analysed to understand the equipment

1. Psycho-physical experiment: an operator trials the equipment layout.

2. Psycho-physical experiment: a wheelchair user on the customer side.

used and how it is operated. Communications and other movements were also analysed. From this, a frequency and complexity analysis was performed to inform an initial proposal for layout of equipment and facilities.

Psycho-physical experiment (Figs 1, 2)

From the results of the task analysis, an initial proposal for workstation layout was established that enabled a full-size mock-up of a serving window to be built for usage trials with operators and customers. Since one important variable was known to be counter height, the mock-up had small hydraulic jacks to easily alter the counter height.

An experiment captured operator and user responses to different layout scenarios and this was then used to inform the final layout. In addition, the whole mock-up was moved to the Spinal Injuries unit at Stoke Mandeville hospital in Buckinghamshire, UK, where further dedicated trials were conducted with 17 wheelchair users.

Conclusions

This whole exercise resulted in a design that featured:

- a sit/stand workstation
- a single counter height usable by able-bodied and wheelchair users
- a workstation design that reduces the risk of musculo-skeletal injuries
- an optimised workstation layout that increases efficiency and improves throughput.

Benefits

The new design underwent a comprehensive post-occupancy evaluation review, and users rated its usability and comfort very positively. This has resulted in less lost work time from musculo-skeletal complaints and an overall increase in operator satisfaction levels. Due to the focus on equipment layout during design development, the efficiency of the customer-facing task also increased, resulting in significant gains in terms of task time and therefore throughput of customers at each serving window (Fig 3).

Implementing single standard-height counters has also resulted in more efficient queuing and handling for wheelchair-bound customers, and the flexibility to allow operators to either sit or stand. The human factor integration process is also perceived to have delivered significant, but less tangible, benefits, including an increased commitment of front line staff and general improvement in industrial relations.

Reference

(1) ROWE, I *and* SMITH, D. Developing a design for the new ticket offices at King's Cross Underground station. Contemporary Ergonomics 2005, pp626-634. Taylor & Francis, 2005.

3. Completed ticket office.

High density boarding and alighting:

A psycho-physical experiment

Ian Rowe Nick Tyler

Arup used a purpose-built pedestrian movement laboratory to examine the effects of variables on train passenger behaviour when boarding and alighting in artificially-created crowded conditions.

Introduction

Thameslink, the UK railway that links Bedford (in the south east) with Brighton (in the south) via London, is currently undergoing a major upgrade to accommodate the volume of demand predicted for the future. This upgrade includes permanent way, signalling, and rolling stock, as well as improvements to stations and facilities.

Arup was appointed by the UK Department for Transport (DfT) in 2007 to provide technical assistance for the specification, design, and procurement of the new rolling stock for this major infrastructure project, effectively becoming responsible for ensuring that all assumptions related to the performance of the system are fully understood and validated, so as to inform the design of the new rolling stock.

The proposed operation of the railway includes train headways of two minutes, and shows that the maintenance of reliable and fast dwell times is critical to delivery of the performance required, thus making dwell times one of the most important factors. How could these headways could be achieved in the context of dense operation at the stations, particularly in the Central London section of the line?

The vertical and horizontal gaps between trains and platforms vary, platforms are sometimes straight and sometimes curved, and both trains and platforms are crowded. The ability of passengers to board and alight trains in a defined time period would be critical to the success of the service, so it was necessary to study their performance when boarding and alighting from the trains, and in particular how the design of rolling stock and train/platform interface could affect this.

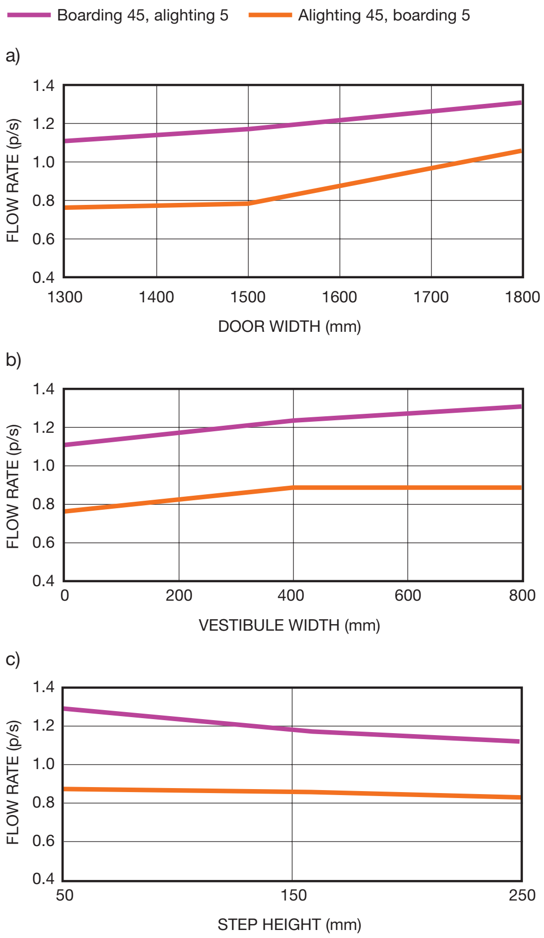
The experiment "exam questions"

To ensure that any further research delivered value to the project, the team approached it through "exam questions", derived using the known system performance necessary to deliver the required service level.

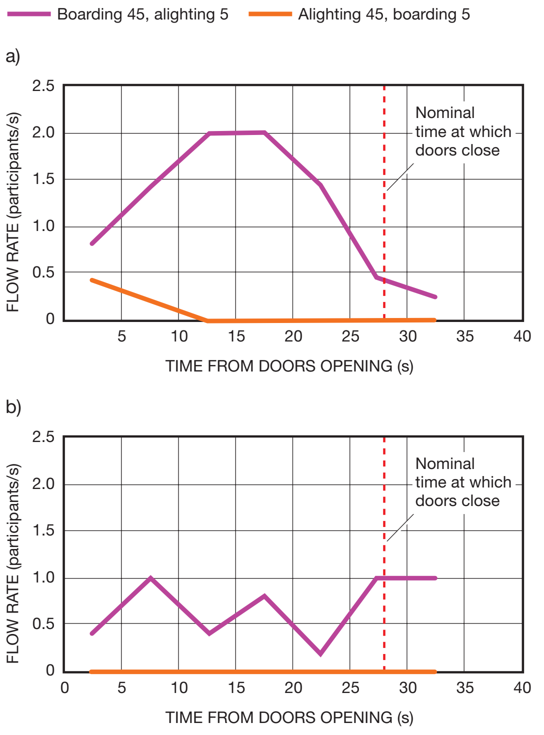
In this case station dwell time was used to derive a maximum door open time, and the demand forecast was used to ascertain the number of boarding and alighting passengers required. The following exam questions were agreed during workshops involving all stakeholders:

- Can we board/alight 50 persons in 27 seconds?
- Which variables have which effects on the performance of passengers?

1. Responses to a) door width, b) vestibule width and c) step height.



2. Profile for a) boarding and b) alighting.



The psycho-physical experiment

Due to the sensitive nature of this human performance element of the system, real-life experiments were needed to determine the ability of passengers to board and alight within the defined timescale. To research the effect that various parameters could have on user performance, the team employed the UCL-designed and operated Pedestrian Access and Movement Environment Laboratory (PAMELA) for a comprehensive psycho-physical experiment.

PAMELA is a purpose-built pedestrian laboratory, engineered by Arup[1], in North London. It includes a fully configurable computer-controlled platform which enables the creation of slopes and steps with different surface materials, fully configurable lighting conditions, video camera gantries, and a state-of-the-art audio system for realistic aural environments.

Using these facilities, the authors designed an experiment which is understood to be one of the largest of its kind ever conducted. The experiment involved building a full-size mock-up of half a standard train carriage (10m long) with windows, seating, luggage racks, and opening door, and then having a representative sample of users perform boarding and alighting tasks.

125 people covering a range of age/gender/ physical fitness/capabilities were recruited for five full days of experiments, during which physical and management elements were varied in order to ascertain their effect on overall human performance.

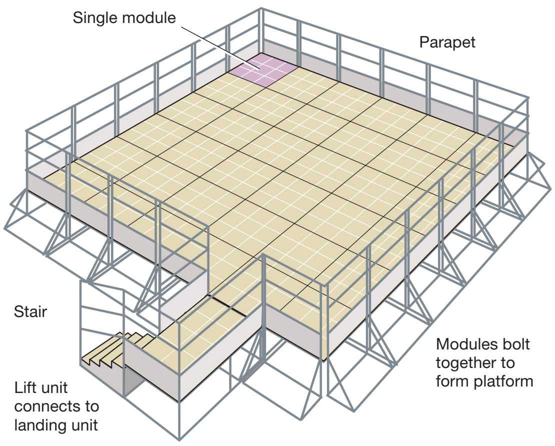
The behaviours of all participants during all runs were video-recorded and these were then analysed to determine the effect that the various parameters had on performance. For each run of the experiment the following sequence was used:

- The participants on both the train and the platform were informed of their required task. Through unique identified numbers, they were told whether they were to board the train, alight from it, or remain in position.
- An audio sequence of a train arriving at a station was then played, so as to provide an increased feeling of reality and give audio cues for the participants to prepare for the task.
- The door alarm sounder was activated.
- The door was opened to allow the boarding/ alighting task to begin.
- After 24 seconds the door close alarm was then activated to warn of door closing.
- Three seconds later the door was then closed, regardless of the boarding/alighting situation.
- The participants were then instructed to complete their required to task once the doors had been opened again.
- The doors were then re-opened.
- Individuals completed their boarding/alighting task.

In all, 224 runs were conducted, involving over 11 000 individual passenger movements under various train/platform height, door width (1.3m, 1.5m, 1.8m), and vestibule setback (0mm, 400mm, 800mm) conditions.

Participants quickly learnt the cues from the audio soundtrack and were observed preparing for movement prior to the event of door opening – similar to the behaviour exhibited by regular commuters.

2. The PAMELA platform, shown here in square format.



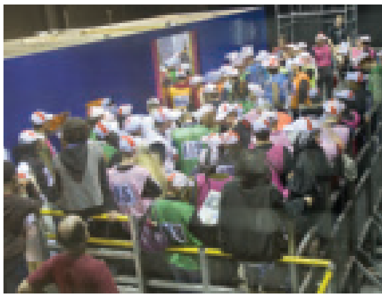
Conclusions

The overall answers to the exam questions were (a) that the successful movement of 50 passengers was not possible within the total 27-second time frame, and (b) that the most successful door width was 1.8m, with a vestibule setback of 400mm; smaller gaps between the train and platform enabled better performance. Behavioural factors investigated included marking clear zones on the platform and organising queuing, but these did not provide significant performance improvements as the crowd density levels (Fruin levels E & F)[2] restricted free movement within the train compartment.

The team therefore concluded that platform measures alone would not provide significant improvement and that further research into the feasibility of behavioural influencing measures within the train compartment during the approach to stations should be tested, along with different internal layouts and seating configurations.

The implications for pedestrian simulation models include evidence that their representation of passenger movements through doorways into and out of crowded spaces is currently inadequate. Further development of software will be required so as to provide improved accuracy in high-density environments.

3. 125 people were recruited for five full days of experiments.



References

(1) HARRISON, A *et al*. Project PAMELA. *The Arup Journal*, *41*(2), pp29-33, 2/2006.

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1. Farringdon Station and curved platform edge.

Quantifying passenger behaviour across a train-platform interface

Kate Fairhall

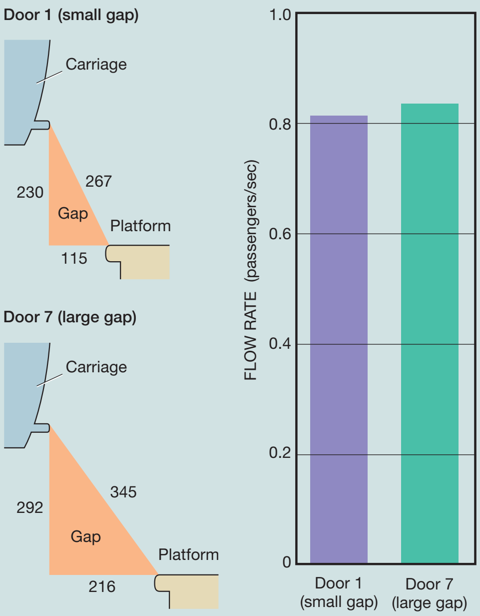
Arup researched passenger flow rate at a busy London commuter station to help determine the potential performance of a proposed new system as part of a major upgrade project.

Background

As part of a major upgrade project, the UK Department for Transport (DfT) engaged Arup to provide technical advice around changes to infrastructure, rolling stock, stations and facilities, so as to ensure that the proposed new system would be operationally efficient, meeting future predicted passenger demands. As part of the new system, the DfT's ambitious target was to reduce the average time a train remained at a station platform to only 27 seconds.

As changes to infrastructure can be costly, the client wanted to investigate other options for how the proposed new system's performance could be optimised, and was keen to understand whether changes to the system design could assist passengers, and hence improve the overall system performance.

Behavioural specialists from Arup were therefore commissioned to study passenger performance in terms of flow rate (passengers per second) across a train-platform interface (TPI). They also wanted to understand whether passenger performance was affected by the station's design – specifically the width of the TPI gap; the station under study was curved, so this width varied at the two ends of the platform (north end/large gap, south end/small gap). Alongside the behavioural work, Arup's transport consultancy team looked at the proposed performance of the new system, using pedestrian modelling software *(LEGION)*, with the intention that results from the observational study could inform the software to further enhance its accuracy in this specific context.



2. Despite the difference in TPI gap width, the effect on passenger flow rate was not statistically significant (approximate dimensions in mm).

3. Larger gap at north end of the platform.

Approach

The study was conducted at Farringdon Station, a popular commuter station in central London serving the Thameslink line from Bedford to Brighton. Over an 11.5 hour period, and thus including both morning and evening peaks, two consultants made over 90 video recordings of passengers boarding and alighting trains at the north (large gap) and south (small gap) ends of the platform. The study additionally aimed to examine the effect of behavioural and train design factors on this flow, including crowd density, walking speeds, and obstructions. The wider contextual and environmental factors were also acknowledged. Coded analysis was performed on the video footage, using *Observer XT* specialist behavioural software, and a real time event log of the coded subject, modifiers, and behaviours was captured at 40ms/frame accuracy. SPSS statistical software was used to test for significant findings.

Findings and results

The study provided a quantifiable measure of passenger flow rate; in this specific context an average of 0.82 passengers per second alighted/boarded the train. However, it was found that neither the width of the TPI nor any of the other variables measured, like the number of obstructive objects and estimated walking speed, had any statistically significant effect on flow rate.

This non-significant finding could be due to the "tipping point" of the width of the TPI, eg at this station the gap may be too large or too small for any effects on passenger flows to be observed. Other findings including crowd density appeared to influence passenger flows but were non-significant; passengers tended to move sequentially across the TPI as opposed to simultaneously; in 13% of the observations one or more passengers disembarked the train in order to make way for others. Also, the weather, station layout, and other environmental/contextual factors appeared to have an influence on passenger behaviour. The results were then used to inform the *LEGION* pedestrian modelling software.

Added value

This study details a novel approach to quantifying passenger behaviours. Other benefits of the study and approach include:

- It gave an accurate and quantifiable measure of passenger performance (in terms of flow rates) to inform system design for enhanced operational effectiveness.
- It facilitated an understanding of how station design features can influence passenger performance, to improve system performance without making ineffective and costly changes to the infrastructure.
- It demonstrated how an holistic approach can be adopted to acknowledge other influencing variables within the wider environment.
- It showed how the use of behavioural results can enhance the accuracy of technical modelling tools.
- It highlighted the need for more empirical research; fittingly, the approach and findings were used to inform the design of a psychophysical experiment jointly by Arup and University College London.[3]

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1.

Modelling the interface between pedestrians and traffic

Andrew Jenkins

An understanding of pedestrian movements, wayfinding, and behaviour in the urban environment is crucial to delivering good design that meets the objectives of all users.

Introduction

While the various elements in the urban environment are often planned and designed separately by different authorities, the challenge to transport planners is to understand human behaviour throughout the system and to deliver well-connected legible routes.

New design tools allow modellers and analysts to simulate people moving through complex systems such as transport interchanges and the public realm. The use of these new tools, together with human behaviour characteristics, can bring significant value to infrastructure projects, influencing design, operations and management strategies, and will enhance the quality and character of urban spaces. This article gives an overview of new simulation tools and how they can be applied to all elements of the urban realm.

Context

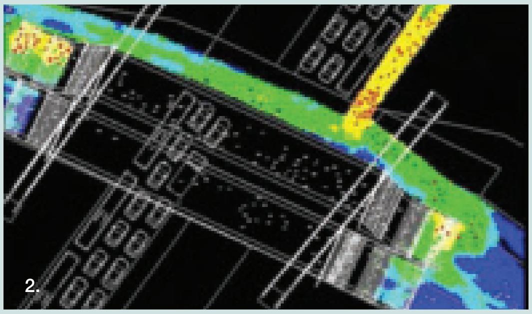
The urban realm is a complex and dynamic environment. It accommodates many and varied functions and includes facilities such as transport interchange, retail, servicing, and meeting-places. Individuals moving through these areas pass through different zones and take on different characteristics as they progress. This all occurs in a limited space and timeframe.

Engineers and planners are required to understand all these needs and develop solutions accordingly. They must overcome the potential for confusion or lack of legibility for all users, both pedestrian and vehicular. They can assist with the organisation and integration of uses, and must set out the design fundamentals.

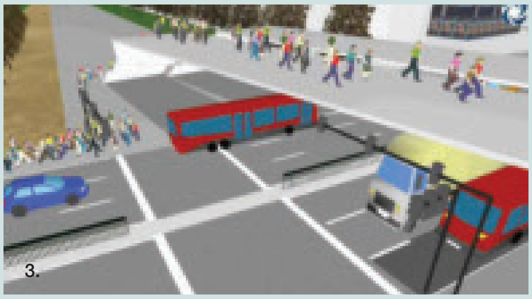
The development of transport models

Arup has been at the forefront of developing and applying new technologies for simulating pedestrians and vehicles, and developing the interface between the two modes. In Britain, *Legion* is a preferred pedestrian planning simulation package for station planning with Transport for London and Network Rail, and Arup has worked

Pedestrian/vehicle integration



2.



3.

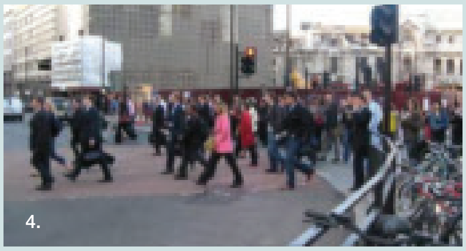
This example examines a problem arising during the movement of crowds across a busy road. Although in the model provision has been made to separate pedestrian movements from road traffic, this has been achieved using a footbridge. Underneath the footbridge is an at-grade crossing where those pedestrians unable to use the bridge will cross the road.

The modelling team's aim was to anticipate and mitigate traffic disruption while allowing people with mobility difficulties access without sacrificing their comfort or safety. Another key question was whether the forecast number of people with mobility impairments use the at-grade crossing without impacting on the traffic flow.

The assessment used two software packages, *Legion* and *Aimsun*, together to accurately model the pedestrian/traffic interface and advise on the level of crowding experienced by pedestrians, whether they could clear the crossing within the "green man" phase, and how this crossing option could be best managed to optimise performance.

These results could only be obtained by running the pedestrian and traffic simulation models concurrently in an integrated manner. The vehicles inside the traffic simulator receive information about the position of pedestrians. This ensures that each driver leaves, not when the lights change from red to green as would be the case in a simulation without pedestrians, but when the roadway is clear.

Victoria station, London: public realm planning



4.

5.

Victoria has an extensive network of pedestrian routes and there are large pedestrian movements between the interchange and the surrounding office uses. Proposals for the area have generally sought to widen footways and provide crossings more appropriate to the pedestrian desire lines, improving wayfinding and reducing conflicts between pedestrians and vehicles.

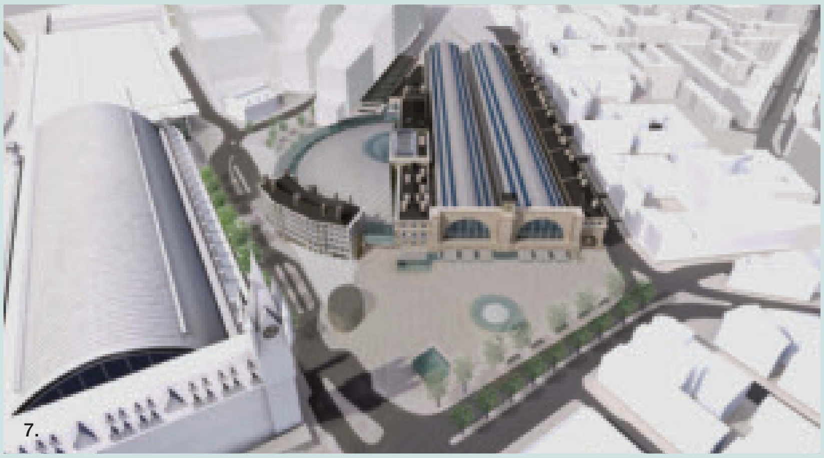
Arup's study required pedestrians and traffic to be assessed as part of an integrated transport study, but the tools available at the time did not permit combined modelling of the two modes together. Pedestrians and traffic were modelled separately.

extensively with planners in developing the software. The development is continuing through presentation of 3-D graphics and integration with the *Aimsun* traffic simulation models. It is this integration with *Aimsun* that enables the accurate modelling of pedestrian/vehicle interface.

Conclusions

The case study examples illustrate how the design of comfortable, safe and efficient spaces for people can benefit significantly from simulation modelling. They further support the case for simulating not just the area being assessed but how it integrates with the surrounding traffic – cars, buses, trams, etc – and all other mobility modes. Most importantly, the complexity of pedestrian-traffic interactions make it necessary to use an integrated simulation approach with two-way interaction between the pedestrian and vehicle movement models.

6.



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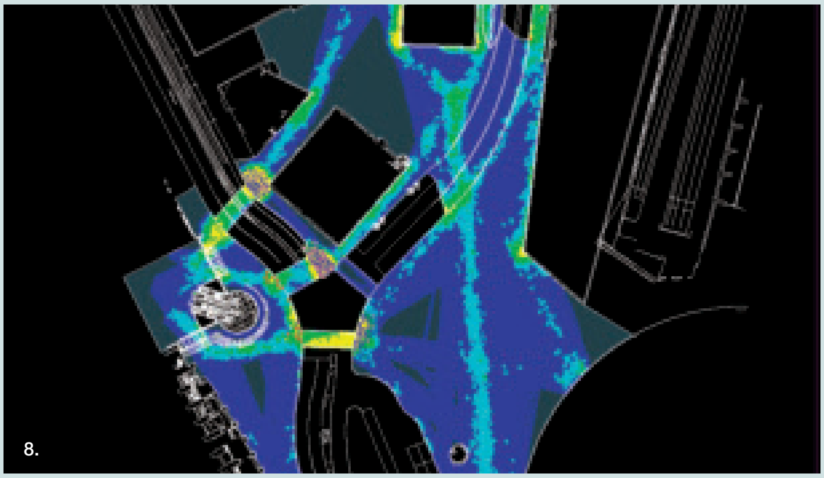


8.

King's Cross station, London

Arup was commissioned to provide pedestrian flow and station management advice at King's Cross station as part of the Western Concourse enhancements. A key part of this assessment was the interface with St Pancras International station, the new Midland Road Thameslink station, and movements to and from the development lands to the north of King's Cross. A *Legion* model of the area was developed to gain an understanding of the public realm between King's Cross and St Pancras stations, and how the pedestrian movements through the Station Square would interact with station activities such as taxi set down, pick up and bus services.

Signal delays at road crossing points were included within the model to simulate the pedestrians waiting prior to crossing the road. The accumulation of pedestrians on the pavements prior to crossing, and the surge following the "green man" signal, could therefore be assessed, but no traffic was included in the simulation.

1. Interactive software enables operations teams to be fully aware of risk situations across the site.

Risk-mapping in buildings:

Pro-active use of 3-D simulation to optimise operational risk management

David Kershaw-Wright

A huge range of risks confronts building clients and designers. Software now exists that represents a step change in operational risk management: a single vehicle for planning, training, operational control, and post-event analysis and debrief.

Introduction

A cost-effective operations plan requires full co-ordination of building planning, manned guarding, operational procedures, occupant management, physical protection measures, and electronic security systems.

Interactive software environments now exist that enable operations teams to be fully aware of a situation throughout any site, facility, or distributed network in real time, merging real and virtual environments.

This involves proactive use of 3-D simulation, including realistic threat scenarios and human behaviour modelling, to ensure faster reactions, more robust operating procedures, an improved decision-making cycle, and lower operational disruption. This system's advanced 3-D geospatial modelling abilities, combined with Arup skills and experience, deliver a tailored operations plan for any site or distributed network.

Planning

During the planning stage of such a project, Arup creates spatially accurate 3-D models, either of existing sites using laser scanning, or from CAD plans for new build projects. Using these models, many different threats and risks are explored, including natural catastrophes, criminal attack, terrorist attack, fire, evacuation/invacuation, and chemical, biological and radiological (CBR) attack.

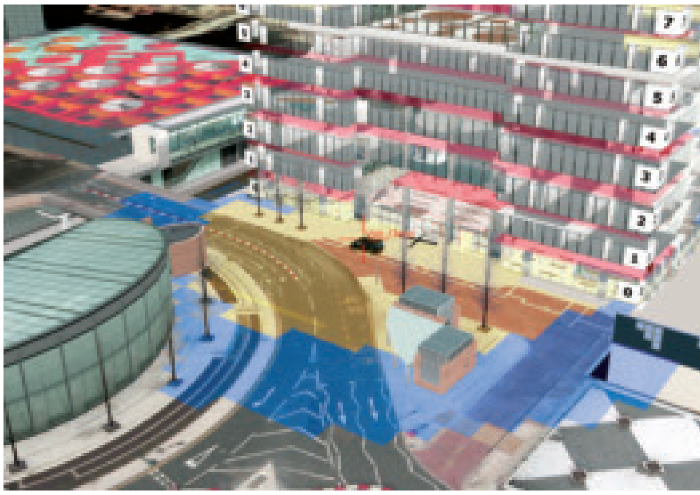
The driving imperatives are the potential effects on occupants and the safe management of these effects. Analysing the various risks and thorough discussion with the client lead to auditable and defensible decisions to either mitigate, insure against, or leave an acceptable group of residual risks. Then follows the design and layout of protection systems and how occupants will be managed.

The team looks at the location of sensors, CCTV coverage, line of sight calculations, resilient façade and structural response to blast, response to fire, protection against CBR attack, and occupant evacuation for all realisable risk scenarios. Early detection of design problems avoids any bottlenecks to potentially slow evacuation.

How the organisation should respond to real or potential incidents or situations is agreed with the client. Standard operating procedures (SOPs) are captured and integrated into the system, ensuring that if and when incidents arise the agreed response is not just automatically available but clearly articulated for the operator to follow without delay.

Training

Training staff and key personnel is pivotal to preparing any business for a major incident or security risk situation. This system's ability to visualise site plans in 3-D gives users an early understanding of security or safety situations before they occur. Immediate consequences of a potential incident can be easily assessed, making scenario-based training or mission rehearsal as effective as a drill, but at far less cost.



2. Predicted blast damage can be mapped onto the virtual model of the building structure.

3. The software provides simultaneous views of different areas of the site.

Operational control

Using knowledge and experience gained during planning and training is critical to a well-managed operations alert. Prior to and during an incident, the software presents real-time information on a “situational awareness” display, enabling operators and managers to grasp quickly an incident’s implications before choosing the best course of action.

Providing timely salient information means that the system can instantly integrate data from multiple stand-alone systems. This crucially affects how an incident is managed; operations managers simply select the area of interest to them on a 3-D model, and the system activates the best camera for viewing that area.

Post-event analysis and debrief

Learning from real-time incidents can greatly enhance an organisation’s potential for improved response. Recording actual incidents as they unfold allows the system to improve security and safety management by creating a time flow of events retrospectively. The behaviour of security staff can be analysed later, in a calmer environment.

The value of in-depth debriefing and communicating findings throughout an organisation cannot be underestimated. Using data already generated by the system as part of incident response is naturally more affordable than traditional methods for evaluating such plans. Digital event logs can also be used to detect patterns and similarities in security breaches, like thefts in the same area.

After devising and executing a security plan, debriefing provides an ideal opportunity to evaluate and improve methodology. Options and recommendations on types of systems and devices identified by the simulation software serve as a briefing tool for the other disciplines on the project, and a basis for the detailed design of the electronic and physical security systems.

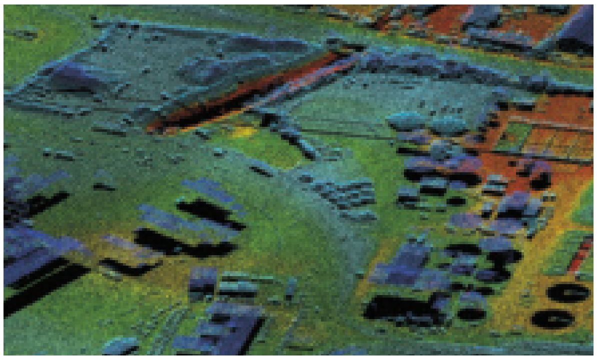
Added value

This approach provides a common tool for effective real estate portfolio management that captures and rationalises risks and responses for facilities management, security, safety, duty of care, and corporate governance issues. Incorporating scenario-based training for management and operational staff, this re-configurable framework allows clients to plan and analyse proposed changes through virtual optimisation and take decisions based on thorough auditable information.

The open common systems integration platform ensures maximum return on existing assets, protecting legacy investment and optimising the deployment of technology and human resources. The intuitive operator interface makes operational resources more effective through common SOPs across the portfolio, and helps retain operational staff.

In addition, the effective management of remote sites results in a lower guarding requirement, quicker incident resolution, and less lost time. Independence from sub-system manufacturers provides the freedom to choose best value sub-systems and the single resilient graphical user interface results in less training and less long-term support costs.

For further information about Arup’s work in risk-mapping, please contact John Haddon, Director, Arup, 13 Fitzroy Street, London, W1T 4BQ, UK
Tel +44 20 7755 3769   e-mail john.haddon@arup.com



4. Southampton Docks, UK, imaged by LIDAR (Light Detection and Ranging) optical remote sensing technology; data captured by Infoterra UK.

5. CCTV tracking and sensor technology can be used to identify potential threats and monitor a live incident.

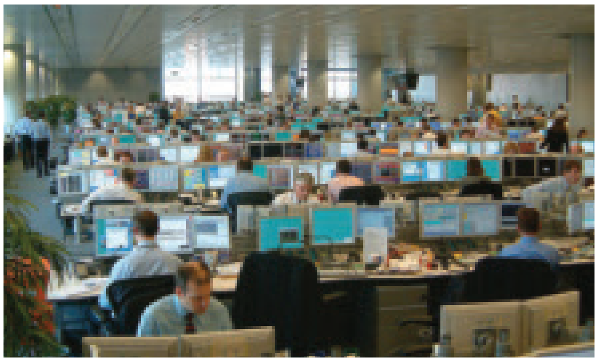
6. Emergency planning and real-time response decision-making are supported by simulations, like crowd evacuation, run within a virtual model of the real-world environment.

Human movement and safety:

New approaches to facilities design

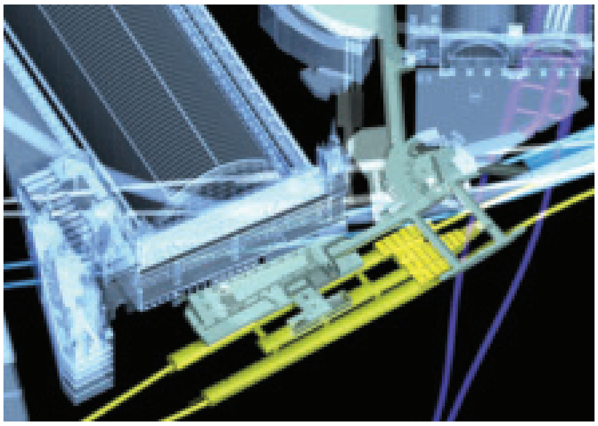
Andrew Dixon Anthony Ferguson
Barbara Lane Richard Wardak

Building developers, architects, and facilities managers need to have premises that are safe and can be profitably operated, but which are also exciting and create positive experiences for their users. This paper illustrates some innovations in the field of human movement and safety that have contributed to the success of recent projects. Four projects – the Beijing Olympics Water Cube, HSBC's London headquarters, King's Cross St Pancras Underground station in London, and the tunnel option for the Fehmarnbelt Fixed Link between Germany and Denmark – are briefly outlined.



1. Typical floor in HSBC's 44-storey London headquarters.

2. Beijing Olympics Water Cube.



3. King's Cross St Pancras Underground redevelopment.

4. Proposed route for the Fehmarnbelt Fixed Link.

Introduction

An existing regulatory environment can be the greatest impediment to optimising a design, but sometimes, as with the Water Cube, it is possible to use quantitative design to break free of these restrictions and get a much better result. The challenge of evacuating people from HSBC's 44-storey London HQ shows how facilities management was helped to adapt procedures in an existing building, in a radical way, to new concerns about terrorism. At King's Cross St Pancras, a modelling tool revealed an unexpected though beneficial interaction between human movement and the design of a circulation route, which changed long-held views on flow rates and space allowances. For the Fehmarnbelt Fixed Link, comparison of traditional hand calculation and computational analysis results gave hitherto unforeseen insight into the behaviours of high densities of people escaping from a possible tunnel accident.

These projects are exciting – through the creation of visual spaces that would not have been possible under traditional prescriptive design; safe – through ensuring escape capacity is fully utilised, which frequently has not happened under traditional design practice; and cost-efficient – through optimal use of existing building human movement capacity.

The importance of human movement and safety

Traditionally, human movement in buildings has been of concern only in the context of regulations for escape from fire, and that is still often the main driver. This regulatory (ie safety) context has expanded to include crowd safety in larger assembly buildings. Commercially, however, operators in the retail sector have developed considerable expertise in other, non-safety, aspects of movement that have been shown to increase revenue, and now find a use in transport hubs and elsewhere.

In the past, building design for human movement often focused on what occupants are expected to do in buildings, not on what they actually do. The approach tended to be conservative and inefficient, and was not necessarily a good way to deal with all the novel circumstances found in new projects. In other words, the old requirements could be solutions to a different problem from the one actually presented.

The need to focus on what occupants actually do raises several challenges for developers, architects, and facility managers. Quantifying how people really behave rather than relying on codes enables the critical benefits to be realised for facility managers, owners and operators, as shown in the case studies.

Developments in human movement and safety research

Buildings are increasing in size and becoming more complex, as are user requirements and customer expectations. Data relied on in the past is decreasing in its applicability. Fruin's observations[1], for example, which led to industry-standard "levels of service" on population flows and density, are now dated. Pauls[2] has recently withdrawn his widely-used data due to the population changes noted above.

Modern design codes and standards increasingly refer to evacuation strategies based on the time occupants may take to react and move, but generally can only offer simplistic guidance. For example, *BS 9999*[3] does not deal with building height and its implications for high-rise evacuations (other than to suggest that you might throw in an extra stair if the building is very tall!).

Human movement researchers therefore have to address the new challenges of large, complex buildings occupied by an aging and less capable population with ever-higher expectations of service and comfort. It also has to be said that there is still much to be learnt, that could directly benefit design, about quite basic aspects of movement such as deference behaviour in stairways.

International conferences bring together researchers and computer modellers to specifically address the design and management of built spaces for human movement and safety, and computer models such as *MassMotion* (see pp38-40) and *Legion* now incorporate more realistic occupant profiles from field studies, reflecting culture, anthropometry, and type of setting.

Such models increasingly blend observation of what a changing population does with advances in fire dynamics and complex social and organisational processes. They can be tailored to almost any type of occupancy, to answer specific design, construction, or management questions.

Designing for human movement and safety

Research has established that people tend to follow familiar routes in a building, with the result that they may ignore carefully provided escape routes and go out the way they came in, even though it is longer, and perhaps crowded and less well-protected. The result of this well-known characteristic can be a building with costly but never-used stairs and corridors. Examples can be found in shopping centres (where they do at least have a servicing function), airport termini, and even schools.

The aim should instead be to avoid the separation of routine and emergency circulation. This will make it easier for users to navigate around, while having the potential to save expensive space for more immediate uses.

Case studies

Beijing Olympics Water Cube: Dual use of circulation and evacuation space using performance-based design

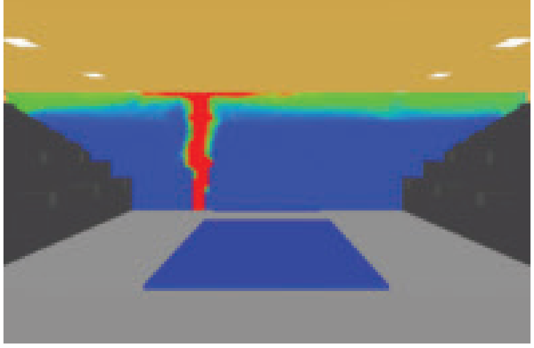
As already noted, research shows that escape routes which are distinct from normal building circulation are often overlooked in an emergency. Building projects and management strategies which avoid this separation result in structures that allow for both efficient and therefore safer evacuation and optimal use of floorspace to increase user enjoyment.

At Beijing, the approach adopted to deliver value on these critical issues was detailed smoke modelling and egress analysis, the latter done using spreadsheet methods, peer reviewed with evacuation modelling software to cross-check results.

This increased the useful area by removing the need for dedicated internal fire corridors, and maximised the number of seats for the Olympic Games (by several thousand). Many more customers were therefore able to see the events than would have been permissible if prescriptive guidance had been adhered to. Dedicated fire egress provisions, including reduction in the number of exit doors, prevented the façade from having 200m of exit doors in Games mode, which would have been detrimental both to the architectural vision and to security.

Greater openness of the internal building layout was also possible. The Chinese building code includes a high degree of fire compartmentation (which would have meant a fire wall through the middle of the main pool hall), but the human movement and fire safety design allowed for interconnection of all above-ground spaces.

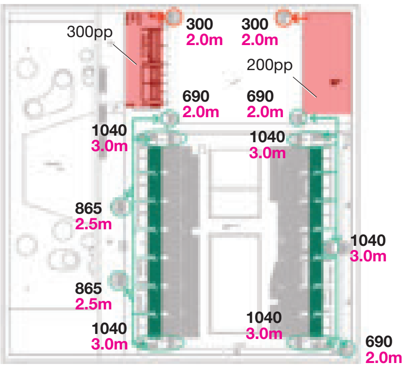
5. Interior of main pool at the Beijing Water Cube.



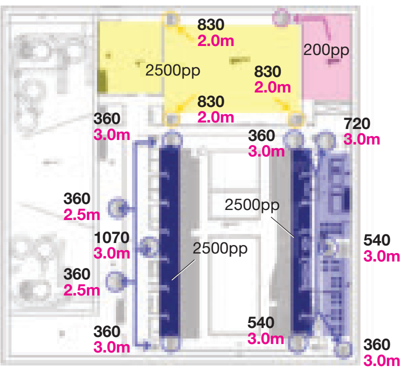
6. Results from smoke modelling were used to calculate available safe egress time.

7. Preliminary emergency egress flow and width assumptions for three of the Water Cube's levels.

a) Level 2



b) Level 1



c) Level 0

Key

900 Assumed exit flow

36.0m Width of exit path

1500pp Assumed population

Total exit to exterior: **12 440**

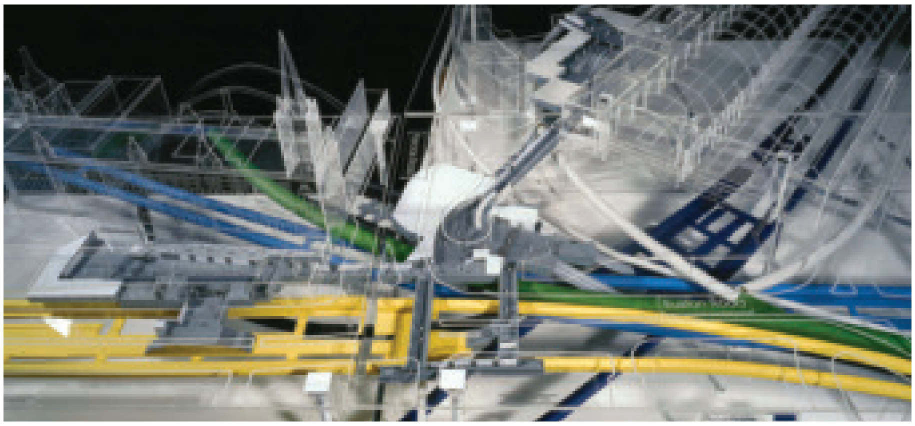
Total door width: **36.0m**

HSBC headquarters, London: the high-rise evacuation challenge

Not only have we been building higher, but it appears that all too many people have become physically incapable of walking out of these tall buildings quickly enough. It is unsurprising that research around the world[4] is currently addressing building evacuation using lifts and escalators, which were once universally prohibited, but have the potential for rapid and "effortless" evacuation from a wide range of building types.

At the HSBC building, human movement under imminent catastrophic event conditions was addressed without expensive retrofitting of staircases and additional exits. The approach came from the client, to look at emergency evacuation post-9/11. Various studies of movement in stairs and the potential to use the passenger lifts in "down peak" mode, led to HSBC adopting a combined lift and stair system, which enables it to evacuate about four times more quickly then with stairs alone.

8. HSBC HQ, Canary Wharf, London. It has 44 floors above ground and four basement levels.



9. The King's Cross St Pancras Underground ticket hall and Metropolitan & Circle line platform were refurbished. The project also involved refurbishing and adding connecting passages and new bored tunnel passageways, and the creation of new western and northern ticket halls.

10. Control room at King's Cross St Pancras Underground station.

King's Cross St Pancras Underground station renewal, London: Optimising circulation in crowded conditions

Massive investment in London's transport infrastructure has presented a new generation of designers with the opportunity to create faster, friendlier, and more efficient Underground and rail stations. But safety standards are higher, the trains carry more passengers, and non-ticket revenue opportunities have to be maximised without impeding operations. The redevelopment of King's Cross St Pancras Underground station shows what can be achieved by addressing developments in human movement and safety within building design and management.

A very detailed analysis of fire propagation, evacuation, and routine crowd circulation was undertaken, which included liaison with clients and their design team throughout. This helped the architects define a simpler, more intuitive layout and facilities, with better sightlines and a significant reduction in station congestion, while integrating retail space.

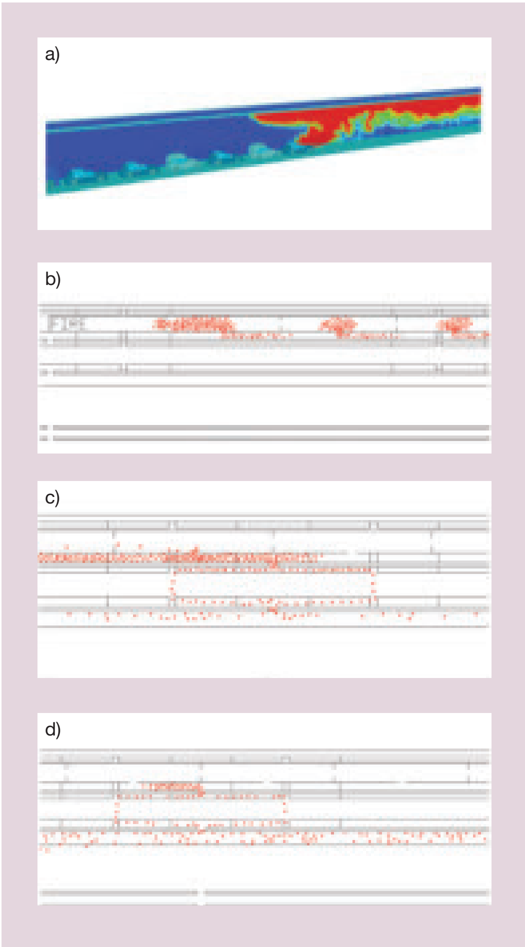
The result was the creation of several alternative exits and three new ticket halls (previously all passengers had to pass through just one, a major limitation highlighted by the 1987 King's Cross St Pancras Underground fire). All routes are now both routine and emergency routes, and all platforms have alternative means of escape. What was a congested, crowded, and stressful daily experience for thousands of customers is now a safe and efficient throughput with minimal disruption.

The Fehmarnbelt Fixed Link

The huge investment in transport infrastructure is not limited to the UK; increased provision of higher quality transport links is a global priority, with particular emphasis being placed on rail. Tunnels inevitably form an integral part of this and are an efficient way of covering large distances under, or through, difficult terrain. The proposed tunnel solution for the Fehmarnbelt Fixed Link across the Baltic Sea between the German island of Fehmarn and the Danish island of Lolland pushes the boundaries of immersed tunnel design, being over 18km long and accommodating both road and rail traffic.

One key area of this project involved evaluating the means of escape within the tunnel. The current design provides exit doors every 100m. This is a closer spacing than recommended by many European and International guidance documents, and aims to reduce the time occupants are in the incident tunnel by reducing the distance they have to walk to enter the adjacent non-incident tunnel. This helps to reduce the required safe egress time (RSET) for occupants.

11. Egress studies for the proposed Fehmarnbelt tunnel: smoke model (a), and evacuation models – at seven seconds (b), 21 seconds (c), and 49 seconds (d).



To validate this, egress analysis was carried out, using both traditional hand calculation and computational analysis with *Legion* software. This was initially done as a test case, to see how the two methods compared. It was clear that with low populations the results compared well, but as the design populations increased, it soon became clear that the computational method produced higher egress times. Scrutiny of the results and interrogation of the model flow rates revealed that at certain positions (primarily, but not limited to the train exit(s) and cross-passage doors) the flow rates experienced for high population densities were much lower than assumed for the static, hand calculation method.

Going through this process highlighted flaws in the traditional methods of egress calculation; specifically that where high populations exist, with numerous "twists and turns" on an escape route, the flow rates experienced are typically much lower than would be expected. This exercise also proved the benefit of using a computational modelling method in what was seemingly a simple evacuation scenario.

Interaction with clients and stakeholders

Each project required extensive liaison and interaction with stakeholders to deliver these critical issues and design innovations.

For the Water Cube, unrivalled access to the whole range of engineering disciplines and modellers, a local office fluent in Chinese, and a strong daily co-ordination with the architects enabled successful project delivery.

For King's Cross St Pancras, the client selected the fire engineers specifically because of their existing portfolio, which showed an in-depth knowledge of the station layout and workings, experience in defining and implementing fire strategies smoothly in high-occupancy buildings that continue to operate throughout, and unrivalled access to human movement and safety expertise. Many face-to-face meetings with design teams, engineers and approval authorities took place.

The Fehmarnbelt Fixed Link is still in the concept design stage and the decisions about whether or not to take the design to construction, and what form the Fixed Link may take, have yet to be made. Whatever the outcome, however, safety/egress issues will remain of the utmost importance.

The future

Escalators are the centrepiece of human movement in a wide range of public buildings and atria, and their safety record is impressive. Evacuation from sub-surface rail stations using escalators is gaining in regulator approval popularity. As yet there is little international agreement on this usage, and virtually no approval for evacuation using escalators in other public spaces. New research is required on human movement and safety across a wide range of buildings where escalators are used to safely carry many tens of thousands of people daily.

As buildings increase in size and complexity, the question of what is an appropriate evacuation strategy becomes more difficult. Whether occupants should stay put or move to a local place of safety, and what happens to them thereafter, are key questions for which research is still outstanding. How will such complex strategies be managed? Blending the all-important business continuity with safety design, communication procedures, management systems, and new research on human movement will be a major challenge in years to come.

12. Escalators are the centrepiece of human movement in a wide range of public buildings and atria, and their safety record is impressive (above: King's Cross St Pancras Underground).

References

(1) FRUIN, J. Pedestrian planning and design. Revised edition, Elevator World Inc, 1987.

(2) PAULS, J. "Movement of people", in SFPE Handbook of Fire Protection Engineering, pp3/263-3/285. Society of Fire Protection Engineers, second edition, 1995.

(3) BRITISH STANDARDS INSTITUTION. *BS9999: 2008*. Code of practice for fire safety in the design, management and use of buildings. BSI, 2008.

(4) http://www.ped-net.org

1. Main concourse of Union station, Toronto.

MassMotion:

Simulating human behaviour to inform design for optimal performance

Erin Morrow

2. Detailed rendering of simulation results during the evening peak period.

***MassMotion* is a suite of software tools that analyses and represents the behaviour of individual pedestrians in their interactions with other people and the built environment through agent-based simulation.**

Introduction

MassMotion is an internally-funded Arup research and development initiative, originally developed within the Toronto and New York offices in response to the needs of the Fulton Street Transit Center project in New York City. The inception and earlier development of *MassMotion* were outlined in a previous edition of *The Arup Journal*[1]. It has since evolved into a powerful and flexible tool for modelling a wide variety of applications including transit facilities, venues, buildings, and urban planning, and it continues to be developed under the auspices of Oasys Ltd, Arup's software house.

This suite of simulation tools is designed to address the irony that, while planners, architects, and engineers design environments for people, they rarely test their designs with people in them until the environments are fully constructed.

MassMotion provides designers with quantitative and qualitative feedback on how people will make use of the environments being designed – and the quality of the experience therein – by analysing the behaviour of individual pedestrians in their interactions with other people and the built environment through agent-based simulation. These simulations are non-deterministic, meaning that the individual agents in the simulation make their own choices about appropriate actions based on the dynamics of their environment.

This approach to simulating human activity reflects the inherent chaos and emergent phenomena of the real world more accurately than other tools. To ensure that the system is accurate in its description of human behaviour, extensive calibration was carried out at Union station in Toronto. Following this calibration, *MassMotion* has been used to predict the utilisation patterns of commuters during the planning process for station revitalisation.

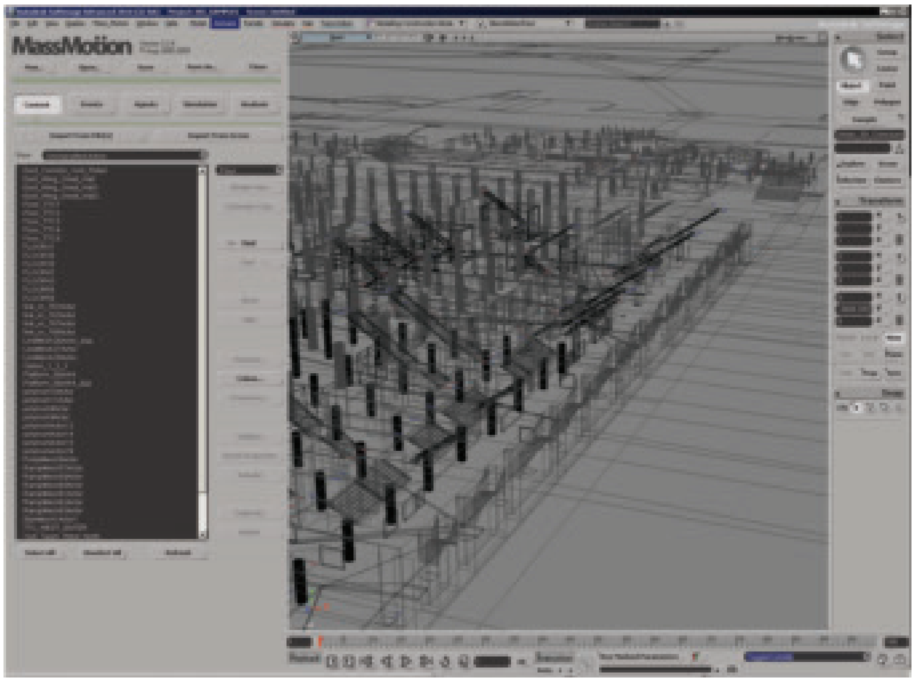
Simulation environment

The 3-D *MassMotion* environment is constructed using CAD tools, and is based on architectural drawings. The information contained in the drawings is used to develop a set of polygon mesh objects that represent the walkable areas of the environment and any obstructions within these areas, the walkable areas then being further broken down into circulation spaces and connection elements. The former can include rooms, sidewalks, platforms, etc, while connection elements might include doors, stairs, crosswalks, etc.

The arrangement of circulation areas and connection elements forms an implicit network, defined by geometric proximity, which defines the possible route permutations for the simulation agents to navigate. For the Union station environment, a detailed station model plus an abstract neighbourhood model were constructed.

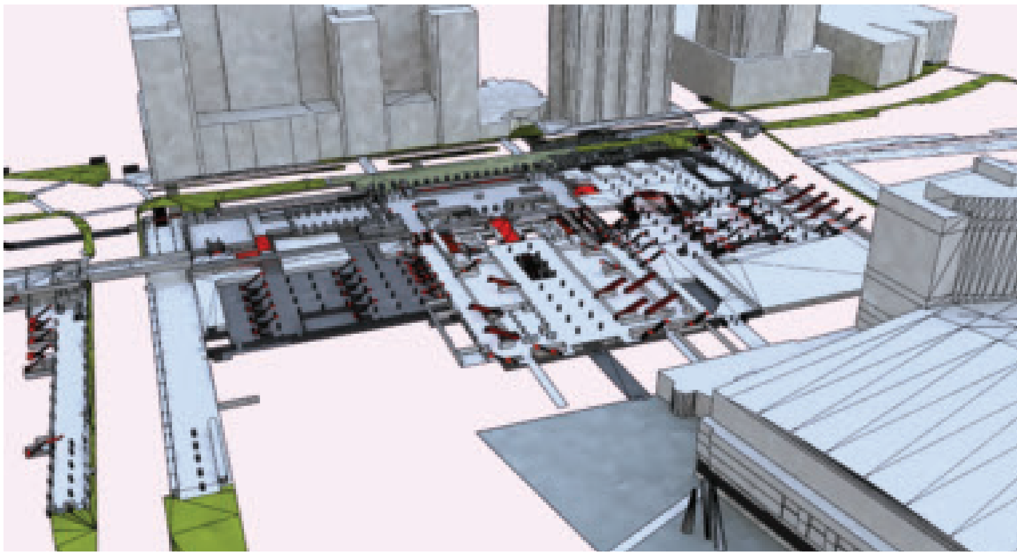
Agent scheduling

Commuter activity at busy transit interchanges such as Union station is primarily the result of transit scheduling and the density of employment in the surrounding neighbourhood. This being the case, typical planning protocol is to describe the high-level

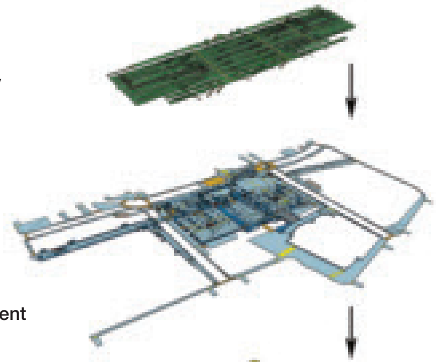


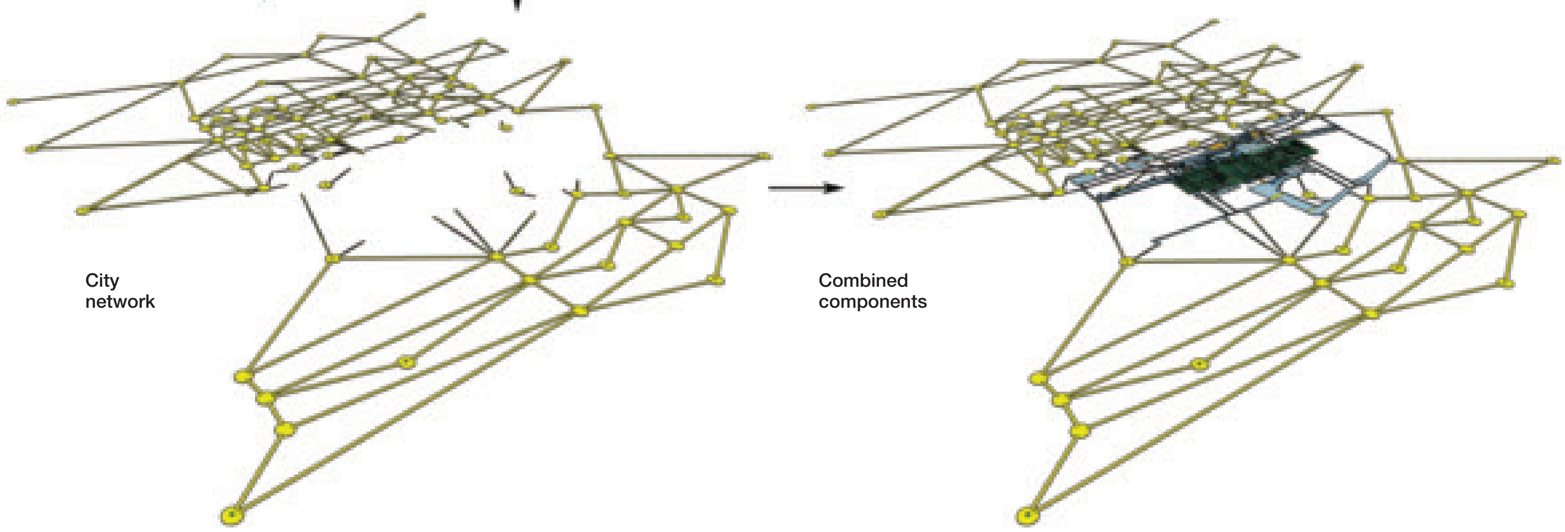
4. 3-D environment geometry being edited and prepared for use in the *MassMotion* simulation software.

5. Overview of the simulation environment, looking northeast towards Toronto's central business district.



3. Overview of the major components of the Union station environment and how they fit together to provide an analysis of the station and its impact on the downtown core of Toronto.





volumes of pedestrian activity in terms of origins and destinations, where the origins might be the downtown blocks and the destination the train station during an evening commuter peak.

MassMotion, however, relies on a third type of environment object, termed "portals", to represent these origin and destination points. These portals are placed within the 3-D environment at appropriate locations to serve as binding points for the agent schedules. Using graph or rule-driven schedules of agent creation timings, any level of agent activity may be defined between various portals within the model.

Logic

Unlike most pedestrian simulation tools, *MassMotion* does not require the user to input the various route assignments for the agents in the model. Instead, it is sufficient for the user to input the schedules of activity between the various origins and destinations and the agents themselves will decide on the most appropriate route through the environment.

This is accomplished through agent analysis of route cost based on distance, congestion, vertical transition, and other factors based on each agent's individual personality profile, which in turn is based on a set of weighting profiles that correspond to the route cost factors.

Each agent is assigned personal weightings based on these profiles, and in any simulation there will be, for example, agents that will walk slowly and always wait for the escalator, agents that move briskly and take the stairs at the first sign of congestion, and everything in between. It is the calibration of these weighting factor profiles that determined the accuracy of the *MassMotion* system.

6. False colour plot of pedestrian density for subway connection over a 15-minute period with red representing the most dense and blue the least dense.

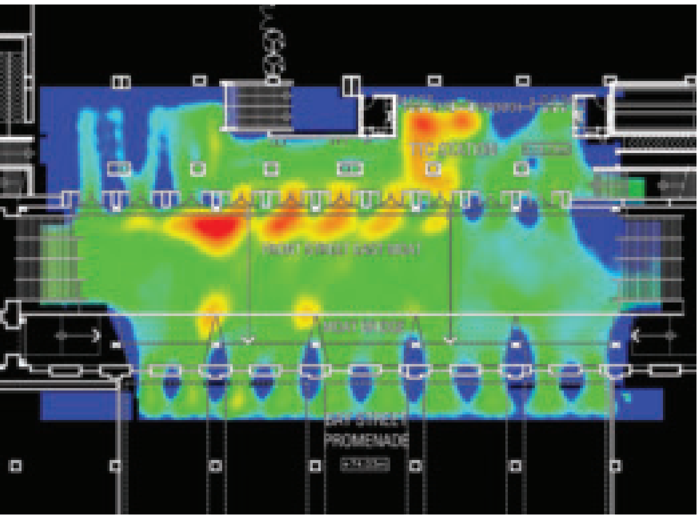


Table 1. Comparison of surveyed and simulated rush-hour peak activity.

	Survey results (two-day average)					Simulation results	
Location	**5:00pm**	**5:05pm**	**5:10pm**	**Total**	**Total%**	**Total**	**%**
Front and York doors	78.5	131.0	62.0	271.5	2.5	350.0	3.4
Skywalk	54.5	69.5	73.0	197.0	1.8	118.0	1.1
Great Hall west	91.0	109.0	78.0	278.0	2.6	327.0	3.2
Great Hall east	238.0	255.0	152.5	645.5	6.0	540.0	5.2
Ramp to VIA Rail Canada	336.5	309.0	209.0	854.5	8.0	615.0	5.9
York teamway north	388.0	407.0	316.5	1111.5	10.4	1152.0	11.1
Toronto Transit Commission doors west	514.0	630.5	535.0	1679.5	15.7	1781.0	17.2
Toronto Transit Commission doors east	645.0	773.0	626.0	2044.0	19.1	1838.0	17.8
Bay Street entrance	492.0	455.0	378.0	1325.0	12.4	1296.0	12.5
Bay Street teamway east	170.0	233.0	212.0	614.0	5.7	554.0	5.4
Bay Street teamway west	116.0	153.0	148.0	416.0	3.9	517.0	5.0
Blue Route northbound	176.0	144.5	118.0	438.5	4.1	312.0	3.0
Blue Route southbound	235.0	272.0	329.0	836.0	7.8	948.0	9.2
Total	**3534.5**	**3941.5**	**3237.0**	**10,713.0**	**100.0**	**10,348.0**	**100.0**

Calibration

Initially, many of the basic characteristics of the *MassMotion* agents are based on John Fruin's observation and analysis of pedestrian behaviour as published in his book "Pedestrian planning and design"[2]. These basic characteristics include average physical size and distribution of walk speeds in a normal population. The calibration of *MassMotion* focused on tuning the agents' response to route distance, congestion, vertical transition, and other factors. Pedestrian volumes were surveyed at all entry points to Union station during a typical weekday evening peak to establish a set of values for comparison.

The distribution of traffic from each neighbourhood block to the station was established through analysis of employment density and train schedules, and occupancy rates were gathered from rail operators for each of the survey days. In the calibration model, the total commuter population was distributed to the downtown origin points based on the train schedules, and each agent was assigned a particular train platform as its destination.

To calibrate the model, the Arup team adjusted the weighting profiles for each route cost factor until the model reported similar volumes at the station entry points as the survey data. As Table 1 (above) shows, the calibration exercise was a success, with excellent correlation between observed and simulated conditions, particularly in high volume locations.

Conclusions and next steps

As a result of the calibration exercise the team observed that the commuters tend to consider route distance and apparent congestion more important than other factors. It was also noticed that within any set of reasonably similar route options, commuters exhibit a degree of randomness in their choices.

Based on the successful calibration, the behavioural profiles for the commuters currently using Union station have been applied to future scenarios including increased volumes and modified station layouts.

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1.

Lighting and health:

A longitudinal study

Mary-Clare Race Bob Venning Roxanna Yarandipour

Research shows a correlation between the strength and colour quality of lighting in the workplace and the resulting impact on human wellbeing and productivity.

Introduction

Research has shown that the physical work environment, including lighting, may impact on human health[1] and performance[2]. Most of the research exploring the impact of lighting on employee health and productivity has been conducted in laboratory settings to minimise the number of variables, but there is an increasing view that investigating the impact of lighting in a real life environment is valuable[3]; rather than such experiments continuing to be replicated, future work should instead focus on conducting research in natural environments. Carefully-designed field investigations, over long periods and with large samples, are needed in order to realistically assess the impact of lighting on wellbeing and productivity.

Background

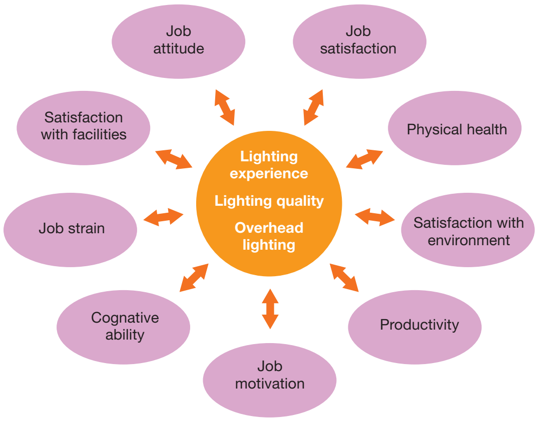
The recent discovery of non-imaging ganglion cells in the eye[4] has led to research into how this system works and what influence it may have on humans, their performance, mood, and wellbeing.

Researchers have determined that this non-imaging system in the eye does not terminate in the cortex of the brain but passes through the suprachiasmatic node and pineal gland to affect our body clock. It has also been discovered that the system has a sensitivity curve that peaks around 460-480nm, which is distinctly in the blue region of the spectrum.

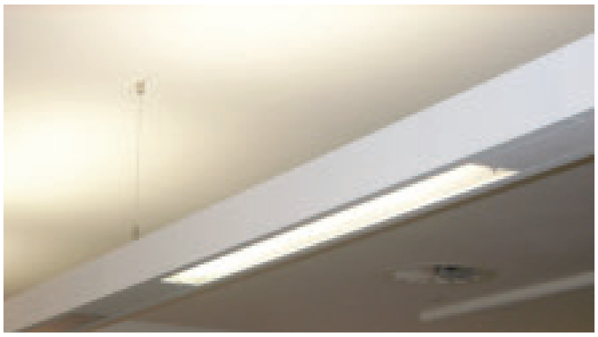
Light of this frequency can delay the release of melatonin, the sleep hormone, and maintain production of cortisol, which influences our alertness and as a consequence improves our productivity and the way we “feel” about our environment.

Research objectives

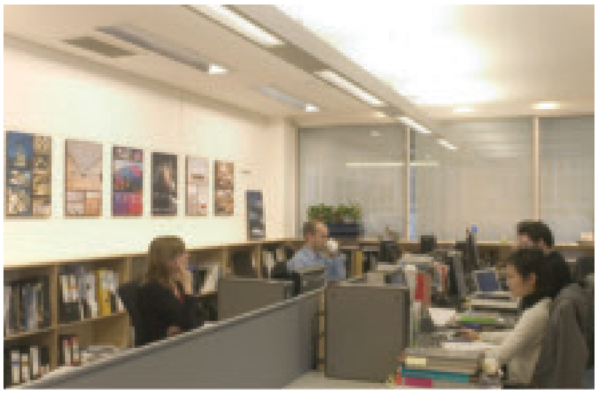
The link between lighting and human performance is well documented, and the particular focus is on the impact on behaviour in the workplace. Research suggests that the design of a lighting system can influence employee behaviour in terms of productivity, satisfaction, wellbeing and motivation.



2. Key outcome variables in the workplace under examination.

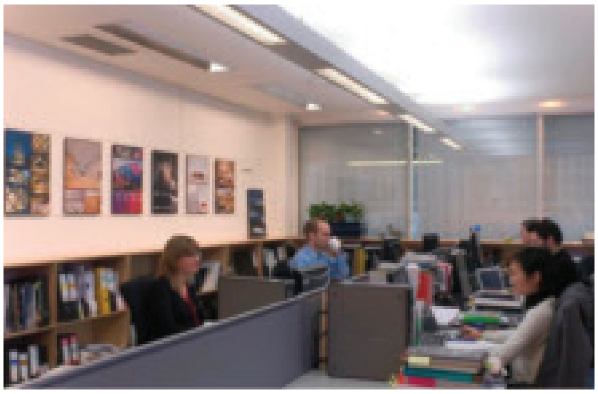


3. The illuminance was set to 300 lux which was achieved using 50% up light and 50% down light.



4. Lighting conditions – Warm colour (4000K).

5. Lighting conditions – Cold (17,000K).



Vast amounts of research demonstrate the link between lighting systems and the productivity and wellbeing of occupants, but there appear to be few studies examining the impact of lighting in field settings.

The research project resported here therefore had three aims:

- to examine the impact of lighting on productivity, wellbeing and other measures of organisational effectiveness
- to determine the impact of "blue-white" light as a means of enhancing performance and wellbeing
- to investigate whether the positive effects of lighting can be realised in a "real" world field setting.

Lighting trials: method

Eleven full-time members of Arup's London lighting team took part in the research – too few for significant conclusions to be drawn but a number large enough to identify trends. Arguably, the use of lighting specialists was also not ideal as there was prior knowledge, but in the time frame it was not possible to find another group that could participate.

This research began in December 2006 when the Arup lighting team was based on the second floor of the Howland House building in London's Fitzrovia. In January 2007, the team moved to a refurbished office close by, at the rear of 12 Fitzroy Street. Occupant satisfaction questionnaires were conducted prior to and just after the move to the new location, and these provided a baseline measure of occupant satisfaction.

Some of the questions asked were concerned with:

- where participants spent most of their time working, eg at home or in the office
- how participants worked, eg alone or in groups
- how participants spend their time working, eg singly or in informal meetings
- participants' sense of wellbeing
- participants' overall work performance
- participants' satisfaction with workplace facilities.

Several key differences between the environments in Howland House and Fitzroy Street are worth noting:

- The amount of natural daylight in Howland House is far greater than that received in Fitzroy Street.
- The lighting installation in Fitzroy Street was a mixture of upward and downward light whereas Howland House contained only upward light.
- The illuminance in 12 Fitzroy Street could be varied.
- The lighting team comprised the only occupants of the space in 12 Fitzroy Street, whereas in Howland House, the office space was shared.

The illuminance was set to 300 lux, which was achieved using 50% up light and 50% down light. One lamp was changed every six weeks, resulting in eight lighting changes throughout the duration of the research. The lighting conditions in periods 1–4 were duplicated in periods 5–8. The purpose of repeating the same lighting conditions at different time points was to establish whether there were any seasonal effects in the results. Table 1 illustrates the lamp rotation.

Results

There was some evidence that the "blue-white" light did have an impact on productivity, wellbeing, and the other measures of organisational effectiveness. The general trend indicated that individuals who experienced a higher quality of lighting also experienced higher levels of job motivation, more positive job attitude, and greater productivity. Lighting also impacted on individual's experiences of job strain, with positive perceptions of the lighting resulting in lower levels.

However, when all lamps were of the blue-white type this condition showed poor results, with a negative impact on most of the occupants. The combination of "blue-white" (17 000K) indirect (up) lighting and warm (4200K) direct (down) lighting was favoured equally with the traditional all warm (4200K) light. Some of the indicators, however, showed slightly improved performance over the all 4200K lamps.

Table 1. Lamp rotation.				
Time	Lamp1 up	Lamp 2 up	Lamp 3 down	Season
Period 1	4000K	4000K	4000K	winter
Period 2	4000K	17 000K	4000K	spring
Period 3	17 000K	17 000K	4000K	spring
Period 4	17 000K	17 000K	17 000K	summer
Period 5	4000K	4000K	4000K	summer
Period 6	4000K	17 000K	4000K	autumn
Period 7	17 000K	17 000K	4000K	winter
Period 8	17 000K	17 000K	17 000K	winter

Comment

Evidence from researchers in this area is growing and shows that benefits in performance, productivity, and health can accrue from using "blue-white light". For example, a recent study at the British Antarctic Survey base showed how the "blue-white light" had a beneficial effect on sleep patterns, sleep length, and latency. The implication of this was that the body clock was set properly each day despite there being no sunlight.

Ensuring that we reset the body's clock each day, even during the winter, will improve workers' sleep/waking patterns, thus improving mood, attitude, and behaviour and helping in turn to improve alertness and productivity.

Conclusions

As noted previously, the number of participants was statistically too small to carry any confidence in the results, but the trend is conclusive that there is, or could be, some benefit in using a mixture of "normal" (4200K) lamps with some "blue-white" (17 000K) lamps. A further study with a larger number of participants, and preferably with the involvement of a control group, would be the next step, using the findings from this work as a starting point.

Knowledge of the relationship between lighting and chronobiology (the study of cyclic phenomena in living organisms, or "biorhythms") is fast-growing, and clearly architects and lighting designers have much to learn from such research, with varying applications in other types of building besides the traditional office workplace. In the field of healthcare, for example, some patients with Alzheimer's disease appear to become more agitated, confused and aggressive late in the day – can this be related to chronobiology? Should this be the case, can it be ameliorated by building designers providing more "blue light" at certain times?

One body at the cutting edge of research in the field is the Society for Light Treatment and Biological Rhythms, and a glance at the programme for its annual conference[5] shows the range of current research that may impinge on the work of building designers.

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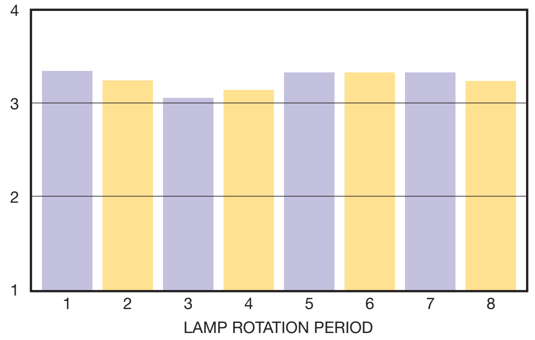
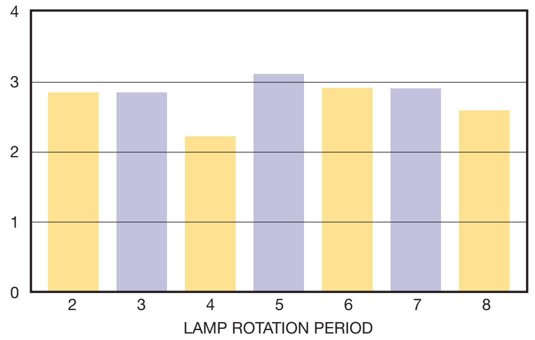
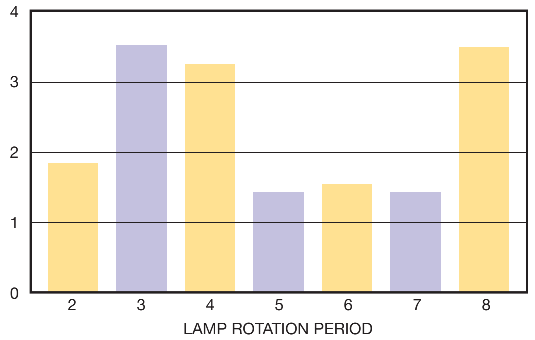


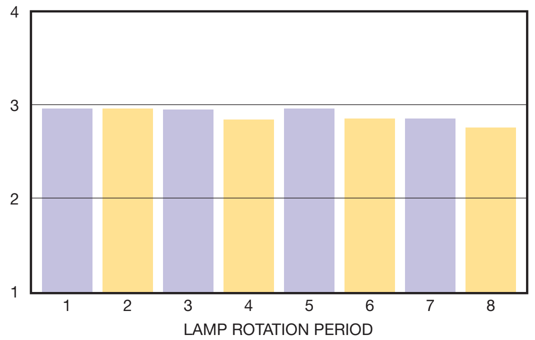
6. Job motivation across eight time periods: a high level of motivation amongst participants with slightly less positive results during periods 3 and 4.



7. Lighting experience was more positive during periods 5, 6 and 7, and most negative during period 4.



8. Physical health: participants reported more instances of trouble with memory, light-headedness, dizzyness, tired eyes, and headaches during periods 2, 5, 6 and 7.



9. Productivity: participants responded positively towards self-perceived levels of productivity, which indicates that they generally felt productive at work. Self-perceived levels of productivity were slightly lower in periods 4, 6, 7 and 8.

1. A row of six desks arranged in three back-to back modules.

Bench F:

New furniture for Arup's London campus

Chris Edwards Rebecca Stewart

This new desk system is designed to transcend changes in technology and workplace habits and remain successful now and in the future.

Introduction

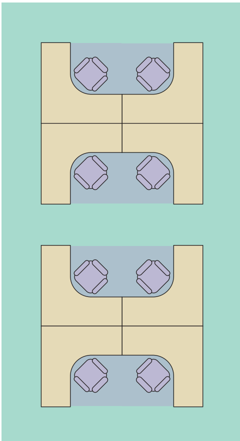
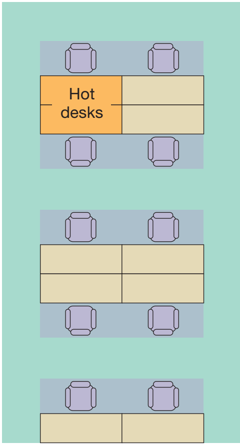
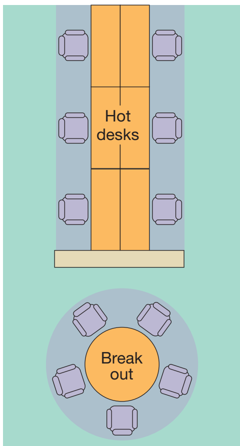
The redevelopment of Arup's head office campus around the Fitzroy Street area in central London ("Fitzrovia") has been ongoing since 2003. Phase 1, at 13 Fitzroy Street, opened in 2005, with Phase 2, opposite at 8 Fitzroy Street, following in April 2008 and December 2009. With the start of the fit-out package for Phase 2 of the redevelopment, a brief was created for new employee furniture and the supplier of that furniture.

"Bench F" was the design response.

The design brief for the new desk system was generated internally and had seemingly conflicting elements:

1. It was to be a continuous bench system (as opposed to a single desk system) to support daily fluctuation in working densities
2. It had to allow Arup's teams to relocate without having to change the furniture – ("churn people not furniture").
3. It need to have individual user height adjustability.

Table 1: Past, present and future desk comparisons

Before Herman Miller	**Now** Bench F	**Future** Bench F + coffee tables
		
L-shaped desk layout	Bench desk layout in same space	Bench desk + break out tables layout
Suitable for cathode ray monitors	Flat screens and laptops	Laptops
Every employee owns a desk	Most employees own a desk, some hot desk, more open team environment	Few desks are owned by any one employee
Work in an arc – potential to twist spine	Work in a line – always face the front – better for back health	A whole new set of ergonomic issues arise as people work on the move
Larger personal footprint per person, less team/break-out space	Smaller "leaner" footprint per desk giving way to larger break-out areas	Large meeting spaces
Expensive to "churn furniture" as it is difficult to reconfigure	Highly flexible to different team arrangements – therefore little churn of furniture	No furniture churn
Six weeks lead time on ability to adjust height adjust (Department of Social Security (DSS) assessment at 2% of London employees)	One minute (DSS assessments rising to 8% as Phase 2 is occupied)	One minute
Personal space ownership	Space ownership is on a team level. The space is flexible – can spread out or bunch up depending on number of people in during the day	No space ownership. Instead more emphasis placed on personal computer devices and technology

2. End view of a row of six desks showing how the pedestals fit in front of the desk legs.

3. Height adjustment is achieved using an Allen key. The level can be read on the inscribed scale on the back of the leg.

4. Power can be accessed from the desk top. The cable tray runs the length of the desk.

5. Shelves cantilevered off the screen divider.

6. A single back-to-back desk for more private working areas.

To develop "Bench F", the firm partnered with Kinnarps, a Swedish furniture manufacturer that has sustainability and ergonomics as key elements in its design philosophy. The new desk system had to support all Arup "worker types", including "hot deskers", draftsmen, heavy filers, (eg legal), A0 paper drafters, site-based workers, and 3-D modellers.

Bench F

A successful design strikes a balance between stakeholders' often conflicting requirements, and it is the design team's belief that Bench F (so named because it was derived from Kinnarps' Series F desking system) has achieved this. The main conflict was the need for a linear bench system, to support worker density fluctuations, whilst also supporting individual desk top height adjustability.

The recent trend for bench systems has led to an influx of relatively cheap systems on the market, but all of these compromise user ergonomics. For this reason Bench F is applicable to a wider usage than just Arup, especially in those countries that are leading the way in employee ergonomics, but have expensive rent bills and therefore higher densities.

Function

Bench F's key characteristics, enabling it to fulfil its various functions, are as follows:

- It has a simple crank handle height adjustment, with a height indicator to set legs at level.
- It is operable with a fully loaded desk, so no disruption to the user's work.
- No extra parts are needed – the user can change the height of a desk instantly and whenever the user wants.
- Throughout its entire length, the desk's legs and whole understructure do not encroach on users' leg area. This enables them to spread out or bunch up as appropriate to the worker density in the office at any one time.
- The cable management is desktop-accessed.
- This does not break up the tabletop, so that the whole top is available for use.
- The cable tray can be accessed anywhere along the length of the bench so as not to define the working area.
- If an object (for example a computer monitor) is placed over the cable tray, up against the screen, the user can still access the cable tray from further along the desk.
- The individual desktops which abut to make up the continuous surface of the bench are height-adjustable. This enables the bench system to be used in many different ways. A shorter or taller team member is not "height-ised" by being put in the only space with height adjustability, and when neighbouring desktops are at the same height, the user can spread out.

Form

The form of Bench F is derived from the selection of a very few components, enabled by the materials technology. The simplicity of the form was not styled, rather left plain, enabling Bench F to be specified in many different styles of interior.

The choice of white gives the feeling of a more open and bright interior. The simplicity of form helps the space feel less cluttered. Finally the simple, chunky aesthetic conforms to a taste that transcends trends and therefore is intended to help employees feel pride in their working environment. All this, it is hoped, adds to employee satisfaction and therefore productivity.

Bench F in five years

Evolution in office furniture is driven by changes in technology, rent cost, and changing working habits. Bench F in its simplest form (ie without accessories) is designed to transcend these changes and remain a successful desking system for now and in the future.

Deliver us from e-mail

Alec Milton

By ensuring that filing is part of the process of sending and receiving e-mail rather than it being a task to do later, Arup's software designers were able to de-stress the process and take critical communications out of personal inboxes. Fast search, the ability to work offline, and also via *BlackBerry* devices reduces the human effort and with it the risk to the business.

E-mail overload

According to the US research firm The Radicati Group, office workers send and receive an average of 156 e-mails per day, so it is no surprise that attention has focused on reducing what comes in. Often spam is blamed and, unsurprisingly, the on-line information source Spamnation[1] showed that by the end of 2007 a single machine was receiving over 1000 e-mails per day. Spam filtering has improved dramatically in response to demand, and only a small percentage now get through.

For example, of the 22M messages received by Arup's London office in one week in February 2010, 96.9% were filtered out, leaving just 669 000 (3.1%) untainted messages (Table 1). Others blamed their own staff, with Intel banning the use of e-mail one day a week, and Phones4U famously banning all internal e-mail.

While the sheer quantity of e-mail will remain a problem as long as people continue to prefer it over other forms of communication, the specific challenge Arup needed to solve was that of finding a given message.

"I know I've got it somewhere"

The management consulting, technology services, and outsourcing company Accenture[2] reports that managers currently spend up to two hours per day searching for information. If the information is required to support a legal proceeding, the pressure is high and costs can rise. Market intelligence specialists IDC[3] estimate the cost of identifying, preserving, collecting, processing, reviewing, analysing, and producing information for litigation (e-disclosure) at $12bn, and Gartner Technology Business Research Insight[4] estimates that the average e-disclosure event costs $1.5M. Yet few organisations take steps to organise their data for easy retrieval.

Too many cooks

As far back as 2002 Arup realised that it had to change. An initial search revealed that five offices had already developed their own unique tools to address the problem, so agreement was reached to combine the best ideas and develop one tool. Everyone involved knew that if this did not make people's lives easier, staff would not use it, so human performance and efficiency were primary factors in the design.

The design

Arup did not want "yet another system" and was well aware that new tools can quickly become legacy applications that are costly to maintain, so it was decided that the messages should simply be placed in normal file system folders and in Microsoft's own file format. To ensure future compatibility, the files were created by *Outlook* and not by the filing software. If the software is replaced in future years or falls into disuse, the data are readily accessible and do not need the original software to be read.

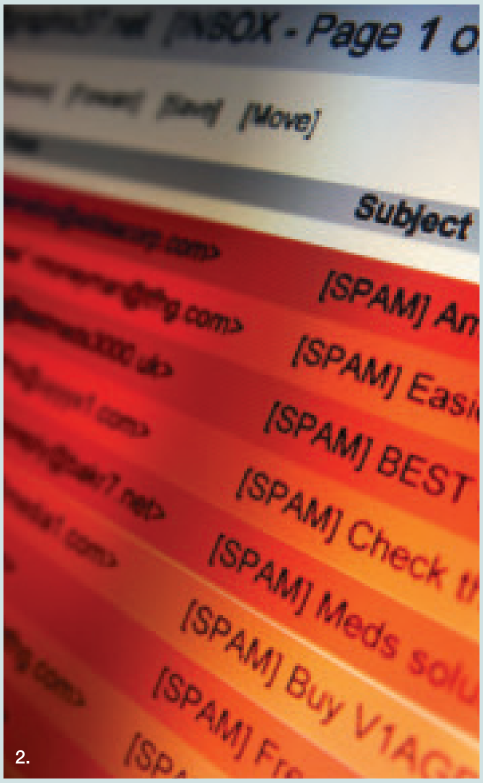


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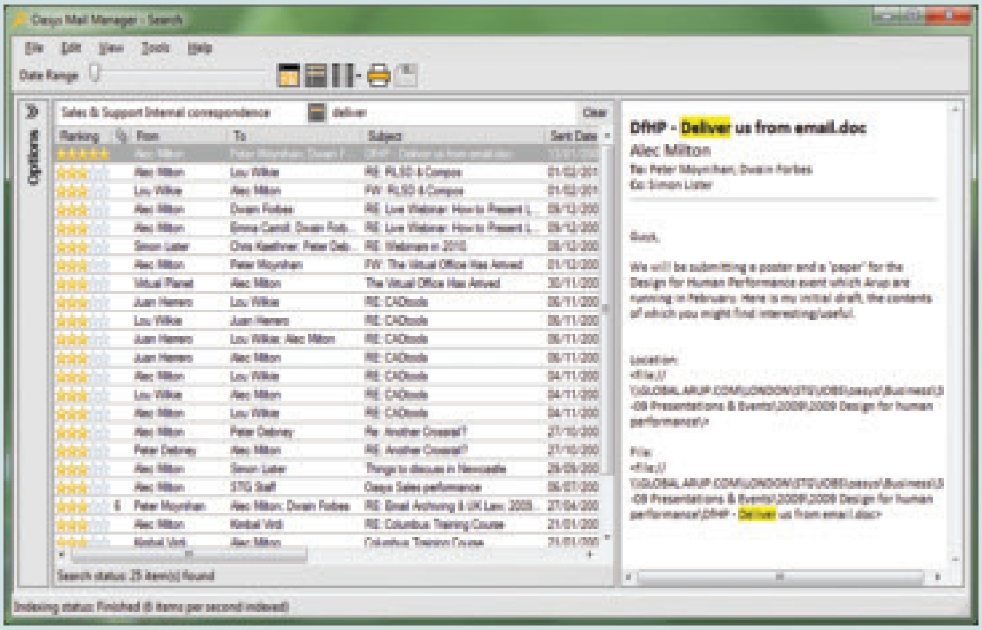
Table 1: Messages received by Arup's London office in a single week.

Message category	%	Messages
Stopped by reputation filtering	96.5%	21 156 643
Stopped as invalid recipients	0.3%	70 189
Spam detected	0.1%	21 168
Virus detected	0.0%	248
Stopped by content filter	0.0%	5369
Total threat messages	96.9%	21 264 617
Clean messages	3.1%	669 231
Total attempted messages		21 933 848

1. Example of Oasys *Mail Manager* search results.



Mobile *Mail Manager* allows you to file messages while out of the office. A couple of clicks and the e-mail is stored centrally and securely.

Filing out-going e-mails is as easy as filing received e-mails. Create the message as you would normally...

... then simply choose "send and file message" on the options menu.

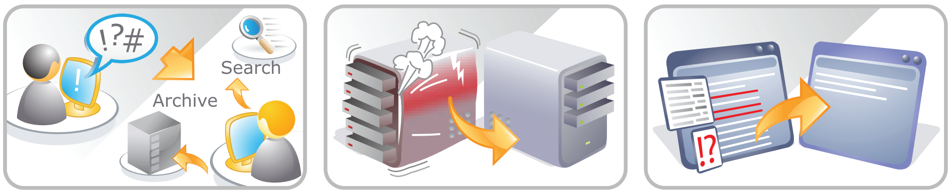
You can choose from the suggested path...

...search by typing in the filter box to speed up the process, or scroll for the preferred storage path.

You can change the filing options or just continue.

It is as simple as that. So rather than catching up with your filing when you get back to the office, you can touch each message once and file it as soon as you have finished with it.

3.



4.

"Me-centric"

Although there was and still is a fashion for centralising data, it was felt that a "me-centric" approach better suited end-users and provided other advantages. So whilst the software was designed to store the messages in centrally managed folders, the search index and list of locations were held locally with the software caching user requests. This ensured responsive operation and allowed messages to be filed while people were out of the office: the system would quietly do the filing when reconnected to the network.

In the early stages, a simple search tool was adequate but once the number of e-mails in any one folder increased to 1000+, speed became an issue. In line with the "me-centric" approach, the designers introduced a search index on the user's own machine which only indexed those areas that were relevant to the user. This ensured that searching worked while away from the network and results were both targeted and quick to obtain.

It was clear that users would not file messages if they had to open another application or indeed if it was an additional task for them, so the team built the application in Outlook and to a large extent hid it from view. They also made it part of the e-mail process itself, so that upon sending an e-mail the user is asked where they would like to file it. As an added aid to the user, the system was designed to learn where he/she liked to file messages from a given person and suggest those locations rather than the full list.

Filing thus became something done as part of sending or receiving an e-mail, and often needing just a single click.

Added value

It was anecdotally understood that users quickly embraced the software because it saved them time and provided the feeling of security that comes from being organised and knowing you can quickly find what you want.

Now that messages were being filed alongside other project documents and would be backed up by the regular backup system, the messages on the e-mail server could be deleted upon filing, which greatly reduced the cost of e-mail server space (typically three times more expensive than regular disk space), and also reduced the e-mail backup burden.

The new tool was able to check for duplicates, so whereas earlier attempts to use "public folders" had resulted in many people filing the same e-mail, the new system was able to prevent duplication.

Back-up restoration also benefited, as everything to do with a project was then in the project's folder structure and hence in one backup set rather than scattered across many personal inboxes which themselves were backed up separately to the file system data.

The way ahead

The *BlackBerry*, *Windows Mobile*, the *iPhone* and, more recently, Google's *Android* platform now allow mobile workers to access e-mail on the move. This brings a new set of challenges. How can the mobile device save to the project folders when by design it does not have access to them? How do you keep the PC and mobile device in synch? How do you cope with one device accessing multiple e-mail accounts?

Arup already has a *BlackBerry* version of the new software, and is rolling out a *Windows Mobile* version in late spring 2010. In addition, the firm is planning to support multiple other devices in the near future.

References

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Subjective factors of sustainability:

Engaging all perspectives for a sustainable built environment

Santiago Torres

Buildings can be thought of as a link between the material world of nature and the symbolic world of human culture. The built environment is necessarily influenced by subjective as well as objective factors, but the former are rarely considered when describing the requirements for a sustainable building.

Introduction

Subjective factors affect, among other things, the acceptance of a built space by its occupiers and how it is operated. This in turn can influence quantifiable measures, such as the performance of environmental controls. Reciprocally, the physical environment will affect the behaviour of occupiers at the individual level, and can also shape culture and a society's modes of dwelling.

The feasibility of a sustainable built environment depends on both sides of the equation being satisfied. All decisions that affect the one will necessarily have an effect on the other. Human performance within a sustainable building cannot be thought of as separate from the physical environment created by it, but neither can it be thought of without considering the values and expectations of its users.

This article outlines a classification method according to four broad perspectives that taken together present a more complete description of the built environment than any one of them, allowing a better understanding of the complex role of human performance in the various requirements of sustainable building. The method is exemplified in the analysis of daylighting in buildings.

Objective quantities vs subjective experience

The built environment is simultaneously a product of technology and the "container" within which different human activities take place. At the scale of an individual, it can be said to be both influenced by and influential on its occupants' behaviour. These are examples of the distinction between subjective and objective factors.

Subjective factors, although they cannot be measured directly, have a distinct effect on a building's outlook. This can materialise in such diverse ways as differences in market value, or the effectiveness of the operation of climatic controls.

For example, although the need for comprehensive life cycle cost analysis that accounts for the benefits of increased productivity has been recognised[1], the effects that the occupants' expectations have on the building's perceived performance, and the ways in which this in turn can affect the occupants' productivity, are usually not considered.

Moreover, it is important to recognise the difference, but also the interdependence, between objective and subjective factors during the design phase.

Notably, the concepts of continuity, scale, and hierarchy can be very different between subjective and objective perspectives, especially when this occurs across disciplines. At the same time, any decision taken in accordance with subjective factors will affect the objective ones, and vice versa.

These relationships need to be considered when communicating a design to avoid placing unnecessary constraints on the other factors.

In the case of daylighting, this is essential for human health at the biological level, as proved for example by the existence of seasonal affective disorder (SAD). Furthermore, it has been determined that daylit environments improve their occupants' performance[2]. Improving daylight availability in buildings is therefore essential, but the incidence of glare caused by extremely bright windows can reduce the usability of daylight.

However, a window that has good views has been found to increase the tolerance of its users to glare[3]. This shows how not only daylight quantity and quality play a part in the overall performance at a biological and psychological level, but also the subjective experience of the space by the user.

Individual conditions vs collective emergence

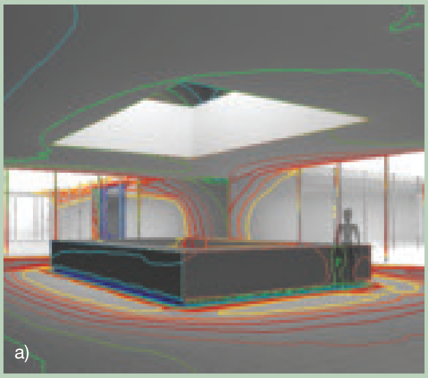
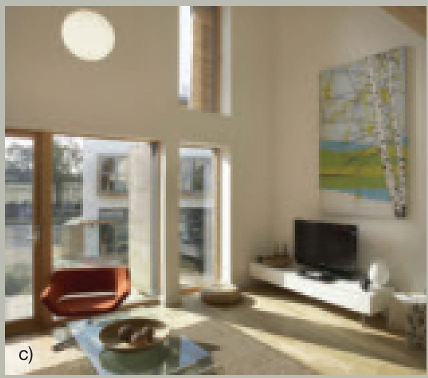
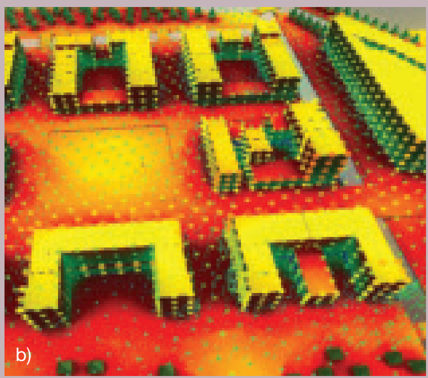
The relationship between subjective and objective factors appears at two different levels of complexity. At the individual level, the personal experience of a single occupant will have a limited effect on the building's environment. At the collective level, the sum of individual preferences will impact on the overall conditions of a system.

These two levels are interrelated, but need to be differentiated. Not only is the whole more than the sum of its parts, but also the part is more than a "mere" part because of its relationship to the whole[4].

As soon as an individual is included in a system, that individual's experience is transformed by that inclusion. In our case, we can state that cultural as well as social circumstances will affect individual performance.

It is important to note that this is different from using statistics to approximate an average behaviour. The meaning of the collective emergence is in the influence that the collective behaviour will have on an individual and vice versa.

Clearly, both individual and collective factors can be, from the first classification, either interior or exterior. In the case of daylighting design, the openness of a façade, or the use of manual shading systems, can be affected by a sense of privacy dictated by culture, thus modifying the real availability of daylight in the interiors.

	OBJECTIVE QUANTITIES	SUBJECTIVE EXPERIENCE
INDIVDUAL CONDITION	 a) Relates to the building itself, as a whole.	 c) Relates to subjective impression as an individual experience.
COLLECTIVE EMERGENCE	 b) Relates to the building as part of its context.	 d) Relates to the influence of society's history, culture, etc.

1.
a) Folkwang Museum, Essen. Arup scope: electrical and lighting design. Architect: David Chipperfield Architects Ltd.

b) Integrated 3-D urbanism demonstration project: part of the planned eco-city at Dongtan, China.

c) Kingspan Lighthouse at BRE Innovation Park, Garston, Watford, UK. Arup scope: Sustainability and MEP engineering design for zero-carbon house, the first to achieve level 6 of the Code for Sustainable Homes assessment. Architect: Kingspan Group PLC / Sheppard Robson.

d) Example of a mashrabiya (screen), Fatephur Sikri, India.

On the other hand, the elements involved in the design of daylighting systems need to perform across various criteria. The façade at the whole-building scale will need to follow the design for the whole building, balancing its different elements.

At the scale of each individual façade element, the requirements will be mostly related to the physical performance of the envelope.

However, the different scales and different criteria affect each other mutually, as a certain building design will not be able to accept certain technological solutions, and vice versa.

Conclusion

These two classifications can produce four main types of factor influencing the performance of buildings and their occupants (see matrix above). Each type will present particular qualities regarding the effect they will produce, the problems they may cause, and the ways they can be addressed.

As already noted, the decisions taken in response to one type of factor will affect the others, so communication is essential in avoiding unnecessary constraints being transferred. This communication could be improved by an explicit understanding of the differences of perspective that are influencing each decision.

Similarly, the integrated analysis of factors during the early design stages can help problems to be foreseen that otherwise would arise at a later time, when they might be more difficult and costly to solve.

Academic research is starting to establish the interrelationships between subjective factors, human performance, and the performance of building systems. The application of such findings will depend on a useful framework that allows for those relations to be included in the design process.

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