Built for living

Understanding behaviour and the built environment through engineering and design

Report from a series of three workshops
hosted by the Royal Academy of Engineering, RIBA and Arup.


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This report captures the issues and themes that emerged from the three workshops and does not necessarily represent the views of the Royal Academy of Engineering or its partner organisations.

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Foreword

This report describes the issues and themes raised during a series of three workshops, which explored the relationship between the design of the built environment and human behaviour. Each workshop addressed the three following areas:

- energy, water and waste
- health and wellbeing
- performance and productivity.

The report is published by the Royal Academy of Engineering and has been supported by experts from a range of organisations and disciplines.

The report summarises existing knowledge, articulates the current level of understanding of the field and makes recommendations for design practice and for research and development, while suggesting implications for policy.

This report will be of interest to all those concerned with developing built environments and with human behaviour.

Executive summary

How does the design of the built environment affect human behaviour? This was the question at the heart of a series of three workshops hosted by the Royal Academy of Engineering, RIBA and Arup.

The workshops were organised in response to the desire of the UK government, specifically the Department for Communities and Local Government (DCLG), to better understand behavioural issues when developing policy for the built environment.

THERE IS MUCH TO BE LEARNED ABOUT HOW THE BUILT ENVIRONMENT FUNCTIONS AS A SOCIO-TECHNICAL SYSTEM WITH PEOPLE AS A CRITICAL COMPONENT

There is much to be learned and understood about how the built environment affects behaviour and how it functions as a socio-technical system with people as a critical component. There are three areas where the interplay between people and the designed environment around them is key. These are:

- the use of resources, particularly energy and water, and the production of waste
- health and wellbeing
- productivity and performance.

The objectives of the workshops were to:

- strengthen understanding of what is known and what is not known about the relationships between design and human behaviour in the built environment
- identify examples of design and engineering that have explicitly considered human behaviour, with the aim of improving stewardship of resources, health and wellbeing, and performance and productivity
- identify ways of working and tools that promote and enable collaboration between stakeholders – including designers, architects, engineers, behavioural scientists and building users
- identify implications for national policy and recommend priorities for research and development.

This report describes the issues and themes raised during the workshops and is supplemented by case studies, literature searches and input from subject matter experts, practitioners and academics. The work was guided by a steering group representing the main sponsors.

The report suggests areas where further research is required, and identifies key practice and policy needs that could be better met by building a firm base of evidence. The report also identifies opportunities for business to create intuitive new products and services that match building users' needs and capabilities.

DESIGN PRINCIPLES WILL HELP STAKEHOLDERS ADDRESS KEY BEHAVIOURAL ISSUES

A set of design principles are introduced to help stakeholders consider, discuss and address key behavioural issues when designing and engineering the built environment, to promote behaviours that will improve resource stewardship, health and wellbeing, and performance and productivity.

Key messages are addressed to built environment stakeholders including practitioners, research funding bodies and policymakers as well as others with an interest in creating a high quality built environment. Key messages include the following:

For built environment stakeholders:

- **Built environments can be viewed as complex socio-technical systems requiring multidisciplinary collaboration throughout their lifecycle. Intellectual frameworks, methods and tools are needed that promote collaborative working between users and other stakeholders during the design process and throughout the lifecycle.**
- **The design of the built environment, in combination with other factors, has the potential to influence human behaviour and thus have a significant impact on health and wellbeing, performance and productivity and the stewardship of resources (energy, water and waste). Behavioural considerations and a recognition of the diversity of users are critical to the success of built environments and need explicit consideration from the very beginning of any project and throughout its lifecycle.**
- **Knowledge about the relationships between design, engineering and human behaviour is extensive but fragmented. There are opportunities to bring together and capitalise on this knowledge, including learning lessons about the application of systems thinking from other domains where such understanding is more mature.**
- **A set of principles for design practice that focus on behavioural issues in the built environment provides a means of putting knowledge into practice (Section 6.1.1).**
- **Guidance based on available evidence and examples of best practice are needed to support the application of design principles in practice. Ongoing assessment of the built environment using post-occupancy evaluation and throughout its lifecycle will be needed to enrich these.**

For research funding bodies:

- **There are outstanding challenges and gaps in this area, which a national research and development programme should address. The report identifies the key requirements of such a programme and questions that need to be considered (Section 6.2).**

For policymakers:

- **The effectiveness of built environment policies may be enhanced by applying an understanding of the relationship between design, engineering and human behaviour. Furthermore, interdependencies between different interventions mean that a more integrated policy approach is needed.**
- **A recognition of the importance of behavioural issues has implications for policymakers and the policy-making process. For example, one proposal from the workshops was to include at the outset of any major policy initiative a behavioural assumptions and impact statement specifying the behavioural goals, underlying assumptions and impacts.**

A WELL-DESIGNED AND MANAGED BUILT ENVIRONMENT CONTRIBUTES TO THE GENERATION OF ECONOMIC, SOCIAL AND ENVIRONMENTAL VALUE

1. Introduction, objectives and method

AN EVIDENCE BASE THAT LINKS THE BUILT ENVIRONMENT AND HUMAN BEHAVIOUR IS NEEDED, AND A MEANS OF APPLYING THE EVIDENCE TO BUILDING PRACTICE

1.1 Introduction

A well-designed and managed built environment contributes to the generation of economic, social and environmental value: in combination with other factors, it can have a positive influence on behaviour and feelings. Through explicit consideration of the interaction between human behaviour and the built environment, in design, engineering or policy-making, there is potential to improve the stewardship of resources, health and wellbeing and performance and productivity.

Value can accrue to end-users and other stakeholders, whether they are owners or tenants of residential buildings, owners or occupants of commercial buildings, patients, visitors and staff using healthcare buildings, building commissioners or more generally citizens of the built environment. In order to achieve the greatest possible value, an evidence base that links the built environment and human behaviour is needed, and a means of applying the evidence to building practice.

Three workshops were organised to investigate the link between behaviour and the built environment. The existing landscape and future directions for research and practice were explored, and examples of the application of behavioural knowledge to the built environment were presented. Detailed objectives for the workshops are outlined in the following section.

This report captures the themes and issues that emerged from the workshops. It suggests priorities for academia and industry, working in collaboration across a wide range of sectors and disciplines, as well as informing government policy.

1.2 Objectives

The objectives of the workshops were to:

- strengthen understanding of what is known and what is not known about the relationships between design, engineering and human behaviour in the built environment
- identify examples of design and engineering that have explicitly considered human behaviour with the aim of improving stewardship of resources, health and wellbeing, and performance and productivity
- identify ways of working and associated tools that promote and enable collaboration between stakeholders, including designers, architects, engineers, behavioural scientists and building users
- make recommendations for future research and development and identify the implications for national policy that will promote significant improvements.

Across these themes, the workshops considered a wide range of design applications – from smaller-scale products, such as tablet computers, to larger-scale buildings, infrastructure, neighbourhoods and cities.

THE FINAL WORKSHOP FOCUSED ON FUTURE THINKING, AND EXPLORED THE APPLICATION OF SYSTEMS THINKING AND INTERDISCIPLINARY APPROACHES

1.3 Method

The work was led and guided by a steering group comprising representatives from the Royal Academy of Engineering, Arup, University College London and the University of Leeds with further support from the Economic and Social Research Council (ESRC). Input was provided by members of the Behavioural Research Network attached to DCLG.

An initial desk study revealed the current state of knowledge about behaviour in the built environment, and helped to define discussion topics for the workshops and identify key stakeholders. The three key areas of focus – use of resources, health and wellbeing and performance and productivity – emerged from the desk study, and the three areas were addressed at each of the workshops.

The first workshop was at RIBA and attended by 60 delegates. It mapped the landscape of existing research and practice. The workshop delivered a picture of the existing research and sources of knowledge and identified areas where research was lacking.

The second workshop, hosted by Arup and attended by 50 delegates, explored lessons from case studies, and focused on identifying specific areas for future research.

The final workshop focused on future thinking, and explored the application of systems thinking and interdisciplinary approaches to design and human behaviour. It was held at the Royal Academy of Engineering and attended by 50 delegates who looked at the challenges of forecasting behavioural trends and the potential for unintended outcomes of design interventions. Participants also helped to identify principles that would support design and engineering practices that consider human behaviour.

Case studies were presented at all the workshops, and further case studies were provided by participants. A number of these are included in this report. The case studies were chosen to illustrate examples of current research and practice, and cover a range of research methods, practical tools and applications. They are placed at the end of the sections to which they are most relevant.

Attendees at the workshops included representatives from government departments, designers, architects, engineers and behavioural specialists, with a balanced mix of practitioners and academics. See Appendix 2 for the list of delegates registered to attend each workshop.

Material from the workshops was supplemented by literature reviews which, although not exhaustive, represent the main topics of interest across a range of disciplines and applications. Advice and input were also sought from subject matter experts. Members of the steering group were tasked with drafting the various sections of the report, which were then used to create an integrated narrative, conclusions and recommendations. These sections were reviewed by experts in the relevant subjects.

2. Understanding design and human behaviour

This section introduces the motivations for applying behavioural understanding to the built environment, and the associated challenges. Relevant aspects of behavioural theory are presented that could be applied across all sectors of the built environment. The need to understand the diversity of users and to involve them in the design, construction and operation of the built environment is also discussed.

At the end of this section, Case study 1 provides an example of how a simulation tool may be used to test users' reactions to a complex built environment facility.

2.1 What needs to change?

A BETTER UNDERSTANDING OF HOW PEOPLE USE ENGINEERED SYSTEMS IS NEEDED, SO THEY ARE USABLE AND INTUITIVE

Understanding interactions between design and human behaviour is a key factor in creating, operating and maintaining a successful built environment that supports resource stewardship, health and wellbeing, and performance and productivity.

For example, a building designed to be energy-efficient will not meet its environmental goals if the people in it are uncomfortable and decide to bypass the building controls to keep warm or cool. A better understanding of how people use engineered systems is needed, so that they are usable and intuitive.

A district may feel less safe and be more prone to street crime if sightlines are not clear and the streets are not well-lit. Districts designed with roads and pedestrian routes that are visually open, direct and well-used, and have sufficient levels of lighting, are likely to be both safer and perceived as safe, thus contributing to wellbeing.

The following factors contribute to the scale of the challenge:

The scope or scale of the problem domain

This thinking applies to the design of cities, neighbourhoods and individual buildings, the technologies that are integrated into buildings, but also to the design of government policies.

The scope of the behaviours concerned

These include, for example, use of resources, creation of waste, health and wellbeing, performance and productivity, crime, and security.

The importance of supply chains

For example, improving the design of hospitals will require changes throughout complex supply chains.

The timescales involved

These can run to decades, given the expected lifetime of a building.

The unpredictability of parts of the system

This is particularly true of the human element and the way it affects other aspects of the system, particularly when timescales are long and the system is complex and open-ended.

The possibility of trade-offs and interdependencies

For example, reducing crime in a neighbourhood through greater use of CCTV cameras may at the same time reduce trust and wellbeing. Positive interdependencies are possible too.

Better strategies are needed for designing and engineering the built environment, given the complexity of the context.

2.2 What is known?

There is a wealth of knowledge about the interrelationships between design and human behaviour, but it is fragmented and distributed across different professions and disciplines, across people who work at different stages in the lifecycle of buildings and across academia and practice.

Architects, designers, engineers, facilities managers and building users all have different experiences and have amassed different knowledge. Much of this knowledge can be generically applied, and some is well-evidenced. However, there is potential to embed evidence to a greater degree into design and engineering practice to achieve the best possible outcomes.

Knowledge within built environment disciplines exists alongside a growing body of behavioural theory and experience in the application of behavioural science to the policy-making process. For policy-making, a more sophisticated understanding of behaviour may be used to achieve better outcomes, either used alongside existing policy tools, or to inform more innovative interventions[1].

Bringing together knowledge about the relationship between design and behaviour from the different built environment professions, in combination with behavioural theories emerging from psychology and other social science disciplines, has the potential to enrich and inform this area.

Designing for end-users

Good design needs to embrace well-established 'inclusive' or 'universal' design principles. Inclusive design refers to the idea that "mainstream products and/or services are accessible to, and usable by, as many people as reasonably possible, without the need for special adaptation or specialised design"[2]. The built environment should be similarly designed to meet the needs, capabilities and aspirations of all potential users[3]. Principles published by the Commission for Architecture and the Built Environment[4] propose that inclusive design:

- places people at the heart of the design process
- acknowledges diversity and difference
- offers choice where a single design solution cannot accommodate all users
- provides for flexibility in use
- provides buildings and environments that are convenient and enjoyable for everyone to use.

The ethos is that inclusive design is user-centred, population-aware and good for business. According to the Engineering Design Centre in Cambridge, too many products are targeted at young, able-bodied users. As a result, they are neither accessible nor desirable to the older user and, in practice, able-bodied users often find them difficult or frustrating to use[5]. Systems that are co-designed with users and 'pulled' by users' needs are much more likely to be successful than systems designed by experts who then try to persuade users to behave in certain ways. User pull beats expert push every time.

There is evidence that design that explicitly considers the full range of human capabilities and needs can have a positive effect on user experience and safety[6].

There is also evidence that products designed to be inclusive are popular with all users, for example, the Ford Focus, whose designers were encouraged to design for the needs of older drivers as well as the usual younger target market[7].

Motivations behind behaviours

Factors that motivate users to undertake particular behaviours are reasonably well understood. For example, users are more likely to undertake particular behaviours if they are easy, obvious, challenging, competitive or fun. They are also more likely to behave in a certain way if the impact of doing so is clear and immediate and if the default option is the desirable behaviour. An example of this is requiring people to opt out of rather than opt in to organ donation.

Users also prefer to be in control of their lives, including aspects of their work environment. They prefer empowerment to 'command and control'.

Much of human behaviour in complex systems is habitual, repeated and the result of quick decision-making that is not subject to careful analysis[8]. Once ingrained, a habit is hard to change – although, with time, habits can be shifted.

THE BUILT ENVIRONMENT SHOULD BE DESIGNED TO MEET THE NEEDS, CAPABILITIES AND ASPIRATIONS OF ALL POTENTIAL USERS

THE DESIGN OF THE BUILT ENVIRONMENT IN COMBINATION WITH SOCIAL FACTORS MUTUALLY REINFORCE HOW PEOPLE BEHAVE AND FEEL

There are particular points when behaviour is more likely to change[9]. For example, people are more likely to switch to public transport for their journey to work when they have just moved house. This is one aspect of the way behaviours are nested in each other, rather than determined in isolation. For example, a parent may choose to do the school run by car so that they can then drive to work and later call in at a supermarket on the way home.

Regulation may still be required in certain situations, such as for enforcing speed limits or curbing drink-driving, but this is much more powerful when social norms are aligned and when other triggers and 'nudges' are in place. The two are mutually reinforcing approaches. A current example is the changing attitude to the use of mobile phones when driving – new driving penalties are reinforcing changes in social attitudes about acceptable behaviours.

The design of the built environment in combination with social factors mutually reinforce how people behave and feel. For example, a hospital may launch a policy to reduce violence against staff that focuses on changing the interactions between staff and visitors by using social norms to point out that most people behave politely. Alongside this, an environment with clear signage, good natural surveillance and better standards of cleanliness may also contribute to reduced stress and fewer incidents of violence[10].

A better understanding of how the design of the built environment in combination with other factors or policy interventions can influence behaviour in a positive way would be of benefit to both policy and practice.

Finding ways to 'nudge' behaviour

There is a growing belief that behaviour responds to 'nudges' using triggers and prompts, and to restructuring the way choices are presented[11 12]. There are gradients of influence, from the straightforward provision of information such as the '5 A Day' public information campaign through to physical constraints on behaviours such as speed bumps.

Other ways of potentially nudging behaviour include social comparisons and norms in areas such as energy use,[13] paying taxes,[14] and alcohol consumption using target and feedback systems. This is especially effective if users set their own targets.

This is not without difficulties. Target and feedback systems can distort behaviours. They can also be too successful in that they unduly focus behaviour on just one factor, such as waiting lists in the NHS or call centre response times. So target and feedback systems need careful and nuanced design if they are to work effectively.

The importance of involving users early in the design process

Experience has shown that the needs and behaviour of users cannot be designed into a system at a late stage because system design choices are almost always constrained by earlier choices. This means that user behaviour needs to be explicitly considered from the outset, during the development of the design brief.

Making behavioural assumptions explicit very early in the process, and opening them up to analysis and challenge need not be costly or take too much time, if they are considered at the beginning of the design process. For large and complex projects, carrying out testing using mock-ups, prototypes and simulations will create financial cost; however the cost is justified because of a reduction in the risk of failure.

Testing behaviours to inform design

Case study 1 illustrates how virtual reality simulation allowed designers to user-test their designs, for a major expansion to MTR Admiralty Underground Station in Hong Kong. Users were able to experience and interact with virtual designs of a station, allowing the designers to test and optimise user navigation and wayfinding.

Physical simulation was used in the design of Thameslink's trains. In this case, £750,000 was spent building realistic mock-ups of trains, in order to simulate train evacuations. A study prepared by UCL's accessibility research group demonstrated that the existing design could not work without significant changes, such as having three doors per carriage[15]. This simulation was expensive, but it prevented a system failure that would have cost millions of pounds.

ONE MAJOR BARRIER IS THAT THERE IS NO SINGLE AGREED MODEL OF HUMAN BEHAVIOUR THAT CAN BE USED IN A DESIGN PROJECT

Dealing with unintended consequences

One of the problems in trying to predict and design for human behaviour is that interventions can lead to unintended consequences, some of which could have been foreseen if the assumptions had been made explicit, and available evidence from research and learning from best practice had been applied.

For example, there is evidence that CCTV cameras in one location shift planned criminal activity elsewhere and that they are not effective in preventing unplanned crime[16] (such as violent outbursts in town centres by people under the influence of alcohol). Any such system has interdependencies and complex feedback loops operating over different timescales. However, if human behaviour is incorporated into the process of identifying and managing risk, the likelihood of such consequences can be reduced.

Barriers to using a behavioural approach

Despite the obvious advantages of understanding more about the interrelations between design and behaviour, there are several potential barriers to explicit consideration of this area. These are typically cost, resource, time, lack of knowledge, current practice and the expectations of key stakeholders.

There is a need to demonstrate and justify the value of using a behavioural approach beyond avoiding failure later in the lifecycle of a building, product or service, and beyond the understanding of human behaviour that architects, engineers and designers already have. The wider benefits and opportunities – particularly for meeting policy challenges – also need to be demonstrated.

One major barrier is that there is no single agreed model of human behaviour that can be used in a design project. Furthermore, some of the most widely used models are criticised for being too individualistic and static, and so lacking in appreciation of context.

2.3 Tools and techniques – how things can change

A useful approach that was discussed at the workshops is to consider buildings and the people who use them as parts of a complex system. Systems thinking (also described as holistic, total, joined-up, socio-technical, or user-centred) requires multidisciplinary collaboration, since no single discipline, profession or stakeholder group has all the necessary expertise to tackle the whole system. Systems thinking complements the detailed knowledge that stakeholders may have of individual components, and helps to identify how different parts of the system interact, and what emergent characteristics it may have.

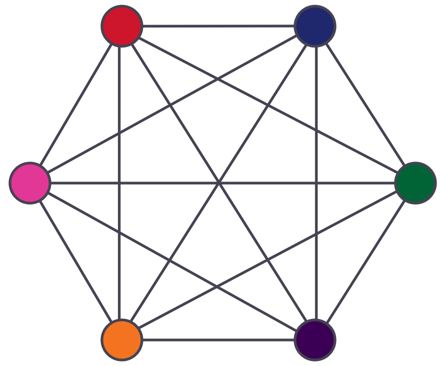
Figure 2.1 provides an example of a socio-technical systems model[17]. The model is based on the assumption that any organisation can be represented by a set of six interacting sub-systems that comprise both social and technical aspects. Linkages and relationships may be analysed using this framework. Case study 11 illustrates the application of this model to the design of a school. In Section 5.2, the use of the model in describing the 'Factory of the future' is discussed.

Practice in the built environment can learn lessons about a systems approach from other domains where it is more mature. These domains include product and IT system design, in particular in the aeronautical and automotive sectors. Indeed, there is a wealth of understanding that can be read across from other domains. Systems thinking is a maturing discipline, and applying it in the built environment will help it develop.

Intellectual frameworks, methods and tools are needed that foster and promote collaborative working between stakeholders throughout the lifecycle of a project. Examples include those described in Case studies 7, 8, 9, 11, 12 and 13. Another example is the Construction Industry Council's Design Quality Indicator[19], in which the ambitions of stakeholders are defined at the start of the project, and monitored

Figure 2.1 Socio-technical system illustrating the interrelated nature of an organisational system[18]

Socio-Technical Centre, Leeds University Business School



END-USER INVOLVEMENT AT AN EARLY STAGE AND THROUGHOUT THE PROJECT IS A KEY COMPONENT

throughout. Government Soft Landings[20], a further example, is a process that enables designers and constructors to stay involved with a building beyond practical completion. It provides a means of ensuring that the building meets the end users' needs and required operational outcomes. End-user involvement at an early stage and throughout the project is a key component, along with post-occupancy evaluation.

Existing tools need to be revisited to ascertain the degree to which behavioural insights are explicitly incorporated, and how the tools might be adapted to include behavioural insights. Tools will also be needed that can support applying a systems approach to built environment problems.

2.4 Conclusions and recommendations

There is a great deal of developing knowledge about the factors that influence behaviour but much of it is fragmented across disciplines. The knowledge held by built environment professions could be brought together along with emerging knowledge about behavioural theory to provide a more comprehensive understanding of the relationship between design of the built environment and behaviour.

Interdisciplinary approaches to design and engineering that enable this knowledge to be used should be promoted through education and best practice examples. Funding is also needed to strengthen the evidence base by means of post-occupancy evaluation and other types of research, and develop practical, evidence-based tools.

A systems approach to design, engineering and the built environment is helpful. More work is needed to identify how this approach can complement or add to existing best practice, along with the development of practical tools. Evidence should be sought on how the design of the built environment, alongside other factors or policy interventions, mutually reinforce behaviours that lead to improved stewardship of resources, health and wellbeing, and performance and productivity.

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Realtime synthetic environment with the data logs of users' slowdown

CASE STUDY 1: CROWD-SOURCING USER BEHAVIOUR WITH SYNTHETIC ENVIRONMENTS

Capturing user behaviour for journeys through a station before it is built

Alvise Simondetti, Global Leader Digital Environments neXt_work, Foresight Research and Innovation, Arup

MTR Admiralty Underground Station in Hong Kong is one of the busiest stations in the world, with more than 800,000 passenger journeys a day. A proposed expansion will double the number of platforms. The station will grow from three levels served by eight escalators to seven levels connected by 48 escalators, increasing the number of vertical passenger interchanges.

The client's objective was to allow passengers to move easily and intuitively around the station and to minimise costly and disruptive changes to existing wayfinding, signage and CCTV installations. To identify the impact of the signs on behaviour, speed was used as a proxy – stopping and looking around for signs implies a more frustrating journey. The client's aspiration was that each user journey should take less than 1.5 minutes. The scenario was modelled using Arup's Realtime synthetic environment, which allows users to experience with the use of a joystick and react to the architecture before it is built. This is easier and more economical than changing the signage once the building is complete.

The completed station will have 970 signs, which are all represented in the model. Over 1,500 users spontaneously navigated the virtual station setup in the Venice Biennale public exhibition, and completed a designated task with start and end points using the signage. The routes they took, along with the locations where they searched for clues, were logged, providing important feedback for the designer.

These results enabled the human factors specialist to capture, analyse and play back user tests. 235 potential problems with the current signage were identified. 145 of these were corrected at this stage, resulting in significant cost savings for the client.

The model accurately represents the proposed three-dimensional geometry and uses several types of representation: realistic visual appearance with peripheral vision, contextual dynamic agents and sound, navigation at an accurate speed and user logs display. As technology and memory bandwidth advances, an improved system could capture users' verbal comments too, such as "I don't know where to go".

Conclusion

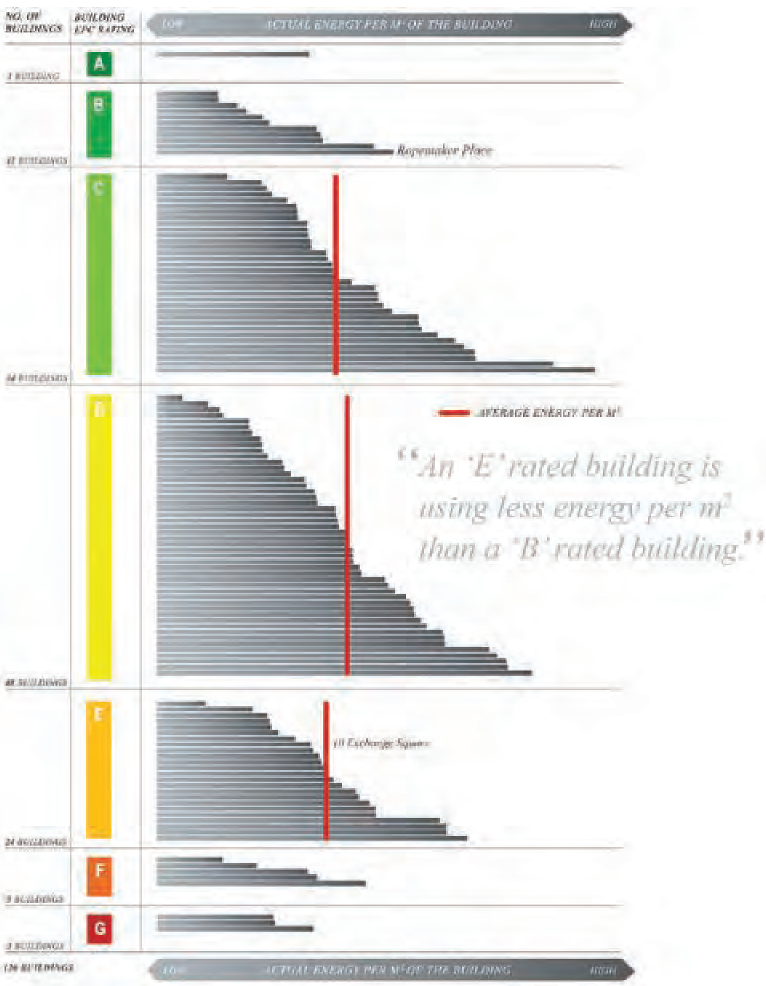
Arup Realtime enabled the client to test and rectify navigation and wayfinding signage in virtual space, using a real user's view.

3. Energy, water and waste

This section explores the interplay between the built environment and behaviour, and how it impacts on energy and water use and waste production. Case studies 2, 3, 4, 5 and 6 provide examples of relevant research methods, tools and techniques and are presented at the end of the section.

Figure 3.1 – Actual energy use of more than 100 BBP member offices grouped by their EPC rating

Source: Jones Lang LaSalle/Better Building Partnership[22]



3.1 What needs to change?

Understanding the role of the built environment in encouraging, or indeed inhibiting, particular sustainable behaviours holds much promise. For example, research has sought to understand how individuals and groups can be encouraged to behave in an environmentally sustainable way using techniques developed within the field of psychology – whether at home, in the public realm or the workplace[21].

The motivation for designing buildings to be more energy-efficient, to use less water and recycle more, and to reduce waste is clear but the link between building design and real-life performance is not straightforward. Predictions of performance, such as those given in an energy performance certificate (EPC) can be poor indicators of the actual energy efficiency of the building when in use. This is in part because of the way that people respond to the building's design and the features intended to promote efficiency. Figure 3.1 shows that energy performance can vary considerably within a particular EPC rating, and buildings with low ratings can even perform better in practice than more highly rated buildings. For example, within the sample of more than 100 office buildings, some buildings rated 'E' had a lower energy intensity than those rated 'B'. Furthermore, the average energy consumption for a particular EPC rating, indicated by the red line, was found to be similar whether the building had an EPC rating of 'C', 'D' or 'E'.

This section sets out what is known about the link between built environment design and sustainable ways of living and working, and identifies gaps in knowledge.

ENGAGING USERS IN THE DESIGN AND IMPLEMENTATION OF TECHNOLOGIES CAN INFLUENCE HOW NEW TECHNOLOGIES ARE ADOPTED

3.2 What is known?

Designers need to engage with users

Designers and engineers have a strong understanding of the technical basis for achieving efficiencies in energy and water use and waste reduction. There is, however, a growing awareness of the importance of human behaviour in contributing to these design objectives[23 24]. Wener and Carmalt[25] note that 'some of the oft-cited ecological benefits of green buildings are dependent on the ability to correctly predict user behaviour'.

Public and commercial attention have focused on the potential of new technologies to reduce the energy and water consumed and the waste generated within buildings. There is recognition that investments in new technology are likely to achieve only limited gains without considering human behaviour in their design and operation[26].

Technological innovations to reduce energy or water demand are often designed and distributed in a hierarchical, top-down manner by developers, policymakers or managers[27]. Furthermore, experts such as IT professionals often design a system, and then push it at its end users[28].

User engagement offers a way to understand how occupants might use buildings, interact with technologies and respond to design cues. Engaging and involving users in the design and implementation of technologies can influence how new technologies are adopted. It enables 'pull-based user-owned change'[29], with users successfully driving the change by taking ownership of it. This helps to ensure that it meets their needs and minimises resistance to change.

User engagement and participation have been shown to be key to the success of a number of sustainable behaviour programmes in home and work contexts. For example, involving staff in the design and running of waste reduction programmes has been identified as a significant factor in their success[30]. Furthermore, in a workplace setting, it appears that employee-initiated recycling interventions produce greater increases in recycling than programmes that are imposed upon staff[31].

This highlights the importance of engaging householders and employees early in the planning of changes within buildings, or in the specification of green technologies. Doing so will increase the likelihood that designs meet users' needs and that the changes will be accepted and championed by those who live and work with them.

It is important to consider how people will respond to more efficient technologies and to engage with them about how to maximise the environmental benefits. This is underscored by the 'rebound effect' – also called the 'take-back factor' – where anticipated environmental savings from technology are not realised. For example, after installing a more efficient boiler, people will often use the efficiency savings to heat their home for longer and/or to a higher temperature[32].

Habits are hard to change

The desire to live more sustainably is very often confounded by habitual behaviour. Further research is needed to understand the factors that drive and change such habits.

Energy efficiency is often a lower priority than other needs in people's everyday lives. So interventions need to appeal through other salient benefits. These could include providing an interesting means of control, social approval, increased convenience or comfort.

Monetary incentives are often considered as a means of increasing motivation for saving energy. More affluent households often consume more energy and offer greater potential efficiency gains[33 34]. However, financial rewards may be less effective for affluent households than for poorer households, where there is a greater incentive to reduce costs.

Making sustainable behaviours easy and convenient

Sustainable behaviours are often influenced by habit, knowledge and convenience. For example, the location of recycling receptacles within public buildings and workplaces can strongly influence recycling rates.

Buildings that provide plenty of recycling bins close to occupants, and only a few general waste bins placed further away, could increase recycling rates[35]. Similarly, altering the timings of lift doors, so that they take longer to close, can reduce the number of lift journeys taken and the energy consumed[36].

These findings show how simple design choices can make sustainable behaviours easy and convenient for individuals to work into their everyday habits, routines and work processes[37].

A commonly reported reason for individuals choosing not to act in sustainable ways within a building is a lack of procedural knowledge. Often they don't understand how to use a piece of technology efficiently or what course of action is the most sustainable[38].

Providing pictures or written examples of the types of waste that can be disposed of in a recycling bin is one way to boost recycling rates within buildings. Similarly, there are many examples of occupants not understanding how to use heating and ventilation systems efficiently, such as when to open windows, or how to position vents optimally. So there is a clear need for controls to be designed to guide occupants.

There is a tipping point, however. If too much information is provided, individuals may feel overwhelmed, or changing behaviour may appear too onerous[39].

A better understanding of consumers' behaviour – such as the choices people make around buying products, how they use them and how long they keep them – would also help designers and engineers create more sustainable products and make it easier for people to make sustainable choices[40].

Sustainable behaviours in the workplace

There is less research on sustainable behaviour in the non-domestic sector, particularly workplaces. Increasing motivation for saving energy in workplaces and in public spaces where individuals are not directly responsible for the energy costs and have less control over their energy use is a significant challenge. This requires designers, engineers, managers and policymakers to develop methods of inducing ownership of energy stewardship. Such approaches could play upon notions of identity, personal goals and competition[41 42 43].

The feeling of lack of personal responsibility in the workplace is also an issue. More research could look at how to promote sustainable responsibility within organisations[44 45].

There needs to be better connection and engagement between individuals and in-house building management systems (BMS) or remote dashboards. There may also be potential for gamification[46] – making interaction with a BMS fun, competitive or social. Case study 4 illustrates how visualisation of energy use in different parts of a commercial headquarters building was used to produce an emotional response in staff and visitors, leading to behavioural change.

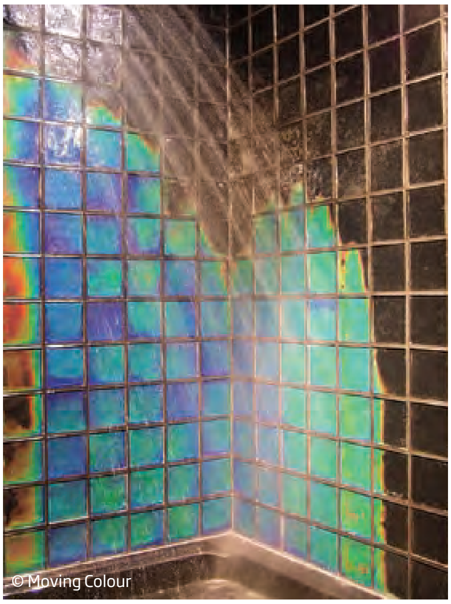
There are steps that employers can take to encourage a wider range of energy-efficient behaviours – for example by updating dress codes and changing heating practices. The introduction of gilets as part of staff uniform by Marks & Spencer, for example, means that employees can feel warmer and therefore tolerate lower shop temperatures. Employers can also adopt guidelines on specifying controls that are easier to use and reflect the routines of working life[47].

Existing social structures and metrics offer an opportunity to change behaviour[48]. Positive sustainable behaviours can be incorporated into formal job roles and performance monitoring. Leaders and managers can publicly demonstrate the behaviours that the company seeks to promote. Role models and authenticity can have a powerful effect[49]. Charismatic leadership and clear commitment to environmental goals from management can help motivate others to reduce energy consumption (eg, Schelly et al.[50]) and drive cultural change[51] as does investing in staff training for operating buildings and technologies efficiently[52].

Can design 'nudge' behaviour?

Creatively designed artefacts and facilities can influence behaviour. For example, temperature-sensitive glass tiles for showers nudge users to cut their shower short when the tiles change colour after lengthy exposure to hot water.

A number of projects from Sweden's Interactive Institute have centred on



© Moving Colour

Temperature-sensitive glass tiles created by Inventibles, Inc

Tio light switch for children

© Tim Holley

ambient, non-numerical energy feedback. They include the Power-Aware Cord – an illuminated power cable that provides a form of 'glowing guilt'[53].

At Brunel University, student Tim Holley created the Tio light switch for children, which changes colour and becomes 'angry' when left on for a long time[54].

Behaviour is social, not just an individual choice

There is a need to clarify individual and communal priorities. This involves understanding how individual behaviours such as frequency of showering and temperatures inside homes are shaped by social conventions[55 56 57].

The rise of average temperatures inside homes[58] and the use of domestic appliances are affected by the interplay between developments in technology and changes in society. Although user choice is very important, policy options that can influence broad, group behaviour can be considered.

Existing research has focused more on individuals' behaviours than communal behaviour and social practices[59 60].

Better data about how people use buildings is needed

Improved data collection methods are needed to help understand better how people use buildings and building-integrated technologies, and would benefit from an accelerated programme.

This should include exploring the most effective forms of real-time and summary feedback on energy use[61 62] and how people incorporate this feedback into their daily lives[63].

Although the significance of domestic heating in overall energy use is understood, there remains plenty of unexplained variation in the energy use data. For example, energy use and occupancy numbers do not always correlate directly.

More can be done to explore ways to help people concentrate their energy use in only some parts of buildings. To do this, it is crucial to understand the different reasons why people heat their homes – including keeping rooms aired and dry, keeping mould at bay and drying laundry – to help determine whether particular interventions are likely to work.

Conversely, a better understanding of the benefits of different heating practices is needed, including 'person heating' as well as space heating[64], and what can be learned from other parts of the world. This is particularly important for an ageing demographic for whom personal warmth is a priority.

In commercial buildings, there is also value in tracking behaviours[65 66] related to energy, water and waste. This should include, for example, comparing the behaviour of occupants of developments built with specific end-users in mind to those working in speculative developments built by commercial developers before the end-user has been identified.

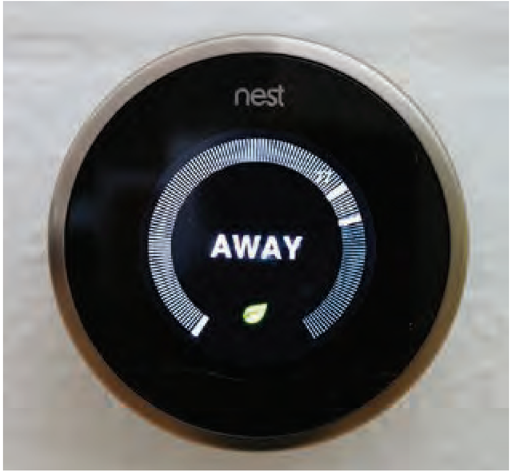
SMART BUILDINGS OFFER AN EFFECTIVE WAY TO REDUCE ENERGY CONSUMPTION AS LONG AS USERS RETAIN A SUFFICIENT DEGREE OF CONTROL

Smart buildings need emotional intelligence

Smart buildings offer an effective way to reduce energy consumption as long as users retain a sufficient degree of control and the system can accommodate, or even learn, users' preferences and needs[67]. Further research into the balance between automation and maintaining user engagement could help to ensure that users of smart buildings do not feel frustrated by automated systems in which they

Smart building

Nest thermostat



THE DESIGN PHILOSOPHY OF MANY BUILDING CONTROLS LACKS A CRUCIAL UNDERSTANDING OF PEOPLE

cannot intervene. However, while active engagement of users has its advantages, it is necessary to recognise its limitations[68].

Neither the designer, the engineer nor the users possess all the information or skills to design and manage the perfect building or system[69 70]. Given that increasingly interconnected systems will be used in smart buildings, there is a role for a socio-technical approach to design. This would involve multidisciplinary design and engineering teams, users, and tools to understand the whole system[71]. Such an approach can also help compensate where it is difficult to directly engage end-users, as is the case in many commercial builds.

The design philosophy of many building controls lacks a crucial understanding of people[72 73]. This has prompted a focus on human-centred design, including products that 'communicate, interact, empathise and stimulate the people involved'[74].

Some research has been conducted into the most effective ways to promote environmentally sustainable behaviours with the help of smart technologies, and it is possible to draw conclusions from this. For example, the use of target and feedback systems can influence behaviour, particularly when using real-time data[75 76 77 78]. The advent of smart metering[79] and smart feedback devices, with real-time displays for householders, offer opportunities for testing redesigned feedback and information presentations on a large scale, including time- or demand-based pricing.

There is an increasing body of evidence on the effects of smart meters and energy feedback in practice, which initiatives such as Energy @ Cambridge and the University of Southampton's Sustainable Energy Research Group are developing. Smart meter options include radical changes to the user interface, smart phone apps and learning systems that provide control. A recent example of this is Nest, a home automation company designing sensor-driven and self-learning thermostats. It helps to optimise energy use, while taking into account users' preferences.

There are widely differing views on the role of controls and smart designs. These are areas where existing knowledge from ergonomics, human factors and human-computer interaction can be applied, along with emerging fields such as persuasive technologies and pervasive computing.

Improving understanding of how users control their environment

Successful control by users of their environment may be limited for the following reasons:

- most human-centred designs have concentrated on technological systems – there has been far less research into how to make the operation of components such as windows, doors, and floors more intuitive and energy-efficient
- user controls may provide too much focus on particular measurements and distort perceptions of how a building is performing, leading to the possibility that 'what doesn't get measured doesn't get done'
- buildings and technologies may be designed with incorrect assumptions about the homogeneity of people's physical and cognitive abilities[80], understanding of the systems with which they are interacting[81], daily routines[82] and individual preferences that do not reflect the reality of everyday life and the diversity of users
- in particular there is a need to extend and apply existing research into the use of controls by ageing and/or less able users. The work being carried out by

DESIGNERS AND ENGINEERS CAN ENCOURAGE THE ENTIRE SUPPLY CHAIN TO BECOME MORE ENERGY EFFICIENT

Rica[83 84] provides an example of how the involvement of older and disabled people in research and product testing can help to improve the usability of products.

Future research should focus on resolving these issues.

Efficiency must engage the whole design chain

Designers and engineers can encourage the entire supply chain to become more energy efficient. Specifications exist that require this behaviour of practitioners, for example, on embodied energy and carbon footprints. However, some approaches need more momentum to become second nature for designers. These include considering water use throughout the lifecycle of a building, whole-life systems and the cradle-to-cradle approach.

Building sites are a major generator of waste, and schemes such as Considerate Constructors and BRE's BeAware project aim to improve this through a more efficient use of materials and processes. Case studies from the Waste and Resource Action Programme (WRAP) demonstrate the benefits and waste savings achieved through the use of modern methods of construction[85]. However, the extent to which whole lifecycle methodologies and zero-waste strategies are integrated into the construction process is not fully known. The impact of design and construction on site wastage warrants more attention; for example, it may be possible to borrow principles such as 'just-in-time' from manufacturing, in order to improve efficiency of resource use. The broader pattern of waste disposal from construction sites also needs to be understood better; for example, the distance that waste materials travel for disposal.

Simple behavioural techniques have reduced waste during the construction of buildings. These include providing visual feedback on waste to construction managers and staff, setting site goals for diverting materials from landfill, and monetary rewards such as a share in the money saved from reducing material waste. These approaches have been shown to realise significant environmental and cost savings[86 87 88].

Towards more efficient water consumption

There seems to be less emphasis on reducing users' water consumption through incentives to change behaviour. This may be because most cities tend to focus on large-scale wastewater management strategies, for example, the treatment and re-use of water on the Olympics 2012 site. This may also reflect the relatively low value placed on water conservation in many Western countries.

Some practitioners have developed water measurement, feedback and management strategies that are also educational[89 90]. There are behavioural techniques that could be used to help occupants use less water within buildings. For example, attunement labels (which give information about a device's water usage) attached to showers have been shown to be effective in cutting water use in domestic settings[91]. These labels may be acting as prompts to users, or altering individuals' perceptions of the devices.

Demonstrating cognitive dissonance – where one's personal beliefs and actual behaviour are not aligned – has been shown to be effective at reducing household water usage[92].

Strengthening the feedback link between resource use and cost has also been shown to be a strong technique in water conservation. Examples include domestic water metering and taps that show users how much water they are using.

3.3 Tools and techniques – how things can change

Case studies 2 and 3 illustrate a range of research approaches to understanding energy use in domestic settings.

Case study 2 describes a collaborative project between the Department for Energy and Climate Change and academic centres to explore the feasibility of setting up an annual energy use survey, examining both social and technical drivers of energy use in

GOVERNMENT COULD MAKE PUBLIC BUILDINGS EXEMPLARS THAT ENCOURAGE PREFERRED BEHAVIOURS ON ENERGY, WATER AND WASTE

the home. This has the potential to provide a substantial evidence base upon which to base future policy and design interventions, alongside other current and future research.

In Case study 3, ethnographic research techniques are used to understand people's interactions with heating, lighting, appliances and energy monitors, and their understanding of energy. The research examines the contexts for energy use in everyday life, again focusing on thermal comfort, and provides evidence which can inform policy and design.

Case studies also illustrate how behaviour may be influenced in practice. Case studies 4 and 5 explore the use of visualisation of energy use and waste transportation, respectively, in order to influence people's understanding of and emotional response to their own behaviours, with the hope that visualisation will have a positive impact on people's behaviours. There is potential to identify new ways to influence behaviour, based on emerging research findings.

Given the complex interdependencies between policy interventions for the built environment and outcomes, tools are also needed to inform policy initiatives. Case study 6 describes a study of the unintended consequences of retrofitting existing housing to improve energy efficiency. This example illustrates the need for systems thinking and a multidisciplinary approach to policy-making.

There is a need for more research to strengthen the evidence base on the link between design of the built environment and stewardship of resources, as well as design guidance based on current understanding. Best practice examples would also support good design practice.

3.4 Conclusions and recommendations

Commercial responsibilities and opportunities

Organisations could be doing far more to promote sustainable behaviours in their buildings, through leadership and commitment to environment goals, and by encouraging and facilitating employees towards sustainable behaviours. For example, they could introduce staff training in the efficient operation of buildings and technologies, or update dress codes while changing heating practices. Both economic and cultural benefits can accrue to organisations as a result.

Feeding a better understanding of user behaviour into the design of products such as intelligent control systems can add to their market value. The Nest thermostat is an example of a product with a well-designed user interface that has had considerable business success. Investment into research for product development and sponsorship with reputational value should be encouraged.

Government actions

Government could make public buildings exemplars of design and engineering that encourage preferred behaviours on energy, water and waste. A trial programme, Energy-efficient Whitehall, was run under a Technology Strategy Board SBRI initiative in 2010[93]. Other programmes such as CarbonCulture[94] have opened up energy and water data for a number of government departments, local authorities, universities and public buildings and engaged staff in behaviour change[95 96].

Government can help by:

- sharing the data it owns on resource use in buildings and encouraging open public data
- consolidating and procuring against best practice
- procuring new projects using a whole-life cost approach
- using its estate to provide role models of sustainable practice

- making available the lessons learned from its experiences.

Researchers

There is much still to be understood about the effects of building design on behaviour and the stewardship of resources. This is an area where the interdependencies between interventions and behaviours are complex.

For example, if individuals adopt more sustainable behaviours in their energy use at home, to what extent does this spill over into their water and waste behaviours? What design initiatives might encourage such effects? Similarly, is there a link between behaviours at home and in other domains, such as at work and in the community?

Clearly, if such behaviours do exist, then this creates opportunities for policy and design initiatives that capitalise on these to create multiplier effects.

Therefore, the following is needed:

- a more in-depth understanding about people's attitudes to resource use in the home and workplace
- a better understanding of how people respond to alternative designs, for example, heating controls and systems of waste management
- a greater understanding of how design and other interventions can lead to unintended consequences, either positive or negative, and how systems thinking can address this.

A GREATER UNDERSTANDING OF HOW DESIGN CAN LEAD TO UNINTENDED CONSEQUENCES IS NEEDED

Central St Giles

CASE STUDY 2: UNDERSTANDING ENERGY IN AND FOR SOCIETY

Developing an evidence base to identify social and technical drivers of energy use

Dr Adam Cooper, Lecturer in Social Science and Public Policy, UCL

At the Department of Energy and Climate Change (DECC) the major sources of data in the department are characterised by their technical and economic slant, with units in GwH, KToEs, BTUs and £/MtCO_2e[97]. Policy documents look at how buildings, rather than people, should be warmed with low-carbon heat and become more efficient[98].

There has been a growing awareness that data about people and their behaviour is needed to understand how to reduce energy consumption and its CO_2 emissions[99]. Analytic innovations that seek to bring a more human element into the picture have invariably ended up more technically than socially focused[100 101].

Data collected in 1996[102 103] showed the basic but important relationship between household size and energy consumption. It showed that two people living as one household use 60% less energy than two people living as two households. When DECC published its *Energy follow-up survey*[104] in January 2014, the equivalent data supported the effect of household size[105].

This is important for two reasons. Firstly, with UK household size decreasing and overall population increasing, little attention is being paid to an important driver of energy demand. By not taking this into account, crucial risks and opportunities are overlooked. Secondly, the latest data are from nearly 20 years ago, demonstrating the paucity of data that helps shed light on what drives energy use in society.

This is why in *Developing DECC's evidence base*[106], DECC focused on the need to gather better data to understand the social and technical drivers for energy consumption. In 2014, a feasibility study[107] explored setting up a nationally representative, annual energy use survey. Importantly, socio-technical thinking is built into this study. This included understanding the implications of trying to sample the UK population of homes – as opposed to households or houses. It included an attempt to understand the implications for undertaking social surveys of the occupants with technical monitoring of the built fabric and technical heating features. The study was called 'LUKES' – a longitudinal UK energy survey.

Until very recently, the costs and practicalities of technical monitoring equipment and methodological barriers prevented progress. Now both those hurdles are close to being overcome, a new era is starting in understanding how best to manage energy for the good of society.

© Arup

A householder in Bethnal Green, East London, explains her strategy for pre-paying for gas

A householder tries out Powerchord, a prototype 'sonified' audio electricity monitor developed by the RCA

CASE STUDY 3: PEOPLE, ENERGY AND EVERYDAY LIFE

Uncovering behavioural design opportunities behind energy use patterns

Dr Dan Lockton, Helen Hamlyn Centre for Design, Royal College of Art and Flora Bowden, Sustain RCA, Royal College of Art

Reducing home energy use is a major societal challenge – involving behaviour change and technological improvements. Many policy approaches treat energy demand as something to be addressed through quantitative feedback and pricing changes, rather than basing interventions on an understanding of why people use energy as they do.

Households use energy differently – the UK's top 10% of gas users use four times as much as the bottom 10%. Yet quantitative modelling based on income and property characteristics explains less than 40% of the variation[108].

Understanding everyday practices could improve understanding of variation and address it through design. Integrating quantitative energy and environmental data with qualitative insights from ethnographic research could produce a more nuanced and inclusive design approach, reflecting the diversity of everyday experience.

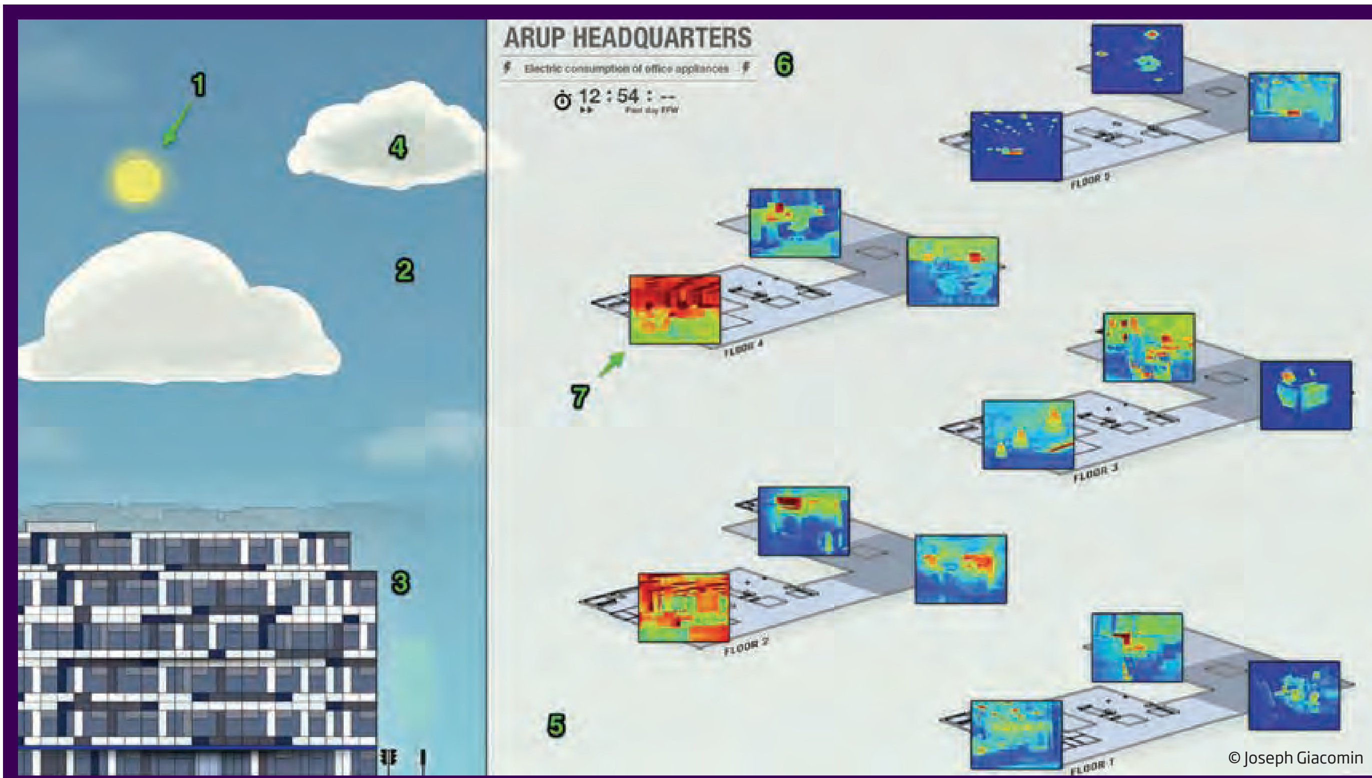
As part of the SusLabNWE project[109], UK researchers have carried out home visits, investigating people's daily interactions with heating, lighting, appliances, and energy monitors, and their understanding of energy, focusing on perceptions of thermal comfort. The aim is to develop a fuller picture of the contexts of energy use in everyday life. Householders have been involved alongside experts to create and explore interventions.

Findings so far confirm something that might seem obvious: people don't set out to use energy. Rather, they are solving everyday problems. They need comfort, light, food, cleaning and entertainment – and there are often emotional dimensions to this. This has consequences for the design of behaviour change interventions[110], and for policy areas such as smart metering and retrofit schemes.

From the wider perspective of design for behaviour change[111], this work confirms the importance of including ethnographic work with the public as part of any research process to understand everyday decision-making.

The research will create commercial implementation opportunities through the SusLabNWE project. Insights will also inform future work on design for behaviour change in the energy sector, a long-term goal being the reduction of energy use based on a better understanding of energy use, and wider research into enhancing public understanding of complex systems.

PEOPLE DON'T SET OUT TO USE ENERGY; RATHER, THEY ARE SOLVING EVERYDAY PROBLEMS



Energy Sixth Sense Display

CASE STUDY 4: ENERGY SIXTH SENSE DISPLAY

If you could see how much energy you were using, would it change your behaviour?

Joseph Giacomin, Human Centred Design Institute, Brunel University

One of the difficulties with cutting energy usage and carbon emissions is their invisibility. You cannot always see that energy is being used. This makes the reduction of energy consumption harder to tackle[112].

At Brunel University's Human Centred Design Institute (HCDI), several studies have measured emotional responses to visual representations of heat and energy use[113].

HCDI has also developed the Energy Sixth Sense Design approach for stimulating behavioural change by making energy use more visible. Its products, systems and services are designed so that their information, materials and interfaces show users their real-time energy consumption in an intuitive, perceptual way[114].

HCDI applied this in an installation at Arup's headquarters building in central London. Arup requested a digital display behind the reception desk, that revealed energy use. So an active floor plan was developed that showed the electricity usage of each zone of the building on a real-time basis.

A photographic survey of the building was carried out to capture easily identifiable images using a thermal camera[115 116]. These were manipulated to produce five versions of each, from a very cold scene of mostly blue to a very warm scene in which most objects appeared in yellow, orange or red. Each version represented a different level of electricity usage.

A floor plan of the building was designed that incorporated the scenes, and developed software to display one of the five thermal images for each zone based on its electricity usage. The scenes were updated every minute. Staff and visitors could see at a glance which zones were using the most electricity. So that people could see the building's 'energy circadian rhythm', the display included a clock that would pop up showing a complete 24-hour cycle.

The Energy Sixth Sense Display was trialled for a week, after which feedback was collected over the course of several days by means of a simple questionnaire. The data suggested that staff found the display interesting and that they did discuss the information with work colleagues to a degree.

While a long time trial of the system was not possible, the degree of stimulation achieved during the short trial would be expected to lead to some behavioural change over a period of 6 to 12 months based on first principles from sociology (discourse theory), marketing (conversational capital) and design (gamification).

Piles of trash

Tracking trash

CASE STUDY 5: TRASH TRACK

Revealing how far waste travels

Professor Carlo Ratti, Director of the SENSEable City Lab, MIT

One of the biggest problems with waste is its lack of visibility. After disposal, opaque bin bags enter a complex network travelling to locations unknown to most people. Local recycling systems have raised awareness, but where people's waste goes is not transparent and so not well understood. Could more exposure to waste influence individuals' behaviour?

Trash Track, designed by the SENSEable City Lab at MIT, used sensor technology to expose journeys for 2,000 items of rubbish from Seattle in the US. The journeys were mapped, visualised and exhibited to reconnect people with their rubbish.

Volunteers were invited to bring an item of rubbish to the Seattle Central Library for tagging. Researchers also visited volunteers' homes to attach tags. Each tag contained a GPS locator linked to a mobile phone network. Volunteers took the tagged rubbish for disposal as normal, the project team then collected real-time data on the trajectory of each item.

This data offered insight into patterns of waste transportation in the US[117]. For example, mean travelling distances for printer cartridges of 1,700km and for lithium batteries of 1,200km led to the conclusion that toxic waste travels the furthest. One plastic bag had a 58km journey.

Public engagement was integral to the programme. An artist generated a visualisation of the individual journeys of the rubbish. Maps, animations and videos were exhibited at the library for the volunteers and the public to view.

To help understand how to influence behaviours at a large scale, the project team wanted to find out whether helping to deploy the sensors altered the long-term attitudes of the volunteers. Statistical modelling indicated that, in this case, the activity did not produce significant changes in attitude or behaviours towards waste generation and disposal. Despite this, feedback from the study indicates that real-time data can engage citizens.

The lab is looking to change attitudes towards waste using the concept of the sentient city and by devising a platform to generate systems formulated entirely out of interactions between citizens.

LOCAL RECYCLING SYSTEMS HAVE RAISED AWARENESS, BUT WHERE PEOPLE'S WASTE GOES IS NOT WELL UNDERSTOOD. COULD MORE EXPOSURE TO WASTE INFLUENCE INDIVIDUALS' BEHAVIOUR?

CASE STUDY 6: THE UNINTENDED CONSEQUENCES OF RETROFITTING

Applying joined-up thinking to housing, energy and wellbeing

Professor Mike Davies, Director of the Institute of Environmental Design and Engineering, UCL

Improving the energy efficiency of existing homes is a key feature of current policy designed to meet the UK's ambitious greenhouse gas reduction targets. Mechanisms include the renewables obligation, the Green Deal, the Energy Company Obligation, feed-in tariffs, and the Renewable Heat Incentive]. However, the dynamic links that exist between buildings, human wellbeing, and societal and environmental impacts could hinder decarbonisation objectives by resulting in a range of unintended consequences. Unexpected benefits or negative effects may occur (or a combination of both), or an effect contrary to the original intention that makes the problem worse.

100 unintended consequences

Databases from disciplines including building physics, construction technology and practices, health and wellbeing and social sciences were investigated. Results found 1,600 potentially relevant studies. From these, more than 100 impacts were found to be unintended consequences of decarbonising housing stock, and many of these were linked in a complex dynamic way.

For example, when increasing air tightness, research showed that indoor air quality and respiratory health were adversely affected. However, some sources also showed wider adverse impacts on work and school sick days. Such impacts were traced back to the original intervention via causal mapping to explore the interdependency[118].

Integrated decision-making about housing, energy and wellbeing

The aim was investigate ways of supporting integrated decision-making so that co-benefits can be optimised and necessary trade-offs identified and made more explicit. A collaborative mapping and simulation method was used to explore the complex relationships between housing, energy and wellbeing, along with a tool to assess different policy options. National and local government, non-government organisations, construction and housing industries, and cross-disciplinary researchers were involved.

Conclusion

Systems thinking in this area is still emerging. However, this work confirms that a more integrated policy approach to the built environment is needed. The deep interconnections mean that policy objectives cannot be considered in isolation.

MORE THAN 100 IMPACTS WERE FOUND TO BE UNINTENDED CONSEQUENCES OF DECARBONISING HOUSING STOCK

4. Health and wellbeing

HEALTH AND WELLBEING ARE INTEGRAL COMPONENTS OF HAPPINESS AND HUMAN PERFORMANCE

This section explores the link between the built environment and behaviour in relation to health and wellbeing. Case studies 7, 8 and 9 provide examples of relevant tools and techniques and are presented at the end of this section.

4.1 What needs to change?

Health and wellbeing are integral components of happiness and human performance and should be essential drivers in shaping built environments. The workshops highlighted the potential of building design and architecture to:

- encourage good physical health
- reinforce mental health by making people feel at home, happy and secure in their environment
- make healthy choices easier and more fun
- strengthen social and cultural wellbeing and community connection
- support a sense of contribution to a thriving local economy.

There is potential to exploit better existing knowledge about the relationship between health and wellbeing and the built environment at building, neighbourhood and city scales, as well as obtaining new knowledge using novel techniques and approaches.

4.2 What is known?

Design can aid healing

When designing for health, key lessons are perhaps most easily understood in the acute care environment, where extensive research reviews exist[119]. Evidence underpins technical building specifications for healthcare environments[120] and other guidelines, such as those for health professionals in design, construction and operation of healthcare environments[121]. However, further evidence-based research is still needed – particularly because of the tight financial framework within which the NHS operates. If effective ways can be found to reduce the length of hospital stays or avoid patients returning to hospital, this will benefit both patients and healthcare providers.

The link between lighting and wellbeing has been explicitly considered. For example, the lighting company Philips looked at the effect of light in improving moods and experiences in hospitals. At an intensive care unit in Maastricht, Philips examined the potential of daylight to affect cortisol and melatonin production, and designed a lighting system that simulates the natural rhythms of daylight to enhance natural sleep patterns in patients. They also designed lighting in hospitals to help reduce parent and child anxiety, as outlined in Case study 7.

There are indications that recovery after surgery can be delayed by intrusive sounds such as the operation of noisy waste bins[122]. Researchers at the University of Warwick have examined the emotional and behavioural influence of hospital soundscapes – the auditory landscape of equipment, alerts, background sounds and people speaking – on patients' experience of

ACCIDENT AND EMERGENCY WAITING AREAS HAVE BEEN REDESIGNED TO REDUCE VIOLENT AND AGGRESSIVE BEHAVIOURS

their stay in hospital[123]. They have created a framework to evaluate these soundscapes as a way of helping people understand what is going on. This includes help for patients to understand the sources of the sounds they hear.

Both these examples demonstrate the important relationship between transient qualities, in this case sound and light, and patient recovery.

Other research into hospital settings has looked at spatial arrangement and its impact on health and behaviour. For example, Accident and Emergency waiting areas have been redesigned to reduce violent and aggressive behaviours[124], while redesigning mental health units can also have positive effects on patients[125].

There has been less research into the spaces that support people before and after delivery of care, such as when they are dealing with grief or coming to terms with a terminal illness. There are however best practice examples, such as Maggie's Centres[126], in which the architectural design reinforces the provision of practical, emotional and social support for cancer patients, their families and friends. Although rooms are provided in acute settings for these emotional needs, the effectiveness of the majority of these spaces in supporting people may be questionable.

There is limited research looking at the layouts of healthcare settings in the community, such as GP practices, although best practice examples exist[127].

Design can reduce the risk of accidents and help to control infection

There are some domains where there are well-established findings on the links between design and health and wellbeing. Three examples illustrate the point:

- there is available evidence and practical advice on how to reduce accidents in the form of slips, trips and falls in the built environment
- it is known that hospital design (for example in layouts and in ventilation) is a key element in controlling the spread of infection[128]
- the study of disasters, such as those at the Hillsborough Football Stadium, the King's Cross Underground Fire, the Bradford City Football Fire, Piper Alpha, and BP's Oil Platform Deepwater Horizon reveals that these all had infrastructural and technological design problems. However, they all also had managerial and organisational problems and so were genuinely systemic problems[129].

The built environment can promote exercise

Physical activity is central to a healthy lifestyle. At an individual level, there is a trend towards wearable smart health monitors, giving more data feedback on activity and exercise, particularly in the home and the workplace.

When planning buildings, designers and engineers should prioritise practical means to encourage users to be more mobile. Suggestive design, such as making the stairs more prominent than the lifts, can encourage activity and still make the building accessible to all. This could be achieved at the design stages of a building but also post-construction, as demonstrated by one study in Milton Keynes. Here, a series of installations, including a set of 'twinkling' lights embedded into the floor, were tested to see if they encouraged the building's users to take the stairs[130].

New York City's Active Design Guidelines provide an example of incorporating principles for encouraging active lifestyles. These were developed by a multidisciplinary team of health, planning, design, and architecture communities with input from academic institutions[131]. A number of Bills have been proposed to improve the visibility of and access to stairs in New York's buildings. The first has been passed and allows some stair doors to be held open by magnetic devices. A second Bill aims to ensure that all newly constructed buildings provide occupants with stairway access to all floors.

In the UK, the National Institute for Health and Care Excellence (NICE) has published guidance for the NHS and for professionals who have responsibility for the built or natural environment on how the design of the built environment can encourage physical activity[132].

SURVEILLANCE SYSTEMS COULD BE DESIGNED TO MINIMISE INTRUSION INTO THE LIVES OF LAW-ABIDING CITIZENS

Where you live can determine how you feel

Health inequalities need to be considered and addressed when planning and developing the built environment at the district level. This is a key objective of Public Health England, and the link between spatial planning and health is recognised explicitly in its strategy[133].

Districts served by the Jubilee Line in London offer an example of health inequality – from West to East, residents' life expectancy declines. Other research has plotted the life expectancy at each tube stop and had found results that further compound this issue – for example, between Lancaster Gate and Mile End, life expectancy decreases by 12 years. There are structural impediments to health, such as a shortage of affordable homes. In addition, the Marmot Review[134] highlighted the impact of social and economic inequalities relating to the built environment on health outcomes. Key factors include pollution, green/open space, transport, housing, community participation and social isolation.

The process of design and construction matters too

The consequences of design for health and welfare on construction sites are another important facet of holistic design. For example, the US-based International Living Future Organisation has created a 'red list' of construction materials that are harmful to health. The level of awareness in the industry of this issue, and how proactively it needs to be promulgated, should be considered further[135]. In the UK, there is a case for reviewing the impact of the Construction Design and Management (CDM) Regulations[136] on health.

Feeling secure matters as much as being secure

Feelings of security are important to wellbeing, but the impact of security interventions is not always straightforward to gauge. The visibility of security technologies may demonstrate that effort is being made to look after people but the social consequences are not always favourable – surveillance is an emotive subject. The trade-offs between having more security and the impact it can have on feelings of wellbeing has been explored by Anna Minton[137]. Confidence in the use of surveillance systems could improve with greater awareness of the extent to which they improve security. Surveillance systems could also be designed to minimise intrusion into the lives of law-abiding citizens, which would help to improve public acceptance[138].

New technologies will help to secure the built environment in the future. The use of physiological recognition will increase, along with the ability to recognise unusual or 'suspicious' actions, using techniques such as time-sequence parsing and agent-based crowd behaviour. The pervasive deployment of the 'internet of things'[139] brings significant benefits, but also cyber risks to society. RSA encryption, a cryptosystem for communications, may be used more widely, for example, to secure data transmission and fingerprint readers. Geographic information systems can be used to interpret intelligence information by combining data on the location of particular events and people with information on critical infrastructure, for example. A clear set of target outcomes, along with a demonstration of benefits, will help to optimise the way in which new technologies are applied.

Health in the home

Health and safety risks in the home, such as fire, carbon monoxide, radon and ladder use have had a considerable amount of attention.

The negative effects associated with poorly designed homes on children's development and on adults' overall happiness are understood. So is the link between wellbeing, the home and social equality[140].

Care for the infirm and the elderly in the home is receiving more attention, because of the need to reduce health and social care costs. There has been a shift from centralised institutional care for those with disabilities to independent living. From a design viewpoint, research has tended to focus on the special needs of the elderly and mentally ill, and of the design of care homes to support patients with dementia. Further research would improve understanding of how the built environment can support people living in the community[141].

The development of new portable IT-based technologies opens up opportunities

to support people with chronic health conditions in their own homes. Home-based telecare systems have the potential to improve care and reduce costs to the NHS by better monitoring, reducing frequency of clinic visits, reducing hospital admissions and giving patients more control over their own health.

Sustainable business models are needed that work for all the stakeholders. For example, should the industrial suppliers sell telecare equipment as capital items to the health services? Or should they lease and support the equipment and receive payment from the health services based on ongoing patient use? These issues would benefit from further exploration.

Health and wellbeing at neighbourhood and city scale

The links between the built environment and individuals' emotions and stress levels are currently a topic of research[142]. It is known that the physical environment in deprived neighbourhoods can have an effect on inhabitants' wellbeing[143]. It is also recognised that the built environment can promote good social relations, resulting in a positive impact on wellbeing; this was championed by Jane Jacobs in the 1960s and has continued through the notion of social capital. 'Lifetime neighbourhoods' and 'age-friendly cities' are concepts that embrace both the physical design and social dimensions of inclusive neighbourhoods for an ageing population[144 145].

There is a body of literature on the relationship between health and the built environment at neighbourhood and city scale[146 147]. Guidance for spatial planners also exists[148].

Space Syntax, a UK-based research group and consultancy, is using analytical tools to measure movement patterns through individual buildings and the city. Findings from these investigations are then applied to learn more about the relationship between the built environment and wellbeing[149].

There is an emerging interest in using neuroscience to understand the effects of the built environment on wellbeing[150]. Still a relatively new field, neuroarchitecture[151] may play an important part in discovering the best environments for promoting wellbeing. Organisations such as the US-based Academy of Neuroscience

HIGH QUALITY GREEN SPACE IN CITIES PROVIDES OPPORTUNITIES FOR PHYSICAL ACTIVITY

for Architecture[152] are exploring ways to develop an evidence-base that could provide the basis for neuroscientific design principles for buildings.

Notwithstanding, there is scope to increase the strength of the existing evidence base. More measurable experiments and analysis of the effects of the built environment on wellbeing at neighbourhood and city scale are needed.

Health outcomes interact with other outcomes

There are positive interactions between promoting health and wellbeing and ensuring environmental sustainability. For example, natural ventilation improves health and wellbeing by giving occupants a sense of control, while reducing the need for energy-intensive air conditioning. High quality green space in cities provides opportunities for physical activity, as well as regulating air quality and temperature, and reducing surface water run-off.

In some cases, negative interactions may be possible. For example, building regulations stipulate that buildings should be airtight with controlled ventilation to minimise energy loss. If, however, a building does not provide sufficient ventilation, this may lead to poor occupant performance or even to 'sick building syndrome' where building occupants experience adverse health and comfort effects that appear to be linked to time spent in a building, but no specific cause can be found. In this case, the need to reduce energy use must be balanced with the need to provide healthy and productive environments. Case study 10 describes research that shows the link between classroom ventilation in schools and pupil performance. This evidence may be used in design to ensure that ventilation rates are sufficient to support the performance of pupils in schools.

4.3 Tools and techniques – how can things change?

Stakeholder involvement in the design of healthcare settings is an important part of achieving high-quality design that promotes health and wellbeing, along with evidence-based practical assessment tools. Case studies 7, 8 and 9 illustrate different approaches and tools used to involve stakeholders in an evidence-based design process.

Case study 7 explores Philips' approach to the design of a hospital building. Philips examined the experience of clinicians and patients in the Emergency Department of Florida Hospital in the US. They used tools to capture the needs and values of stakeholders, and communicated their design using narrative, hand sketches and 3D spatial models. The tools allowed the requirements of patients and staff to be balanced, resulting in both a less stressful environment for patients and a facility that aids staff efficiency.

Case study 8 describes an evidence-based approach to the design of care environments for people with dementia. UK health think tank The Kings Fund developed and applied a suite of evidence-based, practical assessment tools that allow people with dementia, carers and staff to identify how care environments can be improved. The tool has helped to achieve better care environments, resulting in greater wellbeing for both staff and patients.

An evidence-based approach to the refurbishment of cancer care environments is described in Case study 9. Macmillan Cancer Support has developed an initiative to assess patients' experiences in cancer care facilities and to apply objective criteria to inform the upgrade of and subsequently score care environments. Patient satisfaction was found to be greatest in care environments with high scores.

4.4 Conclusions and recommendations

Government actions

The Centre for Active Design in New York serves as a good example of how local government can collaborate with planners, architects and members of the local community to ensure that the design of buildings encourages physical activity. Their success in passing a number of Bills to ensure buildings are designed to promote healthy environments is something worthy of consideration in the UK.

In its strategy[153], Public Health England recognises the importance of place-based approaches, led by local authorities, to improve public health. This is an important way of ensuring that public health is improved through the positive use of spatial planning.

Government should promote collaboration between clinical commissioning groups, designers and other stakeholders, to ensure that the potential to achieve positive health and wellbeing outcomes is addressed explicitly during design and construction, or refurbishment of healthcare buildings.

Researchers and practitioners

Researchers and practitioners need to work together to ensure that the available knowledge is put into practice using evidence-based design principles and guidance. Researchers and practitioners could also collaborate on post-occupancy evaluation to extend understanding of the links between health and wellbeing and the built environment[154].

Designers and researchers should also find ways to influence and collaborate with clinical commissioning groups, local authorities and other organisations concerned with health and wellbeing.

Ensuring that quality of life and wellbeing is maximised through housing and community design is key, especially given the challenge of an ageing population. The impact of this on alleviating pressures on the NHS is still unclear; more evidence based on cost-benefit analysis would help to quantify the impact.

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CASE STUDY 7: IMPROVING THE EMERGENCY EXPERIENCE FOR CHILDREN

A collaborative, user-centred approach to healthcare design

Jos Stuyfzand, Director of Ambient Experience Design, Philips Design

In the US, the Emergency Department (ED) is often the first place that people experience a health system. It is no surprise that the environment plays an important role in patients' anxiety levels. A more comfortable, engaging environment, with positive distractions, would help patients and families to cope better with the stress.

Florida Hospital asked Philips to use their design expertise, technology integration capabilities and patient-centric approach to redesign its paediatric ED. The goal was to create a less stressful and less intimidating environment for young patients and their families undergoing emergency care. The challenge was to balance the patient experience with the needs of clinical staff, who must be able to do their jobs successfully during an emergency.

Reaching a solution

A team of researchers and designers went inside the ED to find out first-hand how the department works and how patients experience it. The team used tools that capture the needs, values and mindset of everyone involved in the care process. The opportunities that arose were explored in collaborative sessions with the clinical teams, project architects and hospital management.

An 'ideal experience journey' from arrival to departure was described using narrative, hand sketches and 3D spatial models of potential solutions. The solution included dynamic illumination at the entrance to the department, indirect lighting in corridors, comfortable waiting areas with interactive play walls, and the ability for children and families to personalise their private emergency room by choosing digitally programmed atmospheric themes.

The reorganised spaces are also more efficient for the clinical staff. The layout includes enhanced lighting around centralised nurse stations and triage rooms. Florida Hospital saw faster process times and increased satisfaction[155]. The ED was ranked as the best paediatric ED in the country for patient satisfaction[156].

Conclusion

The key to creating positive healthcare experiences lies in gathering deeper insights about the end users. It involves thinking carefully about their whole experience. It means employing a collaborative design process and making coordinated and conscious design and engineering choices about architecture, technologies and processes.

A MORE COMFORTABLE, ENGAGING ENVIRONMENT WOULD HELP PATIENTS TO COPE BETTER WITH STRESS

Flower pictures help patients find their beds

CASE STUDY 8: SMALL DESIGN CHANGES CAN MAKE A BIG DIFFERENCE TO PEOPLE WITH DEMENTIA

Evidence-based, practical assessment tools for improving care environments

Sarah Waller CBE, Programme Director, Enhancing the Healing Environment, The King's Fund

At least 25% of people currently accessing acute hospital services, and 80% of those in care homes, are likely to have dementia. Hospital stays are known to have detrimental effects on people with dementia, and poorly designed care environments can lead to further impairment. Relatively inexpensive changes to the care environment can have a considerable impact on wellbeing.

The King's Fund developed principles through a Department of Health funded programme for more supportive design for people with dementia. Initial visits to project sites showed that, even in relatively new buildings, it was common to find poor signage and few cues to aid wayfinding, poor lighting, shiny floor surfaces, clutter, unwelcoming spaces, little personalisation of bedrooms and underused gardens.

A small, local, clinically led multidisciplinary team including carers developed each project site to improve the space. The schemes have involved decluttering, maximising natural light and improved lighting, laying matt flooring and improving wayfinding using colour and contrast, art and better signage. Large nurses' stations have been removed and staff now work in bed bays. This has made staff more visible and led to a reduction in the use of call bells. Creating social spaces and better access to gardens has improved general wellbeing as well as providing activity.

Estates colleagues report that incorporating these design principles has proved better value for money and improved sustainability. The completed schemes have shown impressive results, including an improved care experience, reductions in falls, reductions in incidents of aggressive and disruptive behaviours, increases in non-pharmacological approaches, and improved staff morale, engagement, recruitment and retention.

As part of this programme, a suite of evidence-based, practical assessment tools for care environments has been developed. They take a service user-led approach so that people with dementia, carers and staff can undertake the assessments together. In use nationally and internationally, the tools have been evaluated very positively and have helped secure increased funding for environmental changes[157].

HOSPITAL STAYS ARE KNOWN TO HAVE DETRIMENTAL EFFECTS ON PEOPLE WITH DEMENTIA

CASE STUDY 9: THE MACMILLAN QUALITY ENVIRONMENT MARK

Examining the relationship between cancer environments and patient wellbeing

Ed Gardiner, Behavioural Design Lead, Warwick Business School and Kelly Ann Schmidtke, Research Fellow, Warwick Business School

There is now significant evidence that the environment in which care is delivered can affect patient wellbeing and staff performance, and contribute to better clinical outcomes.

This is why Macmillan Cancer Support created a range of programmes for facilities to aspire to. Perhaps their most developed programme aims to assess the quality of patients' experiences in their facilities, as well as providing a framework to assess the quality of facilities. Named the Macmillan Quality Environment Mark (MQEM), it is informed by empirical research, provides a quantitative tool with which to compare facilities, and offers objective criteria to upgrade them. It is both an evaluative tool and a quality improvement tool, as well as means of recognising quality.

MQEM v2 contains 87 empirically supported items with informative five-point scoring scales. One example is: "All rooms or spaces used by people using the facility, or by staff for prolonged periods, have access to natural light."

Top-scoring facilities have natural lighting in every room; lower-scoring facilities have less natural lighting and poor artificial lighting. Stakeholders can easily compare different facilities and use objective criteria to increase a facility's score.

MQEM v2 is divided into four domains: design and use of physical space, user's journey, service experience and user's voice. Each contains five core principles: accessibility, privacy and dignity, comfort and wellbeing, choice and control, and support. Separating out the domains helps facilities identify the areas in most need of improvement.

Warwick Business School worked with Macmillan to support this programme by assessing the statistical and discriminate validity of the MQEM and its domains.

A patient experience survey was created and implemented at 12 Macmillan facilities. Patients' reports were then correlated with the facilities' MQEM scores. Encouragingly, the results support the MQEM's discriminate validity – those facilities that received the MQEM award had the highest patient satisfaction.

It was suggested that Macmillan could try to further improve the independence of each domain. These findings, along with ongoing data collection, will help Macmillan to refine the tool further.

Royal Derby Hospital

TO ACHIEVE BETTER BUSINESS PERFORMANCE, WORKPLACE DESIGN COULD BENEFIT FROM APPLYING A MORE DETAILED UNDERSTANDING OF BEHAVIOURAL ISSUES

5. Performance and productivity

IT HAS BEEN ESTIMATED THAT WELL-DESIGNED OFFICES CAN ENHANCE PRODUCTIVITY BY AS MUCH AS 20%

This section introduces the link between the design of the built environment and the performance and productivity of its occupants. Case studies 10, 11, 12 and 13 provide examples of relevant research, tools and techniques and are presented at the end of this section.

5.1 What needs to change?

Workspace design can enhance performance and productivity by influencing the retention, motivation and satisfaction of staff, creating better customer relations and improving the efficiency and effectiveness of work processes[158]. This is true of offices, but also hospitals, schools, factories and other types of workspace.

In order to achieve better business performance, workplace design could benefit from applying a more detailed understanding of the relationship between design and behaviour into the design process. The involvement of all the various stakeholders also provides the potential for the building to reflect better the activities and philosophy of the building clients and users.

Better and more predictable outcomes could be achieved if workspace designers took a systems view. This would involve working closely with the client and behavioural specialists, and using shared tools to look at desired behavioural outcomes and design interventions.

5.2 What is known?

It has been estimated that well-designed offices can enhance productivity by as much as 20%[159]. Amoco Oil and Gas redesigned office spaces to incorporate open-plan working and to support and embed teamwork[160]. In addition to lower workspace costs, these changes resulted in a 25% decrease in project cycle times, a 75% decrease in time spent in formal meetings and increases in learning, problem-solving and product quality.

Historically, human factors specialists and ergonomists studying the impact of the work environment on performance have focused on lighting, temperature, furniture and equipment design, physical layouts, and the design of controls, ventilation and noise. These topics have the advantage that they can be studied in laboratory conditions. It is clear that these can have a substantial direct impact on human performance. Case study 10 illustrates a study on the link between classroom ventilation and pupil performance, which could be applied to the design and operation of school buildings.

Examples also exist where design has explicitly sought to influence behaviour. For example, dynamic lighting at Schiphol airport was used to make passengers move more quickly to boarding gates.

In the following sections, key findings from work on the design of offices, manufacturing environments and hospitals are discussed.

THE DOMINANT LONG-TERM TREND IN OFFICE DESIGN HAS BEEN TOWARDS OPEN-PLAN DESIGN

Office design – there is no single solution

The drivers for creating well-designed offices are varied. They include productivity, creativity, wellbeing and contentment, stimulation and the ability to focus or concentrate. One office form may not satisfy all of these requirements, but reconfigurability can help. Complex trade-offs may also be needed[161].

The dominant long-term trend in office design has been towards open-plan environments. By the turn of the century, around 70% of office workers worldwide occupied some form of open-plan office. The rationale is straightforward and well-rehearsed – such designs have the potential to increase overall productivity because they:

- use less space and so cost less to buy, rent and maintain
- are easier to reconfigure when circumstances change
- promote interaction and communication between employees
- promote certain styles of working, such as teamwork, which can improve performance
- may have a symbolic value, such as at BMW where the visible flow of cars through the factory helps to reinforce the purpose of the workplace.

However, this is only part of the picture. There are also disadvantages to open-plan office designs. Under certain circumstances, they can have a negative impact on human performance. For example, they can:

- reduce privacy and inhibit confidential conversations
- increase unwanted interruptions and uncontrolled interactions, and these can create stress and distractions, and reduce concentration
- be noisy environments and this can also reduce concentration and/ or increase the effort required to maintain performance
- alienate staff if they feel they are being badly treated.

These effects can vary by job level (for example, managers are more likely to report that they need privacy) and by job type. Certain jobs demand high levels of concentration – design engineers making critical safety calculations, for example.

The trend towards open-plan working is itself more complex than it may first appear[162]. The nature of work is changing, with more people sharing work remotely and across time zones, enabled in part by new technologies.

Developed economies cannot compete internationally at low-skill, low-cost work. So they need to engage in high-skill work, which typically involves more creativity and innovation. This creates a need for workspaces that foster creativity, and this often means more social and interactive spaces to improve spontaneous communication and stimulate ideas. From this point of view, productivity requires creativity and this requires certain kinds of interactive environments.

Organisations and employees have been experimenting with a whole range of workspace designs, including hot-desking, solo quiet spaces, social spaces and breakout areas for group work, video-conference rooms, satellite offices, social hubs (including cafes), internal streets, and homeworking/teleworking. This is a dynamic and rapidly evolving domain. It reflects changes in work patterns: work is less static than in the past, with many employees spending significant amounts of their time working away from their main desk and engaged in interactive or collaborative work.

There is therefore a need for a range of workspaces that people are empowered to use as and when they are needed. This may well be in direct conflict with an organisational drive to increase occupation density and 'work the available space harder'.

An international, multi-sector study of 40 organisations[163] found that around 90% of the sample was using what they termed 'distributed work programs'. These are characterised by high-density individual spaces, coupled with a wider variety of individual and group settings, collaborative spaces and less emphasis on large formal meeting areas.

PRODUCTIVITY IS ENHANCED WHEN PHYSICAL AND ORGANISATIONAL DESIGN WORK TOGETHER

Design influences productivity in manufacturing

For manufacturing environments, there is a clear link between design and productivity. In manufacturing, the trend has been towards 'lean thinking' and eliminating waste, driven in part by the success of Japanese companies such as Toyota. Good factory design helps reduce wasted movements and journeys, provides easy access to facilities and materials, and helps make problems visible. Good design is one of the central tenets of a productive factory.

Another key point became clear in the workshops for this study: physical design should be tightly coupled to organisational design and productivity is enhanced where the two work together.

There is evidence that empowerment and teamwork are key predictors of productivity in manufacturing companies[164]. The physical environment also contributes to productivity. For example, there has been a consistent trend towards treating production and packing as a single process, and the same for assembly and testing. These are supported by new physical layouts, in combination with teamwork and managerial structures, as are continuous end-to-end processes.

The benefits of a systems design approach are evident here. For example, a confectionery factory achieved a 25% increase in productivity through a series of changes involving:

- a new physical layout (taking down the wall between production and packing)
- teamwork (incorporating both production and packing)
- a new target and feedback system.

The redesign of the physical environment enabled and promoted a set of new organisational designs, which combined to improve productivity[165].

Hospital design can influence performance goals as well as patient health

Hospital design can also influence the productivity and performance of its management operations, as well as affecting patient wellbeing. Performance goals may include faster recovery rates for patients and improved patient satisfaction. For staff, reduced stress and fatigue, combined with improved concentration and accuracy, can lead to better motivation, satisfaction and retention of staff.

Evidence to date has established that:

- the physical design of healthcare facilities has an impact on both staff and patients[166]
- a ward layout that allows good lines of sight between patients and carers promotes easier and better care, and is thereby more productive
- a good ward layout reduces wasted time, for example, by allowing easier access to equipment and facilities
- the ward layout affects the ability of nurses to observe and monitor their patients[167]
- good lighting at workstations can reduce medication errors
- good layouts promote the interactions and communications needed between staff, patients and their carers – whether at workstations or at the bedside
- quieter wards are associated with faster patient recovery and the use of fewer analgesic drugs[168]
- patients who have access to a view of outdoors recover more quickly than those without[169]
- involving staff in the redesign of their wards has positive effects for both staff and patients.

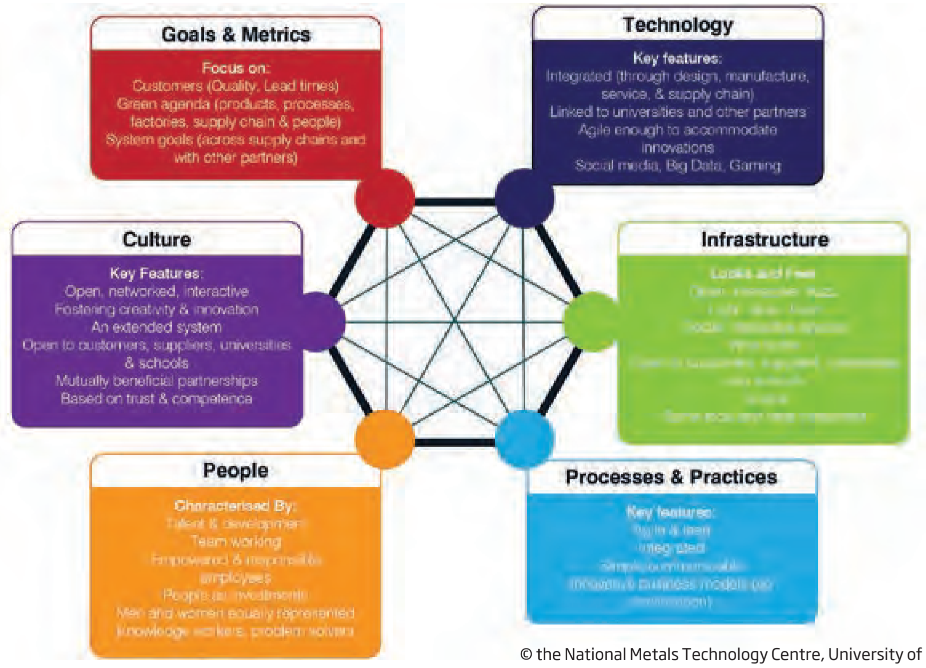
Change needs to be managed

One view is that the design of workspaces is an example of organisational change, and that lessons learned from 'change management' can usefully be applied here. Such lessons include the need for:

- user engagement in the change process
- management leadership to help drive a change programme
- education and training in what to expect and how the new system will work
- clear goals and metrics so everyone understands where they are headed and why

Figure 5.1: Characteristics of The Factory of the Future[171]

Image from *The Factory of the Future* report, commissioned by the UK Government's Foresight Future of Manufacturing Project



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- evaluation over time so that energy can be maintained and people can learn as they go
- clear communications throughout the change process.

Good design supports a brand

The design of the workspace can be part of the branding of the company which can be used to attract and retain staff and to communicate the brand to customers and clients. Small, high-tech start-up companies often exemplify this approach, but it is not new. For example, in the 1960s, advertising agencies and retail outlets made deliberate efforts to break the mould of traditional workspace design.

THE DESIGN OF THE WORKSPACE CAN BE PART OF THE BRANDING OF THE COMPANY WHICH CAN BE USED TO ATTRACT AND RETAIN STAFF

The expectations and aspirations of younger people may well be different from those of the baby boomer generation. Modern workspaces that are open, flexible, and informal will be more likely to attract and retain younger members of staff than workspaces that feel hierarchical.

Design can lead research

Another key point emerged in the workshops – new facilities are evolving rapidly and there is a limited research base for architects, facilities managers and their clients to draw on. Many organisations are 'just doing it' and designers may well be running ahead of the evidence. This is not an area driven by a strong and readily accessible research base. Section 6.2 identifies some of the key research which would enable this area to move forward.

A systems approach as synthesis

It is clear that physical design matters, but in large part this plays out through its interaction with other systemic features.

This systemic approach is exemplified in work by Ridgway, Clegg and Williams[170] on the design of the factory 20+ years from now, undertaken for the UK Department for Business, Innovation and Skills (see figure 5.1 and Case study 11).

In this view, the factory of the future will have goals and metrics focused on meeting the needs of customers and a wider sustainability agenda. The factory works closely with the supply chain and has partnership agreements with local universities and schools, between which there is a sustained flow of people, projects and ideas. The open culture emphasises creativity and innovation, rather than command and control.

Technologies support this. They are integrated through design, manufacture, service and supply, promoting and enabling interaction between the various partners. Social media and big data are used routinely. The organisation and culture are agile enough to accommodate disruptive technologies as and when they become available.

People are talented and have continuing opportunities for development, working in integrated teams that are empowered and responsible. These are knowledge workers and problem-solvers. People may start apprenticeships in their 40s and 50s with plenty to offer and plenty to learn. Men and women are equally represented at all levels.

Processes and practices are agile, cutting through internal and external silos. The systems are simple to communicate and understand. The factory and wider system employ innovative business models (such as servitisation). This is a complex socio-technical system, in which the built environment plays a significant role. All this is supported by the open and welcoming physical environment. It is clean and fresh. It has a 'wow' factor that attracts people to join. In general, these factories are small and near their customers.

In this view, productivity and performance arise from well-designed socio-technical systems in which the design of the physical infrastructure plays a key role.

5.3 Tools and techniques – how things can change

The design process would benefit from tools to help collect and frame specifications for operational performance and facilitate the involvement of stakeholders during the design process. The evolving design of the building may be tested and tuned by stakeholders working in collaboration with the building designers.

Case study 11 illustrates the application of the socio-technical approach represented in Figure 5.1 to the design of the Rolls-Royce Factory of the Future, created for the Advanced Manufacturing Research Centre. Specialist behavioural knowledge was brought to bear during the design process: occupational psychologists worked with stakeholders in a collaborative process, which identified human and organisational issues. This approach has resulted in a facility with high performance levels and high staff satisfaction.

OCCUPATIONAL PSYCHOLOGISTS WORKED WITH STAKEHOLDERS IN A COLLABORATIVE PROCESS

A similar socio-technical approach was applied to the design of a school building in Lancashire, which is described in Case study 12. A socio-technical systems model was used to structure a workshop for students, teachers and administrators. As a result of this approach, the design brief is focused on the needs of stakeholders. The case study identifies the potential for further psychological methodologies to be integrated into the approach to develop a more detailed, holistic view of user needs.

In Case study 13, a collaborative design approach is illustrated for a community project in Aberdeen. Both adults and children were involved in deciding improvements to a community area. The participation of children has been positive resulting in a well-used facility and the area's reputation for safety has been improved.

5.4 Conclusions and recommendations

Accepting that the built environment is simply one part of a complex system for delivering services to customers, it follows that:

- system design is a multidisciplinary endeavour that requires strong end-user engagement (and user pull)
- changing the physical layout without changing other features of the organisation will not achieve the best results – in the same way that new technology alone rarely improves productivity. This is a particular risk when investing heavily in technical support systems in buildings (including smart controls)
- research evidence is lagging behind practice and, despite the risks, many organisations are implementing new designs without a strong and readily accessible evidence base. Evidence of what works for individual organisations is not shared as widely as it could be. A key initial change might be to establish a pool of best practice, curated by a neutral professional body
- organisational and behavioural requirements need to be included in the architectural brief right from the beginning – it is hard to fit new ways of working into a physical infrastructure that was not designed for them at the outset.

Ultimately, the performance and wellbeing outcomes of particular designs should be assessed by means of post-occupancy evaluation to provide detailed evidence on how successful designs are in supporting business objectives. Evaluation would be most beneficial throughout the lifecycle, and not just at the end of the project.

CASE STUDY 10: CLASSROOM VENTILATION AND PUPIL PERFORMANCE

Can changes to ventilation improve levels of attention in pupils?

Derek Clements Croome, University of Reading

Previous productivity studies have highlighted the impact of ventilation and evidence of 'sick building syndrome'[172]. Fresh air has been shown to increase wellbeing and productivity. However, the push for energy efficiency and airtight buildings typically overlooks these findings.

The impact of ventilation rates on pupil performance was researched at the University of Reading using a multidisciplinary team that included psychologists. From 2006–2009, they studied classrooms in eight different primary schools near Reading, all of which were 20 to 40 years old.

The research team found that, with a higher rate of ventilation, the pupils gave faster and more accurate responses, reflecting higher levels of focused attention.

School design needs to focus on teacher and pupil behaviour in learning, so the impact of energy conservation through low ventilation rates represents a threat. This is exacerbated by uncertainty over patterns of use of mechanical or passive ventilation systems by teachers and school management.

This work highlights the need for design standards to take account of potential false economies in energy management. Researchers continue to explore how much air is optimal – not only for children's educational performance, but also for their wellbeing.

WITH A HIGHER RATE OF VENTILATION, PUPILS GAVE FASTER AND MORE ACCURATE RESPONSES

CASE STUDY 11: FACTORY OF THE FUTURE

Involving organisational psychologists in the design of a new manufacturing research facility

Professor Chris Clegg, Director of the Socio-Technical Centre, Leeds University

The Rolls-Royce Factory of the Future[173] is a £15 million research and development facility created for the Advanced Manufacturing Research Centre (AMRC). This is a partnership between Boeing and the University of Sheffield's Faculty of Engineering.

The vision was to create an environment in which research, design and manufacturing can interact to showcase best practice and transfer knowledge meaningfully. It was not designed solely to deploy and test new machining capabilities but rather to promote innovation and creativity. This underlined the need for a factory design that promotes social interactions.

Organisational psychologists worked with AMRC staff – as well as industrial partner representatives, architects, and engineers – to identify the human and organisational issues that are often overlooked in the design process.

The psychologists helped facilitate several events to gain insight into stakeholder and staff requirements, the organisational vision, and the structure and working practices of the future for the new building. Participants were asked to examine different scenarios. Additional stages included defining the working culture, layouts of office and shop floor areas, key social spaces, and also ensuring the overall design was energy-efficient and sustainable. The outcomes of the workshops formed the initial brief for the tendering architects.

Post-occupancy evaluations described the workspace as bright, modern, and flexible and as an environment that allows innovation and collaboration to thrive. It has been praised by staff, management, and industrial partners as supportive of their work and showcased by Boeing and Rolls-Royce as an example of design excellence. The workspace also resulted in performance improvements with productivity levels significantly better than mainstream manufacturing.

The successes of this process have been attributed to the socio-technical and participative design approach. This identified key requirements and also ensured that design aspects of particular importance to stakeholders and staff were not engineered out to reduce costs.

The process resulted in a workspace that caters for the diverse range of tasks AMRC staff undertake. The involvement of staff has helped to strengthen their sense of identity and commitment to the AMRC.

CASE STUDY 12: A SOCIO-TECHNICAL APPROACH TO THE DESIGN OF LANCASTER ROYAL GRAMMAR SCHOOL

Successful brief-taking is a critical first step in designing buildings that work for occupants

Ann Marie Aguilar, Associate Director, Arup Associates

In 2009 Arup Associates teamed up with Arup's organisational psychologists to trial a new approach to architectural brief-taking. The team applied the Socio Technical Systems (STS) model developed by Professor Chris Clegg (Figure 2.1 in Section 2.3). This considers the workplace as a system of interrelated elements. It not only includes all the factors to consider when designing a new workplace; it shows the links between the various parts of the system.

The model was used to structure a workshop for pupils, teachers and administrators. Using a series of key questions to encourage focused discussion, the team elicited key information. This informed the design from users' perspectives in relation to each of the six elements of the model.

From this, a vision for the project emerged; "We want to be a world-class educational establishment – the next-generation learning facility". Some participants wanted to share the building with the community and invite people in. Participants wanted an environmentally sustainable building. In addition, they thought the school should operate on a system of mutual respect between staff and students.

Students thought that the new school building should feel like a home away from home. They also wanted a distinction between formal teaching spaces and informal relaxing spaces. Teaching staff communicated that they need more meeting space, such as a common room and additional meeting rooms.

The socio-technical system model emerged as a useful way of structuring and organising the workshop, focusing discussions and outputs. It was also apparent that this structure did not constrain discussion of the pertinent issues. This process delivered a more human-centred brief for the building – one that speaks to the users about a journey that begins with their voices being heard.

Further value would be gained from demonstrating how other psychological methodologies could be integrated into the approach to develop a more detailed, holistic view of user needs.

View from the rear wall of the Printfield Project Office in Aberdeen

CASE STUDY 13: PRINTFIELD COMMUNITY PROJECT

Design and behaviour change – co-producing the physical environment

Aksel Ersoy, Postdoctoral Researcher, University of Bristol

This case study, based in Aberdeen, highlights the importance of co-production in changing local environments and in influencing wellbeing. Possible forms of co-production for the local environment and community safety in Aberdeen were researched. The research also explored the extent to which individualistic engagement activities would form collective actions.

As part of a wider survey,[174] local organisations were interviewed. One was Printfield Community Project, which runs education, entertainment, life-skills training, healthcare advice and counselling for the local community. The organisation encourages creative activities in the area that are tailored for teenagers and children, demonstrating how everybody, irrespective of age, can be part of co-production.

A survey of 689 respondents found that:

- 97% believed that they can make a positive difference in their area
- 79% have never been involved in any group or association aimed at improvements in their area
- 37% expressed interest in doing so.

Some 60% of teenagers in Aberdeen were interested in a few hours of voluntary work each month to improve their environment.

Jim Duncan, a family development worker, initiated moves to brighten up the local environment in Printfield and stated that "a safe, stimulating but challenging environment is crucial to outdoor play". Children were asked what designs they would like to see in their surroundings. A community artist was commissioned to support these children to paint a wall facing the play area and communal courtyard. In addition, a small prefab, used by teenagers to spend time playing drums, pool or engaging in creative activities, was enhanced.

This unit rapidly became a meeting point and a hub for teenagers to socialise. Children's participation in the local environment in Printfield has been very positive overall and there has been a clear improvement in the area's reputation for safety.

Across the world, children's involvement in developing their environment is being promoted (for example by the UNESCO *Growing Up in Cities*[175] project). Such activities not only embrace partnerships with organisations and groups to create sustainable and inclusive learning opportunities, but also encourage children to realise their potential and open up to creative thinking with the help of arts and crafts. Printfield has taken these opportunities.

6. Lessons for behaviour and the built environment

This section makes recommendations to guide design and engineering practitioners, building users and other stakeholders, researchers and policymakers.

6.1 Design practice

6.1.1 Principles for design practice

Based on the workshops and case studies, a set of practical principles for design has been developed. The purpose of these principles is to help stakeholders consider, discuss and address key behavioural issues when designing and engineering the built environment to promote behaviours that will improve sustainability (in energy, water and waste), health and wellbeing, and performance and productivity.

The principles are intended for use throughout the full lifecycle of a project – from before the architectural brief through to post-occupancy and use. Users of the principles are likely to include designers, architects, engineers, behavioural scientists, building sponsors and owners, and building users.

These design principles are a first step towards putting into practice behavioural knowledge for the built environment. Further work is needed to enrich them with guidance and best practice examples, to explore their universality across scales and sectors, and to investigate how built environment design and other interventions work best together.

DESIGN PRINCIPLES ARE A FIRST STEP TOWARDS PUTTING INTO PRACTICE BEHAVIOURAL KNOWLEDGE FOR THE BUILT ENVIRONMENT

Design practice would benefit from education and training on the interaction between design and behaviour, for tools that enable designers to consider the impact of their design decisions, and for post-occupancy evaluation to test whether design intentions and other interventions work in practice.

Joined-up thinking and working across disciplines and organisations should play a key role in achieving this.

Design principles

Eight interconnected principles are proposed:

1. **View human behaviour in the built environment as a complex socio-technical system**. Design is a multidisciplinary activity. It involves interactions between the users, the physical infrastructure, the tools and technologies they use, the goals of the system, the processes and practices in place and the prevailing culture.
2. **Use collaborative methods and tools to involve all key stakeholders, especially end users, throughout the design process** see Case study 13.
   - continuous user engagement through the lifecycle is key to effective design
   - design should draw on powerful design traditions from the field of human factors, such as human-centred, socio-technical and inclusive design. These approaches focus on human behaviours, needs and capabilities. They have been widely used in successful product and service design (by Alessi, Amazon and Apple among others)
   - other useful methods and tools include prototypes, mock-ups, walk-throughs, simulations, scenario-planning, and risk analysis

DURING DESIGN, EXPLICITLY CONSIDER KEY CHARACTERISTICS OF ALL USERS, INCLUDING THEIR HABITS, GOALS AND PREFERENCES

- with personal smart devices and big data, there is potential to understand actual behaviours in the built environment such as movement patterns, social networks and emotional responses, which can be harnessed to understand and evaluate building use.

3. **Include behavioural issues from the very beginning of the design process, in particular making the behavioural assumptions explicit at the outset** see Case study 12. Behavioural requirements cannot be designed-in late in the process and attempts to do so can be very costly.
   - specify the behavioural outcomes you are pursuing and your underlying behavioural assumptions, along with the behavioural impacts of the design
   - where there is uncertainty, test alternatives – gathering evidence using prototypes, mock-ups, walk-throughs, simulation, experiments or existing data. Use an evidence-based approach and where there is a lack of evidence, make this explicit
   - undertake a risk analysis to consider and evaluate unintended consequences of key design choices. By definition, these are difficult to identify and address, but they should be considered see Case study 6
   - undertake rigorous evaluation of behavioural issues at every stage of the design process, including during post-occupancy evaluation.

4. **During design, explicitly consider key characteristics of all users**, including their habits, goals and preferences, along with any variations in capabilities, needs and aspirations.
   - remember that habits are very powerful and that a great deal of human activity is undertaken on autopilot
   - specify how the design will support users in pursuing their different goals
   - use generic human preferences where possible
   - remember that aspects of a system will have significant meanings for the users – these need to be understood and catered for
   - users of buildings will vary in their capabilities, needs and aspirations – for example, older users may have limited mobility, sight and hearing
   - designers need to be as inclusive as possible to ensure that their products and buildings are usable and functional.

5. **Make it easy, fun and engaging to create and sustain good habits.**
   - make the desired behaviour the default option
   - make it impossible (by good design) to do things that could have a catastrophic impact
   - make it easy for all users to do the right thing
   - make it fun to do the right thing, for example by using gamification and simulation to engage users.

6. **Ensure the system gives users feedback at the right time and in the right format.**
   - feedback should be quick (in as near real-time as feasible), in the right language and format, emotionally engaging, explicit, and, where possible, comparative and therefore meaningful
   - the system should be as transparent as possible, including making problems or inefficiencies visible
   - targets and metrics can be very powerful and need to be designed with great care. They influence behaviour and should reflect the system's goals. If badly designed, they can lead to 'box-ticking' and the creation of perverse incentives
   - beware of targets that are proxies for the true goals of the system and manipulation by people required to meet these targets.

7. **Empower users to handle problems with the system as they occur.**
   - allow the users some freedom of manoeuvre in their use of the system – try not to over-specify or constrain user behaviours

- remember that systems designed to be foolproof often frustrate and annoy their users and this can be counter-productive.

8. **Learn and apply lessons from related domains**. Lessons from product design, the management of change, the design and use of IT systems, socio-technical, inclusive and user-centred design are all relevant to this domain.

6.1.2 Opportunities and challenges for design practice

The workshops included wide-ranging discussions on emerging lessons for those involved in designing, engineering and using the built environment who are keen to incorporate explicit consideration of human behaviour.

This section outlines the main points of the discussion.

Opportunities

The many opportunities for work in this domain include the potential for designers, architects, engineers, behavioural experts and building users to collaborate to improve design practice, knowledge and outcomes.

There are opportunities to develop and utilise a stronger evidence base for decisions through research and post-occupancy evaluation and to help create a framework and toolkit for considering behavioural outcomes[176] as part of the design and engineering process.

It is also necessary to make the best of what is already known. To do this, behavioural experts need to generalise the learning from each project into more widely applicable principles (as in Section 6.1.1). Knowledge may currently exist, but be distributed around different professional groups, and this needs to be aggregated in a useable form.

Understanding of behaviour in the built environment can also be improved by including this in the education of designers and engineers. Educational and training materials could be developed for designers, engineers, users and behavioural experts.

The built environment community has much to learn from areas such as product design, IT system design and the management of change, and from behavioural domains such as human-centred, socio-technical and inclusive design. There are opportunities for experts in such areas to work in this relatively underdeveloped domain.

There will be substantial commercial opportunities for this expertise, through consultancy and through the development of methods and tools to help designers and their clients incorporate behavioural considerations. New commercial opportunities and emerging business models in such areas as smart cities are rapidly developing. For example, there are opportunities for the creation of new services and new service providers who can collate, interpret and visualise big data to predict human behaviour ('predictive analytics') in such diverse fields as crime, security, transport and health.

Challenges

Design has a huge influence on human behaviour but human behaviour also influences design. Designers and engineers make implicit assumptions about user behaviour based on their own experiences.

Dynamic and systemic interactions between design and behaviour in the built environment mean that it is not straightforward for those involved in the design process to identify and make explicit the relationships, and to help develop new design rationales. Designers, engineers, behavioural experts and users will need to find shared languages, goals, metrics, processes and tools. Behavioural experts also need to learn about the goals, challenges and competencies of designers, engineers and their clients.

As with many other disciplines, behavioural experts often specialise in specific areas such as noise or lighting. It may be difficult for designers and clients to source the appropriate behavioural expertise on their project. Evidence is lacking in some areas, such as the financial costs and benefits of alternative designs and on the potential for consistencies and conflicts between choices.

DESIGNERS, ENGINEERS, BEHAVIOURAL EXPERTS AND USERS WILL NEED SHARED LANGUAGES, GOALS, METRICS, PROCESSES AND TOOLS

ONE STRONGLY HELD VIEW WAS THAT NUDGES, SUCH AS POSITIONING STAIRS TO MAKE THEM A MORE OBVIOUS CHOICE, CAN INFLUENCE HUMAN BEHAVIOUR

More research is needed in other areas too. For example, currently, standard models of planned behaviour are inadequate[177]. They do not consider social context and they also tend to be simplistic. A more detailed understanding of users and their habits and decision-making in practice is needed. This is discussed further in Section 6.2.

Discussions during the workshops demonstrated that opinion on design 'nudges' varies. One strongly held view was that nudges, such as positioning stairs to make them a more obvious choice than the lift, can and do influence human behaviour. A related view was that this is just another form of good design, one that draws on a better understanding of human behaviour.

Nudges co-occur with more direct behavioural influences such as legislation. Determining the relative merits of approaches across the behavioural domains is a significant challenge – as is understanding the ways in which the different approaches interact with one another.

In addition, these issues can raise acute ethical concerns about the extent to which designers should exert direct influence on human behaviour. What are the limits to the pursuit of such goals and who should set those limits? At the same time, there are ethical concerns if designers ignore the diversity of human behaviour, especially if this serves to exclude users of certain capabilities from effective use of a building, product or service.

In conclusion, there are huge opportunities but also substantial challenges in the successful development and inclusion of behavioural expertise in this domain.

There is a need to find cost-effective ways in which designers and engineers can work together with behavioural experts to meet these opportunities and challenges, acknowledging that some of these require more research.

6.2 Research needs

The built environment community would benefit from research to develop new knowledge and identify insights about the interaction between design, engineering and human behaviour.

During the workshops, some clear requirements were developed for the methods of such research and development agendas. These include:

- active engagement of all the key stakeholders in any R&D programme
- an emphasis on multidisciplinary and cross-sectoral working, including collaboration between social scientists and engineers
- holistic, 'systems thinking' approaches
- enhanced modelling of human behaviours
- some focus on different behaviours in the same studies (such as energy, productivity and health) so that potential synergies, spillovers and conflicts can be identified and understood
- longitudinal studies to improve understanding of cause and effect
- improved methodologies for data collection relating to behaviours, and accelerated collection.

Potential research questions are included in Appendix 1. Below are some illustrative examples:

- What are the particular challenges for collaborative design of the built environment and how can they be addressed?
- What are the relative roles of regulations, standards and design 'nudges' in these domains?
- What spillovers in human behaviour exist between these domains and within them? For example, under what circumstances do people who are energy-aware at home take such attitudes and behaviours to work and vice versa? Under what circumstances do negative spillovers occur such that positive behaviours in one area are accompanied by negative behaviours in another?

A STRONG MESSAGE FROM THE WORKSHOPS IS THAT POLICYMAKERS ARE DESIGNERS AND THAT POLICY-MAKING IS, AT LEAST IN PART, A CREATIVE PROCESS

- What can be learned from diverse users' workarounds and coping strategies in everyday contexts to improve future designs?
- What is the role of common initiatives in influencing behaviour and how can they be improved? Examples include:
  - smart technologies and 'big data'
  - target and feedback systems
  - behavioural 'nudges'
  - comparisons using social norms.
- What metrics are needed to understand, monitor and assess human behaviours in the built environment?
- What is the role of big data in evidence-based design of the built environment?
- What new business models can be developed to make a significant contribution to these domains? For example, what new business models and opportunities will be created when designing smart cities?
- How do the behaviours and assumptions of designers, engineers and others engaged in the design process influence their designs?
- How do the assumptions (implicit or explicit) held by end users about designers influence their contributions and responses to the design?
- What national policies are required to improve performance in these areas?

6.3 Policy implications

The effectiveness of built environment policies will be enhanced by applying an understanding of the relationship between design, engineering and human behaviour. Key policy areas include planning, which encompasses the quality of design, and energy efficiency in buildings.

Given the interdependencies between different types of policy intervention, a more integrated policy approach is needed. Closer interdepartmental working may help to address this. Guidance and tools would support an integrated policy approach.

Government initiatives could be developed to encourage the application of behavioural insights to the design and refurbishment of public sector buildings and other public sector built environment projects, as a part of improving procurement performance and whole-life value. Again, guidance and tools would support this.

A strong message from the workshops is that policymakers are designers and that policy-making is, at least in part, a creative process. As such, there are opportunities to apply the key lessons identified in this report. In particular, the design principles presented in section 6.1.1. are relevant to policymakers and policy-making.

In addition, policymakers should consider these specific recommendations made in the workshops:

- commission and support new research and development, especially to understand human behaviour in complex socio-technical systems
- value and promote the use of behavioural evidence in briefings to ministers and in policy formulation
- represent design as a generic discipline that recognises and encourages creative thinking
- use the market to help develop and meet needs, focusing on new commercial opportunities and business models
- introduce specific innovations to improve the policy-making process by including expertise on and consideration of human behaviour. For example:
  - planning the long-term development of key staff to include behavioural expertise
  - for any major policy initiative, including at the outset a behavioural assumptions and impact statement with the behavioural outcomes (or goals), underlying behavioural assumptions and behavioural impacts
  - for any major policy initiative, explicitly considering user diversity.
- make policy design more people-orientated, so that perception of, and compliance with the policies is high on the agenda, and address some of the criticisms in behaviour change reviews such as House of Lords Science and Technology Select Committee report[178].

CASE STUDY 14: DESIGNING SMART CITIES FOR HUMAN BEHAVIOUR

Taking a holistic approach to tackle future challenges and opportunities

Claire Hughes, Arup

Cities are best seen as complex systems of systems. Part of the challenge is to understand human behaviour in response to these systems and how humans interact with the services provided by a city. A holistic understanding of the challenges and opportunities that the city may face in the future is needed.

Technologies in smart cities can enable the participation of people in community life, as well as enhancing the performance of services, and reducing costs and resource consumption.

As highlighted in the UK's Department for Business, Innovation and Skills report *Global innovators: international case studies*[179], while all cities are unique, they also have common objectives and face common challenges. The report compares the UK's performance against overseas experience in smart cities through case studies of six cities. It looks at how the cities are addressing their challenges, and adapting their organisations to deliver new digital services to their citizens.

The report indicates that characteristics of successful smart cities include strong political leadership with well-aligned governance structures, recognition of the importance of horizontal and vertical working, investment in superfast broadband infrastructure, community engagement and inclusion projects, investment to support smart city technology innovation, and positioning the city as a 'test-bed' for new technologies.

There is a danger that the debate and action becomes dominated by IT projects and vendors and by an emphasis on 'technology-push'. These dangers are being recognised and challenges are to find ways of engaging citizens (or users), to focus on services and service design (not just IT), and to develop new business models to support those services.

CITIES ARE BEST SEEN AS COMPLEX SYSTEMS OF SYSTEMS.
PART OF THE CHALLENGE IS TO UNDERSTAND HUMAN BEHAVIOUR IN RESPONSE TO THESE SYSTEMS

7. Overall conclusions

THE REALISABLE OBJECTIVES ARE TO IMPROVE THE USE OF RESOURCES; HEALTH AND WELLBEING; AND, PERFORMANCE AND PRODUCTIVITY

This study, based on the presentations and discussions at three workshops, together with case studies and narrative text, includes the views and experience of engineers, designers, architects, social scientists, behavioural researchers and government analysts.

The study concludes that design and human behaviour are systemically interlinked and that the various stakeholders need to collaborate to collate and capitalise on what is already known, and also to improve our knowledge base. The realisable objectives are to improve the use of resources, particularly energy and water, and reduce the production of waste; health and wellbeing; and, productivity and performance.

Ways of improving design outcomes have been identified; design should be undertaken holistically and from a systems viewpoint, user input should be sought from the start of the process, and a multi-disciplinary team including designers, social scientists and engineers should work together using an iterative process, with interdisciplinary feedbacks.

The authors also recognised that policy-making is a design process with behavioural outcomes, and that this too, will benefit from an integrated, multidisciplinary approach.

The ultimate goal of design for behavioural outcomes might be to discover an 'inverse transform' between behavioural and design variables; that is to say, given there is a set of behavioural objectives, it is possible to determine what design characteristics are needed to achieve these objectives. This would require a detailed understanding and modelling of factors which influence behaviour and needs. While generic solutions of this kind may be hard to achieve, research that crosses physical and social science domains will enable much better approximations to be made, increasing positive outcomes and reducing the risk of unexpected consequences.

Appendix 1: List of research questions

Potential questions for research to address are listed below:

- How do the behaviours and assumptions (implicit and explicit) held by designers and others about human behaviour, needs and capabilities influence their designs?
- How do the assumptions (implicit or explicit) held by end users about designers influence their contributions and responses to designs?
- What new integrative theoretical frameworks, methods, tools and metrics are needed to promote better design solutions?
- What further design principles are required to support more human-centred and inclusive design of the built environment?
- What are the particular problems of collaborative design of the built environment and how can they be addressed?
- How can stakeholders learn from one another? For example, how can they share their expertise, experiences and perspectives?
- What differences and commonalities exist between stakeholders, for example in the perspectives they hold on benefits and costs?
- What can be learned from the unintended consequences of design initiatives and how can these be identified and addressed in advance?
- What are the relative roles of regulation, design standards and design 'nudges' in these domains? In what ways do regulations, standards and design nudges interact with one another, for example, in conflict or in support of one another?
- How can habitual behaviours in these areas be best understood and addressed?
- What are the inter-dependencies across these domains? What are the potential trade-offs and conflicts between the three focal areas of interest and how may they be addressed?
- What spillovers in human behaviour exist between these domains and within them? For example, under what circumstances do people who are energy-aware at home take such attitudes and behaviours to work and vice versa? Under what circumstances do negative spillovers occur such that positive behaviours in one area are accompanied by negative behaviours in another?
- What can be learned from users' workarounds and adaptation of environments in everyday contexts to improve future designs? How capable may some users be to use coping strategies?
- What are the linkages between user attitudes to resource use at home and at work and their actual behaviours?
- What educational materials can be developed to promote work in this area?
- What new methods and tools (for example, advanced behavioural simulation) are needed to promote collaborative work?

- What is the role of common initiatives in influencing behaviour and how can they be improved? Examples include:
  – smart technologies and codes (for example, gamification)
  – target and feedback systems
  – behavioural 'nudges'
  – comparisons using social norms.
- What are the underlying relationships between such environmental cues and human behaviour? How can these be developed into generalisable knowledge?
- What problems do the users of existing building stock face when trying to do things such as reduce their energy use, and what can be done by design to help them? What are their decision-making processes and how can they best be supported?
- What metrics are needed to understand and assess human behaviours in the built environment?
- What is the role of big data, data analytics and the Internet of Things in evidence-based design of the built environment?
- What new business models can be developed to make a significant contribution to this domain? For example, what new business models and opportunities will be created when designing new smarter cities?
- What are the costs, benefits and trade-offs between design choices in these areas?
- What new national policies are required to improve performance in these areas?

Appendix 2: Workshop delegates

Workshop 1 – hosted by RIBA

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Muriel Bankhead ESRC

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Richard Cowell Arup

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Frank Duffy Duffy Design

Anne Dye RIBA

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Alan Yates BRE

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Chris Clegg University of Leeds

Richard Cowell Arup

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Sahar Danesh Royal Academy of Engineering

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