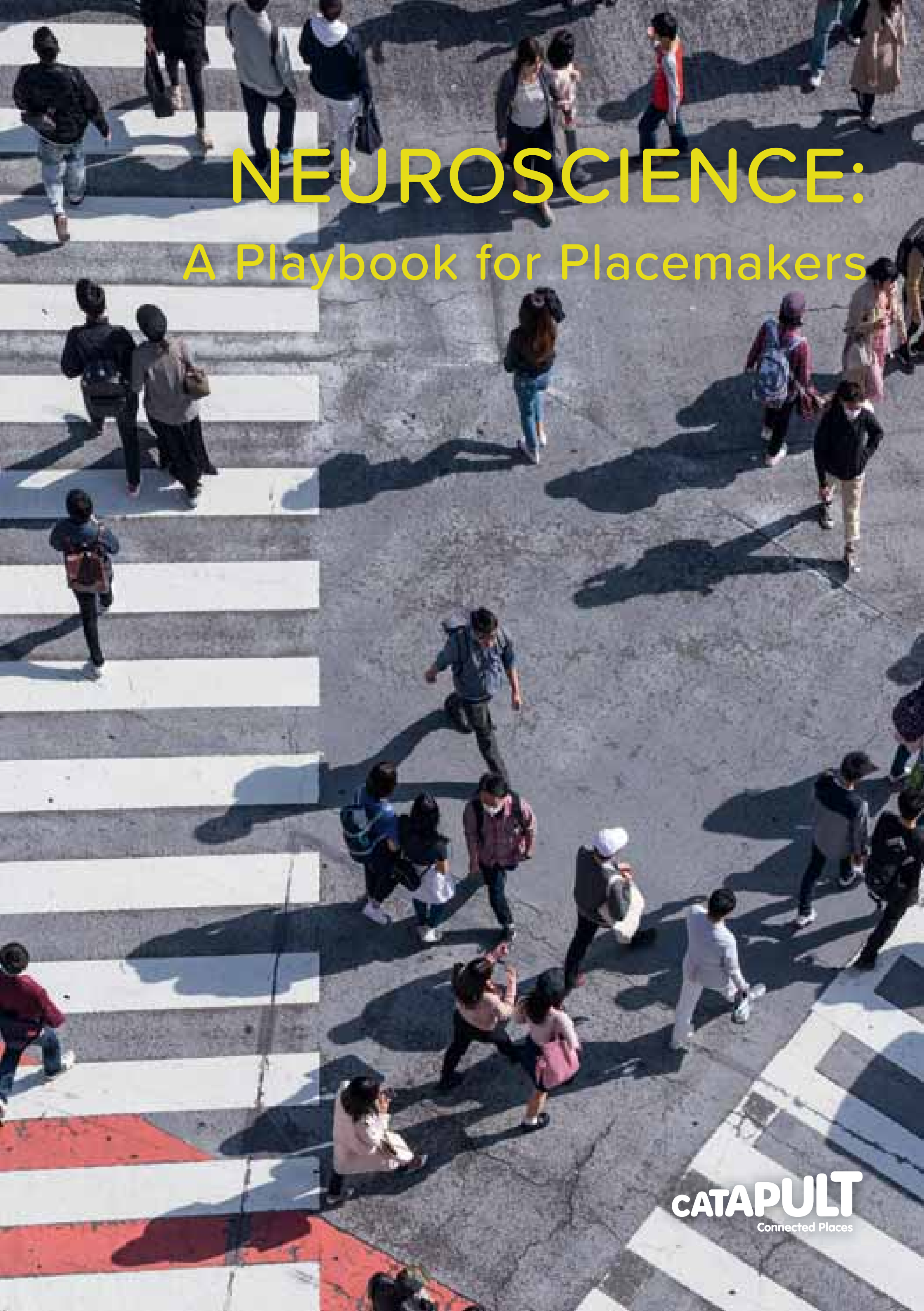
NEUROSCIENCE:

A Playbook for Placemakers



CATAPULT Connected Places

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Connected Places Catapult commissioned the Centric Lab in conjunction with University College London to bridge academic science and industry, with the purpose of providing new ways to understand how people experience the built environment.

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FOREWORD

Nicola Yates OBE
Chief Executive, Connected Places Catapult

At the Connected Places Catapult we work to help UK businesses address the Grand Challenges of today in order to create 'connected places', fit for the future. A key component in delivering that mission is connecting businesses to the latest and emerging academic research so that they can harness that knowledge to develop innovative propositions. This report, developed in close collaboration with the Centric Lab and University College London, is a prime example of that work to translate and communicate cutting edge academic thinking for commercial and public sector audiences.

In a globalised economy, highly mobile talent demands attractive places to live and work that enable high quality of life, maximise productivity and promote innovative problem-solving. City managers and corporates seeking to attract and retain such talent must pay close consideration to the quality of the spaces they provide.

Developments in neuroscience are showing us new ways to understand how people experience the built environment, revealing new opportunities for innovation and improved experiences, leading in turn to greater productivity, wellbeing and attraction. Neuroscientists are also discovering important insights about outcomes for the less advantaged in our cities, providing compelling evidence in support of interventions to tackle the negative health impacts of city living, and ways to reduce barriers to access and opportunity.

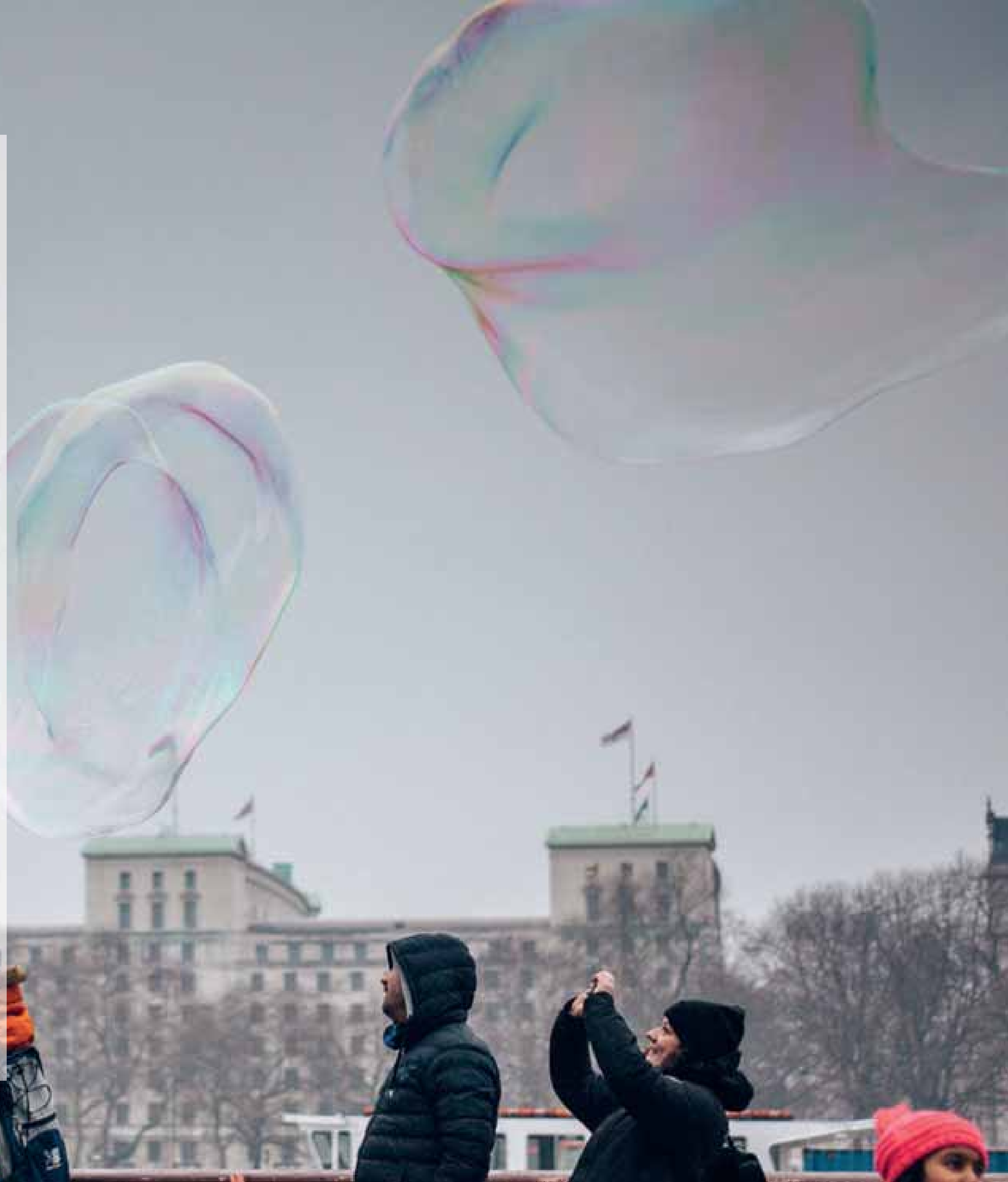
Whether you are reading this playbook from the perspective of business or the public sector, I hope that you will find it a helpful resource to explore the potential applications of this important area of research.

WELCOME

Nick Tyler CBE FREng
Chadwick Professor of Civil Engineering
Faculty of Engineering Science
University College London – UK

Often when we think about a city we think about it on a grand scale and mainly in terms of buildings and tall structures. However, I don't see it that way: a city is people. We should think about the city not at the scale of buildings, but at the scale of people. For me, a person can never walk on the same street twice. People recreate their city every time they experience it; the urban environment is not made up of a combination of static structures and memories, but is instead an ephemeral place where people constantly experience their surroundings afresh. Furthermore, we should think about how to make cities for everyone, this means employing the full range of cognitive, physical and perceptual variety so that everyone can create the city they want, every time they experience it.

This is where neuroscience can help with the making of cities: understanding how people from a wide variety of perspectives can create their individual-yet-collective life in cities. Cities are intricate sensorial ecosystems connecting people for the survival of culture and society. With neuroscience we can discover how to help people respond to their sensorial perceptions so that this ecosystem can really work for them. We can then use this knowledge to orchestrate ever-renewing perceptions and create a responsive 'symphony of the city' that will enable, even inspire, people to meet their constantly changing desires, needs and challenges.



EXECUTIVE SUMMARY

Cities have a long-standing reputation of being epicentres of culture, politics and industry owing to cohesive social networks facilitated by their concentrated infrastructure. From a societal perspective, cities catalyse movements and inventions, making them highly important to human society. While we often think of cities in terms of great buildings or iconic streets, at their core cities are people. It is people who guide the visions of cities across all parameters of influence. Economic growth and culture are driven by human effort. City design and infrastructure are constructs of human imagination. Lives led in cities are based on human aspirations. Therefore it makes sense for cities to be seen as the scaffolding that supports and holds human activity.

This perspective is not new, there has been a strong and historical catalogue of work that supports the theory of 'human centricity'. Many architects, engineers, and urban planners have launched city plans to make cities prosperous, industrious, and exciting places to live. In fact, there is already substantial data on what makes a 'good' city. In her book, The Death and Life of the Great American City, urban theorist, Jane Jacobs highlights four qualities that cornerstone a great city: mixed land use, small blocks, high density, and diverse architecture. Given then inordinate amount of knowledge and theory on cities, it would be redundant for neuroscience to comment from this perspective. Instead it should be seen as a tool that allows those who work in the cities to understand the consequences of their work on human biology.

In a globalised economy, mobile individuals want attractive places to live, work and play, and that provide a high quality of life. City representatives and corporates seeking to attract and retain talent must pay close consideration to the quality of the spaces they provide, and their relationships to key economic attributes of high productivity and complex problem-solving. With neuroscience, we now have the opportunity to think about concepts such as productivity and quality of life from a human biological perspective. Allowing us to go one step further into theories of 'human-centric' city planning. For the use of this playbook, we are defining neuroscience as a multidisciplinary branch of biology and is the scientific study of the brain and nervous system, including its interaction with the other parts of the body.

This playbook illustrates the potential neuroscience can bring to the built environment: ranging discussion of how it works with emerging technology, how it utilises and qualifies urban planning theory, and how it can contribute insight to increase the user experience of cities, which in turn, leads to greater productivity, wellbeing and desirability.

For the full scope of opportunities that neuroscience provides, please see the infographic in the adjacent pages.

City analysts predict the rise of 'mega-cities', much to the excitement of economists, civic leaders, and builders; the construction rate alone will create substantial economic growth. Numbers indicate more job prospects, more goods and services to consume, and boundless opportunities for high-level innovation However, growth without purpose or measure could potentially lead to a high human cost, which could turn living in cities undesirable. Especially as cities are already facing a mental health crisis, which, without immediate intervention, could get worse. Providing solutions to mental and physical health challenges in cities is crucial for economic development. In New York City alone, 4% of the adult population have a serious mental health issue. This equates to roughly 230,000 adults who are not at their productive best and who cannot fully engage with the city's services and products.

Through the merging of technology and neuroscience, urban planners, government, and city experts have the opportunity to turn around the adverse effects of environmental stressors and catapult cities into a new era. Why shouldn't a city be a place of convergence, culture, and knowledge mobility, as well as healthy places to live?

Neuroscience will undoubtedly be a catalyst for new era of built environment innovation. With time and technological advancement, neuroscience will be able to help us understand the nuances of human biology, as it is affected by the built environment. This will lead to the sophisticated orchestration of different physical environmental elements such as light, sound, or street typography.

To reach this level of adaptiveness, we need the support of multi-disciplinary programmes and laboratories. For example, the Ecological Brain Project at University College London (UCL) aims to harness and develop 'new methods and techniques to measure behaviour and brain activity in the wild'. With the objective of understanding how the brain solves real world problems in real time.

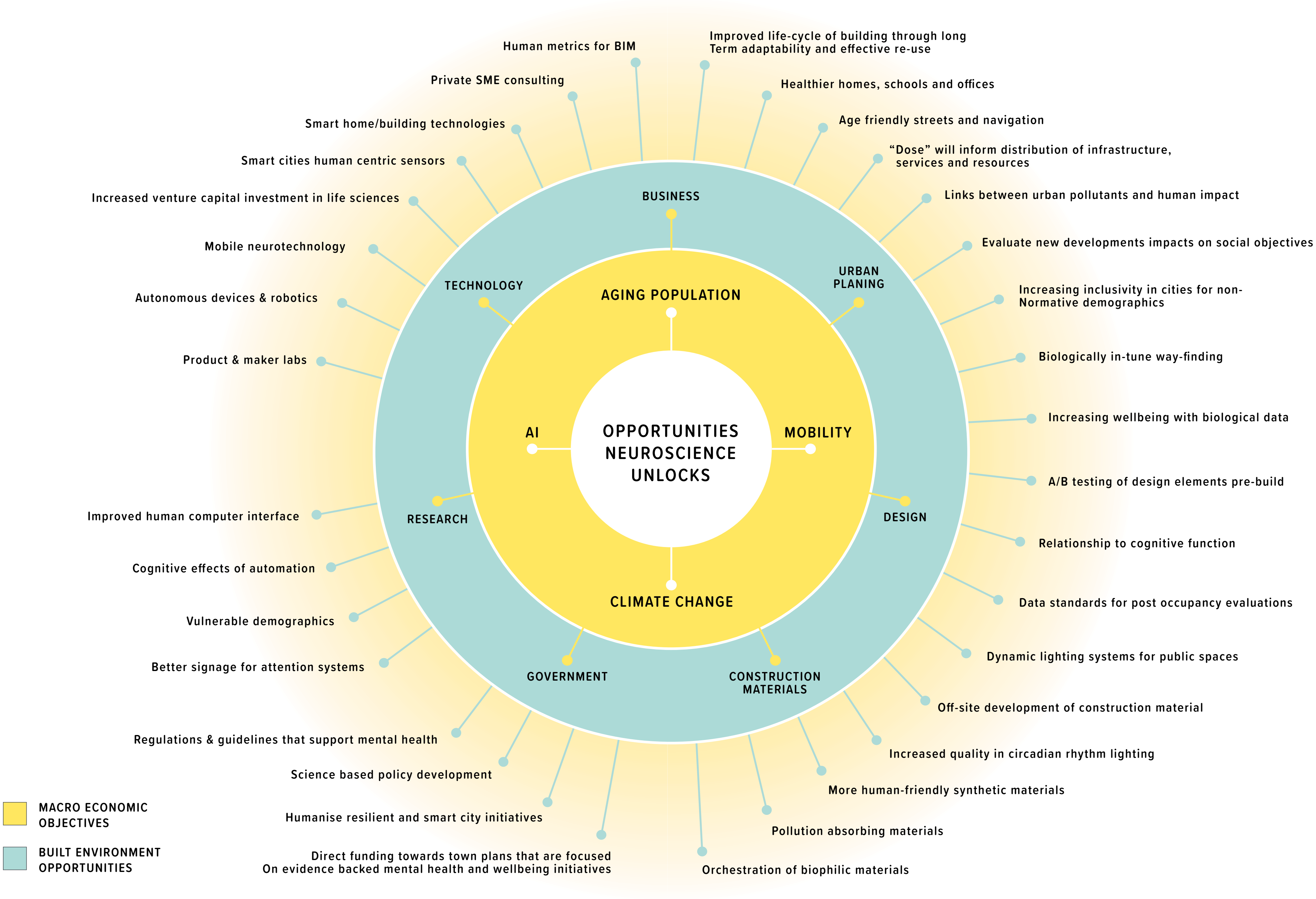
One of the most exciting aspects about these types of programmes is their extensive collaboration between different areas of science and industry. The future of cities looks to be in great hands as they continue to sprout all over the world.

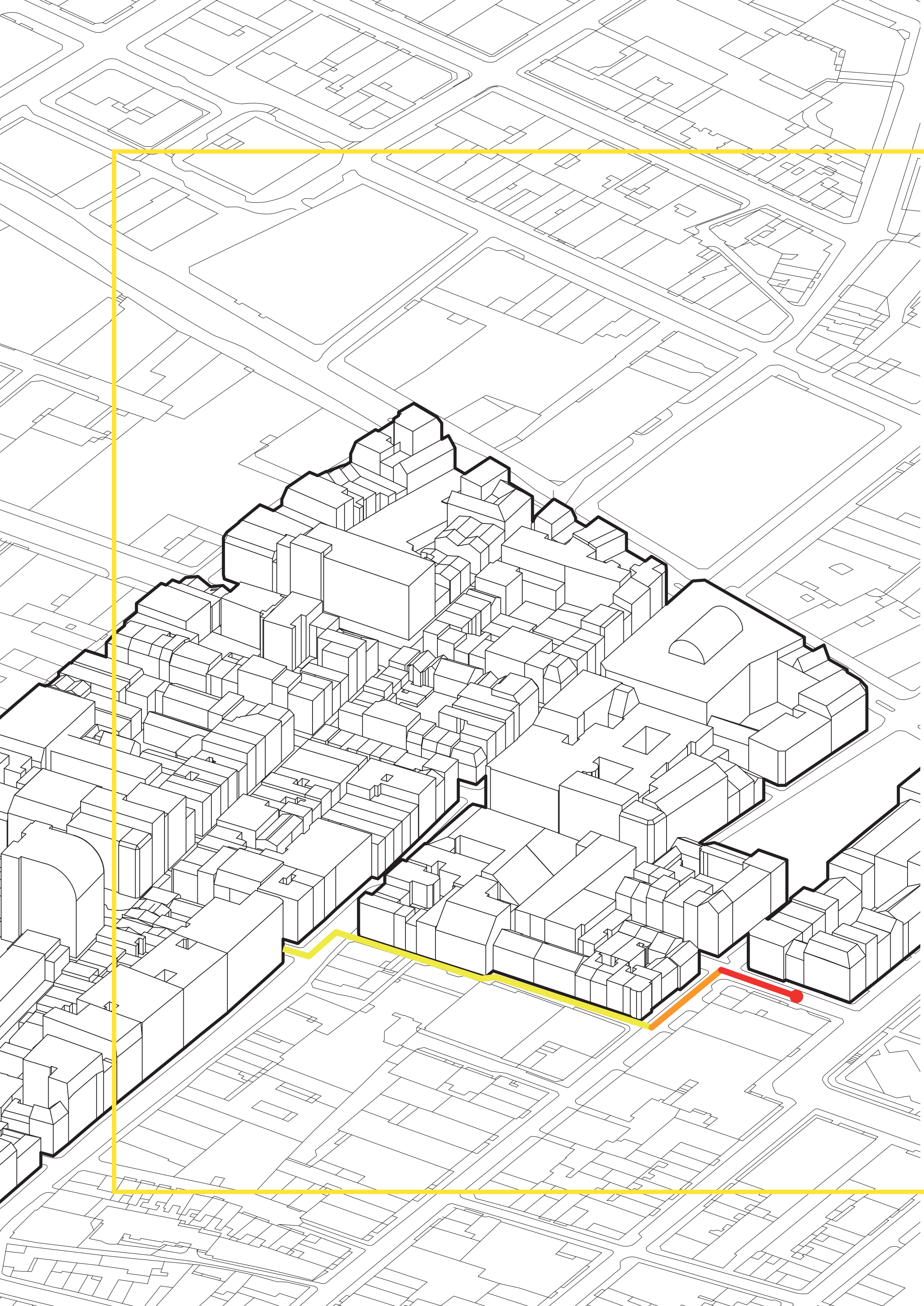
As new neuroscience technologies emerge, such as the recently reported portable Magnetoencephalography system created by UCL and the Wellcome Trust, they will allow for an increased depth of study into humans in 'the wild'. This device will not only help with clinical applications, but could feasibly be used to study brain activity as people navigate in natural environments.

This technology can also be used in tandem with other technology, such as Augmented Reality (AR) or Virtual Reality (VR), to compare the brain activity of different environments. This is especially useful when studying variant demographics which show differences in spatial cognition, such as those with visual challenges, people on the autism spectrum disorder, dementia, or those with depression.

Twenty years ago, to tell a property developer they could virtually walk through their future development using their smart telephone would have seemed impossible. Twenty years from now we may look back and wonder how we ever planned cities without the use of cognitive and biological data.

It is exciting to present a new tool for the advancement of city life and potentially catalyse a new industry.


OPPORTUNITIES NEUROSCIENCE UNLOCKS
AGING POPULATION
AI
MOBILITY
CLIMATE CHANGE
BUSINESS
TECHNOLOGY
URBAN PLANING
RESEARCH
DESIGN
GOVERNMENT
CONSTRUCTION MATERIALS
Human metrics for BIM
Improved life-cycle of building through long
Term adaptability and effective re-use
Private SME consulting
Healthier homes, schools and offices
Smart home/building technologies
Age friendly streets and navigation
Smart cities human centric sensors
"Dose" will inform distribution of infrastructure,
services and resources
Increased venture capital investment in life sciences
Links between urban pollutants and human impact
Mobile neurotechnology
Evaluate new developments impacts on social objectives
Autonomous devices & robotics
Increasing inclusivity in cities for non-
Normative demographics
Product & maker labs
Biologically in-tune way-finding
Increasing wellbeing with biological data
A/B testing of design elements pre-build
Improved human computer interface
Relationship to cognitive function
Cognitive effects of automation
Data standards for post occupancy evaluations
Vulnerable demographics
Dynamic lighting systems for public spaces
Better signage for attention systems
Off-site development of construction material
Regulations & guidelines that support mental health
Increased quality in circadian rhythm lighting
Science based policy development
More human-friendly synthetic materials
Humanise resilient and smart city initiatives
Pollution absorbing materials
Direct funding towards town plans that are focused
On evidence backed mental health and wellbeing initiatives
Orchestration of biophilic materials
MACRO ECONOMIC OBJECTIVES
BUILT ENVIRONMENT OPPORTUNITIES



1. INTRODUCTION

As this playbook will cover a wide range of concepts and scientific research, it is important to start with the definitions and establish context for this work. We would like this playbook to be seen as a framework for applying neuroscience into the built environment and be used as a platform to catalyse new research, business opportunities, and theories for future application.

We expect this document to also instigate debate and further conversation across all industries. This means that whilst this is bringing together a cohesive and detailed instruction for application, it is still within the confinements of exploration.

WHAT IS NEUROSCIENCE

Neuroscience is a multidisciplinary branch of biology and is the scientific study of the brain and nervous system, including its interaction with the other parts of the body[1]. A broad definition, as is used here, includes the study of human thought, emotions and behaviour since each of these functions arise from the brain and nervous system. The study of the mind, without reference to brain function, has a long tradition in the field of experimental psychology. More recently experimental psychological methods and neuroscience methods have been integrated in the field of cognitive neuroscience, which seeks to provide a neural basis for behaviour and cognition. Such an approach has been important for areas such as mental health disorders where cognitive models needs to be integrated with neural data.

To explore the full impact of neuroscience on how humans interact with the built environment, we integrate findings from experimental psychology, mental health research and cognitive neuroscience, with the study of individual brain cells (neurons) and specific brain circuits. We also examine brain-body-environment interactions such as the stress response[2] of certain environmental factors such as light, which can have a potential effect on circadian rhythms, thus affecting our sleep[3].

In this playbook we draw on the field of neuroscience and its related disciplines of psychology and physiology; research across these fields works to inform us about how the human brain reacts and interacts with the built environment.

1. Neuroscience. (n.d.) In: *Oxford Living Dictionaries* [online] Available at: https://en.oxforddictionaries.com/definition/neuroscience [Accessed 19 Apr. 2018]
2. Everly, G.S and Lating, J.M. (2012) The Anatomy and Physiology of the Human Stress Response. In: *A Clinical Guide to the Treatment of the Human Stress Response*, 3rd ed. New York: Springer, pp. 17-51.
3. Jung, C.M et al. (2010). Acute Effects of Bright Light Exposure on Cortisol Levels. *Journal of Biological Rhythms*, 25(3), pp. 208-216.

WHAT IS THE BUILT ENVIRONMENT

In regards to the built environment, it can be defined through macro elements such as urban design, public areas, land use, and transportation systems. As well as through micro elements such as streets, neighbourhoods, and buildings. However, it is of no use to only define the built environment without its main purpose, which is to support "patterns of human activity"[1].

For the businesses in the built environment industries of transport, planning, and development this playbook covers how incorporating neuroscience into brief development and programming stages might help to improve adoption rates and long-term usage. Early-stage risk assessments will help ensure that the allocation of finite resources will lead to an effective and enhanced human-task-space relationship. As the science progresses and refines knowledge, these findings will inform standards and new modelling programmes. Neuroscience will add a sophisticated layer of intelligence onto understanding how urban environments can become resilient from a human perspective.

This will lead to the sophisticated orchestration of different physical environmental elements such as light, sound, or street typography. Imagine planning a neighbourhood that anticipates how a person with visual differences might respond to shadows, heights or grey-scales, or how city sounds might play a role in their spatial navigation.

1. Handy, S.L., Boarnet, M.G., Ewing, R. and Killingsworth, R.E. (2002) How the built environment affects physical activity. *American Journal of Preventive Medicine*, 23(2), pp. 64-73.

WHY IT MAKES SENSE TO USE NEUROSCIENCE IN THE BUILT ENVIRONMENT

All animals adapt their environments to fit their needs and ensure survival. Humans have done the same, except at a far greater scale, allowing us to build cities and societies[1]. The changes and adaptations we impose on our environments have been to ensure survival, both from an immediate point of safety and culturally. For example, the invention of aqueducts provided us access to water more effectively and readily. This adaptation not only ensured our immediate survival as water is an essential element to all living life, it also catalysed an opportunity to create more complex habitats such as cities as we were no longer tied to a specific water source or dependent on weather fluctuations[2].

The level of sophistication of our adaptations is driven by the type of technology and science available to us at any given time. Now that we have entered a new era of rapid advances in technology and insight into the workings of the human brain, it makes sense for us to explore these new tools and insights for even greater adaptation.

To some academics and industry professionals neuroscience may seem like an unlikely ally for the built environment. Afterall one is intrinsically biological whilst the other is intrinsically non-biological, however, the built environment provides the backdrop or the "set" for much human activity. Cities are places where people are birthed, where they create and where they grow old. In informal terms neuroscience is the science of humans; it teaches us about howwe perceive the world, how our brain develops, how we think, why we think, how we problem-solve, and how we interact with the world. Therefore it makes sense to use neuroscience to better understand the relationship between people and the physical world. This could provide us insights to address questions such as; how are people's mental health and sense of place impacted by city expansion? Is air pollution having an effect on the neurodevelopment of children? How do variable demographics such as those with visual impairments use sensorial information differently to navigate cities?

As already stated, humans have learned to adapt and manipulate their environments to ensure survival. Now we have a new knowledge pool and tools to exploit, to help us create more sophisticated adaptations for our evolving needs, ones that ensure our prosperity and good for the greater ecosystem.

1. Poon, L. (2017) Cities are one big evolutionary experiment. Citylab. Available at: https://www.citylab.com/environment/2017/11/urbanization-is-one-big-evolutionary-experiment/544562/ [Accessed 12 Feb. 2018]
2. Encyclopaedia Britannica (2018) Aqueduct. [online]. Available at: https://www.britannica.com/technology/aqueduct-engineering [Accessed 07 Mar. 2018]

ETHICS AND SCIENCE SCRUTINY

As we are breaking new ground with our proposed framework it is important to discuss ethics. In writing this playbook we have carefully selected studies based on their scientific merit and ethical approval. In the media, books and some academic articles, neuroscience is misused to explain phenomena, and interpreted far beyond the data can warrant, for example, the endogenous molecule dopamine is often credited as the 'feel good' chemical in the brain[1]. Whereas its role is much more complex and relates to predictions about possible outcomes[2]. Neuroscience and neuroimaging (brain scanning) research in particular, has been prone to misguided interpretations of reverse inference[3].

To take an example argument:
1. We know that a brain area called the anterior cingulate is involved in reward.
2. We observe the anterior cingulate more activated by red objects than other objects in our neuroimaging task.
3. Therefore red objects are more rewarding to humans than other objects.

This interpretation relies on the assumption that the anterior cingulate is only activated by reward. This, however, is not the case, and the interpretation in our example is an overreach and simplification of the science. This type of interpretation is often taken even further when it is translated to 'industry speak'; one potential impact of this would be to say, 'studies show that the brain is hard-wired to be attracted to the colour red, so we have included the colour in our entrances to attract customers.' In short, for this playbook we have worked to avoid this type of mistranslation.

1. ADHD-BeCalmd, (2007). Neu-BeCalm'd Natural Product For Dopamine Production. [Online] Available at: http://www.adhd-becalmd.com/dopamine.html [Accessed 19 Apr. 2018]
2. Schultz, W., Dayan, P. and Montague, P.R. (1997) A neural substrate of prediction and reward. Science, 275(5306), pp. 1593-1599.
3. Poldrack, R.A. (2006) Can cognitive processes be inferred from neuroimaging data? Trends in Cognitive Science. 10(2), pp. 59-63.

A CALL TO ACTION

Despite the incredible human ability to adapt, currently we are facing a human crisis in cities. This is not to sound alarmist, but to point out the urgency behind this playbook. Scientists all over the world are looking at the adverse effects of city life. Research shows that the prevalence of mental health problems is greater in cities than in rural areas[1], however the full scope of determining factors is not yet known. Both urban and rural environments are complex ecosystems with many variables, so it would be an oversight to assume that 'city life' is a central driver of mental health related illness. Nonetheless, certain toxins (produced by traffic, industrial parks), environmental stressors (noise and light pollution), climate conditions (urban heat islands) and social conditions (isolation), all of which are interlinked with cities, have been found to contribute to mental health problems[1-4]. The research on mental health in cities goes far beyond 'self-reported' questionnaires, and explores the links between the incidence of mental health disorders and the environment. There is direct link between the above factors and the biological aspects of mental health, which we discuss in detail throughout the playbook.

These statistics are to highlight what we are facing rather than give cities a bad reputation. Cities can be places of health and human prosperity, however we must start taking action sooner rather than later.

1. Mayor of London (2014) London mental health: The invisible costs of mental ill health. [online] London: Greater London Authority. Available at: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Mental%20health%20report.pdf [Accessed 19 Apr. 2018]
2. Kearney, L. (2015) New York City finds one in five adults has mental health problems. Reuters, [online]. Available at: https://www.reuters.com/article/us-new-york-mentalhealth/new-york-city-finds-one-in-five-adults-has-mental-health-problems-idUSKCN0T12O020151112 [Accessed 19 Apr. 2018]
3. Black Dog Institute (n.d.) Facts & figures about mental health. [online] Available at: https://www.blackdoginstitute.org.au/docs/default-source/factsheets/facts_figures.pdf?sfvrsn=8 [Accessed 19 Apr. 2018]
4. China Daily, (2016) 100 million people suffer depression in China. [online] Available at: http://www.chinadaily.com.cn/china/2016-11/28/content_27501518.htm [Accessed 19 Apr. 2018]

£26 billion in mental health cost to London[1]

1 in 4 people experience a diagnosable mental health condition in London[1]

1 in 10 children in London experience a diagnosable mental health condition[1]

38.5% in the UK experience high levels of anxiety[1]

42.1% in inner London experience high levels of anxiety[1]

1 in 5 people in New York City suffer from mental health problems[2]

1 in 5 people in Australia suffer from mental health problems[3]

20% of all cases of illness in China are mental health related[4]

2. USING THE PLAYBOOK

In this playbook we use neuroscience research for three types of outcomes. The first is to increase knowledge of well-known environmental stressors, to understand their effects both on our physiological and cognitive development. Secondly, we discuss the potential of new tools to measure the brain activity in relation to the built environment. Finally, neuroscience is used as a biological lens to examine well-known metrics and guide recommendations in relation to physical comforts.

3 PILLARS

PEOPLE

- Enhance social cohesion
- Increase user experience of cities across demographics
- Create places that support human productivity
- Increase engagement of the city at a lower human cost

BUSINESS

- Validate the use and investment support of emerging technology
- Catalyse the beginning of new industry

INFRASTRUCTURE

- Equitable distribution of infrastructure
- Increased mobility across all demographics including the neurologically diverse
- Highlight the effects of environmental stressors

HOW INDUSTRY SHOULD USE THE PLAYBOOK

This outline is a quick glance as to which industries this playbook might be of interest to and suggestions of usage. We hope that this playbook is a springboard for new ideas and opportunities.

URBAN PLANNING

- Scientific evidence to support new city growth strategies
- Understand the physiological and cognitive effect of poor transport infrastructure
- Wayfinding ideas for enhanced inclusive mobility for all demographics

ARCHITECTS & URBAN DESIGNERS

- A deeper understanding of how physical comforts and elements effect people on a physiological and cognitive perspective
- A human-based risk assessment process to avoid unintended consequences of physical elements on experience

BUSINESS

- Evidence for supporting tech products that help enhance user experience of cities and buildings
- New business and start-up opportunities from the evaluations highlighted in this document

CITY REPS & GOVERNMENT AUTHORITIES

- Recommendations for enhancing quality of life
- Insights to help attract talent to cities
- Have a new human lens and toolkit for setting city strategies such as the New London Plan and Local Enterprise Partnership manifestos

PRIVATE DEVELOPMENT INDUSTRY

- Understand how macro-city trends will affect what people will need and expect from developments
- Learn how environmental and urban stressors impact quality of life
- Develop methodologies to avoid low adoption rates through user experience insights and testing
- Scientific insights to deliver the next wave of housing, offices, and leisure spaces fit for multi-generational, differently abled, and neurodiverse use

ACADEMICS & RESEARCHERS

- Gather information from other disciplines to understand how neuroscience can influence the built environment on a global scale, catalysing opportunities for future research
- Provide evidence for future grant applications, specifically in support of impact statements for research councils

LIMITATIONS AND CAVEATS

This section is to ensure there is clarity about the limitations and caveats regarding the use of the playbook.

Architectural Design Determinism

There is a risk of using this playbook to support a line of thought that could be seen as deterministic. The term architectural design determinism is the term applied to the "concept that building environments directly affect behaviour and attitudes[1]." Although neuroscience provides a deeper lens from which to understand people, this is still quite far from thinking it is possible to control with certainty the final output of behaviour by making adjustments to the built environment. It is difficult to define the line, however we shall endeavour to do so by providing a very simple example.

Research into the non visual effects of natural light indicate changes in cortisol levels, cognitive performance, and circadian rhythm[2]. Additionally, natural light has been linked to better scholastic performance in children and higher productivity in the workplace. However, using natural light in a workspace design may not necessarily have a favourable effect on everyone in the space. Nor should it be expected that this factor alone will determine higher levels of the general productivity of a worker. In a real world context we should consider the many factors at play, for instance, if the people are conducting a task (e.g. software coding) that requires a lot of screen time, natural light might have a different effect than for those conducting a task with little screen time (e.g. a face to face meeting)[3]. Most of the literature links productivity with natural light through its effects on the circadian system. Studies have shown the prolonged amount of time in blue light may have an effect on circadian function and thus present a change in sleep patterns[3]. These changes to sleep patterns in turn may affect aspects of productivity, such as focus, due to sleep deprivation[3]. However, one recent study has provided another view, it proposes that the effects of blue light might be related to the circadian phase of light exposure[9]. This means that the effects are related to where in the circadian phase a person is when exposed to blue light rather than it being a universal effect. This is important, as it showcases the nuances in our biology and the need to understand them. In short, when it comes to neuroscience, 'x' does not always equal 'y'.

As we said, the line is fine and a great example of where physical elements have had a perceived positive effect are within varied demographics such as those within the Autism Spectrum Disorder (ASD). Schools designed with considerations for ASD symptomatology such as anxiety and noise sensitivity indicate to be better choices than mainstream schools[7]. These instances should be held up as example of best practice and supported with further neuroscience research.

Relationship doesn't mean causality

A limitation of correlating human behaviour to the built environment is that these relationships are often viewed as causal. This is especially true when creating a through-line between a built environment element (cause) and tying it to a socially complex behaviour (effect).

For example, a recent study investigating the correlates between air pollution and crime, pointed to some compelling evidence[10]. However it would be remiss to interpret its results as "air pollution causes crime". Crime or antisocial behaviour[11] is a highly complex social, biological, genetic, and physiological phenomena, therefore interpreting corollary findings as causal can be misguided and oversimplified.

Context

The final part to consider for this section is context. For example, there have been many studies on the effects of high rise buildings. Some studies suggest that high-rise living promotes unhealthy social and health habits, whilst others indicate that they allow for social cohesion[1]. There is even evidence that those living in the upper floors breathe cleaner air[1]. However, there is a risk and limitation in studying a particular physical element in isolation. In a review of high-rise studies, it argued that new studies need to look at other non-building factors, including "characteristics and qualities of the residents themselves, and the surrounding physical and resource context. These factors moderate the relation between living in high-rise and outcomes of living in one"[12]. In Chapter 5 the playbook will detail what tools and methods can be used to establish further context.

> Autism Spectrum Disorder – "Is one of the most common neurodevelopmental disorders. According to the Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM5), the core symptoms of ASD comprise deficits in social communication and interaction, repetitive and restricted behaviours, and sensory abnormalities."[8]

1. Marmot, A. (2002) Architectural determinism: Does design change behaviour? British Journal of General Practice, 52(476), pp. 252-253.
2. Harb, F., Hidalgo, M.P. and Martau, B. (2015) Lack of exposure to natural light in the workspace is associated with physiological, sleep and depressive symptoms. Chronobiology International, 32(3), pp. 368-375.
3. Webb, A.R. (2006) Considerations for lighting in the built environment: Non-visual effects of light. Energy and Buildings, (38), pp. 721-727.
4. Wikipedia (n.d). Standard deviation. [online] Available at: https://en.wikipedia.org/wiki/Standard_deviation [Accessed 7 Apr. 2018].
5. Swets, J.A. (1961) Is there a sensory threshold? Science, 134(3473), pp. 168-177.
6. Sinding, C., et al. (2017) New determinants of olfactory habituation. Scientific Reports, 7(41047), pp. 1-11.
7. Scott, I. (2009) Designing learning spaces for children on the autism spectrum. Good Autism Practice, 10(1), pp. 36-51.
8. Loth, E., et al. (2016) Identification and validation of biomarkers for autism spectrum disorders. Nature Reviews Drug Discovery, 15(1), pp. 70-73.
9. Jung, C.M. et al., (2010) Acute effects of bright light exposure on cortisol levels. Journal of Biological Rhythms, 25(3), pp. 208-216.
10. Bondy, M., Roth, S. and Sager, L. (2018) Crime is in the air: The contemporaneous relationship between air pollution and crime. [online] London: Institute of Labor Economics. Available at: http://ftp.iza.org/dp11492.pdf [Accessed 17 Apr. 2018].
11. Rowe, D.C. (1986) Genetic and environmental component of antisocial behaviour: a study of 265 twin pairs. Criminology, 24(3), pp. 513-532.
12. Gifford, R. (2007) The consequences of living in high-rise buildings. Architectural Science Review, 50(1), pp. 2-17.

FURTHER POINTS OF CONSIDERATION

1. Recommendations have to work in tandem with other integral elements such as social services and community led initiatives.

2. We must understand the limitations of the built environment effect. In other words we cannot see ourselves as just input/output predictable machines.

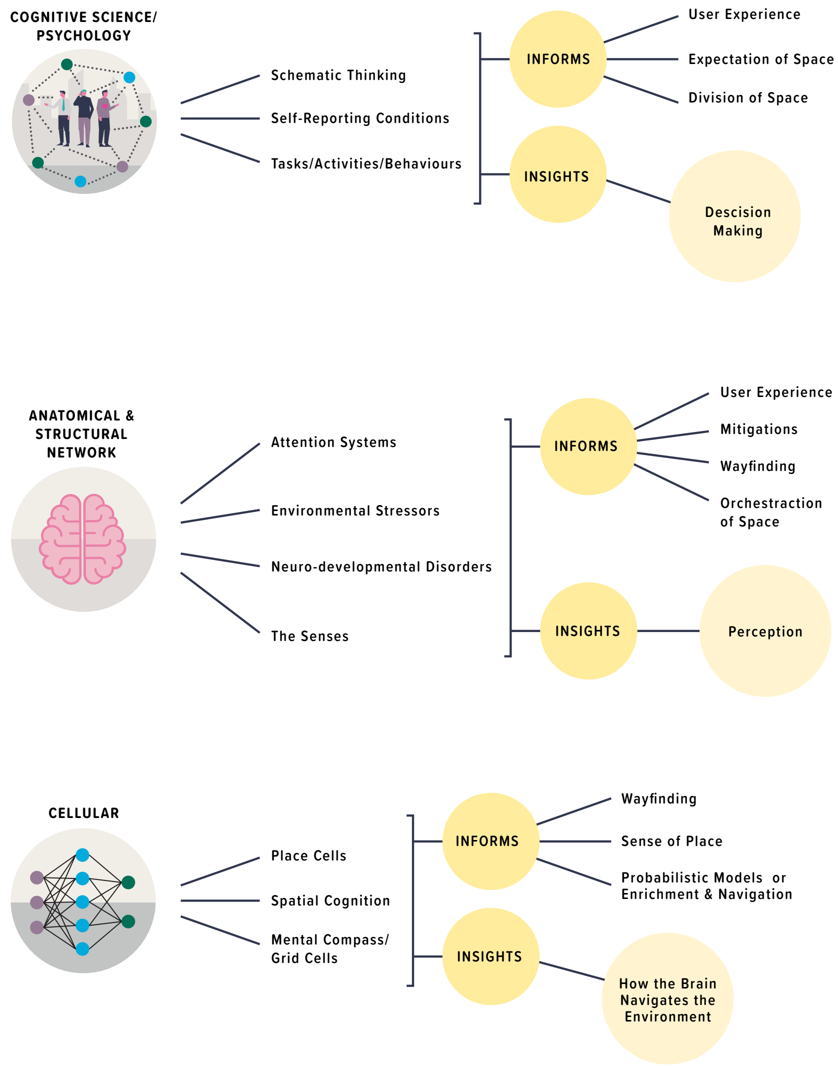
3. We should understand the margin of error and the standard deviation of every intervention made to the built environment.

4. We should understand that the physical elements give affordances to certain
5. tasks and actions, but will not necessarily guide behaviour.

6. Finally, there is a difference between enhancing the user experience of an area and thinking that design will be fix-all-solution to complex societal problems.

THE SCALE OF NEUROSCIENCE

One of the foundational elements that ensures neuroscience is translated and applied appropriately, is through understanding which scale (ranging individual neurons to psychology) is best for different methods of the study of the built environment and application of neuroscience.



NEUROSCIENCE IMPACTING THE BUILT ENVIRONMENT

This table is an index of the various ways neuroscience has the potential to influence and transform the built environment.

LENS	• Understand unintended human consequences (e.g. examine whether well-lit streets cause sleep disturbances for local residents). • A sophisticated lens to understand the biological and cognitive effects of city infrastructure. • Identify methods and mitigation techniques for buildings and cities to increase usability, wellbeing, and productivity for users. (see chapter 6 and 7 for more details) • With the use of VR, AR, mobile biosensing devices (e.g. mobile electroencephalography), and A/B (controlled experiment with two variables) testing of different environments can be used to assess how people navigate different environments. This provides urban planners and architects with a new tool and process to analyse the effectiveness of design options.
QUALITY	• Help streamline a coherent universal strategy for measuring and defining, wellbeing, productivity and the quality of place, based on biological/cognitive baselines. Opening up the opportunity for universal codes and less ambiguity for planners. • Offering a high level of user experience is becoming a primary driver of commercial real estate companies in attracting occupiers, customers and users. Through identifying how people perform tasks from a cognitive perspective it will be possible to orchestrate environments to support them. Removing stressors from this investigatory process will elevate user experience. • Neuroscience compliments the built environment industry's (inc. transport, city planning, services and infrastructure) drive for efficiency and functionality by ensuring a high level of user experience through every stage of their journey.
ADAPTABILITY	• A living lab is a research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts. Deploying co-created and user-centred programs in neighbourhoods would allow scientists and built environment practitioners to observe changes in residents through the use of smart sensors. Any changes can then be studied to assess and mitigate root causes of human problems within the built environment. • Neuroscience, together with living labs and smart city technology, could change cities from passive to dynamic systems that are responsive to human needs by making iterative changes to the built environment using biological and city data.

3. A HISTORY AND REVIEW

This section is a brief overview of the instances where biomechanics, social sciences, and behavioural observations have been introduced to the built environment. This is to highlight that using human based science is not new. The second section will be a brief review of past studies and theories of neuroscience in the built environment.

THE HUMAN SCIENCE OF CITIES

The next three sections discuss how human based sciences have been used in the built environment with great effect. Neuroscience is simply the next evolution.

Biomechanics and Social Sciences

A desire to understand how human biology and cognitive elements relate to the built environment, is not new[1], nor is the application of this understanding to make improvements to specific built environments, for example in industrial factory environments[1]. Industrial engineering has used human data to increase productivity and efficiency in manufacturing economies since the Industrial Revolution[1]. Investigations into the biomechanics of the human body in relationship to a specific task reveal that productivity could be increased if the body was more efficient through being better accommodated by the physical elements of the factory environment. Adjustments to ergonomics, air quality, space layout, thermal conditions and lighting have been used to improve working environments[2]. In lieu of these adjustments, increased worker output is met with reduced physical stress and fewer sick days[2].

The field of industrial engineering was the first to establish a clear structure to understand the relationship between a person, task, and physical space: initially through understanding biomechanics and most recently through the use of psychological research[2].

Industrial engineering has recently become interested in cognitive elements, such as human attention and memory, to help create not only the most efficient physical conditions for a task but also the best cognitive conditions[2]. The next stage is to use the industrial engineering frame work in user experience, through the application of neuroscience.

Behavioural Observations

A key development in understanding how people interact with the built environment has come from the systematic observation of the movement and behaviour of people in Italian public spaces[3], by architect and psychologist respectively, Jan and Ingrid Gehl in 1965. Through their work, they established a taxonomy of 'life' patterns in urban spaces[4]. This work was the inspiration for a life-long study of people in spaces, which led to a successful architectural design practice. The Gehl's work in Copenhagen has turned the city's focus from cars to people, which has drastically increased the quality of experiencing of the city. More recently, between 2007-2009, Gehl's design practice transformed 400,00 square metres in Manhattan's Times Square[5]. The removal of motorised traffic and the construction of places for people to meet, sit down, talk, and people watch has given office workers, for example, a place to take a break.

This has resulted in a 26% increase of people leaving their desks for breaks. A positive intervention and success story: affording people the opportunity to be more physical is important to their general wellbeing[3].

Another important analysis of people's behaviour in public space came from William H. Whyte, whose research on urban space is manifested in the documentary film 'The Social Life of Small Urban Spaces'[4]. Whyte narrates the film, explaining his methods of observation and the need for this type of research.

Whyte's work to be presented clear and practicable metrics which have been used since to design public spaces in New York City.

A final and highly influential piece of research to note is that of Alice Coleman, Professor of Geography. She famously argued there was a corollary between poor design and social malaise[6]. While design can have some influence over behaviour this might have been too much of an overreach. Many of her colleagues at the time criticised her work for being too simplistic in the face of complex social issues, with one colleague commenting that, 'her recommendations are dangerous in offering politicians and planners an over simplistic, yet superficially appealing, panacea for the complex social problems of urban communities in an ailing economy'[7]. Despite these issues, her work is important because it stands as one of the first pieces of academic scientific research to be implemented at a large scale[7]. She led a survey of 4,000 residential blocks, which accommodated nearly 500,000 people in the London boroughs of Tower Hamlets and Southwark. She looked at 4,172 houses in the same borough and an 'out of town estate' in Leys, Oxford[7]. Once she finished her research, a 'disadvantagement score' was allocated to rate the different developments[7]. Despite her work yielding interesting results, the Mozart Estate, one which Coleman was famously associated to, still has the similar statistics and social problems as before. This is despite the use of Coleman's recommendations[8]. This should not be seen as a failure, as it provides a future opportunity to develop better techniques for applying academic research into the built environment to ensure higher adoption rates.

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Space Syntax and Modeling Large-Scale Mobility

Beyond simply observing and categorising behaviour in space, researchers have sought to apply mathematical models to predict the movement of people through space. Such predictions are useful for designing city layouts, transport networks, efficient buildings, and also for safety, where it is paramount that people can easily exit a building or area in case of a threat, such as fire. One approach to predicting the movement of people is 'agent-based modelling'[1,2], where simulated populations of autonomous human 'agents' move according to specific rules (e.g. a 'levy walk')[3]. With this method, agents can be modelled to respond positively or negatively to different environmental spaces and the presence of other agents, and therefore can be used to predict the likely spaces where people accumulate, for example, cognitively 'salient' spaces[4]. New mobility datasets can be used to calibrate and validate models of agent behaviour. Another method for making predictions about the speculated flow of people in a space according to its layout, both in terms of the topological graph structure where parts of space are connected to others, and also in regard to visibility. This second approach is known as 'space syntax' (4, 5), and has been used to make predictions for new city layouts and social outcomes, e.g. in the instance of disconnected communities. These models help evaluate city plans and buildings by predicting social and organisational performance, which can in turn have economic implications. A potential new avenue here will be to integrate population movement modelling and space syntax with neuroscience data, as we discussed in section 3: 'Application'.

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BRIEF LITERATURE REVIEW: NEUROSCIENCE IN THE BUILT ENVIRONMENT

This section highlights how neuroscience has been explored as a plausible ally for the built environment for at least two decades. It is also an opportunity to critique the work so we can understand what we should discard, replicate and advance.

An early attempt to link neuroscience research to architectural practice is presented in a review from 2006 by Esther M. Sternberg and Matthew A. Wilson entitled, Neuroscience and Architecture: Seeking Common Ground[1]. They argue that advances in neuroscience had reached the point where it should be used to help architects minimise 'negative physiological, cognitive, and emotional effects'[1] that can arise from the built environment. Rather than providing a comprehensive coverage of the possible links and ways forward, this review serves to highlight a number of key findings from existing research with rodents that helps us to think about how the environment might impact our orientation and our sense of place within it.

Their review points to key reasons for correlating neuroscience research with architecture, such as, understanding why natural light benefits school children. The authors also point out that visual, thermal, and acoustic comforts can be studied from the perspective of neuroscience. However, the review takes a slight overreach when discussing consciousness, as this subject matter is still ambiguous, and more importantly, it is not applicable to a discussion of neuroscience and the built environment.

Sarah Robinson and Juhani Pallasmaa's seminal volume, Mind in Architecture, makes a compelling argument for the need to understand buildings and cities from a neuroscientific perspective. It provides a sound theoretical foundation to bring neuroscience forward to the architectural industry however it fails to provide tangible tools or methods for its application. Another influential volume is by the neuroscientist Colin Ellard, entitled, Places of the Heart: The Psychogeography of Everyday Life. A key argument is that, 'boring façades' have a measurable negative impact. Ellard's studies have shown that people tend to walk faster and be less likely to dwell in areas that have boring facades[2]. This research has proven popular in the architectural industry, often being cited by mainstream magazines, which in turn has popularised the concept of neuroscience in the built environment[3]. This has been an important step toward obtaining industry acceptance for the perspectives and methods of neuroscience.

When considering more structural built elements rather than design elements, the link between neuroscience and industry is more evident. For example, studies that look into the non-visual effects of light can help shape how light is understood in the context of buildings, such as workspace environments[4]. One area of research that is pertinent here is the study of how the brain processes spatial information to create an internal map of the world. Research in this area was awarded with a Nobel Prize in 2014 to John O'Keefe, May-Brit Moser and Edvard Moser[5], for their influential discoveries of how a rodent brain represents space. Key to this was O'Keefe's discovery of 'place cells'; neurons in a brain region known as the hippocampus signal information about where the rat is in a given environment[6]. Place cells are thought to provide the foundation of an internal map of space along with other spatial cells in neighbouring brain regions[7]. They have also been shown to exist in humans[7]. In recent years researchers such as Kate Jeffery at UCL have begun to explore how these cells process complex, multi-compartmented space that typifies urban environments[8]. Because these neurons give us a precise measure of how an animal reacts to an environment, this work could be used to create better wayfinding techniques to help people navigate their way through a street, city centre, or building.

Research with brain imaging has shown how insights from rats might be applied to humans[9]. Recent developments with humans have been in our capacity to collect data from millions of people navigating in virtual environments. This is exemplified by the smartphone gaming app, Sea Hero Quest[10]. Initiated by one of the authors of this playbook, Dr Hugo Spiers and designed by Prof Ruth Dalton; the app has the potential to provide insights into how humans of different cultures, ages and abilities, navigate different spatial environments and aid the refinement of models of human navigation, outlined above in the section on mobility modelling and space syntax. Studies such as Sea Hero Quest, could help future city planners create cities that are easier for the brain to navigate, reducing confusion and disorientation.

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4. GOING FURTHER WITH NEUROSCIENCE

The previous chapters covered how to use this playbook, the scale of neuroscience it will use, and the challenges of applying neuroscience into the built environment. This new chapter will focus on how human biology can provide those within the built environment with a more sophisticated lens for understanding people in the context of cities.

This chapter has four sections; starting with an explanation of how neuroscience methods advance us beyond psychological methods, then it will look at the historical link to the physical environment from a physiological and social perspective, and the third section will provide an understanding of the senses and perception.

BEYOND PSYCHOLOGY

Linking neuroscience to cities and buildings is both timely and relevant. This is due to increasingly applicable discoveries in a range of neuroscience research areas (such as in attention and with spatial cognition), and also due to new tools that have emerged in recent years. These tools include new mobile brain imaging and biosensors with GPS tracking, meaning that our capacity to understand the link between the human brain and the environment is becoming increasingly sophisticated[1]. The processing capacity of computers now makes it possible to process data from millions of people to make impressive predictions concerning mass scale human behaviour and experiences. The prospects of which are increasingly attractive to both academia and industry, insofar as the application of science to real-world built environment scenarios.

A key point of contention however is the question of what neuroscience can tell us that psychology does not; specifically, why do we need neuroscience if psychology has proven quite useful to industry in the past. Below are four examples of why neuroscience is relevant now and how it works beyond an experimental psychology approach. Neuroscience specifies 'where' and 'how' the brain underpins behaviour. The nuance to this additional depth of human biology is especially important when looking at the built environment:

1. Technologies used by neuroscientists help reveal what demands the environment is placing on us that purely psychological measurements cannot achieve. For example, recent research shows that when we navigate a city, certain parts of our brain process future possible paths at particular times during navigation and only when we rely on our memory, not a Sat Nav[2]. Testing behaviour alone fails to appreciate the specific demands the environment places on us.

2. Neuroscience provides a level of precision that is important when considering people in the population who live with dementia or mental health conditions. Understanding the differences in brain function in these conditions is important towards considering how to build cities that are more inclusive.

3. Whilst self-reporting and questionnaires are a legitimate source of research within neuroscience, it is now possible to become more technical in approach. For example, research into green spaces mainly focuses on self-reported data, concerning how these spaces make people feel, or the perceived benefits to local communities[3]. With the use of neuroscience, we can understand this at a biological level. There is an emerging field that attends to restoration theory, which in part proposes that access to greenery helps to restore the brain[4]. Restorativeness can be a factor in positive reported feelings while being in a green spaces[4]. Understanding this from a biological perspective establishes further insights into the reasons behind the benefits of green spaces[5].

4. We now have the opportunity to look at the mechanisms behind psychological and social theories, such as 'cognitive maps' or 'sense of place'. For a long time psychologists only imagined that the brain had a cognitive process that allowed people to map their physical environment. However, it is the work of neuroscience that has proven this theory to be true, exemplified by the work of Dr. John O'Keefe[6]. Using electrodes in the hippocampus of mice, he determines how the brain maps environments through the identification and locating of 'place-cells'[6].

We are not dismissing psychology as it is still an important area of study, especially when it comes to analysing human to human interaction and the self-reporting of certain experiences. This section was to highlight new methods that are now available for understanding the complexities of human behaviour.

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THE PHYSIOLOGICAL AND SOCIAL TIES TO OUR ENVIRONMENT

We now have the opportunity to take this new knowledge and start to think about cities in much more expansive timelines. We shouldn't be thinking of cities in terms of 15 or 30 years, we would be thinking about 50 to 200 years. How does what we do right now shape our evolution as a species, furthermore, what kind of role do we want to play. A passive role or a proactive role?

There is a core understanding that cities shape us from a societal and cultural perspective. However in the next two sections we evidence how cities can also shape us in a physiological manner.

Physiological

Humans have always had a symbiotic and evolutionary relationship with the physical environment. Physiologically and cognitively human development is dependent on our relationship with external environments; our brain and the cognitive systems it supports, develop in tandem with our interactions with the physical world, including interactions with other people[1]. The structure of the urban environment and its properties, e.g. buildings, streets, noises, light, etc., all have an impact on the brain and cognitive systems, and these impacts vary in scale with the length of exposure[1].

This relationship is highly complex, which makes it very difficult to study in a laboratory setting. Therefore finding real-world studies, which provide data and an insight of how deeply the physical world impacts people are fundamental to the work presented in this playbook. As an example, the Romanian orphan studies[2] provided strong evidence for the link between an individual's ecosystem (physical and social elements) and biological makeup (physiological and brain development) in a real world context, going deeper than short-term physiological or self-reporting studies. In the case of the Romanian orphan children, deprivation was caused by the lack of varied stimulation in the physical environment; no views outdoors, no toys, little wall decoration[2]. From a social perspective, the children were not picked up, and lacked integration and interaction with other children and the attendants[2]. Using Positron Emission Tomography (PET), it has been reported that, compared to healthy matched control children, these children had significantly decreased metabolic function in various brain regions that are crucial for cognitive, behavioural and physiological functions. This dysfunction may have been as a result of the stress from early environmental and social deprivation[2]. The neurodevelopmental and physical impairments of about 10% of the adoptees have shown to be long-term, even after adoption[3]. While this is an extreme case, it highlights that the environment can have long-lasting impacts on brain function, and that its role in nurturing us is vital.

From an industry perspective, this highlights the importance of understanding how the physical elements in the built environment have an effect the biological aspect of human development. We now have the means to define the physical elements or stimuli that have the greatest impact on our quality of life. For example, there is strong evidence that air pollution affects people with asthma and other cardiovascular problems. However, neuroscience research is now concluding that air pollution toxicity is creating problems in the womb, which can later have a significant effect on neurodevelopment. Having this information can build a strong case for moving residential areas away from high-traffic areas, to help reduce the longer-term consequences of toxicity, such as behaviour problems including ADHD[4], or childhood obesity[5].

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The Social Brain

At the core of human interaction is communication, verbal and non-verbal. We can set off a relay of emotions, intentions, and meanings with a flick of an eyebrow or a simple “Hello”. These initial and superficial moments of communication can add up to more profound moments of conversation, which we use to disseminate ideas, negotiate, and collaborate. With time, and more importantly consistency, these conversations can turn into long term bonds. Paving the way for higher types of human activity and outputs, such as knowledge mobility, culture and the creation of societies.

The density of cities makes them ideal ecosystems for sustaining long-term social interactions. The infrastructure of cities brings people in close proximity, which provides the opportunity for dynamic and varied social interaction. This aspect is one of the main reasons people are attracted to cities. Interaction with people means information and information can be used to create new ideas and solve problems. Furthermore, people interacting means bonding, which is essential for our survival as it builds families and friendships. Given how significant human-to-human communication is to cities, it is important to define it in neuroscientific terms.

Communication has biological underpinnings as the task of communication itself requires physiological and brain anatomy for its execution. In the diagram below we explain the different components of human-to-human communication. As we consider the future of cities, we should take into consideration what people need in order to communicate at higher quality levels. We are defining quality as the opportunity to understand context and extract meaning from an interaction, increasing the probability for longer term bonding and building trust.

Additionally, the social aspects of communication also draw on certain circuits of the brain. For instance, social cohesion, defined as the willingness of groups to come together and cooperate for survival and prosperity[1], is a precursor to good health, mental wellbeing, physical and psychological safety, and an overall improvement of life quality. When people do not have strong social cohesion in their communities, feelings of isolation can occur, which have adverse consequences for mental and physical health[2]. A report on old age living concluded that illness was exasperated by feelings of loneliness and lack of social contact[3]. Loneliness can even expedite cognitive decline in older adults[4] and according to some studies it increases the likelihood of mortality by 26%[5]. Robert Weiss in 1973 went as far as to describe it as a ‘gnawing chronic disease’[4]. This is an important insight for city planners, as tackling incidents of isolation through social cohesion can help elevate wellbeing and health in neighbourhoods and cities.

In terms of built environment industry, we should begin to consider how well neighbourhoods afford the opportunity for human interaction and to what level of quality. For example, do the public areas such as parks genuinely offer an opportunity to engage in casual interactions or conversations? Even very basic considerations such as seating that provides closeness to allow for people to hear each other or interact without disruption helps catalyse social collisions. Also consider how the greenery can help mitigate noise levels[8] for more auditory comfort as noise can cause high levels of distraction[6] which can in turn lower the quality of comprehension from a specific mode of communication. A point of inspiration are Italian piazza’s[6], which are centred around human interaction, from conversations to simple people watching. It is also where Jan Gehl based most of his studies on human interaction[7]. Understanding what physical affordances support human to human interaction can help mitigate against isolation, increase wellbeing, and create more opportunities of idea dissemination. All attributes that will make cities attractive places to live.

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HUMAN TO HUMAN COMMUNICATION

This is an overview of what a communication process looks like between two people. It is important to note that in order for the communication to be considered successful there should not be interruption or degradation to any part of the process.

Auditory level: two people (A and B) sharing information have to be at a physical proximity to be able hear each other.

- Comprehension: person B has to be able to understand the auditory stimuli from person A to extract context and meaning. In addition to the audible detection of tone, speed, pitch and the words themselves, this is done through reading facial expressions to detect emotion[1].
- Acknowledgment: once the information is transferred, person B should acknowledge the information as being received and understood. This can be done through facial cues[2] such as nods and words that confirm comprehension.
- Retention: finally, person B will have learned the piece of information and retain it for retrieval and use at a later time[3].

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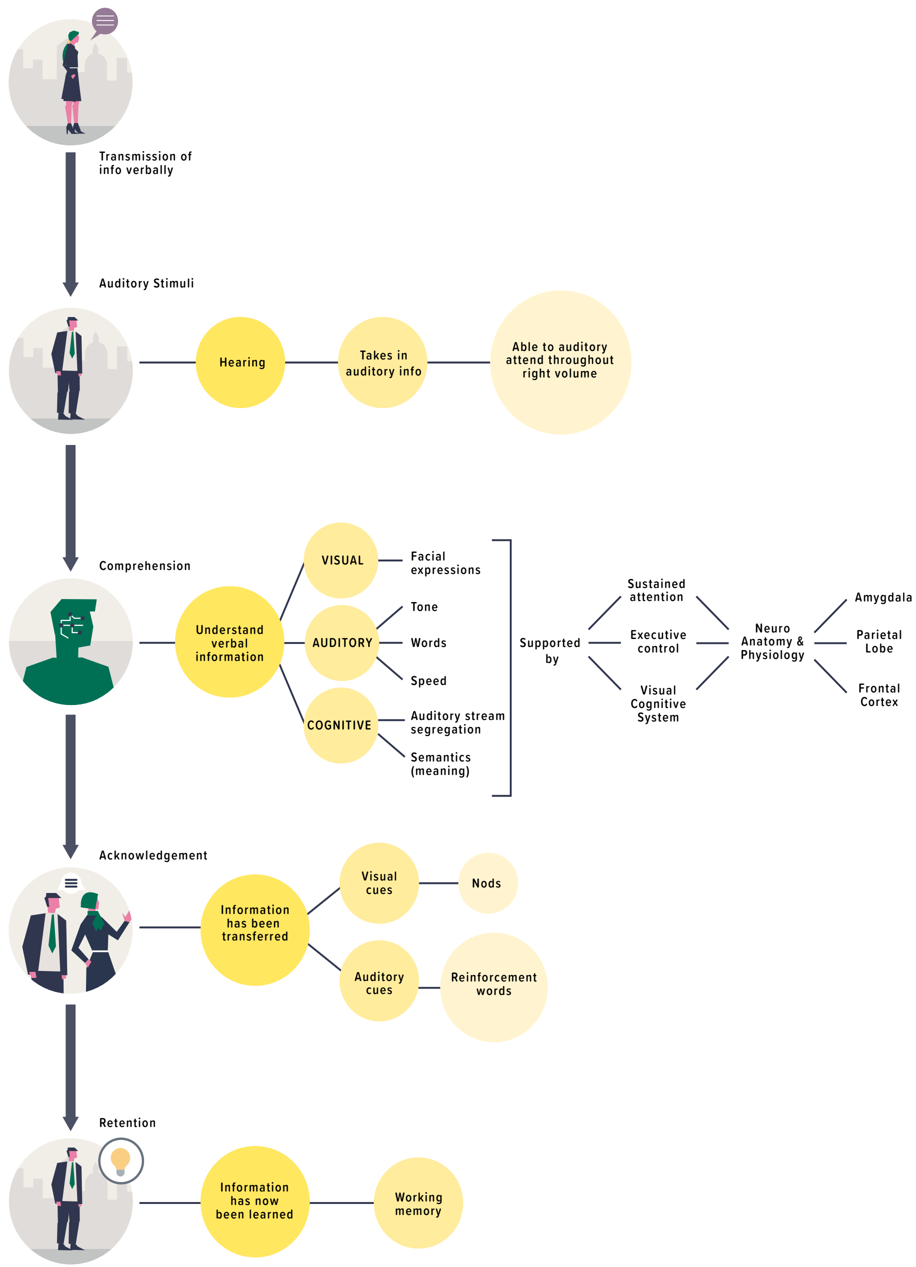

PERCEIVING CITIES

Before going further, it is important that we establish some working principles of human perception.

This section will include 3 parts; perception and senses, visual spatial attention, and orchestration.

Perception and Senses

Perception is one of the most fundamental and significant topics in relation to the built environment, it traverses across psychology and neuroscience. It is a complex and vast subject matter with many working definitions and different elements that underpin its identification. At its most basic level perception can be defined as having an awareness of the external and internal environment generated by the neural processing of the human sensory system[6]. Even though we experience the world as a unified whole, sensory systems do not input to the brain in this way[8]. For instance, different brain areas are specialised for encoding different features of the visual modality such as colour, shape, size, and motion[8].

It would be sensical to assume that what we see, hear, touch, or smell is a literal representation of sensory inputs. In other words, it would be sensible to think that what we experience through our senses (sounds, light, smells, touch) is what we become aware of (shades of colours, loudness, softness, hardness, bitterness, sweetness, forms)[6]. However, this is not the case. The information generated by the first phases of sensory processing is refined, modulated, and integrated with the influence of other factors. These factors may include the recent activity of the sensory system, prior experience with that specific stimuli, the context in which a stimulus occurs, influence from other sensory systems, mood, mental states, and physiological state of the perceiver[6]. There are also other more complex “top down factors”, which also play a role in influence perception such as emotional modulation, culture, past experiences, and social context[6].

Therefore what we perceive goes beyond just sensory input[6].

For built environment practitioners it means considering how physical elements may be interpreted and experienced differently than intended by those who created them. This goes to further support against deterministic design which is discussed in the section "Limitations and Caveats". How we modulate sensorial stimuli is so complex and driven by different variables therefore it would be difficult to assume a literal or linear line from design to adoption.

For example, a local park could have high aesthetic value and be in the right location from a planning perspective. However, if it is perceived as too far (psychological distance), spatially confusing, or even socially intimidating, it can run the probability of not being used by intended demographics. An interesting example of this phenomenon is the New York City High-line. It has been reported that whilst it has been a great achievement for the city on economic metrics, it has not done well on human or society metrics[7]. The author of a recent report concluded that the High Line is failing as a democratic public space[7]. The data gathered indicated that the use of the space was predominantly white, which is out of sync with the racial/ethnic demographics of Manhattan and New York City as a whole. The “level of racial homogeneity significantly exceeds that of other comparable parks[7]. This difference in use is quite surprising as the space is open to the public, has no fee and it is in the middle of the neighbourhood with various access points. However, there might be cognitive factors or cultural top down factors that are responsible for the difference in use. This example presents two opportunities; the first it is an opportunity to understand more about how culture or social factors influence perception and adoption rates. Secondly, it offers an opportunity to study the extent of variation between what is intended by the design and how it is interpreted by the user.

Key protagonists in the built environment are real estate developers who have access to global capital resources. They are often seen as the necessary leaders in urban change, however they are risk averse as often trade in investors capital. This often leads to low levels of innovation and new ideas being implemented. By adding guidelines, underpinned by biological and cognitive data, a more innovative development can be done with greater confidence.

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Visual Spatial Attention

Visual spatial attention is one of the most relevant cognitive processes behind the perception of city scenes, such as an intersection, a street, or a cluster of buildings. "Visual images and scenes are typically comprised of a rich, detailed mosaic of features, surfaces, objects, and events"[1] and which areas or aspects we isolate and decide to focus our attention is called visual spatial attention.

One significant purpose of attentional systems is to rapidly prioritise aspects of a complex scene that are of significant or relevant to a specific goal[3]. Where we decide to look is rooted in complex neurological processing with various cognitive outputs[1]. For example, crossing a busy intersection, we would focus on a selected area of the street to help us cross without causing an accident.

We would select the area where the cars are coming from, light signals or pedestrian crossings. From a neurological perspective, this requires eye movement (frontal lobe, saccades, superior frontal gyrus)[4] head orientation (motor cortex)[3], and ability to switch attention from one place of focus to another (parietal cortex)[5]. On the cognitive side, there are decisions about what speed to drive in, what direction to take, and the distance needed to keep in relation to other cars.

A random selection process would not be very useful as it would impede our ability to successfully interact with our environment. Taking the example from above, if our attention randomly switches to the trees in the nearby park that would not help in decision making processes involved to crossing the intersection safely.

Knowing more about how visual spatial attention works in tandem with decision making can help improve wayfinding techniques related to street and building navigation. It is also important to note that understanding how different cognitive demographics such as those with ASD or visual impairment differ in the in the context of visual spatial attention, this would be a great step forward for inclusive city design.

A wayfinding study conducted by Roger Ulrich and colleagues, found that hospital staff lost 4,500 hours per year giving directions to disoriented patients and hospital visitors, resulting in $220,000 in lost revenue.

Ulrich, R. et al. (2004) The role of the physical environment in the hospital of the 21st century: A once-in-a-lifetime opportunity. [online] Concord: The Centre for Health Design. Available at: https://www.healthdesign.org/system/files/Ulrich_Role%20of%20Physical_2004.pdf [Accessed 23 Mar. 2018].

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Orchestration

The final piece to this section is what we have identified as orchestration. The senses do not work in isolation and the perception of one sense is highly influenced by other senses. For example in the case of olfaction (smell) basic aspects of olfactory processing, such as detection thresholds, adaptation rates, and intensity are all strongly modulated by visual information[1]. This suggests that the interactions between olfaction and other sensory modalities may play a role in effective odour perception[1].

An event-related fMRI study, using a low level odour detection task, demonstrated that olfactory detection was faster and more accurate when odours appeared in context of semantically congruent visual cues[1]. In other words detection improved when the smell of an orange was experienced simultaneously as an image of an orange was shown[1]. The full extent of how the modality happens in the brain still needs more study, however the hippocampus is indicated to be partly involved in the modulation[1].

> "Event-related fMRI involves separating the elements of an experiment into discrete points in time, so that the cognitive processes (and associated brain responses) associated with each element can be analyzed independently"
>
> Huettel, S.A. (2012) Event-related fMRI in cognition. Neuroimage, 62(2), pp. 1152-1156.

> Hippocampus . "It is crucially involved in cognition, particularly in episodic, semantic, and spatial memory processes. It also plays a role in novelty processing"
>
> Konrad et al 2009. Defining the human hippocampus in cerebral magnetic resonance images—an overview of current segmentation protocols. Neuroimage, 47(4), pp.1185-1195.

From the perspective of the built environment orchestration means two things. Firstly, we need to fund more research to further investigate the effects of diverse sensorial information specifically in the context of offices, schools, and hospitals. These are environments where this type of information will be most useful. Secondly, we must start to think in terms of sensorial orchestration rather than saturation. Small environments such as offices, schools, and hospitals are especially vulnerable to incoherent sensorial input that can yield significant impacts. For example, absenteeism and poor performance has been linked to noise in hospitals[2] and in offices[3]. Another challenge is when we focus on one sensorial input, we do not understand it the bigger context. For example, does an office space filled with warm lighting have an effect on thermal perception[4]? Finally, we should also consider those who are neurologically different, to make these spaces more inclusive, for example do noise level affect how a blind person navigates a space? Or does a person with ASD have different sensorial requirements than those who are not on the spectrum?

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FACTORS AFFECTING PEOPLE IN CITIES

As it has been specified in the first section of this chapter, perception is highly influenced by "top down factors". These can range from micro factors such as an immediate goal ('I need to find my keys') to more macro factors such as societal trends. In this section, we will point out the factors that will have the most influence on city dwellers in the next 20-50 years.

There are two parts to this section the first is "technology" and the second is "urban sprawl". Each part will also include sub-parts titled "The unintended human consequence" and "Relevance to the built environment".

Technology

The first major factor that will influence how people perceive and interact with cities is technology. Within this subject there are two further distinctions; digital devices and automation. These have been chosen due to their impact on
our attention systems and human
to human interaction.

I) Device use and information access:
Digital devices are a technology that accesses media and information; laptops, smartphones, tablets, televisions and computer screens[4]. The devices are catalysing and affording a new culture of high information consumption.

A key trait amongst most mammalian species is curiosity, it is a drive to seek new information[1]. It is curiosity that led to access new types of food resources, explore new territories, and it landed us on the moon. Formally curiosity can be defined in terms of emotion, behaviour, and task[1]. We feel a need to be curious, we behave in a curious manner, and we do things based on curiosity.

In the context of today's culture we are satiating our curiosity through digital devices as they are a portal for which to access an ordinate amount of information. Digital devices are fully integrated into nearly every aspect of our lives[2]. Imagine the change in productivity if we couldn't answer emails on a train, or how our social connections would change if we couldn't access loved ones around the clock, or how our perception of autonomy and safety would change if we didn't have our phones to call for help? Ofcom has presented statistics which indicate that people are spending nearly 9 hours per day on various devices[2]. Young people (16-24) are doing 14 hours per day and children are also spending more time on screens than they do on other activities[2].

These stats should be taken with caution as this is not representative to all sections of society. For low income families, their situations is quite opposite. Their lack of access to digital technology is having an effect on their ability to excel at school and work at the same rate as their digitally connected counterparts[3]. This is referred to as digital inequality, which is focusing on how access to, and the use of digital technologies varies among people with or without access to the internet[3].

There are two things to take away from this part; the first is that digital devices are a portal of access to information and the second is the amount and rate of information is the important factor rather than the device. In the next part we will look at what this consumption is doing to our attention systems.

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A) The Unintended Human Consequences

The most affected attention type by our increasing consumption of information is called sustained attention. This type of attention is defined as the ability to direct and focus cognitive activity on a specific stimuli for a specific amount of time. This ability allows us to complete any planned activity, sequenced activity or action, or thought process. We use sustained attention for reading a book or holding a conversation. One of the key factors in being able to sustain attention is the ability to select and focus on specific goal rather than automatically attending to all other stimulus, this is called cognitive control[1]. The length of time a person can sustain attention is defined as "attention span". This type of attention is very important for higher cognitive abilities such as learning. For example if a person is in an important meeting and will later need to recall what was said for future application, it would be necessary for that person to stay focused throughout the conversation[2].

The longer a person keeps their attention on the task at hand the more effective the brain will be at encoding the information. This in turn will allow for higher recall rate at a later point in time (memory)[2].
Our attention spans are perceived to be diminishing since the adoption of digital devices[3], however these indications should be caveated. One, there is little study from a neuroscience perspective, therefore we do not fully understand if these differences are causing brain changes or if they are long term. We should also consider the type of task as we don't seem to have a problem sustaining attention when it comes to our digital phones. This might be driven by novelty, events of high value and interest will still capture and sustain our attention. Therefore it might be more accurate to say that our attention is becoming more selective, we no longer seem to have the patience of "sticking with it" if a task is perceived of low value, i.e. boring[4]. However, this is only based on observation rather than on neuroscience. This knowledge gap presents a place for further neuroscience research to emerge. If there is a evidence that our attention spans are changing then we should take this into consideration when looking at improving wayfinding in cities.

It is important to look at behaviour patterns in children as they will be the next generation of city users. A U.S.-wide observational study of over 600 teachers across kindergarten to high school with varied years of service, subjects and technology knowledge[3] reported that children are facing new challenges due to their high levels of media use. What is interesting is that in the case of children there seems to go beyond attention. The teachers reported trouble with eye contact and face to face communication as well as a lowered ability to "put the effort into areas that don't give them instant gratification."
If this trajectory continues it would be fair to infer that problems with complex problem solving will be a big challenge as well as long term bonding. This could have serious societal consequence as we have already established the importance of productivity and social bonding for city prosperity.

Again we will caveat that we do not understand yet if these behavioural changes are long term or their neurological underpinnings. Furthermore, this is not all children, this very much a western and middle class perspective. However, it is important to include these observations in this playbook as they provide context for future neuroscience led research which could then be used to understand how cognitive changes have an effect on how we perceive and interact with our environment.

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B) Relevance to Cities

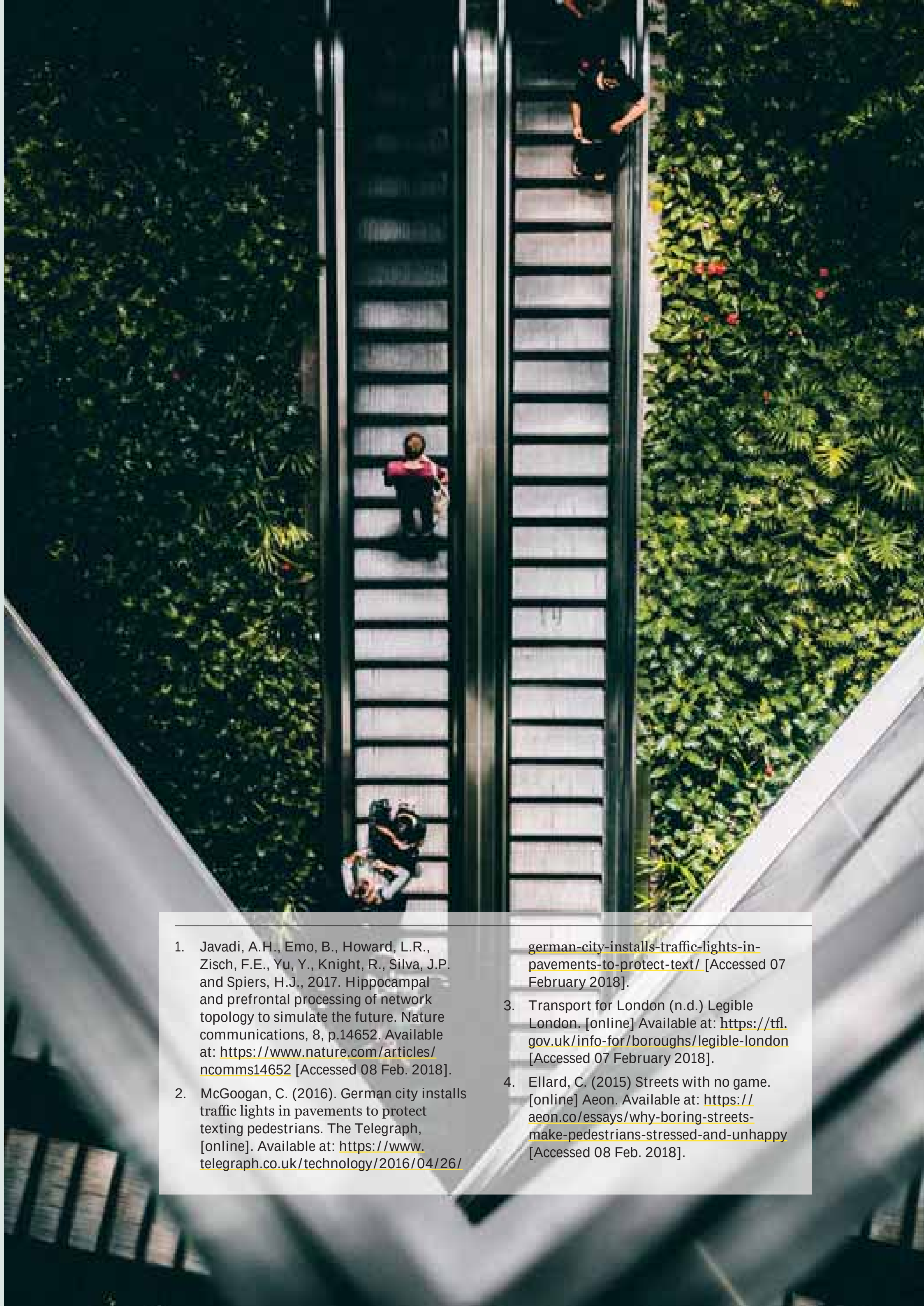
- If attention spans and patterns are changing, there is a need to rethink transport elements such as the design of intersection crossings, pedestrian signals, and signage.

- Research should now look at how spatial cognition is changing due to devices, a recent study showed that when a person is using instructed sat nav devices telling them where to go, certain brain areas like the hippocampus, “simply don't respond to the street network. In that sense our brain has switched off its interest in the streets around us[1]”.

- In Augsburg, Germany, they are changing some of the traffic signals to keep with changing sight lines[2]. They have now installed traffic lights on the pavement, which is in the same sight line as their smartphones. As people spend more time gazing down at their devices when they walk, it impedes gazing at other relevant stimuli including traffic signals. However are these solutions great for the long-term? Should we instead research how to make the physical environment more salient and relevant to people, so they are not needing to seek stimulation from their devices?

- Understand how to design cities with orchestrated visual variance to encourage people to see information from their physical environment rather than turning to their phones. Transport For London’s initiative to afford easy and quick walk-ability to their destination called “Legible London” started this narrative in 2006[3]. We now have an opportunity to use this existing research and enhance it with neuroscience insights for further adoption.

- Neuroscientist Colin Ellard from Waterloo University in Canada proposed the idea that “boring facades” affect engagement and dwell in cities. His self-reporting and observation study claims that “long, unbroken, featureless facades cause passers-by to become unhappy, bored, and perhaps even a little angry[4]”. Whilst this yet to have neuroscientific data, it is important to note that people do not like the facades that are typical to most corporate campuses[4]. When there is a reduction in curiosity due to low levels of relevant or interesting stimuli, people turn away from it and disengage. This is important to take into consideration when planning these big work campuses. Especially, in the phase of changing attention spans. The opposite of boring doesn’t mean the Vegas Strip, we still should take into consideration context and value as it was discussed in the section on perception.



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II) Automation
Automation refers to the use or introduction of automatic equipment, such as robots, machines, or computers into the workforce, with the objective of reducing waste, increasing repetitions of a task, and saving money[1]. Automation is not new, however the current pace and extent is causing some to speculate there will create a change in our economic system and lives.

Automation will be everywhere from retail experiences such as Amazon stores[2] to medicine in the form of diagnostic tools such as Watson[3]. On a very macro level, there are goals for entire cities to operate fully automated. Neom in Saudi Arabia promises to be the first highly automated city, where planning and construction will be initiated with $500 billion from the Public Investment Fund of Saudi Arabia and international investors. Their claim is that "repetitive and arduous tasks will be fully automated and handled by robots, which may exceed the population, likely making Neom's GDP per capita the highest in the world"[2]. Finally, there is the most talked about automation, which is that of driverless cars. Companies like Tesla and Uber are hard at work promising us faster more efficient mobility.

As automation becomes more integrated in our lives, we should consider its consequences on mental health and human to human interaction.

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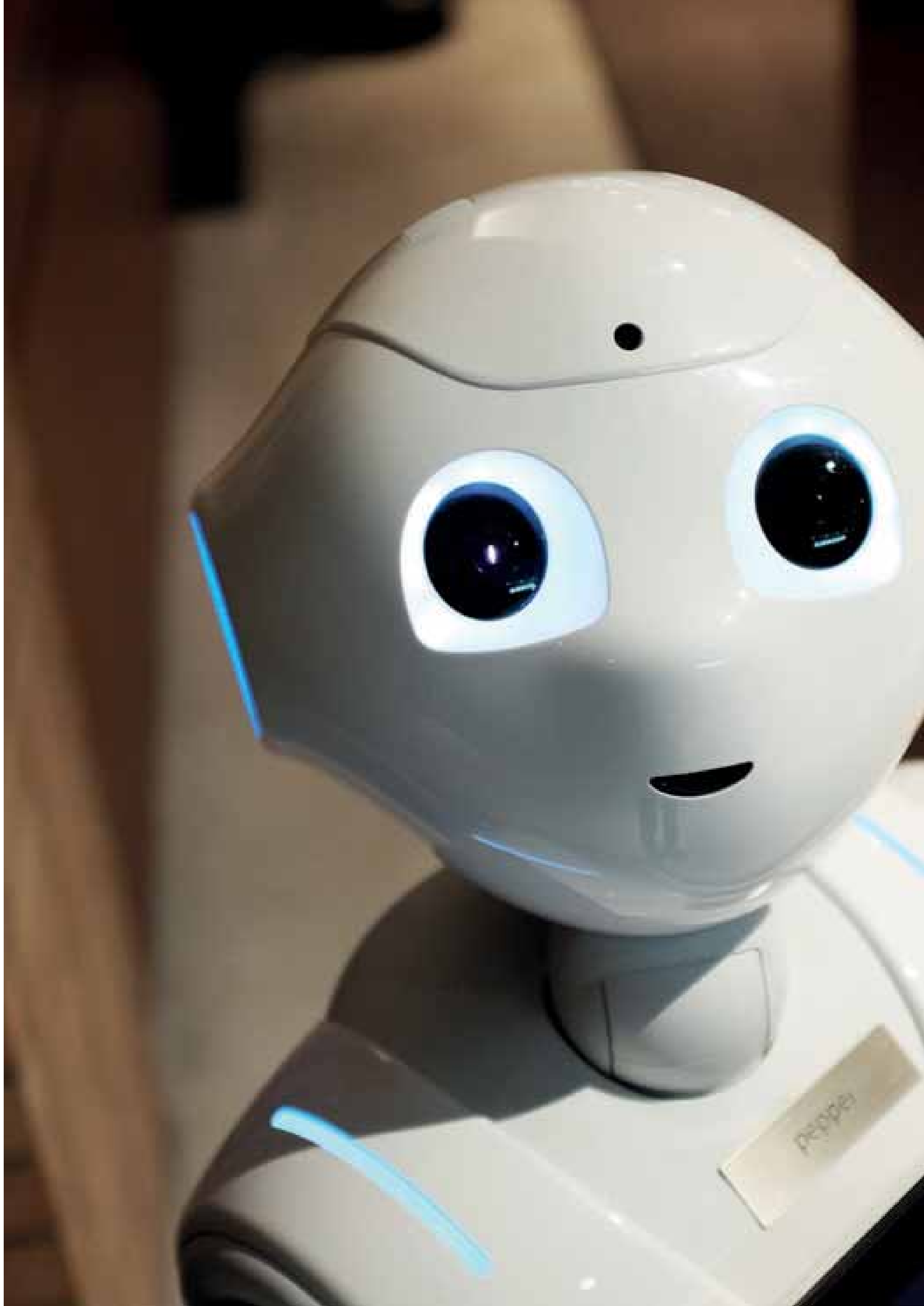

A) The Unintended Human Consequences

Despite all the great advancements automation will catalyse, there are two possible unintended human consequences to highlight. This is not to say automation has to be halted, it means that cities should be aware of the human effect of automation. This will lead to a smoother and smarter integration.

Firstly, we should consider the possible development of situational depression. This type of condition refers to experiencing depressive symptoms resulting from psychosocial stressors, such as sudden death in the family, a divorce, or a sudden job loss[1]. Some cities in the UK are predicting to see between 13-25% jobs losses due to automation by 2030[2]. If there are no plans or provisions to disperse these workers into other industries, we hypothesise a rise in situational depression amongst this segment of the population. This could potentially lead to a lower quality of life as well as increase mental health costs. This theory requires further research as not all people who lose their job will develop situational depression, we must understand all other contributing factors. In doing so we could help mitigate the effects.

The full extent of the consequences to cities and people from fast and widespread unemployment loss can be seen in the history of "ex-factory" towns such as Flint or Detroit, both in the state of Michigan, United States of America. The former is in the depths of a crisis[3] whilst the latter has taken many decades to rise up[4]. We have the opportunity to prevent history from repeating itself and make this transition smoothly.

Highly automated cities are still in the far future. However we should consider how a reduction in face-to-face interaction due to automation could have an effect on cognitive elements, such as empathy.

> "Depression is a mental disorder of the representation and regulation of mood and emotion"[1]. Depression is linked to abnormalities in the frontal cortex, anterior cingulate cortex, amygdala, and hippocampus[1]. This can lead to an array of cognitive differences such as recognising emotions on faces, difference in attention patterns, and differences in regulating emotion[10]. It can also have physiological symptoms such as "chronic joint pain, limb pain, back pain, gastrointestinal problems, tiredness, sleep disturbances, psychomotor activity changes, and appetite changes[2]."
>
> Davidson, R.J., Pizzagalli, D., Nitschke, J.B. and Putnam, K., 2002. Depression: perspectives from affective neuroscience. Annual review of psychology, 53(1), pp.545-574.
>
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Human empathy is a psychological construct which has both cognitive and emotive components providing us with a highly sophisticated ability for emotional understanding[5]. From the emotive perspective it is the ability to experience someone else's emotions, an emotional contagion if you will ('I feel what you feel')[5]. When we perceive through visual and other sensorial cues another person's behaviour it instantly elicits one's own experiences for the behaviour. Output from this shared experience automatically activates the "motor areas of the brain where the responses are prepared and executed"[5]. This means that we experience another person's sadness on a mental and neurological level. This is extraordinary detail into another person's mental state that allows us to make highly intelligent decisions about social interactions. The second component is cognitive empathy, which includes more complex cognitive functions such as empathy perspective-taking and mentalising. This translates to 'I understand what you feel'[5]. Cognitive empathy allows us to extend our minds far away from our mental state, giving way for complex problem solving.

Empathy is necessary for various different tasks from providing the correct emotional support to a conversation or social interaction to understanding the plight of another human being. It can also be involved in more complex outputs, such as a the fast and strategic thinking in negotiations or a doctor developing new diagnostic techniques through constant observation and mind extension to the world of her patients. It is the ability to ask questions such as 'how would a person react or feel if this happened' or 'is there a better way to communicate an idea', or 'how what is a service that people really need?'

This understanding of empathy illustrates how empathy is tied to human to human interaction. We have learned to develop our empathy capacity due to our highly socialised existence. Therefore, if automation begins to strip away the opportunities for human-to-human interaction, there could be a change in how we exhibit empathy as well as our capacity for it.

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B) Relevance To The Built Environment

- Creating opportunities in cities where people can spend time together such as parks, public squares and other third spaces. This will be increasingly important to counterbalance the places where people will have a depletion of human-to-human interaction.

- Automation can have huge implications for the real estate and built environment industries. There is both risk and opportunity. Occupiers of office real estate will likely see their business practices change as a result of technology and automation. A report from McKinsey & Co states that 60% of businesses will see ⅓ of their processes automated, this changes the dynamic of employment and from whom office is rented[1]. There is already a shift occurring in large companies using serviced office centres such as WeWork over traditional office settings due to the cultural and physical offerings[2]. However, these serviced offices are still catering to the 20th century worker. Companies are urgently searching for the best possible talent. Some, like the BBC, HP, and Microsoft are going as far as attracting talent that is on the autism spectrum disorder to fulfil niche jobs. As automation helps with repetitive tasks or analyse large data sets, people will be expected to problem solve more complex problems. This means two opportunities, the opportunity is two fold; offices can evolve to places where people gather to think, meet, and research. Like a modern library or thought salons for those needing to solve complex problems. There is also an opportunity to transition workspaces to labs and makerspaces for future invention and growth. There is no evidence to point towards no longer needing to generate ideas due to automation. Therefore, whilst ideas are still needed, spaces for face to face interaction will still be needed.

- Creating cities only for efficiency should not be the aim of automation, it should be to humanise the city. Autonomous vehicles could result in the reduction of traffic, which in turn allows transporting someone quicker to their family, work, or social activity. We need to think of automation as a tool to enhance and increase the time for human-to-human interaction.

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Urban Sprawl

The second macro category of factors to consider is urban sprawl, especially in the context of transport and climate change. In the next parts we will discuss the cognitive and physiological implications of ever-sprawling cities.

Urban sprawl is defined as the uncoordinated growth of a community, usually away from an urban centre into outlying areas. This is usually without concern or consequence to environment or societal impact[1]. Interestingly, it is not always due to population density, but a mixture of socio-economic factors. Such as means of transportation, price of land, house prices, cultural constraints, preference for rural living, demographic trends, pollution, and changes in city culture[1]. It is one of the most studied phenomena of the last ten years due to rapid rate of expansion and the severe consequences it could have on city dwellers, environment, and infrastructure[1].

I) Transport and Distance

Transportation is one of the most important infrastructure elements for cities. It is the connector of people to resources, opportunities, and social interactions. The transport modes we are referencing are bus, car, trains, and taxis. We are excluding active transport from this section, which is the ability to walk, run or cycle to a destination. Currently, as cities expand the more commuting time increases[2]. However, it does not have to be this way, plenty of studies have shown that density and mix use development helps reduce commuting times as it reduces the distance between places[3].

In this section we will look at the consequences of distance and transport modes on human cognition and physiology.

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A) The Unintended Human Consequences

This section will focus on four consequences of transport; poverty, social exclusion, stress, and toxicity. All of these areas have cognitive and physiological consequences.

A recent report produced by UCL[3], discusses how poor access to transport contributes to poverty and social exclusion. These two factors separately and together have correlates to longer term cognitive and physiological consequences such as obesity, depression, and anxiety[7,8,6]. Furthermore there are also links between obesity, depression, and anxiety, often found as comorbidities of each other[9,10]. In other words people with obesity may also to also be anxious or depressed and visa versa. This is important as it shows the high human cost and significance of the issue.

Stress can be caused by an array of environmental elements or stimuli, long commutes in both automobile and trains are well documented and researched environmental stressors[1]. More research needs to be done to understand the long term cognitive effects of transport, specifically in the context of productivity.

For example, do stressful commutes affect our ability to focus at work? Or do they have an effect on brain systems such as memory and attention? Two systems that are linked to learning new skills and information.

We should also consider the elderly and those with physical variances as they have statistically less opportunity to access transportation due to having personal mobility challenges[4, 3]. Improving access to transport for these groups will have an impact on their feelings of isolation and social exclusion[11, 12]. Which have links to anxiety and depression[7,6]. Additionally in the case of the elderly there is a correlation between feelings of loneliness and cognitive decline[13].

The final consideration is the exposure to toxins in public transport systems as they may have long term has long term effects on our mental and physical health. A Canadian study looked at the level of daily exposure to $PM_{2.5}$ in the underground metro network of three major cities[14]. It identified that a typical 70min commute, which constitutes 4.9% of the day, was estimated to contribute to over 50% of the estimated daily exposure to several $PM_{2.5}$ metals. In turn this has an effect on rates of asthma, developing respiratory inflammation, and lung function[14]. Furthermore, there is now evidence that long term exposure of $PM_{2.5}$ can influence the onset of severe depression, with symptomatology so acute, it is leading some people to request the help of emergency services[15].

The problem is not cities growing, the problem is how they grow. With the right infrastructure we can mitigate many of the challenges mentioned in this section.

$PM_{2.5}$ is the most common term used to describe an array of particle pollutants, they can be solid or liquid [14]

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B) Relevance to Built Environment

- One of the challenges in creating solutions within cities is knowing where to start or what solution will have the most impact. With neuroscience pointing out the infrastructure elements that have the most acute biological consequences, industry can use this data to create guidelines, which can aide with decision making on mix use developments or in understanding what planning initiatives to prioritise.

- Those living on city peripheries can feel excluded and find it hard to take up available jobs unless there is transportation linking them to the centre. The Brazilian city of São Paulo is experiencing commutes of up to 4 hours where almost 70% of journeys are made by bus. In some municipalities like Itaquaquecetuba in the extreme east of the city, bus transportation is the only link to work[1]. This translates to forcing poor people to endure, not only the mental stress of extremely long commutes, but also long exposure times to pollutants as they sit in traffic, which can have severe mental and physical health implications[4].

- There is also a nutritional factor, that many ghettoised places outside of city centres have higher incidences of malnutrition due to poverty and lack of access to fresh food[5]. Malnutrition is not only a physical experience, it also has vast neurodevelopment problems, which can lead to lifelong disorders, such as schizophrenia and antisocial personality disorders[6]. Therefore urban planning concepts like density where there are various options to access food and work can help mitigate against long term debilitating mental disorders.

- How to transport people from A to B is a long studied concept and the role of neuroscience is from two perspectives. The first is research to support the longer term biological effects to validate city planning strategies. The other is wayfinding, especially in public transport. Part of the access problem with the elderly and the physically variant is that it is not intelligible to them. For example, someone with visual impairment may find it difficult to navigate complex tunnels and multiple access points, which can act as deterrent, decreasing their desire to access their local transport link. In the case of the elderly, legible and clear signposting, auditory instructions, and better safety measures would increase use as it would make transport less confusing and daunting[3].

In schizophrenia “the symptoms segregated into three syndromes: psychomotor poverty (poverty of speech, lack of spontaneous movement and various aspects of blunting of affect); disorganisation (inappropriate affect, poverty of content of speech, and disturbances of the form of thought); and reality distortion (particular types of delusions and hallucinations). Both the psychomotor poverty and disorganisation syndromes were associated with social and occupational impairment; in particular, the psychomotor poverty syndrome was associated with impairment of personal relationships, and the disorganisation syndrome with poor self-care and impersistence at work.”

Liddle, P.F., 1987. The symptoms of chronic schizophrenia. A re-examination of the positive-negative dichotomy. The British Journal of Psychiatry, 151(2), pp.145-151.

Antisocial personality disorder is an overt pattern for anti-social acts alongside traits such as impulsivity and irritability.

De Brito, S.A. and Hodgins, S.H.E.I.L.A.G.H., 2009. Antisocial personality disorder. Personality, personality disorder and violence, 42, pp.133-153.

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II) Climate

In this final part, we will be looking at the effects of climate change with a particular focus on heat and displacement. As we mentioned in the introduction of the this section, the playbook should point to long term trends that will affect human dynamics in cities and climate change will continue to be an important factor. We will also like to note that this is not a section on how to solve climate change, rather an understanding of how it affects people on a cognitive and physiological level.

Motor vehicle traffic is a major contributor to climate change due to the release of greenhouse gases. In the US cars account for 26% of greenhouse emissions[9]. Expansion also means deforestation which increases impervious surfaces, making city more vulnerable to flooding. Flooding in turn erodes storm water into water streams, increasing the risk of disease contagion[3]. The third climate change phenomena is urban heat island (UHI) effect, which makes cities several degrees warmer than surrounding areas[2]. The fourth element related to climate change is the rise in extreme weather[10]. This means more frequent floods, hotter summers, colder winters, and hurricane systems[10].

A) The Unintended Human Consequences

The demand for new infrastructure in cities as a result of urbanisation is pushing a city's resilience to breaking points. The replacing of nature with built environments destabilise an ecosystems natural ability to mitigate extreme environmental activities, such as flooding[3]. A recent example of this was the devastation caused by hurricane Harvey in Houston, Texas[2]. One of the major contributors to the high levels of flooding was the ratio of concrete pavement to natural green areas[11]. This caused the city of Houston to become water repellent increasing the expansion and levels of flooding[11].

There is an argument that flooding in cities is a zoning problem, the allocation of land for development (sidewalks, buildings, roads) rather than for green spaces (parks, natural reserves) is causing cities to flood uncontrollably[1]. Hurricane Harvey damaged over 200,000 homes and nearly 40,000 people were displaced to shelters, other cities, and hotels[3]. This is a significant amount of human disruption. Relating this back to neuroscience, we propose that the displacement of people via these natural disasters has mental health implications. The first is post traumatic stress disorder (PTSD) from the initial shock of experiencing extreme trauma[4]. PTSD has devastating long term effects, such as depression and anxiety[5]. As more extreme weather conditions arise and force people to leave well established lives for new and possibly alien environments, industry should think about how this contributes to isolation and alienation[6].

Alienation is feelings of meaninglessness, powerlessness (lack of control) belonging lessness, social and self-isolation.

Clark, J.P., 1959. Measuring alienation within a social system. American Sociological Review, 24(6), pp.849-852.

The second consideration is the UHI effect occurring in urban areas,which is generated from urban structures, such as buildings or large areas of concrete re-radiating the heat coming from vehicles, power plants, air conditioners, and other heat sources[8]. A lack of natural heat-mitigating elements such as trees providing shade and ventilation can result in people increasingly living in “hot ovens”, with no respite[8]. The UHI effect causes demand for more energy as people struggle to keep buildings cool, which in turn adds more pollutants into the air[8]. It increases ground level ozone layer, which can be very harmful to children and infants[8]. Most of the current literature concentrates on UHI's effect on general health and mortality, which are very important factors to consider[7]. However, it is also important to consider what effects UHI has on cognitive performance and in turn productivity due to stress caused by elevated temperatures. Heat stress affects cognitive performance differently, depending on the type of cognitive task and exposure levels[12]. However, one core correlation is that heat contributes to lower cognitive performance as it competes for attentional resources[12]. In other words, as attention is being allocated to respond to the stress of heat it distracts focus from the task at hand. Additional research should be considered to investigate if UHI has an effect on brain development and structure, which could have further effects on productivity.

B) Relevance To The Built Environment

- We need to understand more about the cognitive and psychological effects of displacement. This will help urban designers and engineers understand what type of design interventions and social systems are needed for cities taking in displaced people. Research should especially focus on the effects of social cohesion and social capital.

- Industry should start to consider how extreme weather might change people's interaction with the built environment. Do colder winters or hotter summers cause children and adults to choose shelter over outside activities? What will be the health implications of these new behaviours? What will staying indoors mean for human-to-human interaction? Will it change how we socialise? Social cohesion? Could it increase isolation in varied demographics such as the elderly?

- What will extreme weather do for economically challenged demographics in terms of quality of life, if they cannot afford to mitigate the effects of weather?

- UHI deteriorates the experience of the city as it thermal comfort decreases, this could have an effect on dwell and general engagement with city activities and resources.

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USING NEUROSCIENCE TO UNLOCK OPPORTUNITIES FOR BETTER USER EXPERIENCE IN CITIES

5. FRAMEWORK FOR NEUROSCIENCE

In this chapter we define the framework for applying neuroscience into the built environment. The reason for the framework is to help establish a set of heuristics to integrate neuroscience into built environment, whilst keeping the quality of science intact.

There are three elements to the framework we are proposing.

1. Create a common language, which will facilitate the communication between the two industries
2. A delineation of neuroscientific tools which are available to use, their key principles, and the insights they provide
3. A defined interface

TERMINOLOGY AND TOOLS

This is a list of terms to build a common lexicon between neuroscience and the built environment. They are unique to the framework developed by The Centric Lab therefore they should be seen as working definitions, which will further evolve and be redefined as more research is conducted. Finally, these terms are open access and are available to be used across industry.

Terminology

Specific Human Problem: Every investigation into the built environment needs to start with a specific human problem (SHP). SHP should follow the scientific method, starting with observations that lead to a core question to which a hypothesis can be assigned.
For example;

- How can one create a sense of place for an established neighbourhood?
- What are the effects of light pollution on sleep patterns?
- What are the long-term cognitive effects of deprived neighbourhoods?

Cognitive/Biological Baseline: There is need to have a baseline from the human perspective to create a starting point for comparisons. We are proposing the use of biological and/or cognitive elements of the human condition as baselines due to their low variance levels. These baselines are expressed in terms of tasks or activities. For instance, the activity of sleep proposes little variance in terms of biological and physical requirements to achieve it (everyone needs levels of darkness, to lay flat, low stimulation, low stress, etc). A sample point of enquiry using sleep could be "does long term exposure to night time light pollution affect sleep/wake cycles in children?"

Cognitive Affordance: This term is already in some industry lexicons, but not yet fully employed. In design terms affordances refer to how physical elements provide opportunities for different activities. For example, a cup affords you the possibility to hold liquid. Following the same train of thought a cognitive affordances provides the mental opportunities to achieve certain tasks. For example, calm is the cognitive affordance that affords a better opportunity for the task of reading.

Cognitive Types: Cognitive types are identified through different tasks/ activities a person performs in a specific space. An example of a cognitive type would be a "learner" in the context of an office building, which is someone whose main tasks for the day require reading, learning new information, communicating etc. The "learner" can be gender agnostic, any age group, or social background.

Comfort levels: The built environment already has references to comforts, which are metrics for assessing the level of perceived satisfaction of a specific physical element or stimuli. For example, thermal comfort[1] is how someone perceives the thermal quality of their environment, do they feel too cold, too warm, or are they comfortable.

Dose: Dose is a unit of measurement that is in reference to the adequate level of exposure or ratio of a specific comfort. Already used in terms of green spaces, which have been substantially studied[2]. This is the area that needs the most development and that will have the most impact on the built environment. When neuroscience is able to understand how high a building should be in relationship to the cognitive affordances, cognitive types, and the scale of the area, then the built environment will be changed substantially.

Stimulation: Stimulation describes the amount of sensorial information in a specific environment that impinges upon the user[2].

Environmental Enrichment:
Enrichment has its roots in clinical neuroscience. This area of neuroscience defines an enriched environment as one that provides rodents with enhanced sensory, cognitive, and motor stimulation in comparison to standard housing conditions[3]. Scientists are using these micro environments to study the long term influence an environment has on brain regulation and behaviour[3]. Studies have already resulted in highlighting a strong relationship between the physical elements of an environment and brain activity. Enriched environments "induce a number of neuro-anatomical, neurochemical, and behavioural alterations"[3]. Extending this to the built environment and enriched environment should afford varied social collisions, activities, and tasks to a good quality.

Coherence: How well all the physical elements of an area follow a specific narrative or schema.[2]

Habituation: Habituation is a filter that optimizes the processing of information by our brain in all sensory modalities and is temporally dependent[4]. This is an important element to consider as whatever physical comfort is changed, it can lose its effect over time and adjustments will need to be made. Hypothetically, a lighting setting for a task might need adjusting throughout the day as the sensorial perception of it will diminish overtime, which in turn might change the effect. More research needs to be done in this area to understand how/if adjustments need to happen.

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Tools

EEG: Mobile EEG is the only neural recording tool that can be used within a real-life space (all others require a large, immovable machines). Recording brain waves can inform us of how a person may be feeling in terms of alertness/ comfort in the built environment even as they move around[1].

Eye Tracking: Eye tracking machines to study gaze behaviours and cognition, which can be used to study attention, memory, language, problem solving, decision making as cognitive functions in response to a space[2]. This technology can be used as part of a set of tools to help measure productivity.

VR: Virtual reality, is computer-generated scenarios that stimulates experiences through our senses and perception is increasingly used in neuroscience research. An example of this would be, if a new park was being built in a neighbourhood VR could be used to test its perceived distance from residential areas. This would allow city planners to make decisions on location and topography of the park[3] and further problems humans may face aiming to access it.

Psychometric Questionnaires: These are the primary way to understand people's reaction to space, it is possible to extract perceptions and emotions from them, and are easy to analyse. The are most useful in tandem with neuro/ biological testing to correlate subject responses of subjects to objective data[4].

Cognitive Tests: Used to assess cognitive capabilities eg IQ, attention and memory. Usually in the format of standardised battery tests which usually require licensing however self-designed tests can also be used.[5].

Historical Data: There are studies of the built environment dating as far back as the late 1970's. The data and research from these studies can be used to make recommendations and guidelines.

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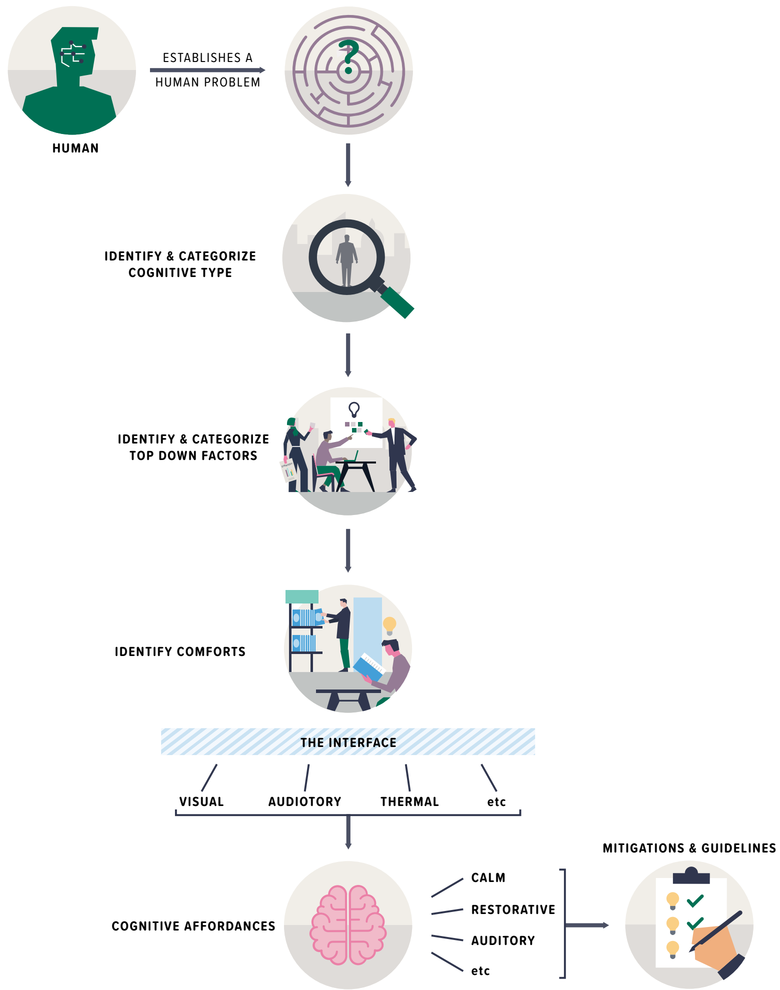
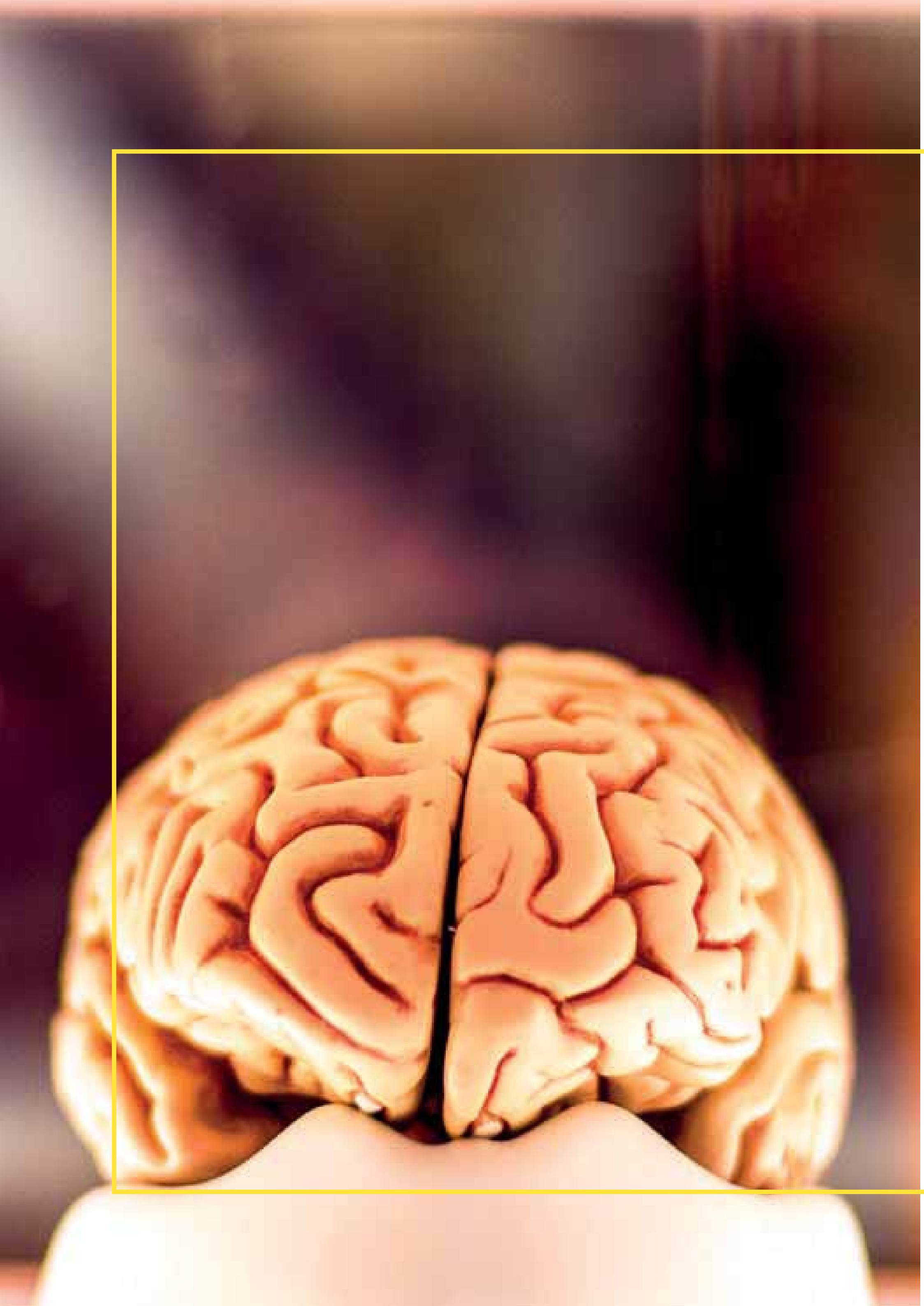
THE INTERFACE

Neuroscience and the built environment can be seen as two different and separate systems, therefore, we are considering an interface to allow for better interaction between them. An interface is a point where two systems, subjects, or practices meet and interact[6].

It shows the progression from the human elements to built environments, ending with mitigations and guidelines.





6. USING NEUROSCIENCE

This chapter will focus on applying what has been learned in previous chapters to explore practical use in the built environment. We are in a very exciting moment in time where we can start to apply neuroscience research to improve the user experience of technology, buildings, and cities.

WHAT WE CAN DO NOW

This section will focus on how neuroscience research can be used right now by built environment industry. The section is broken down into three sub-sectors where impact is greatest; technology, building, and city.

Technology

There is now access to many great technologies which are aimed to improve the experience of the built environment and to make it more inclusive. One of the most important sectors to focus on is wayfinding as it has a significant impact on how people and the environment interact. Spatial cognition, which studies how the brain finds its way from point A to point B is becoming more and more robust. This means it is one of the most useful fields of study to bring forward into industry.

This case study is from a discussion with Danny Ball, who is a PhD Candidate at University College London. He is both a neuroscientist and a potential first person user for wayfinding technology as he is legally blind. First the basics of navigation strategies will be defined, then the technology, and finally some new guidelines for improving the user experience .

There are two types of cognitive navigation strategies allocentric and egocentric, the adjacent map shows how the two strategies work[1].

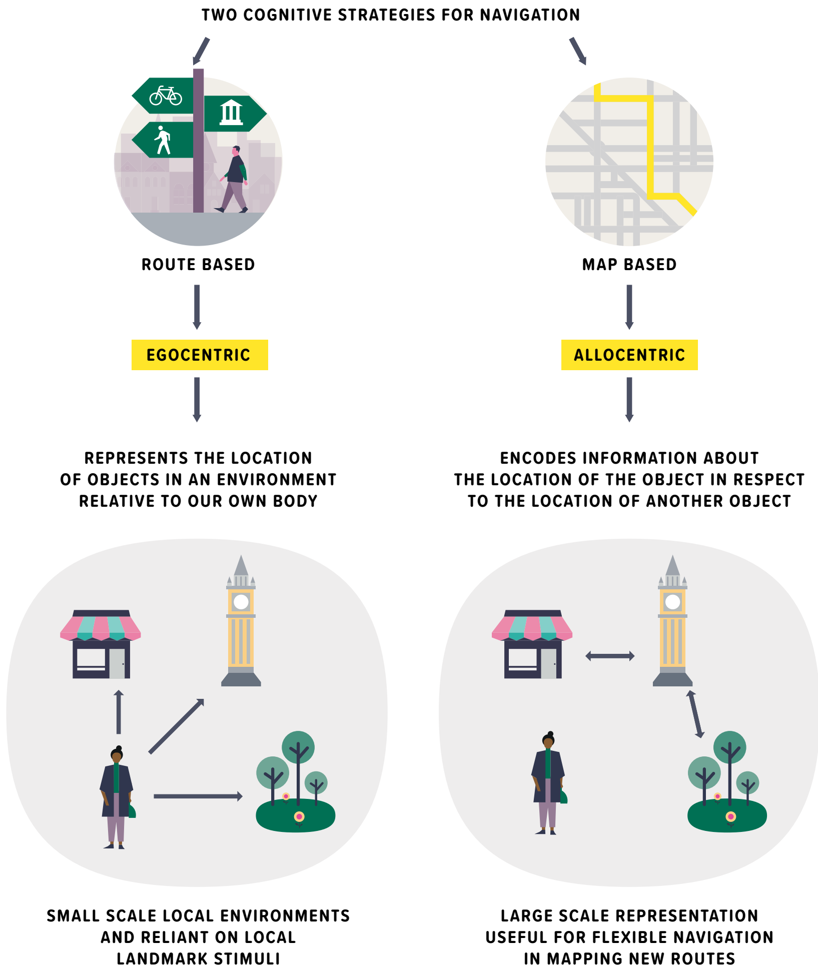
Bluetooth low energy beacons (BLEB's) are being used to help blind people with indoor wayfinding. The technology works through receiving auditory instructions via a smartphone app that connects with the beacons via bluetooth[3]. As it stands this technology is being programmed without the knowledge of human navigation strategies or the neural networks that support their function. Furthermore, as this technology is intended to aide blind people it would be useful for technologist to consider how the absence of vision affects the access of particular brain networks associated with allocentric and egocentric navigation strategies. Most literature suggests that navigation in the blind is not only impaired by the lack visual input, but also the inaccessibility of brain networks that are used for large scale representations.

In a review of standards for BLEB's Danny Ball breaks down the different areas of concern, following these guidelines will already make a difference in the user experience of the technology and increase adoption rates amongst blind users[3]. Below are Danny's guidelines for improving the user experience of wayfinding technology for those who are visually different.

Cardinal coordinates: Means of communicating general directions to a user based on points of a compass where 'North' is straight ahead

GUIDELINE: We do not know if blind individuals can process allocentric information. Using the term "north" may be confusing, in one sense it is arbitrary without orientation information relative to features or objects in far space. As discussed previously, vision is needed to

Please use this map to understand the guidelines on page 90



determine the location of features in the distance. It would be simpler to say straight ahead rather than north.

Sequential delimiter: Word or phrase that limits the relationship of one object to communicate directions, e.g., after (the gates).

GUIDELINE: Not defined, after the gates, next to the door etc. are in essence allocentric. Therefore instructing through step count and then giving an egocentric instruction such to your left or right will be more helpful

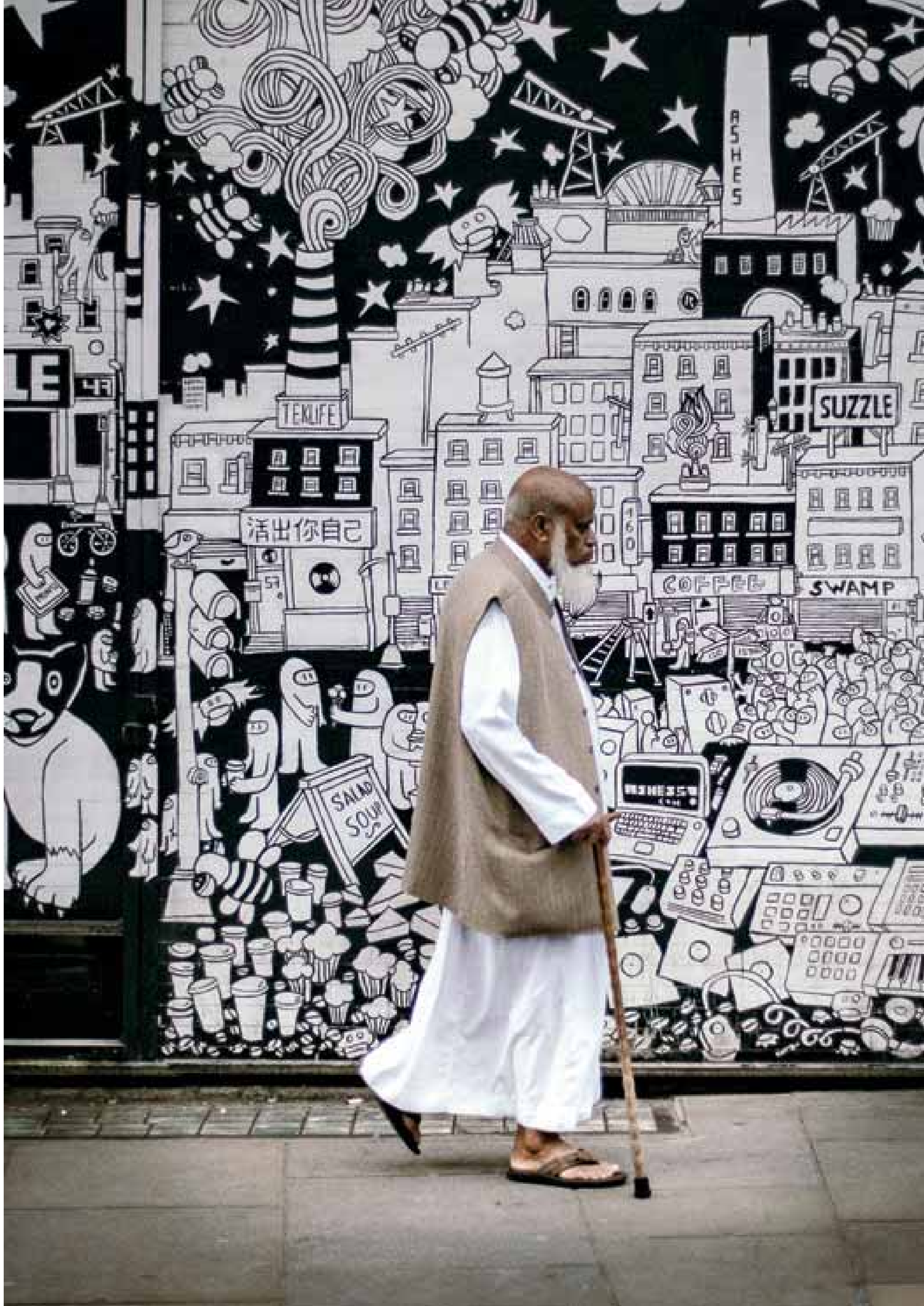
Alerts of the location of the next environmental feature Communicate information about the location of the next environmental feature, e.g., "The down escalator is the one on the left."

GUIDELINE: Describing the location of a feature in relation to another is allocentric. This may be difficult for a blind user to comprehend. The descriptions should always be egocentric until there is sufficient empirical evidence to infer, how and if blind individuals can construct representations of spatial layout.

The main takeaway from Danny Ball's research is "for such systems to be effective they should work with, rather than against the natural tendency of blind individuals to use an egocentric frame of reference for navigation. Going forward, the points raised here should be considered when advising on accessibility features for the built environment."[3]

This information and guidelines are essential to the success and utility of any new technology that endeavours to enhance the user experience of the built environment.

1. Moffat, S.D, Elkins, W. and Resnick, S.M. (2006) Age differences in the neural systems supporting human allocentric spatial navigation. Neurobiology of Ageing, 27(7), pp. 965-972.
2. Schinazi, V.R., Thrash, T. and Chebat, D.R. (2016) spatial navigation by congenitally blind individuals. Wiley Interdisciplinary Reviews: Cognitive Science, 7(1), pp. 37-58.
3. Camargo, A. and Ball, D. Interviews with Danny Ball (2018). Interview with Danny Ball, PhD candidate in Experimental Psychology, UCL.



Buildings and Campuses

A tool that can be used in industry is that of a risk assessment with a mitigation schedule informed by data from a library of neuroscience studies. The risk assessment is intended for early stage development of a building or campus. It assess the relationship between people and their tasks against the built elements.

Purpose

- Inform multidisciplinary teams in large complex projects of the human experiences of physical qualities.
- Understand the unintended human consequence of building programming
- Implement scientific research and findings into routine practice
- Inform programming of culture, services and design.

Outputs

- Increase usability rates
- Reduce margin of error in capital expenditure
- Improve intended adoption rates of spaces by users
- More inclusivity

Another immediate use of neuroscience for this sector is to improve the user experience of buildings or campuses. Specifically focusing on its navigability.

In an interesting case study, Professor Ruth Dalton, examined why the highly acclaimed Seattle Central Library was causing people to feel disorientated and lost. In a book co-edited by Professor Dalton called "Take One Building: Interdisciplinary Research Perspectives of the Seattle Central Library"(5), it goes into detail on the various aspects that make the library conducive to confusion, which can make people feel stressed and psychologically unsafe.

If a building causes people to feel stressed through disorientation, there has been a core failure in making a building inclusive, user friendly, and accessible. Furthermore, this case study highlights that the built environment is in need of more than just "good design" to make a building intelligible to human cognition.

There is now robust spatial cognition research to add to way finding techniques, such as space syntax, that can be combined to elevate the user experience of a building through making it more navigable.

Here is an opportunity to relate navigability and disorientation to economic performance across all built environment scales. For example, does it affect dwell in public realm spaces where socialisation or consumerism are the desired outputs? Or does it have an impact on operational performance of buildings by decreasing lost passengers at airports or patients at hospitals who end up needing staffing assistance to guide them?

City

There are many instances where we can start using neuroscience in cities, from improving the navigation, improving the user experience of transport systems, or mitigating the effects of environmental stressors. We propose that the third option be the first point of action, as it is the most urgent problem to solve.

The four environmental stressors we should focus on are noise, heat light, and air pollution. Whilst there are many more, these four stressors have been identified as they are related to a wide range of illness, mental health issues, and they are indicators of city mismanagement (please refer to charts in subsequent pages.).

A reduction in these stressors has the potential to have a widespread effect on the quality of life and health of city residents. For example, in the UK 40,000 people could be saved per year if there was a reduction in air pollution[1]. Thirdly, concentrating efforts on mitigating these three stressors would help meet the goals of city strategies such as "green cities", "inclusive cities", and "active cities".

The final point to consider is how the rate of exposure to environmental stressors differs between socioeconomic backgrounds. One particular 2006 study by New York University found a direct correlation between air pollution and disproportionately high rates of asthma in a predominately poor South Bronx neighbourhood. They obtained longitudinal data over 5 years of 90,000 residents in 2.2 sq miles neighbourhood. This population was exposed to soot particles from diesel trucks passing through the four major highways[3]. Asthma symptoms doubled during high traffic days, especially for elementary school children whose schools were in close proximity of the heavy goods traffic, because of past inefficient land-use decisions[3]. To make matters worse, this area has now become home to several fossil fuel plants, a waste transfer station and a sewage treatment facility, releasing even more toxins into their neighbourhood[3].

Unfortunately, the effect does not end with asthma; diesel particles also have huge impact on cognition. Especially vulnerable are pregnant women. The womb environment is particularly vulnerable to environmental toxins for three reasons. The first is that the blood-brain barrier is not fully formed making the developing brain more permeable to toxins. Secondly, as the baby develops, cells are dividing at rapid rate – increasing the chance of mutations which increase in the presence of toxins. The brain in particular takes longer to develop than other organs, leaving it more susceptible to consequences of environmental toxins. Thirdly, the brain is made up of different types of neuronal cells, "each type having a distinct growth phase and potentially a different toxicity profile[4]". In a study that looked at four birth cohorts, prenatal exposure to polycyclic aromatic hydrocarbons (PAH) found in polluted air suffered from cognitive deficits. These can range from lower IQ scores to learning and behavioural difficulties[4].

Stress Street Score

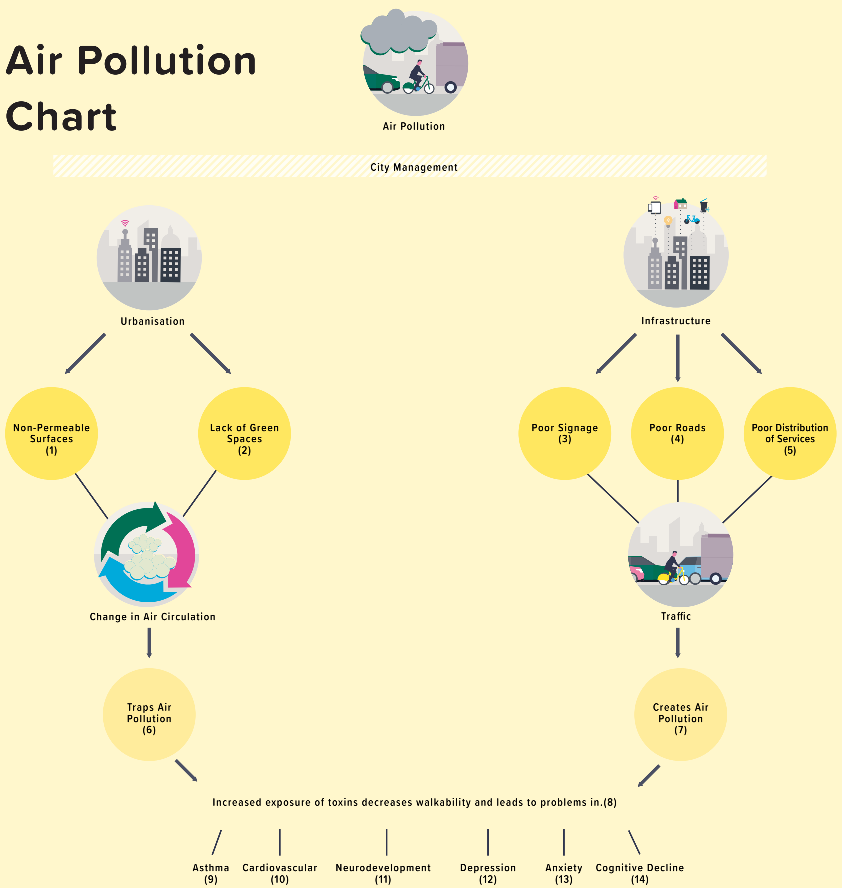
To combat these stressors Centric Lab has created a Stress Risk Score software modelled on the biological stress response. The lab conducted a meta analysis for each stressor to understand at what quantity (degree, decibel, micrograms, or radiance) does a particular stressor begin to cause stress to our biological system. The software produces a scale of 1 (biologically adequate) - 4 (biologically inadequate), that is visualised in heatmaps across all of London. For the first time we can answer questions such as: is this area "good" or "bad" for people or does this area pose a risk to people's health? We can put a number on the quality of experience of a street or area, which has been a long standing question for both neuroscience and the built environment.

Urban planners and place-makers can now use scientific baselines to evaluate current or future risk the built environment can impose on people.

- For urban planners and local authority planning officers it establishes a location based wellbeing risk assessment. This insight can then be used to create the necessary mitigations to improve the quality of experience of an area.
- For housing associations it provides a lens into how habitats are exacerbating or aiding long term health and wellbeing, isolating points for intervention.
- For private companies in transport and real estate it's an opportunity to evaluate how future audiences are likely to engage with an environment or service by understanding their biological user journey. Commuter journeys have a key role to play in the human performance of a worker. For example, one hour of air pollution exposure on an underground system is the equivalent of 24 hour street air pollution exposure. We have to consider what this exposure does to a person's health and its eventual consequence to absenteeism or presenteeism.
- For health related groups it offers a lens to investigate demographics and communities at risk in the face of climate change and urbanisation.

1. Taylor, M. (2017) Death from air pollution would be cut if UK hits walking and cycling targets. The Guardian, [online]. Available at: https://www.theguardian.com/environment/2017/dec/04/death-air-pollution-cut-if-uk-hits-walking-and-cycling-targets [Accessed 11 Apr. 2018].
2. The Atlantic (2017). Environmental racism is the new Jim Crow. [video]. Available at: https://www.theatlantic.com/video/index/529137/environmental-racism-is-the-new-jim-crow/ [Accessed 17 Apr. 2018].
3. New York University (2006) Asthma symptoms linked to soot particles from diesel trucks in South Bronx. [online] Available at: https://www.nyu.edu/about/news-publications/news/2006/october/asthma_symptoms_linked_to_soot.html [Accessed 17 Apr. 2018].
4. Lanphear, B.P. (2015) The impact of toxins on the developing brain. Annual Review of Public Health, 36, pp. 211-230.
5. Dalton, R.C. and Hölscher, C. eds., 2016. Take One Building: Interdisciplinary Research Perspectives of the Seattle Central Library. Taylor & Francis.

Air Pollution Chart



(1) New research focusing on the Houston area suggests that widespread urban development alters weather patterns in a way that can make it easier for pollutants to accumulate during warm summer weather instead of being blown out to sea.

National Center for Atmospheric Research (2011) Air quality worsened by paved surfaces: Widespread urban development alters weather patterns. Science Daily, [online] Available at: https://www.sciencedaily.com/releases/2011/06/110607121137.htm [Accessed 09 Apr. 2018].

(2) The density and spatial configuration of an urban forest, which is the sum of all urban trees, shrubs, lawns and previous soils located in an urban setting has clear affect land surface temperatures in the city and these elements are critical for improving urban air quality.

Zupancic, T., Westmacott, C. and Bulthuis, M. (2015) The impact of green space on heat and air pollution in urban communities: A meta-narrative systematic review. [online]. Vancouver: David Suzuki Foundation. Available at: https://davidsuzuki.org/wp-content/uploads/2017/09/impact-green-space-heat-air-pollution-urban-communities.pdf [Accessed 05 May 2018].

(3-5) An array of infrastructure to human activity can contribute to traffic. A sample from the recent TFL report cites construction, traffic signals, and city works for an increase of traffic.

Transport for London (2017) TLRN performance report. [online]. London: Transport for London. Available at: http://content.tfl.gov.uk/street-performance-report- quarter2-2017-2018.pdf [Accessed 01 May 2018].

(6) "pavement soaks up heat and keeps land areas relatively warm overnight, the contrast between land and sea temperatures is reduced during the summer. This in turn causes a reduction in night-time winds." In turn this can contribute to the trapping of pollutants.

National Center for Atmospheric Research (2011) Air quality worsened by paved surfaces: Widespread urban development alters weather patterns. Science Daily, [online] Available at: https://www.sciencedaily.com/releases/2011/06/110607121137.htm [Accessed 09 Apr. 2018].

(7) Poor distribution of resources can also increase traffic as people are forced to take vehicle transport from low density single use areas to denser multi-use ones to access them.

Downs, A. (2004) Traffic: Why it's getting worse, what government can do. [online] Washington: The Brookings Institution. Available at: https://www.brookings.edu/research/traffic-why-its-getting-worse-what-government-can-do/ [Accessed 09 May 2018].

(8) Walk-ability is a measure of how conducive the built environment is to walking and that predicts physical activity and active transportation.

Marshall, J.D., Brauer, M. and Frank, L.D. (2009) Healthy neighborhoods: walkability and air pollution. Environmental Health Perspectives, 117(11), pp. 1752-1759.

(9-10) "Physical inactivity and outdoor urban air pollution are two of the top 15 global causes of health impairment". These impairments can include poor cardiovascular health and asthma.

Marshall, J.D., Brauer, M. and Frank, L.D. (2009) Healthy neighborhoods: walkability and air pollution. Environmental Health Perspectives, 117(11), pp. 1752-1759.

(11) Urban children exhibit brain structural and volumetric abnormalities, systemic inflammation, olfactory, auditory, vestibular and cognitive deficits v low-pollution controls."

Calderón-Garcidueñas, L., Torres-Jardón, R., Kulesza, R.J., Park, S.B., D'Angiulli, A. Air pollution and detrimental effects on children's brain. The need for a multidisciplinary approach to the issue complexity and challenges, 2014. National Center for Biotechnology Information (USA) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4129915/

(12) A study published by the Global Labor Organization noted "higher air pollution index (API) significantly reduces hedonic happiness and raises the rate of depressive symptoms

Zhang, X., Zhang, X. and Chen, X. (2017) Happiness in the air: How does a dirty sky affect mental health and subjective well-being? Journal of Environmental Economics and Management, IZA, pp. 81-94.

(13) City residents of lower economic areas are shown to show higher associations to anxiety symptoms.

Pun, V.C., Manjourides, J. and Suh, H. (2017) Association of ambient air pollution with depressive and anxiety symptoms in older adults: results from the NSHAP study. Environmental Health Perspectives, 125(3), pp. 342-348.

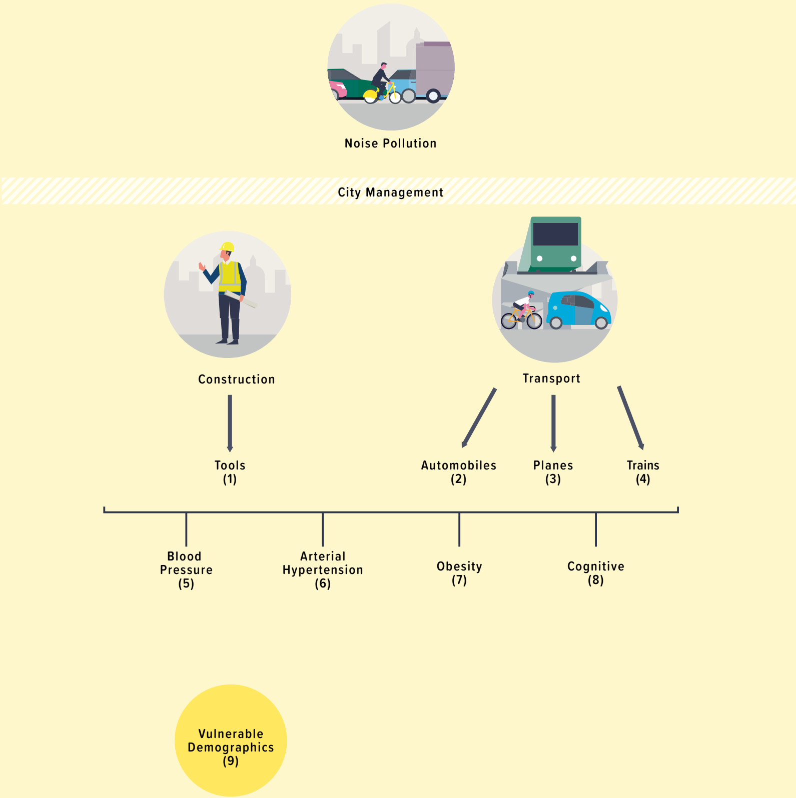
(14) "Long-term exposure to PM2.5-10 and PM2.5 avt levels typically experienced by many individuals in the United States is associated with significantly worse cognitive decline in older women."

Weuve, J., et al. (2012) Exposure to particulate air pollution and cognitive decline in older women. Archives of Internal Medicine, 172(3), pp. 219-227.

(15) "Increased PM2.5 exposure in specific prenatal windows was associated with poorer function across memory and attention domains"

Chiu, Y.H., et al., (2016) Prenatal particulate air pollution and neurodevelopment in urban children: Examining sensitive windows and sex-specific associations. Environment International, 87, pp. 56-65.

Noise Pollution Chart



(1) In London 30% of noise pollution complaints were due to construction works.

National Center for Atmospheric Research (2011) Air quality worsened by paved surfaces: Widespread urban development alters weather patterns. Science Daily, [online] Available at: https://www.sciencedaily.com/releases/2011/06/110607121137.htm [Accessed 09 Apr. 2018].

(2-4) In Europe road traffic is the dominant source of environmental noise, with an estimated 100 million people affected by harmful levels, this is followed by railways and airplane noise.

European Environment Agency (2017) Managing exposure to noise in Europe. [online] N.A: European Environment Agency. Available at: https://www.eea.europa.eu/publications/managing-exposure-to-noise-in-europe [Accessed 06 May 2018].

(5-6) Some studies have shown there is a relationship between chronic exposure to noise pollution and elevated blood pressure, arterial hyperextensions, and obesity.

The effects of noise pollution may in part be driven by the physiological response to the stress of being exposed to a persistent source of discomfort.

Stansfeld., S.A. and Matheson, M.P. (2003) Noise pollution: non-auditory effects on health. British Medical Bulletin, 68(1), pp. 243-257.

(7)"An increase of 10 dB (from the noise level of a dishwasher to a vacuum cleaner) decreases worker productivity by approximately 5%."

Dean, J.T. (2017) Noise, cognitive function, and worker productivity. MIT Economics: Working Paper, [online]. Available at: https://economics.mit.edu/files/13747 [Accessed 14 Apr. 2018].

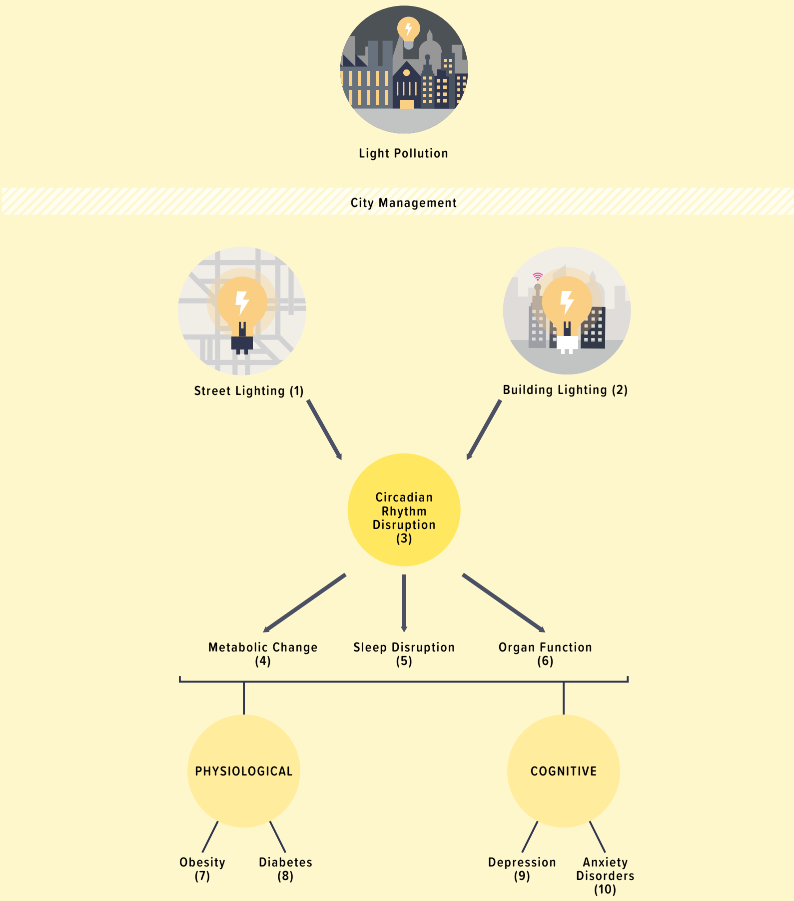
(8) "A study in France among 10-year-old schoolchildren showed that school noise exposure was associated with fatigue, headaches and higher cortisol level indicative of a stress reaction. "

Van Kamp, J. and Davies, H. (2013) Noise and health in vulnerable groups: A review. Noise and Health, 15(64), pp. 153-159.

(9) Another demographic that is vulnerable to the effects of noise those with ASD. For those that have auditory hypersensitivity, noise can lead to great physiological stress and anxiety. Which in turn can exacerbate symptomatology or in extreme cases cause outburst of panic, fear and distress.

O'Connor, K. (2012) Auditory processing in autism spectrum disorder: a review. Neuroscience & Biobehavioral Reviews, 36(2), pp. 836-854.

Light Pollution Chart



(1-2) Light pollution comes in many forms, including sky glow, light trespass, glare, and over illumination. Sky glow is the bright halo that appears over urban areas at night, a product of light being scattered by water droplets or particles in the air. Light trespass occurs when unwanted artificial light from, for instance, a floodlight or streetlight spills onto an adjacent property, lighting an area that would otherwise be dark. Glare is created by light that shines horizontally. Over illumination refers to the use of artificial light well beyond what is required for a specific activity, such as keeping the lights on all night in an empty office building.

National Center for Atmospheric Research (2011) Air quality worsened by paved surfaces: Widespread urban development alters weather patterns. Science Daily, [online] Available at: https://www.sciencedaily.com/releases/2011/06/110607121137.htm [Accessed 09 Apr. 2018].

(3) Circadian rhythms are defined as oscillations that calibrate approximately every 24hrs. “Circadian rhythms are generated by an interactive network of transcriptional and translational loops in the expression of a panel of clock genes, and this molecular ‘‘clock’’ is present in virtually all mammalian cells.” This means that a disruption to it has a potential to have wide and varied effects on our physical and mental health.

Wyse, C.A., et al. (2011) Circadian desynchrony and metabolic dysfunction: Did light pollution make us fat? Medical Hypotheses, 77(6), pp. 1139-1144.

(4-6) The disruption of circadian rhythm can cause disruption in melatonin production, which regulates sleep. There can also be changes in organ function and metabolic function.

Wyse, C.A., et al. (2011) Circadian desynchrony and metabolic dysfunction: Did light pollution make us fat? Medical Hypotheses, 77(6), pp. 1139-1144.

(7-8) Changes in fundamental functions as described above can lead to serious and long term physiological (diabetes, obesity) and cognitive problems (depression, anxiety disorders, cognitive decline).

Wyse, C.A., et al. (2011) Circadian desynchrony and metabolic dysfunction: Did light pollution make us fat? Medical Hypotheses, 77(6), pp. 1139-1144.

(9-10) “Although these sleep and circadian abnormalities were once dismissed as consequences of the disease process, accumulating evidence suggests that sleep and circadian disturbances likely occur very early in the disease process and may contribute to the pathogenesis of Alzheimer’s.”

Musiek, E.S., Xiong, D.D. and Holtzman, D.M. (2015) Sleep, circadian rhythms, and the pathogenesis of Alzheimer Disease. Experimental & Molecular Medicine, 47(3), doi: doi:10.1038/emm.2014.121.

NEAR FUTURE

As technology advances neurosciences methods, the applications to industry will become more sophisticated. This next section will look at how the use of artificial intelligence in neuroscience could soon be used in cities in the near future.

Using Artificial Intelligence to Forecast Behaviour and Cognitive States of Individuals and Groups in the Built Environment

Artificial intelligence (AI) holds many promises for the future. One of these is in providing information to aid the design of cities and buildings for better navigation and inclusivity. As we noted in our Historical Review section, simulated agent-modelling of population flow has been used for some time to assess buildings and transport networks. Simulated agents in these models provide useful insights as to where people might be attracted to or avoid and congregate. However, these models are relatively unsophisticated, particularly with regard to predicting how individuals learn to adapt to a city of building, or the different demographics of the population might behave or the cognitive demands associated with certain activities and places in an environment. For example different entrance lobbies would all make demands on deciding 'where to next', but some would be more 'confusing' than others. Predicting where in the space someone might need extra help is crucial and requires more sophisticated models. Neuroscience methods combined with approaches in AI offer the potential for providing models to make predictions for not only where groups of people might go or aggregate in a space, but what they might do in a place, when they might be lost and the cognitive demands with different parts of space. Neuroscience is essential it provides the raw material (data) to make the AI simulations provide good predictions about human behaviour.

Current research in neuroscience and AI has begun to explore methods for predicting how people may explore a space and how they might learn about a space depending on the structure of the space[1]. As noted on page 52 poor design in hospitals has had a significant impact on the delivery of healthcare and hospital costs. Thus, testing out how 'human-like' AI agents would perform finding their way in a newly designed hospital would help mitigate against the consequences of poor hospital layout. Key to this approach is to model artificial agents with advance methods in AI, draws on reinforcement learning (RL) and more recently deep reinforcement learning[1,2]. In this approach models agents that learn about their environment updating stored knowledge about space and enact policies as to how to find their way or perform tasks. The complexity of the knowledge stored and use varies. For example, knowing that after entering the building turning left is useful is distinct from knowing how the whole building space is connected. These future AI agents will find their way in simulated buildings or cities, travel to multiple goals and adapt to changes in the building or city layout. In figuring out how to navigate an environment these agents make mistakes and their computational demands at different

points in space can be measured. Both cognitive processing demands and errors give metric by which to examine building design. If these agents were able to mimic human behaviour to high level this would mean that they can predict A) where people will go, B) when they will get lost, C) how they will learn, and C) crucially the cognitive costs associated with new buildings or city layouts. The challenge for research is to created simulated agents that are as accurate in their predictions as possible. Current research by the UCL Spatial Cognition Group led by Dr Hugo Spiers has been exploring this issue by studying the behaviour of humans, rats and AI's in similar matching environments with the same layout and task demands. Study both humans and rats and matching their behaviour to AI's is helpful because rats can help give precise insights in the neural systems involved in spatial navigation and decision making (see our previous section on place cells). Recording from populations of neurons directly allows the scientist to test aspects of AI systems and improve them. Methods like optogenetics allow scientists the capacity to disrupt the neural circuits and understand causal relationships between brain and environments. In humans we can cross validate these measurements spatial processing from fMR or MEG.

Combining fMRI with film simulations of London its has been possible to identify how particular regions of the brain respond at different moments when navigating a city, what properties of the city are driving their activity, and what computations might be performed by these brain areas[3]. For example, entering a new street with lots of street connections drives more posterior hippocampus (the area that is larger in London taxi drivers[4]), but only when navigating from memory, not when guided by instructions such as with a 'sat nav'[3]. Based on activity dynamics the prefrontal cortex appears to perform a 'breadth-first-search' of possible streets ahead when the intended path is blocked[3]. Building on these results certain AI agents can be simulated to perform more like a human, predicting novel circumstances where humans would make errors of find challenging and the impact that conditions such a dementia might have since dementia will impact certain brain regions.

One challenge to sculpting accurate AI agents is having enough data to really support the process of tuning the model AI's. Testing how 100,000's or millions of people navigate a building or interact in a space is a significant challenge. This has recently been overcome by Dr Spiers and collaborators of the project Sea Hero Quest, which over 4 million people navigated a set of virtual environments and provided demographics via an online app[5]. This would allow predictions about how people of different backgrounds (e.g. older vs. younger people) and mixes of background will explore and navigate a space.

This approach is especially ground-breaking as it can help understand how neurologically diverse people will make sense of a space. For example, how might a person with depression vary from that with autism spectrum disorder. This work is crucial for creating buildings and streets that are optimised for all demographics, helping create genuine inclusive cities.

For industry it allows for engineers and planners to understand complexity levels of environments measured against their commercial goals. This goes into how easy it is to navigate town centres and retail districts and whether difficulties proposed will alienate demographics and discourage return and engagement. Ultimately lowering user experience.

1. Hassabis, D., Kumaran, D., Summerfield, C. and Botvinick, M., 2017. Neuroscience-inspired artificial intelligence. Neuron, 95(2), pp.245-258.
2. Sutton, R.S. and Barto, A.G., 1998. Reinforcement learning: An introduction (Vol. 1, No. 1). Cambridge: MIT press.
3. Javadi, A.H., et al. (2017) Hippocampal and prefrontal processing of network topology to simulate the future. Nature Communications, 8: 14652.
4. Maguire, E.A., Gadian, D.G., Johnsrude, I.S., Good, C.D., Ashburner, J., Frackowiak, R.S. and Frith, C.D., 2000. Navigation-related structural change in the hippocampi of taxi drivers. Proceedings of the National Academy of Sciences, 97(8), pp.4398-4403.
5. Coutrot, A., Silva, R., Manley, E., de Cothi, W., Sami, S., Bohbot, V., Wiener, J., Hölscher, C., Dalton, R.C., Hornberger, M. and Spiers, H., 2017. Global determinants of navigation ability. bioRxiv, p.188870.

7. FUTURE OPPORTUNITIES

This chapter will focus on the opportunities for government, planning, transport, and private development. Within each sector, it will look at the top 3 opportunities, how they can be achieved, and why they are important.

OPPORTUNITIES BY SECTOR

These tables are broken down by sector and indicate where what we need to focus for future work. It also explains what these opportunities will lead to.

Macro

SECTOR: Government

TOP OPPORTUNITIES

- Developing more advanced mobile technologies would allow researchers to conduct in the wild experimentations.
- The advancement in the technology would mean more reliable data.

HOW

TECH: Strategic long term funding to aid the development of new neurotechnologies such as mobile neuroimaging devices and mobile EEG machines.

SCIENCE: Neurophysics, Computational Neuroscience, Spatial Cognition, Perception (sensorial processing), Attention and Memory

RESEARCH: Lead groundbreaking discoveries about human to human interactions, navigation, and perception.

RESULTS

Taking neuroscience studies out of the lab is an important next step for this area of science. Uncovering the neurological mechanisms of the brain by using neuroimaging in situ will allow scientists to observe brain function whilst people are engaged in real-world scenarios.

Kasai, K., Fukuda, M., Yahata, N., Morita, K. and Fujii, N., 2015. The future of real-world neuroscience: imaging techniques to assess active brains in social environments. Neuroscience research, 90, pp.65-71.

Macro

SECTOR: Government

TOP OPPORTUNITIES

Long term funding for multi disciplinary projects.

HOW

TECH: A wide range of neurotechnology, machine learning, virtual reality, IoT sensors,

SCIENCE: Study the aspects of the brain relating to how people makes sense of environments and navigate from point A to point B.

RESEARCH:

- Advance the research of perception; how sensorial information is processed in the brain.
- Advance the research for spatial navigation amongst varied demographics such as the blind, those experiencing depression, dementia, and ASD.
- Advance research into how noise, light, air pollution and other environmental stressors affect cognitive performance long term at building and neighbourhood level.
- Advancing the research into enriched environments at the human scale.

RESULTS

- It would lead to more projects like the Ecological Brain. Whose aim is to "equip the next generation of brain scientists in harnessing and further developing new methods and technologies to measure behaviour and brain activity in the wild, to bring real-world complexity into the lab and to analyse the wealth of data these methods produce."1
- There is also The Human Project in NYC. This project is also multi-industry and multidisciplinary. Aimed to "help scientists reveal how all the millions of tiny puzzle pieces in our lives connect together."2
- These type of multi-disciplinary programmes would also facilitate "real-world" studies, which can have direct industry impact.
- Update building and built environment standards that incorporate mental health conditions. Resulting in healthier homes, schools, hospitals and commercial buildings.

UCL (n.d.) The Leverhulme Doctoral Training Programme for the Ecological Study of the Brain. [online] Available at: http://ecologicalbrain.org/ [14 Apr. 2018].

The Human Project (n.d.) The human project. [online]. Available at: https://www.thehumanproject.org/about/ [Accessed 08 May 2018].

Micro

SECTOR: Transport

TOP OPPORTUNITIES
Increasing mobility opportunities for socially, culturally and economically excluded demographics.

HOW
TECH: Space Syntax, Virtual Reality, Mobile EEG, fMRI, Artificial agent modeling.

SCIENCE:

- More studies on how different cognitive demographics perceive distance.
- More studies on how different cognitive demographics use the two types of navigation strategies

RESULTS
MITIGATION: Isolation, Depression, Social & Economic Exclusion.

AFFORDANCE: Inclusion to wider culture and economy, Economic opportunity

SECTOR: Transport

TOP OPPORTUNITIES
Create age-friendly and inclusive streets and neighbourhoods.

HOW
TECH: Geospatial analysis, Space Syntax , IoT Sensors monitoring pollution, Artificial agent modeling, fMRI

SCIENCE:

- Studies into how people with dementia or in old age process different sensorial information.
- Studies into how people with dementia or in old age perceive distances.
- Studies into dementia or in old age effects on both allocentric and egocentric navigation strategies.

RESULTS
MITIGATION: Isolation, Stress, Social Care Cost

AFFORDANCE: Physical exercise, Inclusiveness, Autonomy, Wellbeing

Micro

SECTOR: Planning

TOP OPPORTUNITIES
New methods to evaluate the effectiveness and impacts of proposed new construction activities and developments.

HOW
TECH: Space Syntax, Mobile EEG, VR, Living labs

SCIENCE: Longitudinal studies on measuring “dose” of different combinations of built environment elements.

RESULTS
MITIGATION: Environmental Stressors, Mental health issues, Inequality

AFFORDANCE: Increased quality of tools to reduce long term social problems. Improved quality of life

SECTOR: Planning

TOP OPPORTUNITIES
Increasing effectiveness of green areas in neighbourhoods and cities

HOW
TECH: Geospatial analysis, Technology apps which allow us to question human activity in the "real world" as per Urban Mind Project, fMRI, Mobile EEG

RESEARCH: Understanding dosage levels of green typology and topography relation to cognitive benefit.

RESULTS
MITIGATION: Respiratory Issues. Stress & Anxiety. Isolation and loneliness.

AFFORDANCE: Calm, Restorativeness, Physical Exercise, Social Inclusion, Social Cohesion, Increased Wellbeing

Micro

SECTOR: Planning

TOP OPPORTUNITIES

Development of Area Design Codes that are inclusive of vulnerable demographics, such as children with autism and elderly residents with mental impairments.

HOW

TECH: Data Standards, Space Syntax, Mobile EEG, VR, Living labs

SCIENCE: Longitudinal studies on measuring “dose” of different combinations of built environment elements.

RESULTS

MITIGATION: Disorientation. Alienation and Exclusion. Stress. Impact of social care

AFFORDANCE: Inclusivity. Autonomy. Walk-ability. Dwell. Social Engagement. Sense of Place

SECTOR: Architecture/ Construction/Engineering/Development

TOP OPPORTUNITIES

Improved quality of residential, commercial and leisure environments that are accommodating to later life living, working and playing.

HOW

TECH: Smart Home and smart building operating systems and technologies. IoT sensors and devices

SCIENCE:

- Advancing research in how the environment plays a role in the later development of dementia and other neurodevelopmental conditions. Advancing research into sense of place and place attachment using neuroscience research.
- Living lab based research to understand enrichment at a human scale.

RESULTS

MITIGATION: Personal health issues. Social care cost.

AFFORDANCE: Autonomy, Quality of Life, Productive contribution to wider economy later in life

Micro

SECTOR: Architecture/ Construction/Engineering/Development

TOP OPPORTUNITIES

Smart materials that are more biophilic which support both indoor and outdoor health. This would include off-site manufacturing and bioengineering.

HOW

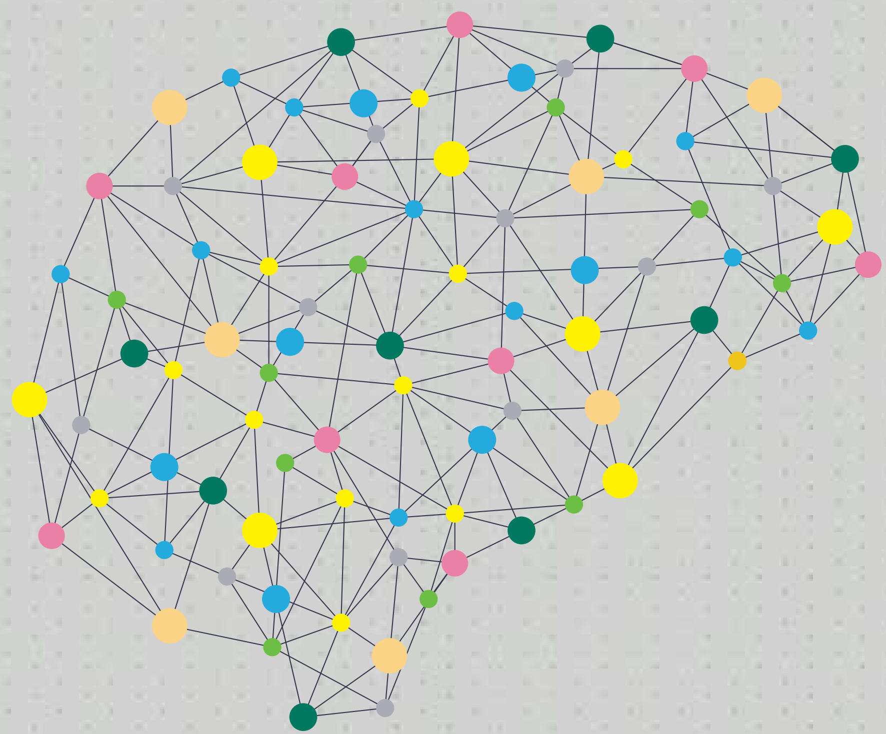
TECH: VR, neurotechnology

SCIENCE: Use historical neuroscience to validate products and enhance user experience. Living Labs to observe the performance of the materials as well as monitor the long term physiological on users

RESULTS

MITIGATION: Reduction of pollution from construction traffic. Less environmental toxins at city and building level. Decrease "sick building syndrome". Reduce environmental stressors.

AFFORDANCE: Increased User Experience. Healthier environments. Increase productivity.



CONCLUSION

There is no greater time than right now, we have the state-of-the-art technology at our fingertips, great advancements in science, and amazing human resources to push city innovation into groundbreaking areas. Neuroscience can serve as a lens to identify the united human consequence of built environment elements, with the purpose of enhancing the user experience of buildings and cities.

Neuroscience is a very attractive science as it unlocks insights of the human condition. It tells how we experience the world around us, how we solve problems, and now, with the help of this playbook it will allow us to build cities that are interesting, healthy, and prosperous.

HONOURABLE MENTIONS

This section is to highlight that there is outstanding amount of amazing work being done around the world to help enhance the experience of cities. These are the laboratories and tools that neuroscience can help categorise and deploy into city innovation for maximum usability and adoption.

CITY RESEARCH LABS

Senseable City Lab | Boston, MA (USA)
Through design and science, the lab develops and deploys tools to learn about cities—so that cities can learn about us.
http://senseable.mit.edu/

Urban Realities Laboratory | Waterloo, ON (Canada)
"In our laboratory, we study the impact of urban design on human psychology. We employ a wide variety of methods ranging from field studies of behaviour in urban and architectural settings to the use of immersive virtual reality to test predictions about urban behaviour in simulations."
https://uwaterloo.ca/urban-realities-laboratory/

Beijing City Lab | Beijing (China)
The Beijing City Lab (BCL) is a research network, dedicated to studying, but not limited to, China's capital Beijing. The lab focuses on employing interdisciplinary methods to quantify urban dynamics, generating new insights for urban planning and governance, and ultimately producing the science of cities required for sustainable urban development.
https://www.beijingcitylab.com/

Complex City Lab | Shanghai (China)
ComplexCity Lab is an interdisciplinary sino-french joint research laboratory. It aims to study the city, and to a greater extent, urban systems. We are taking an innovative approach which combines the analytical and computational capabilities of engineering sciences with the openness and creativeness of humanities and social sciences.
http://www.complexcity.org/

Urban Systems Lab | New York, NY (USA)
Rapidly expanding urbanization, biodiversity loss, and climate change pose potentially dramatic implications for the wellbeing of urban residents and the natural systems they depend on. Our research, from theory to practice, aims to reveal and support the social-ecological-technical system processes that together drive everyday experiences in cities and urban areas.
http://urbansystemslab.com/

MATERIAL INNOVATIONS

CoeLux | Lake Como (Italy)
CoeLux is an optical system based on nano-technology to artificially reproduce the natural light and visual appearance of the sun and sky. CoeLux offers a breakthrough opportunity for indoor architecture by creating the sensation of infinite space.
http://www.coelux.com/

Airlite | Milan (Italy)
Accoya® is the world's leading high technology long life wood. Accoya® modified timber has properties that match or exceed those of the best tropical hardwoods and treated woods, yet is manufactured using wood from sustainable sources.
https://www.accoya.com/

Saint-Gobain Multicomfort | Courbevoie, Paris (France)
Saint-Gobain has pioneered the development of innovative building materials and solutions that shape the way we live today. Saint-Gobain is recognised as one of the world's Top 100 Global Innovators (Thomson Reuters Index, 2014) employing 3,700 R&D and building science specialists worldwide. Their experts work closely with the user experience team to help customers create buildings that are designed from the ground up to maximise comfort and performance – for all users, at all times.
http://multicomfort.saint-gobain.com/

Sigma-Aldrich Corporation | St. Louis, MO (USA)
An American chemical, life science and biotechnology company. Its purpose is to solve the toughest problems in life science by collaborating with the global scientific community to accelerate access to better health for people everywhere.
https://www.sigmaaldrich.com/

ENVIRONMENTAL RESPONSIVE INNOVATIONS

Studio Roosegaarde | Rotterdam (Netherlands)
The Smog Free Project is a series of urban innovations led by Daan Roosegaarde to reduce pollution and provide an inspirational experience of a clean future. It provides a local solution of clean air in public spaces. Along with governments, students and the clean-tech industry, they believe people can work together to make a whole city smog free.
https://www.studioroosegaarde.net/project/smog-free-tower

ID2 Studio | Vienna (Austria)
The pebble like device lets you reclaim silence for your home. It turns your window into an advanced noise cancelling system that allows you to eliminate and/or control the sounds that pass through. With its concentric broadband antenna rings, it harvests the energy of electromagnetic noise from Wi-Fi, and similar signals and this way also reduces the level of e-smog pollution in your environment.
http://id2studio.at/content/noise/

Comlight | Grålum (Norway)
Motion Sensing Street lighting features a radar detector that senses all activity that requires optimal lighting on the road or in the area. It only registers the activity that is relevant for safety. As a result, drivers, cyclists and pedestrians will experience normal illumination levels all along their route. It reduces wasteful lighting of roads and other public places, without compromising the safety.
http://www.comlight.no/product/technology

Ital Cementi | Bergamo (Italy)
The combined action of light and the active ingredient TX Active® decomposes the pollutants produced by human activity (factories, traffic, domestic heating), returning better air quality. It activates a strong oxidative process that leads to the transformation of harmful organic and inorganic substances into harmless compounds.
https://www.italcementi.it/it/iactive

StarPath | Surrey (UK)
Starpath-Pro absorbs UV rays during the day and expelling them at night as a soft blue glow to provide a safe, more environmentally friendly and cost effective alternative to outside lighting.
http://www.pro-teqsurfacing.com/

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