Perspective

Sustainable Urban Futures and Sustainable Urban Systems in the Built Environment: Towards an Integrated Urban Science Research Agenda

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ABSTRACT

Today the built environment (or the human-made spaces and related infrastructures in which we live, work and play) is a vitally important element of our urban-oriented world. Increasingly we also see a closer focus on long-term 'sustainable urban futures' research, as both academics and national and international interest groups frame their discourses, policy and practice guidance, and current research agendas not only on the best and most effective ways of transitioning to a sustainable future, but also recognising the inherent complexity in existing 'urban systems'. This perspective paper aims to trace the evolution of such thinking, drawing on both scholarly work and previous national and international high-level publications from relevant research programmes to identify key themes and commonalities of approach. The paper focuses on highlighting the importance of two interconnected research themes within the wider context of built environment research: (i) 'sustainable urban systems' (SUS) and (ii) 'sustainable urban futures' (SUF). In doing this the paper aims to synthesise the literature, distil emergent research findings from a range of publications to develop an integrated research agenda positioned at the nexus between these themes, and to explain what these and other key related concepts mean, and why they are important to understand. Adopting an international perspective and drawing on previous research from the 'Global North' and 'Global South', the paper concludes by highlighting the emerging lessons and challenges for research practice and suggests areas for future transdisciplinary research in what is termed 'urban science'.

KEYWORDS: built environment; natural environment; sustainable development; urban systems; urban futures; foresight; urban science; visioning; convergence; transdisciplinarity

ABBREVIATIONS

SUS, sustainable urban systems; SUF, sustainable urban futures

INTRODUCTION

Our world is already heavily urbanised, with more than 55% of people across the globe living in cities, and by 2050 this is set to grow to 70% [1,2]. In the context of the current climate crisis, it is little wonder therefore that cities are seen not only as the major source of greenhouse gas emissions, but also as the primary source of technological innovation, social learning, and financial capital, that is necessary to tackle and arrest global warming, and which in combination also represents a form of 'urban paradox' [3,4]. Moreover, the 'built environment', or human-made spaces and related infrastructures in which we live, work and play, is a major contributor to global emissions and energy consumption (38% of energy-related emissions and 36% of final energy use) [5]. Additionally, as cities emerge from the COVID pandemic they also face many other common environmental and socio-economic challenges such as congestion, shortage of adequate housing, poor air quality, declining infrastructures, and migratory pressures. The importance of cities globally not only raises important questions about how we need to understand them in a changing context, but also directly influences the built environment research agenda of which they form an important part [6].

For example, a city can be thought of as a 'system' which envisages sets of components within a city (including transportation, energy, water, waste, retail, health, welfare, finance, and so on) tied together or networked, with 'complexity' (based on the many and varied connections in the city) and 'adaptiveness' (ability to adjust and adapt) at the heart of this thinking [3,7–11]. This relatively new 'science of cities' (or 'urban science') is partly based on some of the urban planning thinking of Jane Jacobs ('organised complexity') during the 1960s [12], but has also interwoven a range of other disciplines which include engineering, cybernetics, mathematics, and social science through the work of Michael Batty and others [7–11,13]. It is also true that cities have often been at the heart of what we might broadly call 'futures studies' for many years. Just as cities themselves have a long history stretching back some 3000 years, so over many hundreds of years we have tried to imagine (through literature art and film, for example) how cities might be (for better or for worse) in the long-term future. For example, writers such as Plato and Thomas More were early thinkers before the visionary work of planners such as Ebenezer Howard and Patrick Geddes [3,10]. However, particularly over the last decade, and in an era often referred to as the 'urban age', we have seen an increasing focus on practical 'urban futures' thinking from both academics, and 'knowledge alliances' (or research networks and hubs) at national and international level [3,13,14]. In this respect 'sustainable urban futures' thinking can be thought of as a

framework for imagining what cities will be like in the long term, what sort of governance structures are needed and how they are best shaped by their primary stakeholders (including people, broader civil society, governments, businesses, and academia) in order to transition and to transform our existing cities and urban areas into places that are sustainable (in environmental, social and economic terms) [3].

In short therefore, recent literature has highlighted the importance of two interconnected research themes in the wider context of built environment research: (i) sustainable urban systems (SUS) (or the way in which complex systems thinking about cities can help create more sustainable outcomes); and (ii) sustainable urban futures (SUF) (or the way in which futures (or foresight-based) thinking and city visioning can aid our understanding of achieving a sustainable, long-term future). These themes have also been at the heart of an increasing number of funded research projects at national and international level and in combination they lie increasingly at the heart of what is referred to as 'urban science' [7,9,15].

It should be noted that the literature cited in this perspective paper is not intended to be exhaustive and so does not contain a quantitative bibliographic analysis, but does include a discussion and critique, from the author's position at least, of the most important papers and reports from recent scholarly activity and influential research programmes and knowledge alliances in both the Global North and Global South. The format of the paper is as follows. The first section of the paper identifies the field of study in more detail by providing definitions and explaining the key themes and their interrelationship. The paper then explores the evolution of 'sustainable urban futures' (SUF) thinking and 'sustainable urban systems' (SUF) thinking from the early concepts of 'sustainable city' through to more recent research which has focused on 'urban science'. The third section of the paper focuses on describing the past and present research landscape in focus of major SUS and SUF research programmes, and synthesised research findings, before the key emerging cross-cutting themes from these previous research programmes and networks are discussed. Finally, the paper concludes by highlighting the emerging lessons for research practice and suggests areas for future built environment research in the growing field of 'urban science'.

THE DEFINED FIELDS OF STUDY: DEFINITIONS AND KEY CONCEPTS

This paper links previous literature from two fields in the wider context of 'built environment research'. These are (i) sustainable urban systems (SUS) and (ii) sustainable urban futures (SUF). In many respects there is overlap, interconnectivity and didactic discourse across the 'boundaries' of study, which can also involve different disciplinary lenses, varying timeframes, and different geographic foci. These themes are now explored in detail to offer definitions and identify the linked boundaries of interest.

Firstly, the field of built environment (BE) research is a broad, multi-scale one involving interactions and processes at individual/personal level; building level; neighbourhood/community level; and city level [16]. The term, 'built environment', has been defined in a number of ways by different researchers since its origins in the 1970s, but in general refers to the physical part of our environment that is human-made [17]. For example, the UK All Party Parliamentary Group for Excellence in the Built Environment defines built environment as encompassing 'all forms of building (housing, industrial, commercial, hospitals, schools, etc.) and civil engineering infrastructure, both above and below ground and includes the managed landscapes between and around buildings' [18]. Health Canada provide a more detailed definition as follows: "The built environment includes our homes, schools, workplaces, parks/recreation areas, business areas and roads. It extends overhead in the form of electric transmission lines, underground in the form of waste disposal sites and subway trains, and across the country in the form of highways. The built environment encompasses all buildings, spaces and products that are created or modified by people. It impacts indoor and outdoor physical environments (e.g., climatic conditions and indoor/outdoor air quality), as well as social environments (e.g., civic participation, community capacity and investment) and subsequently our health and quality of life" [19]. In this respect it differs from the term 'natural environment', which is more concerned with nature and natural world and objects that are not human-made but may be impacted by humans [20] although, as we shall see later in this paper, both terms need to be considered in a more holistic and integrated way.

Built environment research can therefore encompass many diverse themes and disciplines ranging from science and engineering through to arts and humanities. Similarly, built environment research can connect with the work of different professional bodies and institutions such as planners, surveyors, real estate specialists, engineers, and architects. In the UK, the three areas of research within the built environment (BE) receiving most funding through the UK Government-funded Engineering and Physical Science Research Council (EPSRC) during 2021/22 were 'end use energy demand' (£5.4 million); 'infrastructure and urban systems' (£4.9 million) and 'engineering' (£3.4 million), but in comparison with other areas the total funding over time for BE research at £34 million (as at October 2022) is relatively small in comparison with, for example, manufacturing (£625 million) and AI (£484 million) [21]. The EPSRC BE research area in the UK also includes processes such as procurement, project management, innovation management and use of information and communication technologies, and the focus of the EPSRC in this respect is 'on long-term transformative challenges within a whole systems context to consider the use of ICT in construction, building performance and public health in the built environment' [21]. Built environment research therefore covers a broad range of work and this fact is also underpinned

by a recent survey of built environment research in the Global South which found work ranging from urban planning through to energy and infrastructure research [22].

We now turn to the two themes which are the focus of this paper, and which have grown in importance within the context of the wider BE research agenda and which both focus on the city scale.

Firstly, the concept of 'urban systems' is not new as authors such as Norbert Wiener, a mathematician and engineer, showed how cities could be viewed as systems in the 1940s using the study of cybernetics [23]. Indeed, even the earlier 20th century work of Patrick Geddes, the visionary town planner, appreciated the organic complexity of cities [24]. In its most general sense, a 'system' refers to the abstract identifiable organisation of phenomena [25], and inherently cities possess systemic characteristics. For example, they exhibit 'emergent' properties (or the formation of novel and coherent structures and patterns during self-organisation), some of which can be difficult to explain. These include not only nonlinear dynamics, feedbacks, and high interconnectivity and unpredictability, but also having interlinked subsystems that can create redundancy and exhibit resiliency [13]. This has led to the concept of the 'science of cities' (or 'urban science') which uses a range of evidence to understand how cities work. Essentially this seeks to understand the important processes that drive, shape, and sustain cities and urbanisation, based on bringing together a range of disciplines encompassing the social, natural, engineering, and computational sciences, along with the humanities but is focused very much on systems thinking [7].

In the USA the National Science Foundation (NSF) has defined urban systems as: 'geographical areas with a high concentration of human activity and interactions, embedded within multiscale interdependent social, engineered, and natural systems that impact human and planetary wellbeing across spatial (local to global) and temporal scales' [26]. Moreover, given the growing emphasis on sustainable development as a pathway to sustainability in cities across the world, NSF also provide a helpful definition on 'sustainable urban systems' as being 'those that are transforming their structures and processes with the goal of measurably advancing the well-being of people and planet' [26]. This implicitly links with the Brundtland definition of sustainable development [27], which places an emphasis on protecting the needs of future generations (see below).

Secondly, taking the other main theme, the term, 'urban futures' has been defined as meaning: 'to imagine what cities and urban areas will be like in the long-term (beyond 20 years), how they will operate, what infrastructure and governance systems will underpin and co-ordinate them and how they are best shaped and influenced by their primary stakeholders (civil society, governments, businesses and investors, academia and others)' [3]. Following on from this, if we subscribe to the concept of 'sustainable development' then we can use the Brundtland

definition to identify a primary goal or aspiration of what a shared and desirable urban future should be: namely, that the urban future should, through sustainable development, 'meet the needs of the present, without compromising the ability of future generations to meet their own needs' [27]. Therefore 'sustainable urban futures' (SUF) is the process of imagining what our cities will be in the long-term future to enable the end goal of sustainability to be achieved through sustainable development, which is based on the environmental, social, and economic pillars underpinned by sound governance. In the academic literature the concept of 'sustainable urban futures' is also closely linked with the idea of a 'sustainable city', which has been defined by the UN as 'a city where achievements in social, economic and physical development are made to last' [28].

Despite the clear potential these two research areas offer in helping our understanding of the built environment, examples of funded projects which bring them together in an integrated way are often quite rare because of the siloed and fragmented nature of the built environment research [29]. The next section of the paper explores how SUF and SUS thinking has evolved and how the two areas overlap and are, in many ways, linked.

THE DEVELOPMENT OF SUSTAINABLE URBAN SYSTEMS AND SUSTAINABLE URBAN FUTURES THINKING

The development of both the SUF and SUS research themes are closely linked to the 'sustainable city' discourse. The origins of the term, 'sustainable city' (or 'eco city'), can be found in previous 'organic' city visions such as Patrick Geddes, 'biopolis' and Ebenezer Howard's 'garden city' in the late 19th and early 20th centuries [3]. It was not until the 1960s and 1970s, however, that the concept of the 'sustainable city' started to become part of the world of urban studies, and this was the result of the interweaving of an 'ecological crisis' and the 'urban crisis' in the discourse at that time [30,31] As a result of this increasing attention on cities and their environmental impact heightened, and as other texts such as the Club of Rome's Limits to Growth report [32] which highlighted the instabilities of population growth and resource use, were published, the focus on the role of cities in the growing ecological crisis increased further [33]. This growing interest was also reinforced by pioneering moves to develop alternative 'eco-communities', set aside physically away from cities: for example, the Findhorn project in 1962 in Scotland and the Arcosanti complex built in the Arizona desert in 1970 both of which gained in recognition [3,34].

The growing concerns about cities were first addressed in a systematic way in the United Nations (UN) Centre for Human Settlements (Habitat) Conference in Vancouver in 1976, which laid the foundations for the principles of sustainable urban development. Although the conference did not formally define the term, 'sustainable city', it was important for debating crucial issues such as the challenges of providing clean water and

sanitation, migration to cities and slum living, and the potential that lay behind a more sustainable approach to urban development [35,36].

This period also coincides with the publication of what is widely known as the Brundtland report [27]) which defined sustainable development as:

'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- The concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs'.

Many present-day issues and problems, relating to urban sustainability (and sustainable cities), can be viewed through the lens of the 'triple bottom line' approach, which views the sustainable development concept in terms of social, economic and environmental dimensions, underpinned by appropriate governance structures [37], although the 'praxis' of sustainable development often lacks consistency in an urban context, as the wider concept is contested and debated [3].

The increasing recognition of the importance of 'sustainable cities' also led to a plethora of major international and EU-level policies during the 1990s culminating in the Habitat II City Summit in 1996 which focused on the Local Agenda 21 (LA21) in urban areas. LA21 was a voluntary process of local community consultation with the aim of creating local policies and programmes that work with the aim of achieving sustainable development [30,31]. More recently the UN Sustainable Development Goals have refocused attention on 'sustainable cities and communities' through SDG 11 [38]. However, definitions still vary and other terms such as 'eco city', 'green city' and 'liveable city' have been applied. One such definition is from the UN Human Settlement Programme (see also above) [28]:

'A sustainable city has a lasting supply of natural resources on which its development depends (using them only a level of sustainable yield (and) maintains a lasting security from environmental hazards which may threaten development achievements (allowing only for acceptable risks)'.

The core elements of this are implicitly recognised by the UN's Sustainable Development Goal (SDG 11) which aims to renew and plan cities and other human settlements in a way that offers opportunities for all, with access to basic services, energy, housing, transportation, and green public spaces, while reducing resource use and environmental impact (i.e., to make cities and human settlements inclusive, safe, resilient, and sustainable) [38].

The question remained, however, if the 'sustainable city' was (and still is) such an important 'normative' end goal for city authorities to attain how could city be planned and managed to achieve a sustainable future? In the context of urban planning, the idea of 'city visioning' (or having a

clear and formal sense of where a particular city wants to be in the long-term future) therefore emerged during the 1980s and 1990s, particularly in the USA, not only as a way of understanding the future, but also to plan for a desirable, or preferred, set of sustainable outcomes (see for example, Atlanta, and Portland) [39]. Other research [40] has highlighted successful examples of city visions (which often involved participatory methods working with the public and other stakeholders to construct the visions) in Perth, Vancouver, and Chicago during the same period. This emergence of thinking about the future of cities also reflected a growing body of literature focusing on 'visioning sustainability' in a range of other contexts, such as energy futures [41,42]. Increasingly urban futures thinking at this time also reflected a growing emphasis on using foresight-based methods in city visioning, and included a wide range of studies including scenario-planning, horizon-scanning, community-visioning, anticipatory policy intelligence, road-mapping and similar techniques. The common features of these include: (1) longer time horizons; (2) wider communities of stakeholders; and (3) deeper layers of systems change, than can be addressed by mainstream functional urban planning [3].

Also, during this time a key UK Government Office of Science (GofS) Future of Cities Programme (2013–2016) highlighted the importance of 'city foresight', founded on the science of thinking about the future of cities, and which can be used to enable city stakeholders to explore urban futures not only in a local and regional context, but as part of a wider connected network of cities [43–47] (Table 1). Several UK city visions were created as part of this programme (for example, Reading, and Newcastle) resulting from partnerships between academia, local authorities, business, and civil society (the combination of which form the basis of the 'quadruple helix' model of innovation [48] Some of these visions have also linked with and underpinned the existing statutory local plans in cities [49]. A primary focus of the work in this programme was city foresight which used visioning activities based on foresight methods (for example, backcasting, and scenario-building) to construct specific visions.

In this sense 'foresight' can broadly be defined as the discipline of exploring, anticipating, and shaping the future, which helps build and use collective intelligence in a structured and systematic way to anticipate developments and better prepare for change [3,50]. Although futures studies have a long history stretching back to early oral and written traditions (for example, the scholar Sima Qian in the 2nd century BCE), the term 'foresight' as understood today is thought to have first originated in a BBC broadcast by the famous science fiction author, HG Wells, in 1932. Usually, foresight is concerned with the study of longer-term futures of more than 20 years (or at least 10–15 years) away, and with alternative futures and how to achieve them. Such futures may be 'possible', 'preferred' or 'prospective'. Foresight is usually qualitative and not predictive, and often explores a range of possible or desirable futures. Foresight's early origins, in the 1940s to 1960s, lie in the government and

business sectors (for example, the RAND corporation in the USA), but has focused more recently on environmental issues and related socio-economic impacts through the work of such organisations as the World Economic Forum and the International Resource Panel [3].

Table 1. Sustainable Urban Futures and Sustainable Urban Systems: Examples of Key Research Programmes.

Programme/Report /Network	Geographic focus	Time period	Overall focus	Key references	Website
1. National/International Cities					
Future of Cities (Government Office for Science)	UK	2013–16	SUS/SUF	[43–46]	https://www.gov.uk/government/collections/future-of-cities
Cities of the Future	Norway	2008–14	SUF	[51]	https://archive.nordregio.se/en/Publications/Publications-2016/GREEN-GROWTH-IN-NORDIC-REGIONS-50-ways-to-make-/Green-cities-and-municipalities-/Cities/index.html
Saudi Future Cities	Kingdom of Saudi Arabia	2016–18	SUF	[52]	https://unhabitat.org/saudi-cities-report-2019
Future Cities Africa	African continent	2014–present	SUF	[53]	https://futurecitiesafrica.com/
2. Sustainable Urban Systems (SUS)					
Complex Urban Systems for Sustainability and Health (CUSSH)	UK/international	2018–23	SUS	[54]	https://www.ucl.ac.uk/complex-urban-systems/
UK Collaboratorium for Research in Infrastructure and Cities (UKRIC)	UK	2016–present	SUS	[55]	https://www.ukcric.com/
3. Sustainable Urban Futures (SUF)					
EPSRC Retrofit 2050	UK	2010–14	SUF	[56]	https://www.retrofit2050.org.uk/
Visions and Pathways 2040	Australia	2013–17	SUF	[57]	http://www.ecoacupuncture.com/visions-and-pathways-2040
ERDF MUSIC	International	2010–15	SUF	[58]	https://drift.eur.nl/projects/music/
Mistra Urban Futures	UK/International	2010-20		[59]	https://www.mistraurbanfutures.org/en
4. Integrating Sustainable Urban Systems (SUS) and Sustainable Urban Futures (SUF)					
PEAK URBAN	UK/international	2017–21	SUF/SUS	[60]	https://www.peak-urban.org/
Urban Resilience to Extremes Sustainability Research Network (URExSRN)	North and South America	2015–present	SUF/SUS	[61]	https://sustainability-innovation.asu.edu/urbanresilience/

Building on previous more general foresight or futures studies, the Future of Cities programme provided, perhaps for the first time, a major

'turn' in bringing together SUS and SUF thinking in an urban context, and was important for several other reasons. Firstly, it not only highlighted the importance of systemic thinking in the context of cities, but also gave a practical focus to evidence gathering and baseline data to improve our knowledge of urban systems, so that city visions could be created and co-produced with relevant actors/stakeholders in particular UK cities. In that sense the programme brought together elements of both SUS and SUF as an integrated whole, where the 'science of cities' (or 'urban science'), or the way that we understand cities in terms of their nature and structure, incorporated a strong element of both science/engineering and social science interdisciplinarity. Secondly, the programme identified seven key themes which underline the need for future areas of research, and which again, quite rarely, combines elements of both SUS and SUF thinking (Table 2).

Table 2. Research priorities for the future of cities (source: [45]).

Research Priority	Associated questions
Interdependencies and integration in city systems	How can we best develop integrated systems analytics for cities?
Living in cities in the future	How can disciplines be integrated to address questions about how people might live in our cities of the future?
Urban economies	Why do cities differ so much in terms of their economic performance and success?
Urban metabolism	What will a sustainable urban future look like for cities?
Urban form	How can we create better places to live, work and play?
Urban infrastructure	How can we use smart technologies and infrastructure to improve the efficiency of our cities?
Urban governance	How can we develop agile, resilient and adaptable city governance systems?

Although the GoFS programme did not explicitly consider transitions theory within its remit, the concept of visioning and indeed foresight are also closely connected with systemic change and 'transitions theory' [3]. Two main 'ontological' strands (or the foundational assumptions about the world and its causal relationships) for understanding systemic change within cities can be distinguished [62,63] and these are closely linked to SUS thinking [3].

The first strand of socio-ecological system (SES) frameworks includes institutional analysis and development [64] and resilience thinking [65]. This complex interdependency has been especially important in the study of the place-based impact of climate change [66]. The second strand of 'socio-technical transition' (STT) studies, includes what is known as the multilevel perspective (MLP) [67]. In general, the climate change research community has frequently focused on SES whilst the transition studies community has focused on socio-technical systems, which comprise the

interactions and resultant structures in the intersect between society and technology [63].

In contrast to SES, the STT strand emerged in the Netherlands in the late 1990s (especially in the science policy debate leading up to the fourth National Environmental Policy Plan (NMP4) in 2001 [68], with a strong focus on energy studies and technological innovation and has grown in importance since the mid-2000s in other sectors and at a variety of scales. Within what can broadly be described as 'transitions theory', the main STT frameworks are the multi-level perspective (MLP) which is often used as an analytical framework for understanding past transitions, and Transition Management (TM), which focuses on the governance systems required in the transition towards the goal of sustainability [69]. The TM approach is appropriate to cities because this envisages a managed and planned transition to a wider societal challenge (rather than a technological innovation), based on systems thinking across multiple domains, actors and scales; long-term thinking (or visioning) as a frame for short-term policy; backcasting, and forecasting; a focus on learning and experimenting on a variety of options; and stakeholder participation and management [70].

There is, therefore, a distinction between TM and strategic urban planning. In contrast to planning, TM focuses on transformative change; facilitates co-production and co-creation processes to provide pathways to visionary futures; and links long-term visions to medium- and short-term actions, using experimentation as the foundation for reflexive planning, and at the same time emphasizing the importance of transformation of the existing system through system innovation [3,71]. Despite their differences, the SES and STT strands emphasise the need to include the interactions between technical innovations, the structure and type of socio-economic system, and system functions and services at multiple levels.

In summary, therefore in both the SUS and SUF approaches there are close areas of linkage, particularly in respect of SUF's acknowledgement of systems thinking and the recognition of complexity. The Future of Cities programme was perhaps the first major programme of research which brought together SUS and SUF thinking in an integrated way, and also led to an increasing focus on 'urban science' as characterized for example by the International Expert Panel on Science and the Future of Cities [7]. Despite this advancement, most of the research programmes that have been developed over the last 10–15 years, as we shall see in the next section, have often focused on each area (SUS and SUF) singly, rather than in an integrated or combined way.

PAST AND PRESENT THEMATIC SUS/SUF RESEARCH LANDSCAPE

The emergence of SUS and SUF thinking has led to the development of a variety of research programmes, projects, and other knowledge and research networks with a focus on the built environment (both through some of the disciplines involved and the focus of the research itself) (Table

1). Besides the UK Future of Cities programme, there have also been national programmes of work which adopted an SUF focus. These include the Norwegian Cities of the Future project (2008–14) which had a strong focus on reducing greenhouse gas emissions and making the cities greener and more 'liveable'. As a result, action plans for 13 of the largest Norwegian cities were developed to focus on land use and transportation, consumption and waste, energy, climate adaptation and the built environment [3,51]. Again, in Saudi Arabi the Saudi Future Cities programme (2016–18) took a strong focus on linking futures thinking about cities with the Saudi Vision 2030 [52]. Finally, Future Cities Africa is a partnership launched by Cities Alliance and the UK Department of International Development in 2014. The programme is designed to support the development of inclusive and resilient cities with a strong focus on environment and quality of life [53].

There are also several recent examples of UK-based programmes of research which have a strong SUS focus (Table 1). The CUSSH programme is a five-year Wellcome Trust funded project led by UCL (UK) that is designed to deliver key global research on the systems that connect urban development and population health. CUSSH is working with thirteen partner organisations across four continents to help cities develop in ways which improve population health and environmental sustainability. In each of six cities London (UK), Rennes (France), Kisumu and Nairobi (Kenya), and Beijing and Ningbo (China) its work focuses on local priorities and city-scale actions aligned with 'planetary health'. The research programme is designed to focus on population-level changes in areas including energy provision, transport infrastructure, green infrastructure, water and sanitation, and housing. As the project programme suggests: 'Our transdisciplinary research will address the unprecedented constellation of changes affecting urban environments as complex systems and threatening future progress, including population growth and movement, climate change and natural disaster risks, declining natural resources, environmental pollution, emerging diseases and inequalities' [72]. The project is also interesting because it suggests that participatory methods are deployed to evaluate and understand processes, which then leads to the use of evidence by decision-makers, although explicit 'foresight' and futures thinking, and visioning (SUF) do not appear to be a specific part of the programme.

The UK Collaboratorium for Research in Infrastructure and Cities (UKRIC) is a major network of fourteen UK universities funded to carry out research with a strong SUS focus. Funded by the EPSRC, the aim of UKRIC is to: 'provide the transdisciplinary, systems-based research for the transformation of infrastructure and urban systems, enabling safe, resilient and sustainable living, and generating economic opportunities for the UK' [73]. There is therefore a strong focus on 'transdisciplinary research', which can be defined in its purest form as: 'research which promotes collaboration between academic research and practice, between

different disciplines, and between different types of organisations. Transdisciplinarity engages with a wide group of stakeholders; listening to the public voice as well as engaging with policy makers. Participants become cocreators of knowledge' [74]. UKRIC has four main scientific missions: (i) infrastructure and urban systems for one planet living; (ii) transformational infrastructure and urban systems for a changing world; (iii) ownership, governance and business models for infrastructure and urban systems; and (iv) infrastructure and urban systems as drivers of equity, inclusion and social justice [73]. Again, however, urban futures thinking is not an explicit part of its research focus.

Turning to SUF there are several examples of recent research projects. The EPSRC Retrofit 2050 programme (2010–14) brought together several UK universities to examine realistic social and technical pathways for the systemic retrofitting of UK city-regions [56]. This programme of research drew strongly on transition theory as an analytical framework to examine city retrofit futures while recognising cities as complex adaptive systems (Eames eat al). Using backcasting and visioning techniques, various futures were constructed ('smart-networked city'; 'compact city'; and 'self-reliant green city') and these were grounded in more specific co-created visions for Cardiff city-region [75].

The Visions and Pathways 2040 (VP2040) project was an investigation of possible and plausible pathways for the transformation of the southern capital cities of Australia and aimed for an 80 percent reduction of their greenhouse gas emissions by 2040 [57,76] The project ran from 2013 to 2017 and was based on developing, analysing and communicating visions, scenarios and pathways for this transformation. Using MLP and TM as a 'loose reference', VP2040 focused on eight inter-related urban systems of provision: energy, water, food, transport, buildings and open-space, waste disposal, information, products and services [57]. The research used (i) scenario-building methods to examine a range of different futures, and (ii) futures-based imagery as part of the visioning and backcasting process.

The MUSIC project ran from 2010–15 and was funded through the European Regional Development Fund (ERDF). The five cities involved in the MUSIC project (Aberdeen, Scotland; Ghent, Belgium; Ludwigsburg, Germany; Montreuil, France; and Rotterdam, Holland), and all used a common TM approach as a methodological basis, although this was grounded in distinctive local urban contexts [58]. In Ghent and Ludwigsburg, local actors were brought together to help develop a future vision for each city. In Rotterdam, the TM approach was more limited and brought together local stakeholders to draft a policy agenda which formed part of a wider visioning exercise. In Aberdeen and Montreuil, the approach was driven by the need to develop new forms of governance for climate change and energy, and therefore the TM element was a separate exercise [3]. As a result of the work in Aberdeen and the other MUSIC cities, a guidance manual on transition management in an urban context was produced [77].

The MISTRA Urban Futures project was established in Gothenburg, Sweden in 2010 to promote urban sustainability through transdisciplinary co-production of knowledge undertaken through a series of 'Local Interaction Platforms' (LIPs). In this sense 'co-production' is seen by MISTRA as encompassing co-creation and co-design and refers to participatory processes where the users of research are active in the design of the work, the research itself and its implementation [59]. The bottom-up initiatives of LIPs led to linked projects in Gothenburg (Sweden); Sheffield/Manchester (UK; Cape Town (South Africa); and Kisumu (Kenya), and more recently in Malmo and Lund (Sweden)and which formed the MISTRA Urban Futures work. A strong theme in the research has also been 'Realising Just Cities' which reflected important concerns about urban equity and justice through three related themes ('socio-spatial'; 'socio-ecological'; and 'socio-cultural'). The projects that formed the basis of this work again did not explicitly use foresight techniques to co-produce visions; rather the emphasis was on co-production of comparative research to help shape and influence policy and practice outcomes [59].

There are also, as Table 1 shows, several examples of programmes which attempted to join up elements of SUF and SUS thinking. The PEAK Urban programme of research which formed part of the UK's ESRC-funded Urban Transformations Programme. Like MISTRA Urban Futures, the PEAK Urban programme (which ran from 2017–21) was important for its comparative research focus on both the Global North and Global South. Essentially this research was part of the broader Economic and Social Science Council (ESRC) Urban Transformations programme, which ran from 2015 to 2019, and which focused on how, in urban economies, new technologies and responses to environmental change are reshaping the distribution of power, resources and information in cities. Part of the focus of the programme was to draw international scholars and practitioners together and develop a new conceptualization for thinking about the future of cities (and city regions). This drew on interdisciplinary thinking and a 'systems-of-systems approach' to develop an original PEAK urban conceptual framing [60], which was based on PEAK thinking: (1) Prediction and projection in the city; (2) Emergence, combination, material cities and complex systems; (3) Adopting innovation and metropolitan commensuration; and (4) Knowledge exchange and urban co-production. However, foresight and visioning for cities were not an explicit part of the programme.

Another interesting example of acknowledging the combination of SUF and SUS thinking is the Urban Resilience to Extremes Sustainability Research Network (URExSRN) which is an international network based at Arizona State University and focuses 'on integrating social, ecological, and technical systems to devise, analyze, and support urban infrastructure decisions in the face of climatic uncertainty' [78]. The network, which brings together universities and nine cities in North and South America is unusual in that it combines both SUF and SUS thinking, the latter based on

social-ecological-technical (SET)/infrastructural systems thinking set within an urban sustainability approach. Visioning and positive sustainable urban futures methods are also an important part of the work: 'We seek to position the coproduction of resilient urban futures within urban systems science as an anticipatory knowledge practice to address the current deficit of futures thinking in urban planning and decision-making' [61].

Finally, there are a range of other urban knowledge exchange institutions and networks, many of which have been catalogued in previous research [79], often operating at the nexus between urban governance and urban sustainability. An example of this is the Coalition for Urban Transitions (CUT) which had strong focus on sustainable urban futures. It was a major collaboration between over 40 research institutes, intergovernmental organizations, investors, infrastructure providers, strategic advisory companies, NGOs and was designed to support national governments address pressing economic, inequality and climate challenges by making their cities liveable and sustainable [80].

In the next section the lessons emerging from this previous research are synthesised with findings from other recent knowledge exchange reports to highlight key cross-cutting themes which can help us to understand how a more integrated approach to SUS/SUF research could be developed in the context of a built environment agenda. These are discussed under the following themes: (i) geographic focus; (ii) multi-scale approaches; (iii) the disciplinary focus of current research; and (iv) urban science.

DISCUSSION: KEY EMERGING CROSS-CUTTING ISSUES AT THE SUS/SUF INTERFACE

Geographic Focus

A recent report on the nature of funding and the overall landscape of built environment research in the Global South found several research gaps and opportunities within the 48 research centres and 336 projects covered [22]. Using existing data, survey work and interviews, the research showed that in the Global South, most of the built environment research projects focused on urban planning, transport, housing, water, and energy, with perhaps less emphasis on engineering-led projects than is the case in the UK (see above). There was also a marked lack of urban systems research in the built environment in the Global South [22]. This report was also important in highlighting key issues which are important in linking built environment research with the UN Sustainable Development Goals, particularly on SDG 3 (health and wellbeing), SDG 8 (decent work and economic growth) and SDG 10 (reduced inequalities). In particular, the report showed the disconnection between the countries where the built environment research was being carried out and the reality of rapid urbanisation in other parts of the Global South, where

research often continued to be absent (or 'neglected geographies' in parts of Africa, Asia, and Latin America) [22]. This report also showed that in the Global South there is a need for further research which looks at informality, access to housing, climate change and migration issues, all of which are interlinked. This issue of 'geographic focus' is also a continuing problem in other connected areas of research, for example, city-regional futures. Recent research [81] has shown that articles studying the Global North (in a range of social sciences, including urban studies) are systematically less likely to mention the name of the country they study in their title compared with articles on the Global South. This could then lead to a potentially unwarranted claim on 'universality' and may lead to lesser recognition of Global South studies. In short, despite the growth in international research programmes (Table 1) much more needs to be done in built environment research (and in the SUF/SUS nexus) to address the geospatial deficiencies and disparities in our knowledge and understanding [82]. However, we should be mindful of the fact that although we might assume concepts from the Global North such as 'city regional futures' are themselves applicable to the Global South the reality and the nuances of such terminology may be very different [82]. Despite this there is a growing belief that despite cultural and contextual differences between countries (and indeed cities) in the Global South and Global North that more comparative research is also needed to develop generalisable theories of change across different geographies for diverse city types and this applies to both SUS and SUF thinking [3,7,82].

Multiscale Approaches

As we saw earlier, the built environment is a multiscale arena encompassing space from individual to city scale [16]. In systems terms, however, a recent US report showed that three levels of city scale can be theorised in relation to SUS: (i) single city scale; (ii) multiple cities and communities; and (iii) internationally connected cities and urban areas [26]. In turn this means developing new data and methods to assess the current drivers in urban systems (built, natural and social) and the impact on sustainability across scales, and it also means developing better understanding of the science to link processes and outcomes in sustainability, as well as understanding the levers for change (theories of change) combining a knowledge of transitions and a focus on multilevel actors in the city [26]. In this respect the idea of 'urban transformations' is relevant and to some extent also reflects the disciplinary bias of some research: some technical disciplines such as civil engineering, for example, may still struggle with the concept of interdependencies and complexity and so any interventions or outcomes are necessarily weakened or dissipated [11]. Holscher and Frantzeskaki [83] outline three perspectives which are important in understanding urban transformation which is relevant to research in the SUS/SUF interface (and to 'urban sustainability science') [84]: firstly, transformation in cities which focuses on the diverse

factors, processes and dynamics driving place-based transformations in cities; secondly, transformation of cities, which examines the outcomes of transformative changes in urban sub-systems and systems; and thirdly, transformation by cities which looks at the changes taking place on a global and a regional level. Increasingly, we are also seeing the recognition that urban challenges are 'wicked problems' operating across scales and with complex interdependencies which mean they are difficult or sometimes even impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognise [3,85].

Disciplinary Focus of Current Research

Given the inherent complexity in both SUS and SUF and at their interface, there have been growing calls for 'interdisciplinary' and 'transdisciplinary' thinking. These terms are important to distinguish: 'interdisciplinary' refers to scientific practices emerging from multiple disciplines to create novel and innovative approaches within academia, but 'transdisciplinary' refers to scientific practices to co-produce knowledge with a range of stakeholders [15]. In SUF research the concept of a 'quadruple helix' is also an important part of conceptualising futures thinking [3]. In the quadruple helix (QH) model there is an emphasis on four groups working together to drive innovation and structural change: government, business, academia, and civil society/users, the latter of which is an additional source of knowledge required to 'shape and test' university research [48,49]. Yet examples of funding calls which invite such thinking are relatively rare, although a recent example which does adopt a more integrated focus is the EU-funded 'Driving Urban Transitions (DUT) to a Sustainable Future' programme (https://dutpartnership.eu/). In the USA, in organisations such as the National Science Foundation, we have seen an increasing focus on 'convergence science', which although related to other kinds of disciplinary thinking, such as transdisciplinarity, interdisciplinarity and multidisciplinarity, is characterised by problems and questions which are scientifically and societally interesting and important and offer opportunities for integration across academic disciplines and scientific fields [26,86,87]. Evidence of the growing importance of transdisciplinary thinking and an increasing focus on convergence science is also evidenced by the presence of more than 200 urban-oriented global networks bringing together key stakeholders from academia, NGOs, government, business and civil society: examples from this 'community of practice' include the Rockefeller 100 Resilient Cities programme, and the C40 Cities Climate Leadership Group [15,88]. Other vehicles for this type of collaborative and shared learning are through more specific 'place-based' projects focusing on specific towns and cities, and the emergence of 'urban living labs', 'innovation districts', and other testbeds for experiments in urban sustainability are examples of this trend [3,15].

Urban Science

Cities and city-regions today face many complex and interrelated problems and challenges revolving around environment, resources, and socio-economic pressures. These problems are complex, systemic in nature, interrelated and interdependent and are often related not only to the built environment but also the natural environment. As a result, we have seen calls for a new global 'urban science' which transcends monodisciplinary reductionism and brings together stakeholders to tackle and examine real world problems in a way which is founded on transdisciplinary research and convergent thinking [7,60,87]. The new urban science in its purest form is designed brings together disciplines from science, engineering, social science and arts and humanities and, as Townsend has shown, has been developed and shaped in a formal sense in academia over nearly thirty years stretching back to the establishment of CASA at University College London in 1995 and other centres in the USA, UK, Australia and Europe [89]. Lobo et al offer a helpful definition:

'Urban science seeks to understand the fundamental processes that drive, shape and sustain cities and urbanization. It is a multi/transdisciplinary approach involving concepts, methods and research from the social, natural, engineering and computational sciences, along with the humanities' [86].

The goals of this new urban science are to address: (i) the joint social, ecological, and technological nature of urban systems; (ii) the role of disruptive actors in urban transformation; (iii) the capacity of urban systems to adapt; (iv) the dynamic and interlinked nature of urban spatial form; and (v) transboundary flows at multiple scales [87]. This also means that SUS and SUF could become integral parts of a new pluralistic urban science with sustainability at its heart, and encompassing a wide range of disciplines. However, to develop this new disciplinary lens nationally and internationally requires national governments and regional actors to advocate much more strongly for urban innovation in sustainability and for more place-based projects and 'urban observatories' to be developed [7]. Finally, the new urban science is also characterized by an increased focus on 'big data' (or data that contains greater variety, arriving in increasing volumes and with more velocity) and analytics, as the Internet of Things (IoT) (or physical objects with sensors, processing ability, software, and other technologies that connect and exchange data over the Internet or through other communication networks) can provide real-time data on a host of urban conditions including air quality, traffic movement and energy and water consumption. Urban science can use statistical analysis and data analytics to identify causal relationships in a city and predict and forecast how the city systems could work more effectively. In contrast to the wider field of 'urban studies', which sees cities as linked places which are usually analysed with relatively small location-specific samples, urban science sees cities as systems, or a 'system of systems', with analysis based on much larger linked and integrated big datasets [90].

CONCLUSIONS: TOWARDS AN INTEGRATED RESEARCH AGENDA IN URBAN SCIENCE

This perspective paper started from the premise that within the context of built environment research, there were two separate but interrelated fields of study: SUS and SUF. Until now, as we have seen, research has frequently treated these two fields as binary choices. As a result, an integrated approach to 'urban science' has often been lacking in a built environment context. There are, however, strong reasons why the built environment disciplines of construction, architecture, engineering, and real estate, and indeed other disciplines, should all play an important role in this mode of studying our urban world. The built environment, after all, intersects with some of the most important challenges the world faces, such as climate change, socio-economic inequalities, sustainable development, and rapid urbanisation [74]. This requires thinking that transcends disciplinary and siloed thinking, however. As Zhou et al suggest: 'The field (of urban science) cannot be represented by any single academic unit or professional school; it is, by construction, an interdisciplinary field, involving work across traditionally defined disciplines, using diverse methods, and addressing multiple scales from local issues to global challenges' [87]. Indeed, in this respect there is merit in thinking about urban science as a transdisciplinary subject field, because of its potential focus on end user engagement and co-production, taking it beyond even interdisciplinarity thinking.

Moreover, the ways in which the built environment and natural environment interact are also important to recognise in a systems view of the world. Green space, biodiversity and nature are all affected by and impact on the built environment and the built environment in turn has huge impacts on the natural world. Therefore, a holistic built environment focus must also recognise the importance of the natural environment as well [20].

Figure 1 posits a conceptual framework in the context of built environment (and its connectedness to 'natural environment') research. The new urban science that is postulated here builds on the previous thinking highlighted in this paper and provides a framework that can potentially be applied to the Global North and Global South. In this framework the importance of sustainability in the built and natural environment is recognised, and transdisciplinarity and convergence, which bring a range of disciplines and stakeholders together, are explicitly linked. Linking SUS and SUF in place-based locales could potentially create opportunities to address such questions as [86]:

- How can we best understand urban areas as interacting systems which influence and shape sustainability outcomes over temporal and spatial scales?
- How do transformative changes in urban systems affect well-being and equity across urban and non-urban communities?

- How can we balance continued urbanisation within environmental limits?
- How can we best plan, adapt and manage future urban systems in the long-term to achieve the end goal of sustainability?
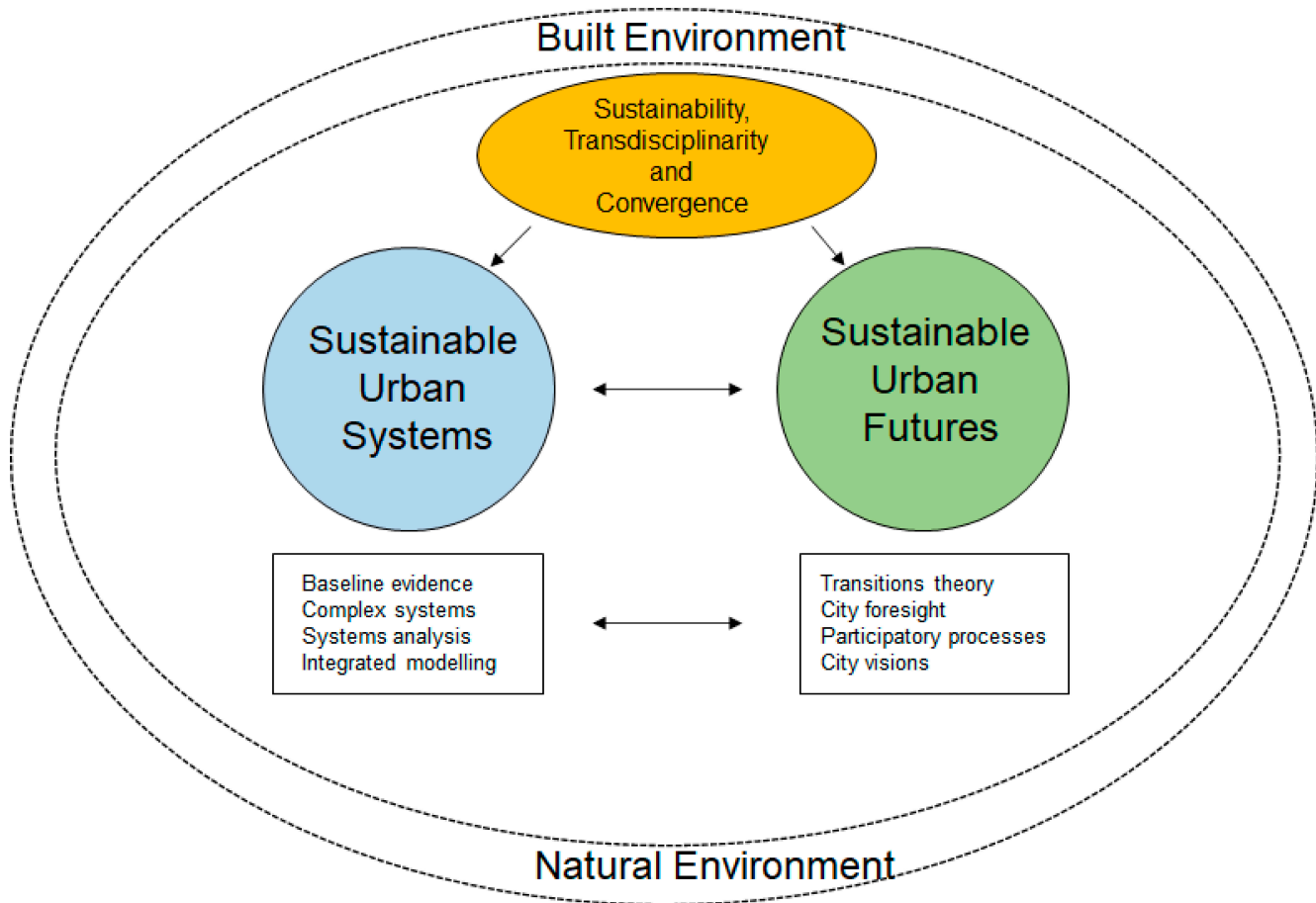

Figure 1. Urban science: the primary foci of SUS and SUF in the context of the built and natural environments.

In terms of SUS, we would expect to see baseline evidence gathering, the study of complex systems, systems analysis and integrated modelling of urban systems, and in SUF, core methods such as visioning, and foresight would be based on participatory methods (using models of engagement such as the quadruple helix framework) founded on transitions theory. As we saw earlier in this paper, however, we do need to recognise the differences between cities within and between the Global North and Global South: in this sense while comparison strengthens the research base, the 'eigenart' (or special characteristics) of cities within their national and international context are important to understand [3].

There are, of course, many challenges associated with such an ambitious approach which are often related to institutional and disciplinary 'inertia'. This transformation would require major restructuring and a changing focus in both education and research to

include futures thinking as part of a new urban science, as well as a training of new urban scientists [86,91]. However, adopting this 'boundary spanning' approach is fundamental to a new understanding of cities and the development of built environment research [29]. As Acuto et al (quoted in [15]) suggest:

"In order for urban science to be collectively greater than the sum of its parts, it needs to draw from all the sciences—natural, engineering, and social, as well as the arts, and humanities—whilst linking directly into practice, and offering effective global assessments of the state of our planet's urban condition" [7].

DATA AVAILABILITY

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest.

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