UK-RAS White papers

ISSN 2398-4414

UK-RAS NETWORK
ROBOTICS & AUTONOMOUS SYSTEMS

Urban Robotics and Automation: **Critical Challenges, International Experiments and Transferable Lessons for the UK**

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FOREWORD

Welcome to the UK-RAS White Paper Series on Robotics and Autonomous Systems (RAS). This is one of the core activities of UK-RAS Network, funded by the Engineering and Physical Sciences Research Council (EPSRC).

By bringing together academic centres of excellence, industry, government, funding bodies and charities, the Network provides academic leadership, expands collaboration with industry while integrating and coordinating activities at EPSRC funded RAS capital facilities, Centres for Doctoral Training and partner universities.

Advances in urban automation and transport are continuously shaping up our urban life and environment. Good city governance and resource utilisation enable smooth flow of services, data, and people. Many cities are also becoming test beds for both national and local governments for experimenting with robots in social spaces to explore their roles to facilitate everyday life and demonstrate good city governance. Whether through autonomous cars or drones, cities are being automated at a steady pace. Connected and autonomous vehicles are also set to take another leap forward in the UK, following a series of recent government funding announcements. We continue to see major industry shift towards automation, connectivity, shared mobility and the electrification of vehicles. Such market disruption is changing the way how urban environment is organised and transforming the way people will travel, especially in cities.

This white paper aims to provide an overview of the application of RAS technology in supporting urban growth in the UK. The urban potential in various aspects of urban life, such as health care, construction and maintenance as well as transport and socio-economic impacts, are discussed. The paper also points to the distinctive ‘urban’ dimensions of RAS innovation from laboratory to real world applications, and how current and future challenges can be addressed. We have included recommendations to some of the challenges identified and hope this paper provides a basis for discussing the future technological roadmaps, engaging the wider community and stakeholders, as well as policy makers, in assessing the potential social, economic and ethical/legal impact of RAS in Urban Automation and Transport.

It is our plan to provide annual updates for these white papers so your feedback is essential - whether it is to point out inadvertent omissions of specific areas of development that need to covered, or to suggest major future trends that deserve further debate and in-depth analysis. Please direct all your feedback to whitepaper@ukras.org. We look forward to hearing from you!

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EXECUTIVE SUMMARY

The future of the world is urban. The majority of the world's population live in cities and the global urban population will continue to grow. Urban growth creates opportunities to enhance social life but they also bring challenges in terms of congestion, air pollution and increased demands for energy, water and open space. One challenge is to ensure that the opportunities of urban development are available to all urban citizens. Managing the challenges of urban development is essential for economic development, health, social welfare, environmental protection and equality.

This paper makes the case for thinking more strategically about the application of RAS technology in supporting urban growth in the UK and internationally. Rapid technological developments are leading to the vastly extended application of Robotics and Automated Systems (RAS) in transportation, logistics, policing, health care, maintenance, construction and many other areas of economic and social life. The urban potential of RAS has been recognised in various applications and in work on 'smart' and future cities, but so far there has been limited discussion of the full potential of RAS to address pressing urban issues.

The development of urban RAS applications requires real world experimentation 'beyond the laboratory' to develop commercial applications and address concerns about public safety in dynamic and complex environments. Cities have become a key site of applied RAS experimentation, but the development of RAS – in particular drone delivery and AVs - has been constrained in the UK and other countries by restrictive regulation.

Urban test-beds provide spaces where applications can be tested in real world contexts and where problems can be identified and potentially resolved to enhance the efficiency and speed of innovation processes and the development of commercial services and products. Well-managed and visible ULL can build public and political support for the application of urban RAS technology. Governments are interested in trying to establish 'first mover' advantage by becoming exemplary sites for the development of robotic applications, with the aspiration that early adopters will be able to capture wider economic, employment and competitive benefits as applications are scaled up. Investment and innovation in urban applications of RAS is focused on countries and cities that support real world experiments.
This report outlines the distinctive 'urban' dimensions of RAS innovation and the challenges and opportunities in moving from laboratory to real world applications. The report starts by demonstrating the role of RAS in addressing pressing current and future urban challenges. It then outlines the issues and challenges involved in creating space for urban RAS test beds in the UK and internationally.

The report concludes with four key recommendations for the future development of urban RAS technologies and their implementation:

1. National sectoral priorities and plans for RAS should have a stronger place based dimension that extends existing commercial and university research capacities into different urban contexts. In the UK, there is scope to build stronger links between RAS communities and Future Cities.

2. Governments have recognised that creating space for urban experimentation is vital in supporting RAS innovation and attracting international expertise and investment. Governments need to **ensure that conditions are created for urban RAS innovation in the UK through innovation priorities, supportive regulation, incentives and political leadership.**

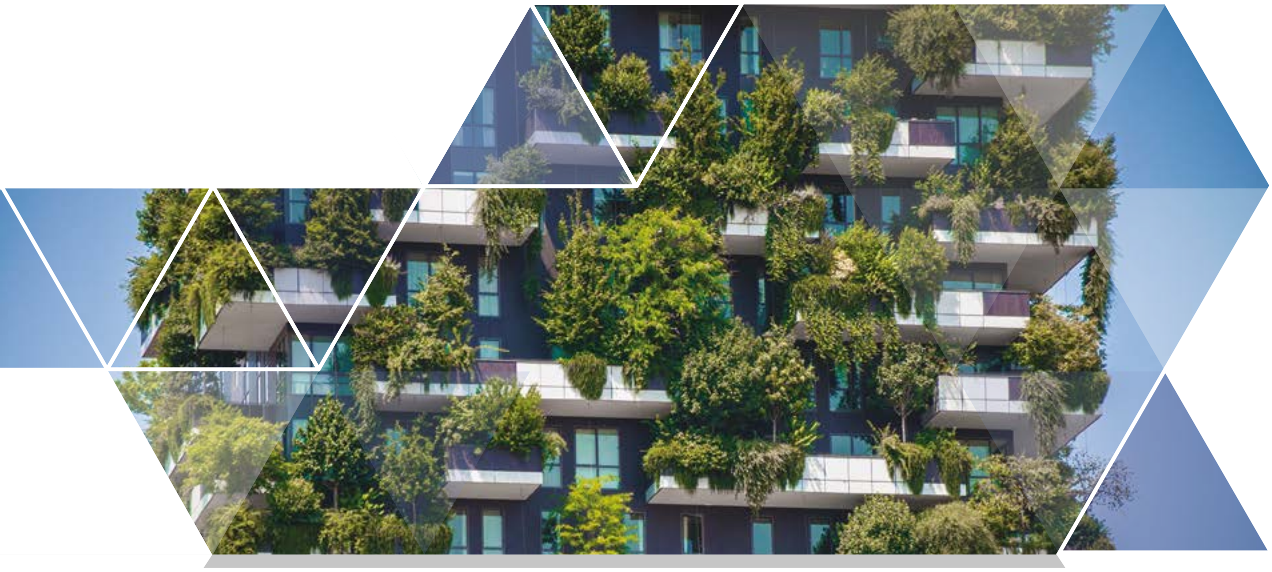
3. **Different types of living lab are required.** There are different types of ULL configured around distinctive types of experimentation with different levels of resources and organisational capacity.

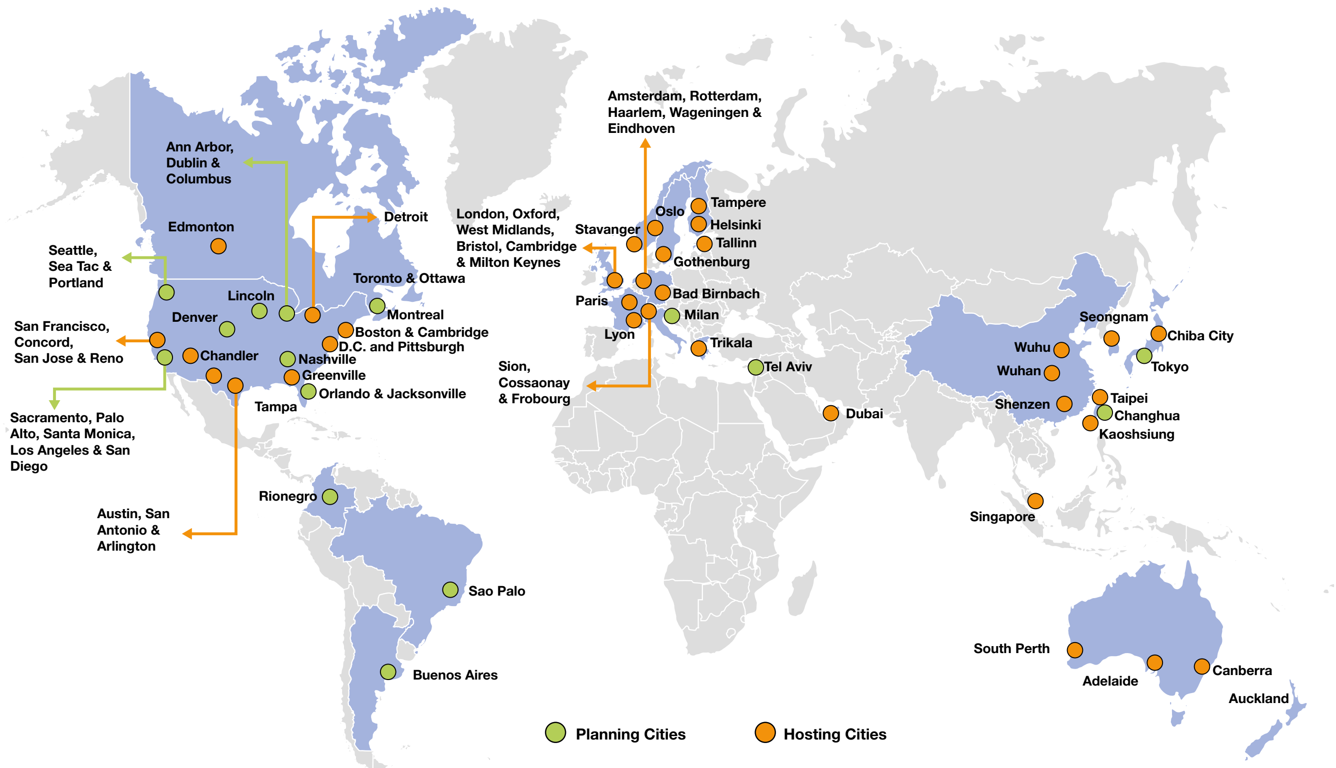
4. **A whole city approach is important in connecting RAS applications.** Urban RAS experiment will benefit increasingly from opportunities to link different RAS applications.

"A woman drives to the outskirts of the city and steps directly on to a train; her electric car then drives itself off to park and recharge. A man has a heart attack in the street; the emergency services send a drone equipped with a defibrillator to arrive crucial minutes before an ambulance can. A family of flying maintenance robots lives atop an apartment block – able to autonomously repair cracks or leaks and clear leaves from the gutters."

Reference: Poole S (2014) The truth about smart cities The Guardian 17 Dec 2014
https://www.theguardian.com/cities/2014/dec/17/truth-smart-city-destroy-democracy-urban-thinkers-buzzphrase

CONTENTS





Source: Bloomberg Philanthropies, Aspen Institute, Bloomberg New Energy Finance. Note: See Bloomberg Philanthropies' iinteractive "Global Atlas of Autonomous Vehicles (AVs) in Cities" (web). 'AV' stands for 'autonomous vehicle'. This map only covers AV pilots and policymaking efforts where city, municipal, or metropolitan governments are playing a substantial role

Figure 1

Urban AV Pilots

1. INTRODUCTION

The future of the world will be urban with more people living in cities. Future cities bring opportunities but there are also major challenges for urban management in terms of congestion, pollution, the provision of (low carbon) energy and water, ecological management, inequality and meeting the needs of young and older people. Rapid technological developments are opening up exciting new horizons for vastly extended application of Robotics and Automated Systems (RAS) in production, transportation, logistics, policing, health care, construction and maintenance, urban planning and service provision and many other areas relevant to the management of future cities. Although some of these issues are covered in smart city strategy,[1] the full implications of new and future developments in RAS for the city have yet to be explored.

RAS are technological systems that can sense and manipulate their physical environment. The autonomy of such systems is likely to become increasingly important as advanced techniques allow robots to accomplish goals without human intervention. So far, RAS systems have been largely developed and applied in tightly regulated contexts – research labs, industrial production, defence applications, hazardous and hostile environments.[2]

Technology developers, researchers, innovation agencies often in partnership with urban authorities are now testing and experimenting with these applications in the real-world contexts of everyday cities around the globe.

RAS are moving from protected spaces of labs to the more open and complex, less predictable and congested spaces of contemporary cities in which people are less controlled. There is thus a critical need to understand the wider social, economic and cultural issues and benefits involved in such applications. How will RAS technologies shape the organisation of cities and everyday life and also how will the technologies themselves be shaped by users and different urban contexts? There are five key reasons why the RAS community and urban policy communities need to engage, in order to understand where their agendas intersect and are mutually dependent:

Cities and New Technology - Technology creates new possibilities for cities and urban life. The development of the factory system helped accelerate the concentration of people and production in the Victorian City.[3] Modern infrastructure of energy, water and mobility networks facilitated the concentration of larger cities and later dispersal through suburbanisation. RAS has the potential to influence and bring benefits in different dimensions of urban life, shaping the future of cities in distinctive ways that are not yet fully understood.

The Urban and RAS innovation - New infrastructural services are often pioneered in urban areas where problems are particularly acute and there are large-scale opportunities for innovation. National and municipal governments worldwide are actively promoting robotisation and automation of infrastructure, healthcare and a variety of urban services – see figure 1. Particular cities and urban areas are likely to play a central role in shaping how RAS is used, which may create applications and business models that are later transferred to other urban contexts. There will be significant opportunities for the RAS community to work more closely with receptive cities.

Urban markets for RAS - It is forecast the global smart cities market will grow from US$ 540.6 Bn in 2015 to US$ 3,482.2 Bn by 2026,[4] with significant investment in robotics and automation. The market for non-military drones alone is growing at 15 to 20 per cent rate each year.[5] RAS investment is likely to take an increasingly urban focus as providers and vendors seek to understand the opportunities and potential of urban applications.

Urban Competition for RAS - Amazon now ranks US cities according to their take-up of domestic automation services.[6] The five "most automated" big cities are Seattle, Miami, San Francisco, Atlanta and Portland. Cities will want to be associated with new automated technology to capture the economic and employment potential of new sectors and markets. Urban authorities and their partners – such as businesses and universities – are likely to become more active in attempting to promote their cities both as hubs for RAS business growth, and as test-bed sites, in order to capture first mover status.

Urban Resistance to RAS - The history of urban technological development shows that there can be challenges for national and urban governments in responding to the potential of new technology. It will be

1 Marvin, Simon, Luque-Ayala, Andres, McFarlane, Colin (2015).
2 The UK-RAS Network White Papers (2017a); The UK-RAS Network White Papers (2017b).
3 Morris, John Robert & Rodger, Richard (1993).
4 Persistence Market Research (2007).
5 McKinsey, Gartner, Robocap LLP, Bank of America Merill Lynch in Robocap Fund. n. d.
6 Business Wire (2014).

important to understand how RAS is potentially constrained or even resisted in some contexts because of concerns about sharing congested footpaths with delivery robots, controversy about job losses and questions about the safety of human-robotic interactions. Meaningful engagement with citizens and users will be necessary to understand which issues need to be anticipated and managed.

The key element of this extended application of RAS is the move from tightly controlled laboratory or industrial contexts to more open and dynamic robotic-human interactions in the real-world. A critical dimension of the move ‘beyond the laboratory’ is the prospect for robotic applications in ‘urban’ contexts in the form of automated systems and decision making, autonomous vehicles, and extended automation of transport management, urban service robots, automated homes, automated healthcare support, drone delivery and policing, amongst other applications.

However, the potential applications being developed in the protected and regulated spaces of commercial and university research laboratories will need to be translated to real world sites of application. Urban RAS applications need to be trialled and tested, their possibilities explored, and concerns about regulations, human health and safety assessed and allayed through demonstration. Internationally urban areas are being positioned as key sites for field-testing new RAS technologies and applications.

Urban test-beds provide spaces where applications can be tested in real world contexts, interact with people and communities, and where problems can be identified and potentially resolved to enhance the efficiency and speed of innovation processes and the development of commercial services and products. Governments are interested in trying to establish ‘first mover’ advantage by becoming exemplary sites for the development of robotic applications, with the aspiration that early adopters will be able to capture wider economic, employment and competitive benefits as applications are scaled up. But urban contexts can also constrain or even prevent RAS experiments through local regulations. US restrictions on drone experiments, for instance, have led US companies such as Zipline to set up experiments in the more amenable context of African states such as Rwanda, Malawi and Tanzania, which are all seeking to establish themselves as drone test-beds.[7]

The aim of this report is to promote discussion about the role and importance of urban test beds in RAS innovation. What sorts of spaces and support are needed to create real world experimentation at different stages of the R&D process, and where should that take place? How are urban test beds effectively organised and regulated? And what are the emerging issues and potential benefits of urbanising RAS?

The pressing issue for countries like the UK is whether R&D is being held back by constraints on real world urban experimentation, either because of existing regulatory frameworks or because other factors of urban governance are not sufficiently supportive. A critical concern is that other nation states are gaining competitive advantage because of their ability to organise experiments and gain first mover advantage. Restrictions on testing and political resistance may be slowing down innovation and the development of commercial applications.

This report seeks to:

1. Provide a distinctive overview of the ‘urban’ experimentation dimensions of RAS, examining the role of field research in the development of applied technology.
2. Offer insights into the international landscape of experimental testing of urban robotics and autonomous systems, including the constraints on innovation, urban resistance to RAS and how they might be addressed.
3. Examine emerging state of the art and future thinking around international urban RAS experimentation, and identify the transferable lessons for UK research and policy priorities.

The report is structured in 6 further sections. Section Two identifies the critical urban challenges for future cities. Section Three examines the potential of RAS systems to respond to these challenges. Section Four explores the role of urban living labs in moving from labs to real-world sites of application. Section Five examines the key barriers and constraints on RAS experimentation in urban contexts. Section Six reviews selected international experiences of urban living labs identifying how initiatives are made relevant to local contexts and how they are organised. Section Seven draws out lessons for the UK and priorities for taking forward the urban RAS agenda.

[7] Rosen, J. W. (2017).

2. THE NEW URBAN AGE - FUTURE CITY CHALLENGES

The 21st Century has been labelled the New Urban Age. Now more than half the world's population lives in cities. By 2030 it is projected that at least 6 in 10 people will be urban dwellers. These projects suggest that by 2050 more than 6 billion people, more than 60% of the total world population will live in urban areas[8].

Despite numerous challenges, cities can offer more efficient economies of scale on many levels, including the provision of goods, services and transportation. The first specifically Urban Sustainable Development Goal (SDG11) is designed to "make cities and human settlements inclusive, safe, resilient and sustainable". The aspiration is that with new technologies, improved planning and management cities can become incubators for social and economic innovation and growth and drivers of sustainable development. Urbanisation will continue through the world but different types of cities are emerging. The critical challenges of the urban age will vary depending upon the particular local context but others may be shared across the global north and south.

Maintaining and extending the quality of urban life and the effective functioning of cities creates a series of challenges for decision makers. For example, most urban areas face issues of transport congestion, primarily the result of the expansion of personal car use and road-based urban planning. Transport congestion exacerbates problems of urban air pollution. But cities can also provide a platform for addressing pressing social and health issues in society. Cities can be reorganised to create environments that support assisted living for an ageing population and groups that need support. Cities are also leading the way on climate change through new approaches to energy generation and supply, urban greening and intelligent buildings.

[8] United Nations (2014).

The Challenge of Existing Cities

Overall in Europe and North America the urban population is expected to rise slowly but this masks important differences. In central and eastern Europe, cities have been declining due to remoteness from markets and poor quality infrastructure, whereas cities in northern and southern Europe have been growing faster. Metropolitan expansion in the US has been concentrated in the growth of outer suburbs which have grown at three times the rates of inner cities. The critical challenges in these contexts are how to reconfigure existing built environment and infrastructure to meet new societal and environmental demands. Issues include:

- Managing increased demand for resources – energy, food and water.
- Providing distribution, logistical and mobility services.
- Ageing populations and increased demands for healthcare.
- New environmental standards and expectations.
- Incorporation of new control and digital technologies into infrastructure networks to enhanced efficiency, flexibility and the incorporation of renewable energy.
- Adjusting to climate change and reducing greenhouse gas emissions
- The high cost of monitoring and maintaining buildings and infrastructures hidden underground and exceeding planned lifespan.
- Accelerating the retrofitting existing infrastructure and buildings to meet changed performance and sustainability requirements.

These challenges need to be addressed without adding substantially to the costs of urban management.

The Challenge of New and Rapidly Expanding Cities

In the next 20 years Africa and Asia will experience the fastest growth in urban areas. Africa is urbanizing at 4% annually and between 2010 and 2020 the urban population is expected to rise from 413 million 40% to 569 Million 45% in 2020. Asia is also experiencing rapid urbanization largely due to growth in China and India. In the Asian region population is likely to grow from 1675M 41% in 2010 to 2086 m 47% in 2020.[9] Although existing cities face many of the same challenges there are also distinct challenges of new urban areas:

- Designing infrastructure and built form to high performance and environmental standards.
- Problem of absent infrastructure and making do in informally until infrastructure catch up.
- Major social and economic disparities between those living in slums and others in high quality housing.
- World youth population will be located in Africa and Asia – in 2050 90% youth 15-24 will be in developing countries.
- Ensuring sufficient material resources to build infrastructure and environments.

The Challenge of Inclusive Cities

Cities are often characterized by significant social and economic differences between populations. Much of the growth in the global south will take place in informal settlements without adequate services. Urban development will need to find ways of formalizing settlement patterns and providing infrastructure. Cities in global south will also need to deal with how to provide education, economic opportunities and services to youth while in the global north the issue of providing health and social services to an aging population will be an increasing challenge

[9] Division for Sustainable Development of the United Nations Department of Economic and Social Affairs (2012), xiii.

The Challenge of Urban Mobility and Congested Infrastructure
Cities will need to develop new ways of overcoming congested infrastructure and providing more effective mobility services. Congestion imposes significant economic costs on both sectors and individuals. Urban policy will need to find new ways of managing demand, squeezing more capacity out of existing infrastructure and using new technologies to significantly improve the efficiency of new infrastructure.

The Challenge of Urban Resilience
Cities will be at the forefront of environmental management, requiring innovation approaches to energy and water conservation, waste management and ecological protection. Urban development will need to be climate-proofed to adapt to increased turbulence and variability in extreme weather conditions.

These future city challenges are about the business of maintaining the urban economic and social life. The critical questions are how automation could improve on human decision making processes and how robotics could enhance or displace human capacity in rapidly expanding and already congested cities.

3. RAS TECHNOLOGIES TO ADDRESS URBAN PRIORITIES

Urban development has long been facilitated by technological innovation and mechanisation. Urban water and sewerage infrastructure, electricity, traffic lights, electric lifts and other technical advances have facilitated the growth of cities and enhanced human wellbeing. Cities are combinations of the social, technological and environmental that co-evolve over time and together helps expand the possibilities for urban social life. There is considerable opportunity, see table 1, for advances in RAS to help address the pressing urban issues outlined in the previous section. Potential applications of RAS in urban areas includes:

UAVs, AVs and road congestion – Unmanned Aerial Vehicles (UAVs) can exploit urban airspace for the efficient delivery of goods in congested urban environments, supplementing road based delivery. Autonomous Vehicles (AVs) and automated traffic management create potential to use existing road space differently, routing traffic in real time, and removing some of the bottlenecks associated with existing modes of car use. AVs and enhanced traffic management create opportunities for safer and better quality urban environments.

Low carbon urban energy – technologies for low-carbon energy infrastructure are maximized through automation, including the automatic adjustment of buildings to changes in weather or temperature or the use of 'smart grids' that help balance energy generation, supply and demand and make use of new energy storage technologies.

Assisted living for ageing and inclusion – the UK RAS White Paper on Assisted Living outlines the significant possibilities to extend and enhance healthcare and assisted living through telecare and robotics[10]. Ageing is a challenge for cities but also an opportunity if services can be located in age-friendly built environments that support assisted living. RAS healthcare technologies can be 'urbanized' in cities as part of age-friendly environments.

Urban ecological management – sensors and monitoring enable urban authorities to manage changes in ecological conditions more effectively. Weather prediction is increasingly used by cities to help manage fluctuations and turbulence in climate and weather.

Urban maintenance – the infrastructure of cities is complex and much of it is underground. Robots can improve urban service provision, undertaking maintenance and routine work that is difficult or unpleasant for humans, reducing the costs of maintenance and improving the efficiency of urban infrastructure and service.

Controlled internal environments – many fast-growing cities internationally face challenges in providing leisure spaces for urban populations because of adverse weather conditions or pollution. There is considerable scope for extended urban food production in climatically controlled growing environments. These demands will increase as climate changes alters temperatures and weather patterns. Automation is essential for the management of controlled environments that extend the living space of future cities.

Urban security – UAVs and robots are increasingly used by police forces, making better use of police resources and extending the scale and scope of policing activity.

The issue for cities is that robotics and automation do not simply replace the human. Instead they facilitate the extension of 'life support' infrastructures that can facilitate urban growth and maximize the potential of sustainable living in cities. Many of the applications are about a blending of the human and robotic. The RAS contribution lies in:

- **Extending human capability –** providing support for people and service providers to undertake actions that would otherwise be difficult or not possible.
- **Improved management of dynamic environments and flows –** automation, robotics and AI have particular benefits in managing complex demands for mobility, services and healthcare in dense and dynamic urban environments.
- **New solutions to congested infrastructure to facilitate urban growth –** congestion is a major problem for growing cities and a constraint on future economic development and welfare. Automation and robotics can help make better use of infrastructure to facilitate development.
- **More cost effective and dependable service provision –** from policing to pipe maintenance, to help improve the efficiency of maintenance and repair throughout cities.

RAS and smart cities

In many respects, the RAS agenda fits into the wider interest in 'smart cities' whereby ICT technology is deployed to support sustainable urban management. An urban RAS agenda overlaps with smart cities in terms of its goals and technologies but significantly extends and focuses the possibilities for technologically enhanced urban development. The RAS urban perspective provides specificity and focus that has often been lacking in the smart city approach.

[10] The UK-RAS Network (2017b).

Urban Challenge	RAS potential
Congested transport infrastructure in growing cities	UAVs exploit underused urban airspace. Automated AVs allow make more efficient use of transport infrastructure. Automated traffic control systems making use of AI and real-time sensor information.
Low carbon energy networks and ecological management	Automation enables buildings and infrastructure to respond to climatic change. Sensors and AI can underpin development and management of green infrastructure.
Assisted living for an ageing population and inclusion.	Automated and robotic health and social care support assisted living. Scope to extend age-friendly urban environments. AVs extend personal mobility.
Infrastructure maintenance and repair	More efficient monitoring, repair and control through robotics, especially in contexts where human accessibility is difficult or unpleasant.
Controlled internal environments for leisure and food	Automation and AI provide the climate control needed to manage advances in controlled internal environments for food growing and leisure.
Urban security and policing	UAVs and automated robotic policing help extend policing and surveillance.

TABLE 1.

Urban RAS Applications

4. MOVING FROM THE LAB TO URBAN LIVING LAB

The next stage of RAS development must be a shift from the enclosed and protected spaces of university research or corporate laboratories into real world contexts of everyday life. This aspect of RAS development is based around technologies that replicate, replace and extend provision of goods and services in dynamic urban environments.

The critical issue faced by urban RAS technologies is that the scope of their application, their commercial viability, safety, and effectiveness are only partially demonstrated or tested in closed laboratory settings. Understanding the potential of RAS is not just a matter of gathering more data, creating technical fixes or establishing the right institutions. Rather, changes are required in the ways in which services are designed, organised and delivered. How to organise such experimentation remains a key challenge for policymakers, planners and practitioners. The key insight is that these diverse issues need to be tested in real world contexts:

"Living laboratories in existing infrastructure can have a key role to play. Capability based demonstrations in realistic environments provide a sharp focus to aim developments from basic RAS scientific research into first prototype demonstrators. Thereafter, the same living laboratories provide the playground where commercial prototypes are de-risked and certified though long hours of operation and modification in the spiral of requirements and technology development."[11]

Consequently, it is not surprising that there is growing interest internationally in the application of RAS within urban environments. In situ urban experiments in real world conditions are important in testing and demonstrating the potential (and limits) of RAS. The UK Government Office for Science White Paper, Technology and Innovation Futures 2017, identifies the crucial role of cities as sites of RAS experimentation in developing disruptive technologies.[12]

This, however, raises a critical challenge for national governments and urban and regional authorities in creating the conditions for real world experimentation. Creating these settings is not straightforward. There will be major concerns about public safety associated with robot-human interactions, and experimentation with RAS applications will need to be carefully balanced with the existing users of road space or airspace. Decisions will need to be made about the granting of licences to R&D organisations and selective changes in regulation. New collaborations between universities, private companies and public agencies will be needed to undertake and learn from experiments. The wider public will also need to be actively involved in understanding the purposes and potential of testing in their local communities, as well as how what is learned will be used in the future.

[11] Lloyd's Register Foundation (2016).

[12] The UK Government Office for Science White Paper (2017), 10.

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Robots are leaving factories and entering urban spaces'

Reference: Nagenborg M (2018) Urban robotics and responsible urban innovation' Ethics and Information Technology https://link.springer.com/content/pdf/10.1007%2Fs10676-018-9446-8.pdf

Urban living labs (ULL) are sites devised to design, test and learn about the wider issues involved in the application of new technologies in real world conditions, and are rapidly proliferating in cities across the world.[13] While the notion of ULL is broad, at its core is the idea that urban sites can provide a learning arena within which the co-creation of innovation can be pursued between research organisations, public institutions, private sector and community actors.[14] ULL have 3 key characteristics:

1. Experimentation: The testing of new technologies, solutions and policies in real world conditions, often in highly visible ways.
2. Participation and user involvement: Co-designing, collaboration and engagement with many stakeholders is often central to the experimental approach.
3. Evaluation of actions and impact: Systemic processes of evaluation underpins the ability of ULL to facilitate formalised learning and upscaling of applications.

Through the design and development of ULL, public, private and community-based actors are seeking to deliver innovative and transformative improvements across the urban context, ranging from buildings, green space, transport and energy systems, to local food systems and sustainable forms of consumption. For leading practitioners and advocates, ULL are seen not only as a means through which to gain experience, demonstrate, and test technologies, but also as a step towards developing responses that have the potential to be scaled up across different domains, in order to support more systemic change.

Yet there remains relatively little analysis of what types of ULL might be needed for different aspects of RAS applications. Most ULL have to date been focussed on innovations in digital technologies, smart cities and urban infrastructure. Consequently, there is a need to consider how ULL might address key deficits and challenges in the UK to accelerate the application of RAS, and review how international experience might provide lessons for effective urban experimentation domestically.

[13] Marvin, S, Bulkeley, H., Mai, L. McCormick, K, and Voytenko Palgan, Y. (Eds) (2018).

[14] Liedtke, C., Welfens,M.J., Rohn, H., and Nordmann, J. (2012).

5. CREATING RAS LIVING LABS

Urban Living Labs require a number of inputs in order to support R&D development. Governmental organisations need to understand the requirements of socio-technical applications and facilitate space for real world experiments. Applications of urban RAS will benefit from co-production and ongoing learning between R&D teams and national government, private partners and urban authorities.

In many countries the potential for RAS living labs is restricted – see table 2 – by a combination of:

- Limited governmental understanding of the potential for urban RAS and the importance of real world experiments.
- Unhelpful or restrictive regulation that limits the potential for experimenting with, or demonstrating the utility and safety of, new RAS technologies. In some cases this is because new RAS technologies would complicate the existing regulation of public or semi-public space (for example the use of airspace). It is also because governments are understandably risk averse on issues of public health and safety.
- Restrictive regulation can reflect governmental and public concerns about public health and safety and there can be societal and political resistance to new technology.

In the UK, USA and other countries, restrictions on autonomous drone flying have severely restricted experimentation with UAVs and drone infrastructure because of concerns about human safety, privacy and the management of airspace. Drone law tends to be risk averse. With increased demand for drone experiments the solution has been to create managed airspace corridors where unmanned aircraft and drones can be tested for safety and performance. In 2017 a 50km unmanned aircraft corridor was created in New York State around a former Air Force base for drone experiments.

Governments in Europe and North America have been increasingly flexible in creating living lab spaces for demonstration and experimentation with Autonomous Vehicles (AV).[15] Perhaps the most radical example is the state of Arizona in the US, which has sought to make itself a centre for AV testing by allowing self-driving cars to operate without a human backup driver or detailed registering and logging of AV activity.[16] California allows for AVs on public roads but requires that automated vehicles have to be registered and data including incidents have to be logged and reported. In the UK, the government is now revising the regulations on AV testing to make experimentation more flexible[17]. Public resistance needs to be managed. For example, since changes to US regulation allowed the testing of autonomous cars without human presence in October 2017, there have been at least two recorded cases of driverless cars being attacked by members of the public.[18]

In the UK, Innovate UK and the Centre for Connected and Autonomous Vehicles are running a competition to create a AV testing ecosystem that would include a real-word public test environment in a "dense city location" and semi-controlled environment such as a university campus or business part. The facility must be located within a pre-defined geographical area to ensure that there are a cluster of test facilities, relevant businesses and research organisation. Public trials of AV are underway in Milton Keynes and Coventry initially on segregated sections of road before moving on to open road trials.

In California, street delivery robots have been widely used in commercial applications until Walk San Francisco, a pedestrian advocacy organisation, came forward and expressed concerns about the safety of pedestrians. The city's Board of Supervisors then restricted areas in which robots could be used to avoid congestion, and limited the number of robots in operation to nine[19].

[15] National Conference of State Legislatures (2018); Connected and Automated Driving Europe (n. d.).

[16] Coppola, G., Beene, R., and Hull,D. (2018).

[17] UK Government (2018).

[18] Galeon, D. (2018).

[19] Said, C,. & Evangelista, B. (2017).

RAS application	Potential barriers to real world experimentation
Autonomous Vehicles and automated transportation management.	Restrictions on the use of driverless vehicles on public roads. Safety concerns and public resistance.
Drone surveillance and policing - including swarm drones. Drone delivery and logistics	Tendency is to restrict drone use given concerns about safety and privacy. Commercial drone applications are constrained by airspace regulations, especially in urban areas. However there are often significant experiments with drone policing in countries with restrictions on private drone use.
Service robots in public spaces.	Significant barriers to real world testing in most urban contexts in Europe and North America because of concerns about public safety in dynamic public spaces. Theft and damage.
Maintenance robots underground and in buildings.	Health and safety, insurance in controlled spaces. Experimentation is in controlled spaces that are easy to manage than public space experiments.
Healthcare robots	Ensuring adequate public protection. However experimentation is often in semi-controlled environments that are less complicated to manage than robotic experiments in public space.

Table 2

Regulatory issues in key urban RAS applications

Regulatory responses to the new era of urban RAS technologies have not been consistent across countries or within them. In the US, states have taken different approaches to the regulation of AV and drone use. In the UK, while commercial or public drone use is severely restricted, police forces have more freedom to use drones for urban policing.

In summary urban living labs require the creation of relatively open yet protected spaces for experimentation, learning and innovation. Once created, those spaces are likely to attract innovative research teams and investment, especially in a context of limited opportunities for R&D firms internationally. Regulatory concerns about safety and security can be managed within Urban Living Labs. The question is whether governments are sufficiently aware, committed or flexible to create the conditions for urban living lab experiments. Coordinated action is often required to ensure that national regulation supports initiatives at the urban scale.

6. INTERNATIONAL EXPERIENCE OF URBAN RAS

There are growing examples of real world urban experiments with new RAS technologies across different domains. Figure 2 maps out three of the key international sites of urban RAS experimentation. Alongside rapid technological development, this has been spurred by the establishment of RAS as a strategic innovation and infrastructure priority for various national governments. This has, for example, taken the form of countries striving to become the ‘smartest’ (Dubai, Singapore); the most robotised (Japan, South Korea); the most artificially intelligent (China); the most AV-friendly - (UK, California); and, the most drone -connected (Rwanda, Tanzania). The following examples highlight the key overlaps between government support and urban RAS experimentation.

Japan/Tokyo

Japan has a proactive national strategy for supporting the extended use of robotics in public life. A national Robot Revolution Strategy (2015) seeks to develop and roll out robots across Japan drawing on the country’s strengths in RAS technology. Tokyo-based ZMP has been testing self-driving vehicles on Tokyo roads since 2016 and robot taxis are being tested by DeNA and ZMP and developed by Toyota, Honda and Nissan. Urban living lab experiments in Japan include robot cashiers and autonomous tractors in Osaka and assisted robotic shopping for the senior citizens in Kyoto. There is strong central control and coordination between the Japanese government, Japanese firms and research institutions.

Figure 2

Urban RAS experimentation hotspots

The opportunity afforded by the spectacle of the upcoming Tokyo Olympics in 2020 is being used as platform for the introduction of robotics technologies, demonstrating the benefits of its programme of strategic economic investment and innovation. The organisers plan to make the Games a “showcase of robots,”. The organising committee is working with central government, the Tokyo metropolitan government and private companies on plans for using robots. These include

- Placing artificial intelligence-equipped robots in municipal buildings to provide tourist information in several languages, including English and Chinese.
- At Haneda Airport in central Tokyo, robots are being tested to guide international tourists arriving for the games.
- Demonstration tests of self-driving cars are also underway with the aim of setting up a fleet of robot taxis for athletes and guests.

Dubai

The Dubai government has been active in opening up public spaces for experiments with RAS as part of its ambitious smart city strategy, aimed at using technology to ‘make Dubai the happiest city on Earth’.[20] Dubai’s Autonomous Transportation Strategy aims to automate 25% of Dubai’s transport system by 2030 to reduce traffic accidents, increase productivity and reduce space needed for parking.[21] With much of its urban public life in controlled internal environments Dubai is well suited to urban technological experiments. Emphasis is placed on working with external innovation and commercial expertise.

Key Examples of RAS living labs in Dubai include:

- An electric flying taxi, developed by German drone firm Volocopter was tested in September 2017.
- Barcelona-based PAL Robotics’ humanoid police officer and Singapore-based miniature surveillance autonomous vehicle OUTSAW have been tested on Dubai streets. The Dubai government aims to robotise 25% of the police force by 2030.[22]
- Service robots are being employed across government agencies to facilitate administrative procedures for the citizens and workers.

California

California is a significant hub for innovation of RAS technology and infrastructure, but living labs have so far been more limited by regulatory controls set at the state level and, in some cases, public resistance, with street robots and AV attacked and vandalised.[23] In 2016, Uber even moved its AV experiment to the less regulated state of Arizona, due to the more onerous monitoring and reporting rules in California.

Yet conditions are being created in California for real world experiments with a range of RAS technologies for economic and social benefit. In 2017, California followed Arizona in allowing for the testing of autonomous vehicles without the presence of a human driver, and currently has 285 AVs on public roads being tested by 42 companies.[24] The cost of testing permits and monitoring has been criticised by firms, but this ensures long-term commitment by the companies and helps manage concerns about public safety. There are similar experiments with delivery and service robots. Delivery robots will now need permits to operate and are restricted to less congested city areas, where they can be used for testing purposes only.[25] Key examples of RAS urban experimentation include: automated farms and agro-robots for picking fruit and vegetables (e.g. the Iron Ox lettuce robot, and AgroBot and Planttape used by Fresco and Driscoll); inventory and delivery robots and service robots.

International examples, see table 3, demonstrate the importance of government support in creating the conditions for real world RAS experimentation, linking national innovation priorities to future cities and pressing urban issues such as ageing or congestion to create a social context for RAS applications.

In the United States and UK innovation capacity is fragmented and dispersed. In Japan and Dubai urban experiments are part of a strategic organisational capacity to undertake programmes of urban experimentation with selected stakeholders and partners, including research organisations, private companies, and service and infrastructure providers. This supports the capacity to learn from individual experiments in a systematic manner, supporting learning across different urban contexts and scaling up application.

[20] Happiness Agenda (n.d.).
[21] Dubai Future Foundation (n.d.).
[22] OpenGov Asia (2017).
[23] Galeon, D. (2018).
[24] Edelstein, S. (2017).
[25] Krishna, S. (2017).

Urban Living Labs	Living lab enablers	Constraints
Tokyo	Strong state support Strong public private cooperation and cooperation between research institutions, businesses and the state. Wide range of urban applications. Clear national vision and long-term national agenda. Ability to create supportive regulatory frameworks.	Public safety. State directed less bottom-up innovation.
Dubai	Strong state support Clear national vision and long-term national agendas. Limited scope for public resistance. Ability to create supportive regulatory frameworks.	Dependence on overseas expertise might not match government priorities.
California	Hub of dynamic private sector expertise. Openness to bottom-up innovation and experimentation Growing political support for RAS applications.	Political and public concerns about safety can lead to restrictive regulation. Protecting urban robots from vandalism.

Table 3
Comparison of Approaches to urban RAS in Tokyo, Dubai and California


Pizza
Pizza
AUTONOMOUS
Delivery

7. CONCLUSIONS

This report has reviewed the potential to bring RAS more centrally into strategies for future cities. There are very significant opportunities for RAS to help address pressing urban issues and improve urban quality of life. However the report has also highlighted challenges in promoting the urban RAS agenda and ensuring that there are opportunities for meaningful urban test beds.

There are four key recommendations for taking forward this important agenda:

1. **National sectoral priorities and plans for RAS should have a stronger place based dimension that extends existing commercial and university research capacities into different urban contexts.** Governments have recognised that creating space for urban experimentation is vital in supporting RAS innovation and attracting international expertise and investment. Well managed and visible urban experiments help to build public and political support for the application of urban RAS technology. Urban Living Labs can be especially valuable in demonstrating the benefits of accountable and responsible innovation. Experiments help to construct wider societal visions that connect RAS to particular place based urban problems such as population aging or congestion.

2. **Governments need to ensure that conditions are created for urban RAS innovation** through innovation priorities, supportive regulation, incentives and political leadership. Urban experiments help extend the scope of RAS applications through collaboration and joint learning between RAS and urban governance. In the UK there is scope to build stronger links between RAS networks and Future Cities.

3. **Governments need to ensure that there are opportunities for different types of living lab,** from experimental tests to more systemic platform capacities that can support programmes of experimentation and learning. Different types of living lab support distinctive forms of experimentation with different levels of resources and organisational capacity. Examples include: experimental trials that test RAS under what are often termed 'real world' conditions; protected enclaves that allow for RAS innovation under protected conditions; demonstration of future possibilities; and platforms that seek to create a systemic capacity to organise and learn from programmes of related experiments.

4. **A whole city approach is important in connecting RAS applications.** While the current UK focus is on autonomous vehicles and drones there is a need consider the relevance of the other bundles of 'urban' applications where the UK has competitive potential, including Artificial Intelligence and robotics, resilient infrastructure, emergency response, disaster relief and resilience, and social care. This will require a 'whole city' approach across urban governance. Urban RAS experiment will benefit from opportunities to link different RAS applications.

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Living laboratories in existing infrastructure can have a key role to play. Capability based demonstrations in realistic environments provide a sharp focus to aim developments from basic RAS scientific research into first prototype demonstrators. Thereafter, the same living laboratories provide the playground where commercial prototypes are de-risked and certified though long hours of operation and modification in the spiral of requirements and technology development.

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