Intelligent Buildings and Infrastructure with Sustainable and Social Values

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Intelligent Buildings and Infrastructure with Sustainable and Social Values

Third edition

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Foreword

I well remember attending a Green Building conference in Crown Hall at IIT in Chicago in the mid-1990s where Mike Davies of the Richard Rogers Partnership reprised part of his 1987 talk on *Design for the Information Age* with this vision statement for the future.

> *Look up at a spectrum-washed envelope whose surface is a map of its instantaneous performance, stealing energy from the air with an iridescent shrug, rippling its photogrids as a cloud runs across the sun, a wall which, as the night chill falls, fluffs up its feathers and turning white on its north face and blue on the south, closes its eyes but not without remembering to pump a little glow down to the night porter, clear a view patch for the lovers on the south side of level 22 and to turn 12% silver just below dawn.*

Welcome, it announced, to the realm of intelligent buildings — the arena where technology and architecture converge to redefine the essence of our efforts for an 'intelligent' built environment.

In truth one could argue that man has been building with a greater or lesser degree of intelligence since *Homo sapiens* first developed rudimentary shelter millennia ago, and the notion of 'intelligent buildings' as defined by this book and its predecessors embraces both the intelligence of designing with passive natural design principles and the more contemporary journey into the digital and even sentient, as imagined by Mike Davis in his call to arms.

More than thirty years on from this vision for the future, how have we done?

We are certainly in a transformative age of digitalisation, where every facet of our lives is intertwined with technology, where the concept of intelligent buildings emerges not merely as a novelty but as a necessity. As we embark on a new era where the digital is amplified through artificial intelligence, the design, management and operation of our buildings and cities has begun to transcend traditional paradigms, paving the way for a revolution in how we interact with our surroundings.

This book serves as a comprehensive guide to navigating the intricate landscape of intelligent buildings. From the fundamental principles that underpin their design to the cutting-edge technologies that drive their operation, the chapters delve into the crucial aspect of this multifaceted domain. Whether you are an architect or engineer striving to push the boundaries of design, a facilities manager tasked with optimising building performance, or an urban planner envisioning the cities of

tomorrow, the insights contained within these pages will serve as invaluable resources in your quest for ideas and opportunities.

The journey into the realm of intelligent buildings begins with a deep dive into the foundational concepts that define them. From sustainable design practices to the integration of smart technologies, every decision made in the creation of these buildings reflects a commitment to innovation and efficiency. By embracing principles of energy efficiency, environmental stewardship and occupant comfort, intelligent buildings embody the ethos of responsible architecture in an ever-changing world.

At the heart of a truly intelligent building lies a sophisticated network of sensors, actuators and control systems that form the backbone of its operation. These interconnected systems, typically referred to as the building management system (BMS), serve as the brain of the building, orchestrating a symphony of functions to ensure optimal performance. Through advanced analytics and predictive algorithms, the intelligent building enables proactive maintenance, real-time monitoring and energy optimisation, empowering stakeholders with actionable insights to enhance building efficiency and resilience.

However, the journey towards intelligent buildings extends far beyond the realm of technology. It encompasses a holistic approach to building design and management – one that prioritises the well-being of occupants and the surrounding community. By fostering spaces that are not only intelligent but also inclusive and adaptable, we can create environments that enhance productivity, promote health and wellness and foster a sense of belonging.

As we embark on this journey, it is essential to acknowledge the challenges that lie ahead. From cybersecurity threats to data privacy concerns, the proliferation of smart technologies brings with it a host of complex issues that must be addressed. By adopting a proactive approach to risk management and governance, we can safeguard the integrity and security of intelligent buildings, ensuring that they remain resilient in the face of evolving threats.

Ultimately, the success of intelligent buildings hinges on collaboration and innovation. It requires a diverse array of stakeholders – from architects and engineers to policymakers and technology providers – to come together in pursuit of a common vision. By fostering an ecosystem of creativity and collaboration, we can unlock the full potential of intelligent buildings to transform our cities, our societies and our lives for the better.

In a rapidly changing and de-carbonising world, we need to take every opportunity to bring carbon-effective decision making to the construction and operation of our buildings, districts and cities. We have at our fingertips the knowledge and expertise of millennia of masterful builders and designers, to which we can now add the self-learning possibilities embedded in the digital realm. I am sure that the insights shared within these pages will inspire readers to embark on their own journey into the realm of intelligent buildings, where innovation knows no bounds and the future is limited only by our imagination.

I extend my sincere congratulations to the contributors, researchers and practitioners whose tireless efforts have made this book possible and to the indomitable Professor Derek Clements-Croome who has so skilfully brought this symphony of thought together into a coherent work.

Patrick Bellew RDI
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Preface to the third edition

The pathway to this third edition began with the government-funded MSc course in Intelligent Buildings in 1996 at University of Reading. The course had a syllabus covering a large span of knowledge encompassing science, engineering, architecture and practice about the planning, design and management of intelligent buildings. This led to the first edition of this book being published in 2004. The next step was to form the CIBSE Intelligent Group in 2006 which included academics and practitioners in its membership which currently is about 14 000 worldwide. The journal *Intelligent Buildings International* published by Taylor and Francis began publication in 2009 and is now a recognised journal worldwide in this field. A second edition of the book was published in 2013 and now, just over a decade later, this 3rd edition.

Over this time span there have been vast and rapid changes in attitudes, expectations of society and advances in technology. The pinnacle of concerns are the impacts of climate change and the health and well-being of a growing world population. Economies have fluctuated wildly, and then in 2020 the Covid-19 pandemic struck, affecting people worldwide. It is not surprising that mental health has suffered a great deal in many countries. Stress in society has been magnified even more by the daily outpourings of news in the media headlining wars in various countries.

We spend most of our lives in buildings so the impact of the environment they create is important whether in a home, a school, an office or a building of any kind and this, to some extent, can help to offset the stresses of the daily news. Buildings can be stressful and boring places to be, but they can also be the opposite of this and be places which inspire and motivate the human spirit. The pandemic made us rethink the value of green space around buildings and ways of working whether at home or in another building which involves travelling some distance away. Unsurprisingly not everyone wants to work at home continually. People missed the value of the social dynamic; schools were closed in the UK and children missed their friends. But also, the flexibility offered by hybrid working brought a better work–life balance for some families, especially those with children. It also affirmed that our connection with nature is vital and nourishes our mind and body.

There is a yin-yang perspective in all we do. Collective decision making has to resolve conflicting interactions and achieve the best connectivity in planning, designing and constructing or restoring buildings and cities. The barriers are many. AI can help to unravel the intricacies of data-loaded projects and enable them to be resolved, but like humans,

generative AI is fallible. The future to some extent will be governed by how well the human–machine relationship can work harmoniously to achieve beneficial outputs.

The book has 18 chapters written by over 30 authors, including academics and practitioners, and covers a lot of the knowledge base which enables the concept of the intelligent building or city to be understood. There is of course always more to learn. The experience of those authors in practice is invaluable as is the knowledge from history, science, psychology and architecture. The interpretation stated here is that intelligent buildings are ones that are functional and sentient for the occupants; they are connected to nature and sustainable for the planet; and they are embedded with enabling smart technology that help these aims to be successfully achieved. Intelligent refers to the response of the building in different situations and locations, not the amount of technology they contain. Some buildings will operate with a low-tech approach but others will use high-tech systems, depending on the context for the building.

More than ever, we see the need for transdisciplinary working. We cannot claim our buildings to be liveable or sustainable without the interventions of specialists with the best up-to-date knowledge in, for example, health, ergonomics, occupational psychology, innovations like wearable technology, neuroscience, ecology, biomimetics, biophilia and vernacular architecture. Everything in the end is interconnected. It is easy today to measure not only the environment but also the impacts it has on people's physiological and psychological states, and this process of monitoring deepens our understanding.

Hopefully this book will stir the imaginations of readers with fresh insights and contribute towards overcoming barriers like fragmentation, siloed thinking, cheap first cost, poor supply chain connectivity, short-term vision and an inflexible narrow compass of knowledge.

I wish to thank all those who sacrificed their time to help produce the contents and the production of the book. I am in debt to all the authors; Cathy Sellars and Viktoria Hartl-Vida at Emerald Publishing; Dr Mehdi Shahrestani (University of Reading); Dr Yan Xingang (Nottingham Trent University); Dr Gulay Ozkan (NTU); Dr Tong Yang (Middlesex University); Patrick Bellew (Atelier Ten); PLP Architecture; Professor Rachel Armstrong (Leuven University); Joyce Chan-Schoof (Parliament Sustainability Lead and Loughborough University); members of the CIBSE Intelligent Buildings Group; many of my colleagues at the British Council for Offices; my colleagues at University College

London; members of CIB Commission W098 on Intelligent and Responsive Buildings; my colleagues at Taylor and Francis; Mollie Broadhead and her colleagues at Crowood Press; and many others not mentioned by name here. Please do write to me with comments and ideas.

Derek Clements-Croome
Professor Emeritus
University of Reading

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Preface to the second edition

Since the 2004 edition many things have changed in society and technology. And yet there are many things that remain the same, particularly the need for buildings to enhance the living and work experience of the occupants. The increased public awareness of the world need to promote sustainable development in all areas of our lives and realising that we as well as the artefacts around us play an important role in this by the way we purchase and use things which reflect our attitudes, behaviour and lifestyle. And now the emergence of eco-cities which require intelligent infrastructures as well as buildings at a pace which is trying to keep ahead of the 70% of the world population that will inhabit cities by 2050 (about 7bn of 10bn). Technology is feasting at a table which has some aspects of nanotechnology, advanced information and communications, wireless sensor networks and robotics in design beginning now and into the future. Renewable energy resources are gathering pace but there are other offerings such as the hydrogen economy and nuclear fusion to develop too for the long term future.

In August 2011 the UK Television Channel 4 showed a three-part series on The Secret Life of Buildings where the challenge of designing and constructing beautiful memorable buildings whilst at the same time meeting the varying demands of their occupants was illustrated in stark terms. Scientific evidence was presented concluding what we already know: that our surroundings, and for most of our daily lives these are inside buildings, affect us physiologically and psychologically.

Another thread in the story is about how we simplify the complex web of decision making by assuming non-dynamic linear processes when they are dynamic and non-linear. Complexity theory and fractal geometry may help us to make a transition so that the complications we have tried to avoid can be handled confidently.

The design and management processes are also undergoing change. Whole life economics are emphasising value analysis balancing whole life costing and quality. Building Information Modelling (BIM) is making integrated team working more effective. Enhanced feedback systems using post occupancy evaluation are becoming part of the total building design process. Facilities management is now an advanced topic which stresses how the care of buildings is so important in order to maintain high performance. Performance rating schemes are being derived in many countries to assess how sustainable buildings are.

Amidst all these changes passive environmental design remains fundamentally important. Simple technology exemplified in vernacular architecture leads to low energy solutions with less demand on active

systems. Naturally responsive architecture is appealing because it is less complex, more durable and easier to operate. Biophilic design and biomimetic architecture are ways of exploring Nature's economic uses of materials and energy, leading to even more innovative yet simple approaches to naturally responsive architecture whilst responding to the innate human need for a direct link with Nature so landscaping is not just beautiful but affects the human spirit. Architectural neuroscience may open up new ways of thinking too, as a paper in the Intelligent Buildings International Journal 2012 titled Brains, Machines and Buildings shows.

This edition has chapters devoted to many of these topics. The world of intelligent buildings and cities has a wide vocabulary including smart, digital, cyber, sentient, sustainable, green and ecological descriptors. There will be continual change and this book is just a milestone at this point in time on a long journey ahead.

I would like to thank all those who have shared their visions, thoughts and energy with me over the years. There are too many to mention all individually but they include the authors in this book besides myself for their hard work and offering to imbue the book with their knowledge and experience; all the graduates and staff of the MSc Intelligent Buildings course from 1996–2012 and more recently those at the University of Dundee School of Architecture; Dr Qiu Baoxing ,Vice Minister of Urban Construction in Beijing for his continuing encouragement; all members of the Chartered Institution of Building Services Engineers Intelligent Buildings Group; Ron Zimmer and David Katz of the Continental Automated Buildings Association; all members of the CIB W098 Commission on Intelligent and Responsive Buildings; all members of the British Council for Offices; Dr Xiaoshu Lu at the University of Technology in Helsinki; Dr Husam AlWaer at the University of Dundee; Joe D'Angelo, Sirina Jamieson and the Editorial Board who help me edit the Intelligent Buildings International Journal; all those PhD graduates I have examined in many universities internationally; Jennifer Barratt of ICE Publishing who has guided the book production throughout; and Gulay Ozkan formerly at University of Reading who for 10 years administratively supported the MSc IB course in such a dedicated, heartfelt and efficient way.

Derek Clements-Croome
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Editor Intelligent Buildings International Journal

Preface to the first edition

Technology has been viewed at various stages of civilisation as leading to future progress. The rate of change of technology is faster today than at any other time in history. It not only enters our work life, but that of our home life too, where advanced communication systems are becoming common. The world is shrinking owing to ever quickening communication systems. It is also a period of rapid changes in society and this affects our expectations, lifestyle, attitudes and behaviour.

Intelligent buildings may be increasingly viewed as ones that provide a responsive, effective and supportive environment within which an organisation can meet its performance objectives. The technology, although still generally considered to be fundamental, is now seen as the enabler rather than as an end in itself.

Buildings affect people in various ways. They can help us to work more effectively; they also present a wide range of stimuli for our senses to react to. If this is a common vision then it is essential for architects, engineers and clients to work closely together throughout the design, construction and operational stages of the conception, birth and life of the building. There has to be an understanding of how patterns of work are best suited to one building form or another served by the appropriate environmental system. There are a host of modern technologies emerging that help these processes but in the end it is how we think about achieving responsive buildings that matters. Intelligent buildings can cope with social and technological change and are adaptable to short- and long-term human needs. This is the fundamental meaning of the term intelligent building.

Most of our lives are spent in buildings and they, together with the people, provide the stimuli to which our senses respond. They can enhance or dull our creative endeavour; they can aid or hinder productivity. Buildings consume immense human, material and fossil fuel resources in their production and operation. They deplete resources and also produce pollution and waste during operation. Their impacts on the biosphere are continuous and long lasting.

The future will concentrate on developing naturally responsive buildings with the discriminate use of appropriate high-technology interactive systems. They will have low environmental impact on external and internal environments and will have sustainable water and waste systems. Healthy environments, low energy consumption and good management are a virtuous cluster which distinguish ‘green’ intelligent buildings. It might be considered that these should be the strategic aims of any intelligent building. That leaves the question of how they

will operate. It is now commonly accepted that intelligent buildings have effective building management, space management and business management systems. Intelligent buildings enhance the business by the environment they create, by the adaptability and the flexibility that the space offers and by the communication systems provided.

In 1996, the Engineering and Physical Sciences Research Council made an Integrated Development Scheme (IGDS) five year award for an MSc course entitled Intelligent Buildings: Design, Construction and Operation. The course was planned in conjunction with industry, principally with the European Intelligent Building Group (now IBG), which comprises a network of some 60 companies in Western Europe and which has now extended as far as China. The course was designed to be flexible so that it was more convenient for those in industry to come and study for an MSc part-time or simply to take any module they chose on a Continuing Professional Development basis. The course now also attracts students from around the world who study full-time. This book reflects the philosophy of this course. It was felt that the course would create a platform for interdisciplinary working and would make a contribution toward leading the construction industry through the twenty-first century, by teaching leading edge technology in the context of the changes that are taking place in society. The delegates who attend come from a range of professional backgrounds and include architects, engineers, quantity surveyors, managers and others.

The architectural engineering, scientific and human issues related to intelligent buildings and the design of their components and systems are universal. The need for healthy, sustainable and responsive environments is national and international and covers all types of buildings. Knowledge about intelligent buildings needs to be disseminated to the construction industry, manufacturers, building owners and users. The course provides a knowledge base that will benefit consultants, contractors, manufacturers and facilities managers as well as building developers, owners and tenants.

Delegates have attended the course from several countries in addition to the UK and their professions have covered architecture, engineering, building and facilities management. There is no doubt that mixed disciplinary groups provide a rich learning experience for the students and the staff. The course has also been enriched by contributions from some 100 contributors, 70 from leading companies and the remainder from academia, mainly from various departments at the University of Reading but also from other universities.

There are many definitions of intelligent buildings and there was even some discussion at the time as to whether we should use the term intelligent building. The latter can be seen as rather constrictive in the sense of confining the work to the construction phase, whereas intelligent buildings are created at the design stage but they also need intelligent management in operation if they are to be effective. The prime intention of intelligent buildings is that they will create an environment that allows organisations to achieve their business objectives.

The principal aim of the course is to provide advanced knowledge of intelligent buildings and hence educate those who will commission, design and operate such buildings. Skills as well as knowledge and understanding are emphasised. The principal objectives are:

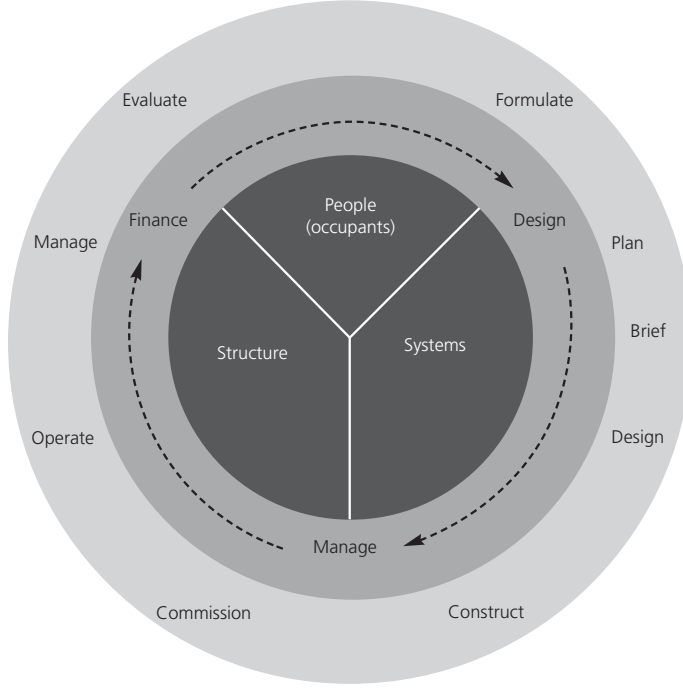
- to provide an interdisciplinary approach to understanding intelligent buildings;
- to provide a modern and up-to-date account of the technologies involved;
- to consider the economic, social and technical issues which underpin an effective decision-making approach to the design, construction and management processes;
- to introduce the latest innovations applicable to buildings;
- to study how intelligent buildings may be sustainable and healthy.

One of the comments frequently made about the course by those who have completed it is that it has made them think differently about their discipline.

The choice of modules for the course is centred around the basic elements of people, the building structure and the systems which make the building work. The resources needed to produce an integrated working solution are land, people and money. First-class management of the design, construction and operation processes is vital. What emerges is a product derived from an interplay of processes using material resources and a team of creative yet practical human minds and skills. The figure below summarises these ideas, which form the backbone of the course.

The course is built around a core of five modules, the first of which emphasises the Concepts, Strategy and Management required to develop a conceptual model of buildings and people, which can be achieved by an integrated approach towards buildings systems, environmental systems and the management of organisations.

Backbone of MSc Intelligent Buildings, Design, Construction and Operation course



The second module is entitled Building Systems, Architecture and People. Evans *et al.*, in their 1998 report entitled The Long Term Cost of Owning and Using Buildings for the Royal Academy of Engineering, made the point that the cost of ownership and maintenance of a building is typically about 3% of the overall cost of people working there. As a guide to the whole life cost of operation of office buildings, the life cost ratios quoted were 1:10:200 representing design and construction (1) operations management and maintenance (10) and staff costs (200) (see Chapter 13, page 342). In other words, the environment where people are is crucially important and affects the productivity of the organisation. It is often said that some buildings that have been deemed to have failed are satisfactory from the point of view of building regulations and codes. The point is that these are insufficient to guarantee a stimulating place to live and work over the whole life of a building because building regulations and codes are just a starting point which provide important health and safety guidelines only. This module concentrates on the relationships between people inside buildings and the environment created by the architecture.

The third module is entitled Information Technology and Communications Systems. Technology is advancing more rapidly than ever and so it is essential that companies can cope and adapt to change. The meaning of intelligence is probed and the argument for artificial intelligence is examined. The module also includes applications of the most recent technology to a number of case studies.

The fourth module is entitled Designing Intelligence into Buildings. The phrase intelligent building is interpreted as a building that achieves the needs of the occupier by the means of the intelligent application of building principles, materials and construction methods, both at the design stage and throughout the building's life time. This is a further development of the passive and active design principles studied in Module 2. The impact of successful passive design throughout history and also challenging designs for the future are studied. Not only is the current state of façade engineering described but also the exciting field of biomimetics, which could hold the key to many of our future building envelopes.

The fifth and last core module is entitled Financial Analysis and Investment Appraisal. This module has whole life value as its central focus. How this can be achieved by life cycle costing and more effective design, construction and facilities management procedures is developed throughout the module.

Delegates also study three of the following elective modules:

- Facilities Management
- Principles of Project Management
- Design Management and Briefing
- Sustainable Design, Construction and Management.

The chapters in this book are heavily referenced for academic and professional uses. They also emphasise particular bodies of work which are worth further study. Even though the chapter titles are not exactly the same as the modules in some cases, this book not only reflects the contents of these modules but in a way goes far beyond them.

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Acknowledgements

I would like to pay tribute to all of the authors, module coordinators and those in industry and academia whose talents have helped to make this course successful, and to the executive assistants throughout the course who have helped me run the intricate administration side of the work. There are many names I should mention but I must particularly pay tribute to the Chairman of the Management Steering Committee, Vic Fairey (Dytecna Ltd), former Chairman Alan Kell (i & i Ltd), Robert Barden, Maureen Taylor, Gülay Özkan, Irene Williams, Stephanie Wilkinson, Jane Draper, John Jewell, Hseih-Min Loy, Godfaurd John and Shaomin Wu, who have all provided invaluable support at various times. Last but not least, the Engineering and Physical Sciences Research Council is acknowledged for financing the course from 1997 to 2002. We have had wonderful delegates attending the course and any success is also largely due to them.

Derek Clements-Croome
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About the editor

Professor Emeritus Derek Clements-Croome at the University of Reading worked in the building design and contracting industry before entering university life. He has founded and directed courses, including a BSc in building environmental engineering at Loughborough University in 1970 and an interdisciplinary government-funded MSc in Intelligent Buildings at University of Reading in 1996. He has also worked in architecture and building engineering at the University of Bath (1978–1988) with Professor Sir Ted Happold.

He founded the CIBSE Intelligent Buildings Group in 2006, co-founded the CIBSE Natural Ventilation Group in 1992, and was commended by the CIB for linking the CIBSE IBG with his work as Coordinator for the W098 Commission on Intelligent and Responsive Buildings. He was Vice President for CIBSE in 2007–9 and holds their Bronze and Silver Medals. Derek has been a commissioner on air quality and also biodiversity for some London Boroughs. He was a member of the UK Green Building Council team who wrote the Report *Health and Wellbeing in Homes* in 2016 and the World Green Council Report on *Health and Wellbeing in Offices* in 2014. He contributed to the BCO Report on *Wellness Matters*: the *Guide to Specification* in 2018, reports on *Ventilation for Covid-19* in 2021 and *The Use of Wearables in the Office* in 2021.

He is a research project reviewer for government ministries in New Zealand and Denmark. He is an adviser for the British Society of Lifestyle Medicine and a Fellow of the Royal Society of Medicine.

He edits the INBI Journal and has edited and written chapters in the 3rd Edition of *Creating the Productive Workplace*. His book *Designing Buildings for People: Sustainable Liveable Architecture* was published in 2020 and includes his work on assessing the impact on the environment on people's health and well-being, including the economic and sustainability implications.

He collaborated with Clare Bowman at RCZM Architects on designing biophilic classrooms at Putney High School and was a team recipient of a Gold Medal at the Royal Horticultural Society Chelsea Flower Show in 2021.

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About the contributors

Midori Ainoura has two decades of professional experience with a focus on complex office, master planning, residential, academic and institutional projects across the globe. She led the design of The Edge, the multi-award-winning sustainable beacon in Amsterdam created for Deloitte. The project set new standards for sustainable design through actively integrated environmental features and proactively intelligent workplace design. In London, she designed Bankside Yards, a hyper-mixed neighbourhood in central London; the Westferry Printworks Masterplan, a residential-led development on the Isle of Dogs; and a library extension for the National Maritime Museum in Greenwich. Before this, Midori's experience encompassed a wide range of projects across Europe, Asia and the USA including large scale master plans in India; a media centre in Abu Dhabi; headquarters in Amsterdam; and the new National Theatre of Cyprus. She is a founding member of PLP Labs, the practice's in-house interdisciplinary research and consulting unit that challenges future urban issues from urban, human and digital perspectives. She lectures regularly across Europe and Asia on next-generation workplace design and cultural placemaking. Her work has been widely covered in the media and Midori was featured as one of nine new leading contemporary Japanese architects. Following a Master of Environmental Engineering from Tokyo Institute of Technology, Midori received a Master of Architecture from the University of Pennsylvania.

Ir Ron Bakker has contributed many award-winning buildings and urban design projects to major world cities and his work is widely recognised for its civic and environmental responsiveness. Ron is excited about the contribution that architecture can make to the quality of urban life and the role of new technologies in the built environment. He designed The Edge in Amsterdam and is currently working on a super-high-rise in Kunming, China; a Crossrail over-station development in Mayfair, London; Tree House, a tall mixed-use project in central Rotterdam; an extension to the World Trade Center in Amsterdam; and Assima, a large urban retail, residential and office project in Kuwait City. Ron is frequently invited to address academic and professional symposia and besides leading the design teams on various projects at PLP Architecture he is also director of PLP Labs, where he is involved in research and collaboration projects with academic institutions, government organisations and commercial clients – operating at the intersection of people, planet and technology. His book on architecture and technology, *Smart Buildings*, was published last year by RIBA Publishing.

Guy Battle is the CEO and Founder of Social Value Portal, Co-Chair of the Public Sector Chapter for The Sustainable Procurement Pledge and Facilitator and Associate Manager for the National Social Value Taskforce. He is also a Chair of Riversimple, which builds hydrogen fuel cars to deliver net zero carbon personal mobility. Guy's dedication to sustainability and social value has made him a prominent figure in the built environment sector. He has been involved in the design of a number of iconic sustainable building projects, including Agostinho Neto University (Angola), Sadler's Wells Theatre (London), ENDESA Headquarters (Spain) and the new Home Office (London). Guy's experience ranges from providing sustainability solutions for the built environment sector, to serving as Director at BattleMcCarthy Ltd in 1993, to founding Planet Positive in 2007. From 2010 to 2014, Guy was Lead Partner for Sustainability Services at Deloitte dcarbon8. In 2014, Guy founded Social Value Portal. Under Guy's leadership as CEO, Social Value Portal has become a pivotal tool for stakeholders across the built environment sector, empowering them to assess, manage and enhance their contributions to society.

Clare Bowman is a University Lecturer of Sustainable and Biophilic Architecture and practising architect with over with over 25 years' experience advising and delivering environmental architectural projects worldwide. In 2014 Clare co-founded RCZM to support research into building performance analysis to understand the benefit of sustainable design on our built environment. During the last decade this has expanded to include nature-based and biophilic design solutions in education to support well-being of students and staff. *The Biophilic Classroom, benefits of nature in learning environments* at Putney High School research paper and exhibit was awarded the RHS Chelsea Gold Medal in 2021.

Kiron Campbell is Content Manager for Social Value Portal, where he drives the business's thought leadership programme and creates social value best practice case studies. Prior to joining Social Value Portal, Kiron worked as a content producer and copywriter across the events, life sciences and professional services spaces. Kiron studied English Literature at Queen Mary University of London, where he achieved a first class Bachelor's degree and a distinction in his Master's degree. As an experienced communications professional, he is passionate about the power of the written word to drive essential social, economic and environmental change.

Joyce Chan-Schoof is an Architect and a PhD Researcher. She is currently the Head of Programme Requirements of the UK Parliament; her role involves strategically planning the Palace of Westminster's

restoration and renewal works. Joyce advocates for integrating academic research into the practice of designing a more sustainable and inclusive built environment; she has two decades of experience embedding environmental, social and economic well-being into business functions. She is conducting a doctoral research study on Social Value and natural-based design solutions at the School of Design and Creative Arts, Loughborough University. Recently, she won the 2023 WICE Awards* for Environment & Sustainability.

Kamal Dhawan holds a BTech from Jawaharlal Nehru University and an MTech from the Indian Institute of Technology Delhi, India. He is a professional who gained expertise in the maintenance, repair and overhaul (MRO) domain of mission-critical equipment while in India. He has been intimately involved with supply chains comprising domestic Indian and foreign business entities and has worked extensively on projects pertaining to life cycle management of complex engineering assets, including life extension and upgradation. He is currently a lecturer in the School of Future Environments at Auckland University of Technology, New Zealand. His research interests lie in the domain of logistics, specifically the sustainability of transport and sustainable construction. He is also a member of industry action groups for reduction of waste in construction and is working actively on developing solutions for decarbonisation of freight transport in New Zealand.

Dan Fernbank BSc AMEI has been Energy and Sustainability Director at University of Reading since 2011, leading their estate-wide sustainability programmes. Dan has overseen some of the largest carbon reductions in the UK higher education sector, delivering a 61% cut in the university's carbon emissions, saving £45 million cumulatively. He wrote the university's net zero carbon plan for 2030 and has secured numerous sector and industry awards for its carbon reduction work. He is also a voluntary Director for Reading Community Energy Society, which to date has installed over 600 kWp of community-funded solar PV in and around Reading. In 2014, he completed a first-class honours Environmental Studies BSc through the Open University.

Ali Ghaffarianhoseini PhD MSc BArch Hons is a Professor, Head of Department, Senior Academic Representative on the University Academic Board and an Appointed Leading Researcher at the School of Future Environments, Auckland University of Technology, New Zealand, as well as a Scholar at the Office of the Prime Minister's Chief Science Advisor, an Evaluator at Ministry of Business, Innovation and Employment, a Professional Architectural Engineer/Designer

* *WICE is the European Women in Construction & Engineering Awards.*

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Professor Brenda Vale is a Professorial Research Fellow in the School of Architecture at Victoria University of Wellington. She has extended her lifetime interest in low energy and autonomous buildings to embrace the environmental impact of those that live in them through a focus on ecological footprinting. This interest has led to a number of recent books on reducing the impact of buildings and the built environment, and numerically establishing what type of built environment might be possible within the resources of the planet, given that humanity is currently living beyond these. Some of these books, like the chapter in this one, have been written with former students.

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Chapter 1
Intelligent buildings: present and future

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Executive summary

Buildings that are intelligent respond to the demands of the human sensory system in terms of physical, psychological and social needs. In doing this they are havens for work, learning and life in general. In the world today with increasing populations, climate change pressures dominate our thinking; intelligent buildings need to be interconnected with the web of circumstances that are evolving; they need to be resilient while also giving healthy contentment to the occupants within them. This chapter discusses various ways in which this can be achieved by valuing the lessons that vernacular architecture and nature can teach us. Beyond this there is a debate on how to use technology wisely to enable smart operations that can be helpful in human and environmental ways.

> I find the marriage in architecture between space, society and politics fascinating – it embraces the whole story of mankind (Stefan Brüggemann, 2023).

> Architecture is more than the art of constructing individual buildings. It is also the creation of environment. Buildings do not exist in isolation. They not only impose their character on their surroundings but also have an incalculable effect on the lives of human beings who inhabit them. Homes, workplaces and infrastructure are the principal components of the built environment. They serve the basic human needs for shelter, warmth and communication, as well as providing water and taking waste away. Too often buildings are seen as costly static containers rather than as an investment which, if they are healthy and sustainable, can add value (*Intelligent Buildings*, Clements-Croome, 2004).

1.1. Intelligent buildings for people and the planet

Intelligent buildings have existed for thousands of years but different centuries and cultures express them in different ways, so what is an intelligent building? An intelligent building is one that serves the needs of people in functional ways but also provides a multi-sensory experience for the occupants. It has to be sustainable with regards to decreasing energy and water consumptions; decreasing the generation of waste and pollution. Changing conditions means intelligent buildings have to be flexible and adaptable to short- and long-term changes.

Buildings consume a great amount of energy and water in their construction and during their total life cycle. They use large quantities of materials and aggregates and generate waste and pollution at every stage of their production. It is no longer acceptable to consider a building and its systems in isolation from its social impacts. This becomes critical with the growth of megacities which

are part of a rising trend towards urban living. Modern liveable cities comprise intelligent and sustainable buildings and infrastructures; however, they should be designed to show respect for the natural environment and the health of the inhabitants. In other words, sustainable and intelligent cities are composed of buildings supported by intelligent infrastructures created for the well-being of residential, commercial and industrial communities. Becerik-Gerber *et al*. (2022) describe the human–building interaction (HBI) as 'a convergent field that represents the growing complexities of the dynamic interplay between the human experience and intelligence within built environments'. Three research domains are defined covering

- people (human experiences, performance and well-being)
- buildings (design, operation and management)
- technology (sensing systems, inference and awareness).

In the 21st century, intelligent buildings tend to be ones that are very technology-driven, but already we can see the impact of changes in society in that they need to be for the health and well-being of the occupants and so bring in a caring and humane approach. Then there is climate change which means old as well as new buildings need to achieve net zero carbon or even be energy-generating, zero waste and pollution and have low water demands.

Achieving these basic primary needs can be interpreted in various ways. Each building will be nuanced in a particular way according to its location and the way the client and design team interact. A building is a composition but, unlike a music score, which is composed by one mind, buildings are a composite of many thoughts from many minds that make up the design, construction and operation team. The various stakeholders do have a common purpose but have different mindsets emanating from a variety of educational experiences and this leads to a design which may be interpreted in different ways by constructors and managers. Attaining seamless connectivity of thoughts to achieve a unified vision is not easy but, when successful, it is very powerful. It means collaboration, coordination and communication are key. Digital technology can help with planning smooth processes for putting the design into practice. Although advanced automated programmes help to dispel many impediments in the processes, human input is still vital. All the stakeholders need to come together at the beginning of any project to set the mission, aims and objectives and so make the work a truly meaningful experience for everyone. This helps to heighten everyone's motivation to innovate, to be creative and practical, and each one to have a sense of pride in the work they contribute to the project.

1.2. Lessons from history and nature

Changes in technology are rapid so selecting the right technology can be challenging. Technology is an enabler not a master. Evolving technologies can enable high levels of functionality and environmental performance to meet sustainability goals. But the starting point is learning the lessons from history in which one can see how vernacular architecture has met these ideals through simple passive design, which is still so relevant today in this technological age.

Examples might be an igloo, a Japanese tea house, a Malaysian house or a courtyard design but there are many other vernacular types throughout history, each offering ingredients that make up the recipe for what is the essence of an intelligent building. Wotton in *The Elements of Architecture* (1624) writes: 'A well building hath three conditions: firmness, commodity, and delight'. Today this paraphrase might be 'durability, resilience, function and beauty'. The International Living Future Institute in Seattle (2024) proposes seven performance categories

- place
- water
- energy
- materials
- beauty
- health and happiness
- equity.

Vernacular architecture offers these values which are fundamental to achieving low carbon emissions and a circular economy. They echo simplicity rather than the complexity which can make some buildings over-complicated today.

Lessons from history are valuable but so are those from nature. Biomimetics, biophilia and synthetic biology all play their part (Clements-Croome, 2020; Contreras, 2023; Kapsali, 2016; Pawlyn, 2016). Synthetic biology (synbio) applies engineering principles to biological systems to create new functions and materials. It has an increasing role to play in many fields, including health and climate change (Healey, 2023; Mischel, 2023). Chapters 5 (*Biomimetic Architecture: Exploring Adaptive Facades Inspired by Nature*) and 6 (*En Route to Nature Integrated Design: Opportunities and Challenges*) of this book describe bio-architecture in more detail.

1.3. Intelligent or smart?

The words *intelligent* and *smart* are often interchanged but is this valid? Intelligence is having a sense of curiosity to develop new ideas based on knowledge with a deep understanding. An intelligent person has a high mental capacity to quickly comprehend and solve problems. Intelligence is characterised by quickness of understanding, logical thought and reasoning which underpin good judgement. When a person is inherently intelligent, they can also be smart but a smart person may not necessarily be very intelligent. Smartness comes from learning facts from the situation or circumstances being experienced but not necessarily developing knowledge and understanding based on the facts: intelligence is believed to be innate.

There are three types of intelligence which recognise cognitive, emotional and practical reasoning and abilities. Many of the things we do involve head (reasoning), heart (emotions) and hands (practicality). Smartness concentrates more on cognitive intelligence whereas most decisions in life depend on a mixture of all three types of intelligence. Artificial intelligence (AI) is smart but not really intelligent because it does not have the human qualities of emotional intelligence or even common sense. We can conclude that intelligence is a more embracing term than smart and hence the use of these terms needs to be differentiated.

We can conclude that an intelligent building has a higher level of expectancies than a smart one. It has to enhance health and well-being by providing wholesome sensory and social experiences; it has to be sustainable in its use of resources but it also needs to be adaptable and flexible to deal with quick changes of demand in temperature, ventilation or lighting, for example. The spaces in a building need to flow to meet the needs for reflective thinking or meeting people formally and informally.

1.4. Buildings, systems and people

Vernacular architecture show us that measures like building form, orientation, mass and choice of materials respond to changes in a more natural way. Such passive means help to reduce the energy requirements of buildings.

AI and digital technology can enable the building to be smart (see Chapter 2) rather than intelligent. The Edge Olympic building in Amsterdam with its advanced technologies might be an example of a smart building but it also embraces other sentient and social features which show it to be an intelligent one, too (Clements-Croome, 2020).

Alternatively, a low-tech building such as the Jean-Marie Tjibaou Cultural Centre in Noumea can be effective using passive control (Clements-Croome, 2020). The facades of the Cultural Centre are composed of a series of pavilions and these are part of a passive ventilation system which control environmental conditions in what is a humid, semi-tropical climate; the Pacific Ocean is nearby. The double outer walls allow air to circulate between the two layers of slatted wood. The apertures in the external shell have adjustable louvres to take advantage of ocean breezes to circulate the air around the building using stack effect. This is a low-tech intelligent building.

The Edge Olympic is a high-tech building, but it is also focused on the health and well-being of the users besides minimising its environmental impact. It creates inspiring spaces for people to work in. It uses a digital infrastructure to connect everything and everyone to a single cloud platform. Energy is supplied from solar panels with geothermal storage to meet the energy consumption of 72 kWh/m^2. It has a green roof, highly insulated facades including glass to flood the spaces with natural light, together with 15 000 sensors to measure environmental quality. The spaces are filled with natural daylight and have circadian lighting systems. The spaces have been carefully spatially planned and are rich with biophilic features. The Edge principal architect Ir Ron Bakker, together with Savannah Willits, describe the earlier Edge Deloitte building in detail in Chapter 18.2 of this book.

How can we refit old buildings to be sustainable? Edge The Hague is a project to be completed in 2025, renovating De Groene Toren using a sustainable approach which respects the circular economy and health and well-being of the occupants. Spacious interiors will have an abundance of daylight, places to exercise and a renovated facade linking the external and internal environments in a sustainable way. It is designed as an all-electric building with air source heat pumps serving radiant heating and cooling systems. A comprehensive array of sensors will monitor the building and systems besides registering some of the occupants' reactions to their environment.

Energy costs are uppermost in many minds as world events disturb the fuel markets, but energy choices are a major concern anyway as all the Conference of the Parties (COP) climate change meetings show. There is an acceleration which is gathering pace towards renewable fuel economies but first, how much energy do we use and also waste? Margaret Harris (2022) reveals in *Home, Green Home* that not just homes, but the keepers of our cathedrals too are considering their operating costs as well as playing their part in climate change – after all, they manage huge spaces with highly variable occupancies. Gloucester Cathedral was the first to install solar photovoltaic (PV) panels on its roof in 2016 and now Bath Abbey may do the same, having already used the heat from the Roman baths as a source for a geothermal heating system.

The age of some 25.5 million UK homes means the housing stock brings immense problems: 76% are pre-1980 and 20% pre-1919. Half of the stock is poorly insulated and rates of upgrading homes has decreased since 2012, with poor incentives for homeowners to do so. The recent death of a child from oedema due to mould in a home was reported in the *British Medical Journal* (Dyer, 2022), questioning the value of UK housing policies. Well-insulated homes are needed for energy and health reasons which makes it an urgent issue; besides, it is

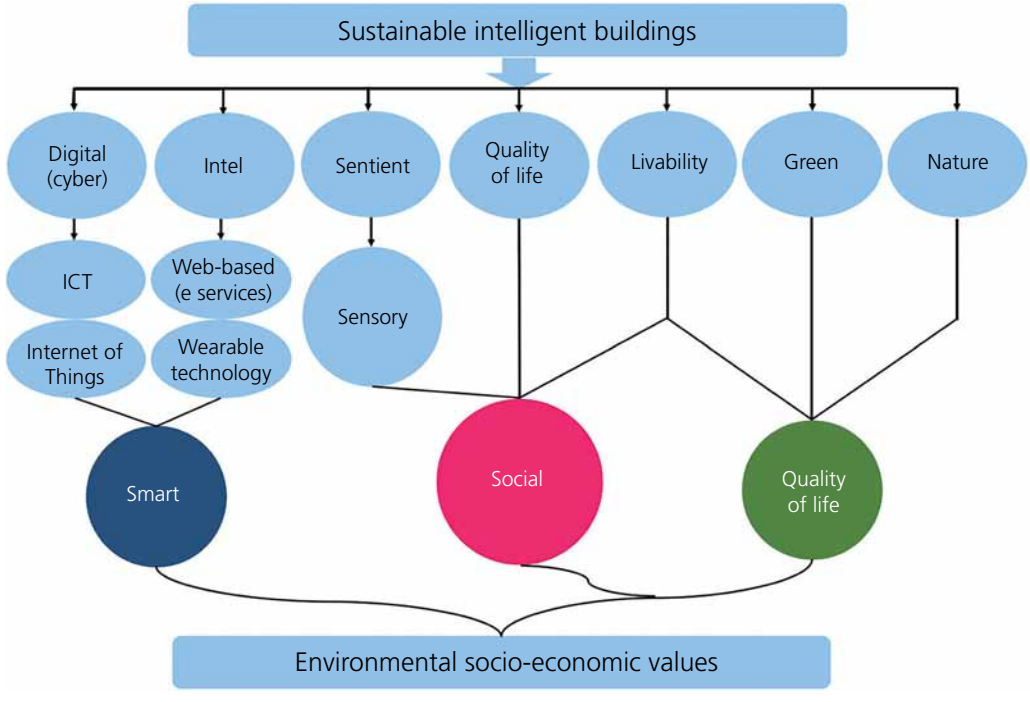
often quoted that the UK has the most poorly insulated homes in Europe. This simple measure of ensuring all homes are well insulated could be effective but, for rented and occupier-owned homes, difficult to put into practice without sufficient financial outlay. The mistake was assuming that because the UK has a temperate climate, insulation is less important than in colder regions like Scandinavia.

Heat pumps and hydrogen are ways being frequently discussed for well-insulated homes, but solar PV is becoming cheaper and attractive to install as the latest perovskite solar cells are becoming available and bringing efficiencies in the range of 25–40%, which are much higher than the present (2023) solar cells which are about 20% (see *Solar Superpower*, Stevenson, 2021). Energy storage with lithium batteries is becoming more feasible. Zhibin Yu (2017) at Glasgow University proposes that we should consider homes as integrated energy systems. This could mean an AI regulation of energy flows between all the systems and appliances, moving towards zero waste energy. The barrier to this might be human behaviour, so increasing the awareness of us all in respect of the energy profile we create is essential. Another problem is the skills gap as technology races ahead of our ability to install and operate newer technologies properly.

We hear a lot about net zero carbon buildings but much less about net positive carbon ones in which there is energy spare to feed back to the grid. It was welcoming, especially at this time of very high fuel costs, to read the article *Cutting Bills with Energy-Positive Homes* (Moloney *et al*., 2022). Research on this topic has been carried out at Cardiff University in recent years and so unsurprisingly these 14 new low-cost social homes are located at Stormy Downs in Bridgend and are part of the Welsh Government's three-year Innovative Housing Progamme. The homes are passively designed for low energy and use solar PV, lithium-ion battery storage and heat pumps to collect, store and distribute the energy flows. There are no other heating or cooling appliances. The construction cost is about 35% higher than the average build cost for Building Regulations-designed social housing but the typical annual running costs are £59 lower, as reported by Hoare Lea (2022). As energy loads for the building decrease to very low levels, the energy loads for equipment become even more significant – that is, loads that are highly affected by homeowner use, such as washing machines, fridges, dishwashers, ovens, plug-in sockets and towel rails. To attain carbon positive, which results in money being paid back to the consumer, residents need to be aware of how they can manage their energy consumption pattern. Care is also needed in choosing the tariff offered by the energy supplier.

Windows play a big role in achieving healthy and happy environments to work in. They are the entry points for natural light which is so important for health and well-being. They provide us with views which can offer interesting stimuli to our minds and offset the close eye focus needed for seeing computer screens which can be tiring. But then the downsides are overheating or high heat losses which can result in high energy consumption, glare and the transmission of ultraviolet (UV) radiation. The article *A Novel Window into Smart Glass* (Allen, 2022), which covers a range of research on increasing the performance and functionality of glass, is focused on windows for buildings. Electrochromic windows are not new but thermochromic ones are more recent. The window energy performance is controlled by changes in temperature rather than voltage. This is achieved by using a coating of vanadium dioxide or other materials such as perovskites (semiconductors which when light is incident on them transport electric charge and are used in the latest high-efficiency solar cells) which undergo phase transitions, hence becoming less or more transparent to solar radiation. There is still more research needed but early indications are that thermochromic windows could offer significant energy savings.

Figure 1.1 Key domains of focus for intelligent buildings (Clements-Croome, 2013)



1.5. Environment impacts people's minds and bodies

Human beings have physiological, psychological and social needs. Architecture has to reflect these. Well-being needs relevant to building design include

- social milieu
- freedom for solitary or group working
- opportunities to develop self-expression
- an interesting visual scene
- acceptable acoustic conditions
- contrast and random changes for the senses to react to
- opportunities to exercise or switch over from work to other stimulating activities

to which one may add the need for clean fresh air and a connection with nature.

A recent study from the Paris Brain Institute (ICM) explains why daylong cognitive work drains one's energy and can affect decision making (see Wiehler *et al*., 2022). Does concentration, memorising, multi-tasking and problem solving cause the brain to tire and hence decrease its efficacy in making decisions? They describe how nerve cells in the brain break down nutrients to release energy to think but, during this process, toxic by-products called metabolites are accumulated and one of these that proliferates is glutamate. Incidentally, one function of sleep is to clear these toxins. During the day, this build-up of toxins occurs in the lateral prefrontal cortex area of the brain but is particularly prevalent in subjects who are employed in high-demand jobs. Should we rearrange the

working day? For example, air traffic controllers work for 2 hours then break for 30 minutes, but should we consider this work pattern for other jobs requiring sustained concentration, like doctors, nurses and others? In general, this highlights the importance of mental well-being – a topic which has been neglected for far too long.

For some jobs, since the pandemic there has been more homeworking. It is thought this may be why there has been an increase in medical absenteeism and presenteeism due to musculoskeletal disorders in the UK at least. Backache and arm muscles often suffer as a result of prolonged sitting at computers.

The WELL V2 (IWBI, 2020) certification system for rating health and well-being seems to be a valid approach. A recent study from the USA entitled *Impact of WELL Certification on Occupant Satisfaction and Perceived Health, Well-Being, and Productivity: A Multi-Office Pre-Versus Post-Occupancy Evaluation* (Ildiri *et al*., 2022) concludes that occupants in WELL-certified office spaces reported improved satisfaction, health and productivity. No doubt replica studies will follow in other countries.

1.6. Some practical realities

Buildings need to be cared for otherwise they quickly deteriorate. Building maintenance has had little status except where safety is compromised and yet preventive maintenance not only costs less than repairing building failures, it also reduces ill health. Occupants become frustrated by systems that continually break down; buildings become non-sustainable and wasteful. Commissioning is another stage of the design process which is often neglected. Post-occupancy evaluation and continual commissioning are spoken of but too often not done, although this is now improving with the more recent emphasis on the health and well-being of occupants.

The three things that change a building most are economic and fashion markets, money and weather (temperature, moisture, water, frost). To protect a building over a long period it must be protected from markets and weather by maintaining it. Money should be sufficient to maintain the building so that it can run efficiently and effectively for its intended purposes and provide for renovation, but sadly too often maintenance budgets are seen unwisely as an opportunity to reduce costs in the short term.

The facilities manager has an essential role to cover the planning and design related to construction and renovation; coordinating facility changes and relocation; purchasing furnishings, equipment and external services as well as inventory management; developing facilities policies; long-term planning; building operations, maintenance and engineering; real estate procurement; disposal, reuse or recycling; post-occupancy evaluation and continual commissioning.

Human values are always overwhelmingly important, however sophisticated the technology. It is the people who use the space who understand best how it can be altered to be conducive to the work being undertaken. Materials and structural systems can be used which allow changes to be made easily.

Long-term outlooks are preferable to keeping only to short-term ones. Providing healthy environments should be seen as an investment not only as an expenditure. Good design and management of buildings with low energy demands tend to produce healthier buildings, for example. Capital cost outlooks without considering value do not respect these approaches; besides, cheap costs

usually turn out to be more expensive. More fundamentally, sustainability means sustaining for future generations, which can only be achieved with long-term outlooks.

Why is it that so many building projects overrun in terms of time and costs? Buildings take a long time to plan, design and construct. Within these spans of time to complete, economic markets change; human or material resources alter; priorities are viewed differently; technology zooms ahead. All this involves many stakeholders. It is not surprising that with this mix of inputs that produce a wealth of data, costs and time overrun. Flyvbjerg and Gardner (2023) propose eleven heuristics to improve project leadership and so decrease those risks described by Flyvbjerg (2003), which in some ways seem like common sense but, as many projects show, this is often sadly lacking.

The Grenfell tragedy in London in 2017 should never have happened. The book *Show Me the Bodies: How We Let Grenfell Happen* (Apps, 2022) paints a vivid but heart-wrenching story of how bad planning, design, construction and management decision-making can be in the 21st century. Apps concludes that 'it is a story of corporate structures that allowed human beings to abandon their own conscience and sense of agency and to think only about sales and profit margins'. We must heed the lessons learnt and ensure that this is never allowed to happen again.

All of these aspirations, hopes and ideas need leadership. The media recently highlighted the lack of leadership there is from government down to various sectors, whether it be in health, education, policing or local authorities. Isaiah Berlin (see Gill, 2014) comments on the virtues that a leader should have. He believed that the qualities that leaders or heads of organisations need are justice, kindness, imagination and intellectual power. I would add that a degree of humility is necessary too in a world in which this is sadly lacking.

1.7. Nature's intelligence

> Look deep into nature, and then you will understand everything better (Albert Einstein).
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> Biomimicry and biophilic design are approaches that seek to integrate nature into architecture to improve people's quality of life and reduce the environmental impact of buildings. Both approaches take into account natural processes and patterns to create more efficient, healthy and sustainable spaces. While there is still much to be done in this field, growing awareness of the importance of sustainability and health in building is driving greater adoption of these approaches in architecture (Contreras *et al*., 2023).

One of the advantages of studying behaviour in nature is that it makes us think laterally across several domains of knowledge. McGinley (2015) describes morphogenesis as the biological process which causes an organism to develop its shape. This concept is the inspiration which McGinley believes draws our attention to the transdisciplinary nature of the morphogenetic growth processes. He applies this to the building design process which he argues will let integration be more natural and easier to handle.

Our connection with nature is so important for our health and well-being besides presenting to us how plants and animals adapt to their surroundings, however harsh they may be, which they achieve with the minimum use of materials and energy expenditure. Trees cool our environment and sequester carbon dioxide. In his book *The Power of Trees* (Wohlleben, 2023) Peter Wohlleben argues we should trust and learn from nature on how to control global warming.