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Research Roadmap Report

Smart City Vision

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Executive summary of the CIB Smart City Roadmap and Vision

Urbanization is a growing trend. As more and more people get together, smart systems and their integration need to be developed, not only to provide the services that people need but also to do so efficiently with minimum impact on the environment. It can be said that efficient technologies and ICT, one part of which is the Internet of Things, is a common dominator: tying together services, residency, mobility, infrastructure and energy.

Our challenge is to reduce environmental impact and the carbon footprint. At the same time, societal development needs to be addressed and the focus put on people's wellbeing. Pressure is growing to reduce our environmental impact, and there is a parallel compelling need for business to remain globally competitive. The need for investment and expenditure to improve energy efficiency, modernize infrastructure and create high quality living environments is enormous. At the same time, cities have limited access to financial resources. Sustainable transformation of cities is only possible when it is done in a smart way.

Holistically operating resource-efficient cities are better able to react to changes. Multifunctioning systems not only create cost savings but also increase safety and reliability through better utilization of intelligent, integrated and optimized networks. Smart management is the key to maintaining people's wellbeing under the pressure of resource efficiency.

This novel integrating approach by different sectors would make use of the synergistic opportunities provided by advanced ICT. It comprises citizens and business-based services and solutions. It also requires higher-level cooperation with the city administration and its agencies. The integration should be based on a real PPPP (public, private and people partnership) model in which all actors are committed to development and innovation together.

The main cross-cutting conclusion in specific roadmap areas were following:

- Digitalisation in enabling new services and innovation as well as more efficient systems
- Integrated and cross-sectoral planning and management is essential
- Cities have many stakeholders; value-chains and changing and new eco-systems are emerging
- Importance of energy management at building and district level increases as well as the increased use of low carbon energies
- New services, e.g. mobility as a service, building as a service, energy as-a-service, X-as-a-service are coming
- Importance of resiliency, safety and security is highlighted
- Upgrading existing infrastructure asks for new business concepts including new models for ownership

The essence of being smart in modern society lies in acting locally but being networked outside one's own geographical location. The technological systems can only be managed if they are properly integrated. ICT is the enabler that, when properly used for networking and integration, provides social, environmental and economic benefits for all. Cities all over the world see this as an opportunity for better quality of life.

Contents

Forewords

The CIB Programme Committee established the New Task Group TG88 on Smart Cities in the end of the year 2013. The task group started its work in the beginning of the year 2014 and completed it in mid-2016. The task group has had very active members and contributors in the workshops and other communications. The members of this task group are listed in Annex, but in addition to active members the task group has had the privilege to gain from many CIB members

The roadmap is structured according to seven main themes in the smart city needs, namely Energy and buildings, Infrastructure, Land use, Transport & mobility and Communities & users. The CIB roadmap has identified trends and drivers and created a common CIB vision. In addition implements actions are given.

The roadmap is based on the work at task group workshops and webinars, from which findings have been formulated and further developed by the authors and participating organisations. Altogether, the task group had 19 members but over 50 participants were joining and giving their expert comments during the work. The group has a wide geographical coverage and cross-sectoral expertise. CIB task group is grateful for the extensive expert engagement and fruitful discussions during the process.

On 20th of May 2016 In Espoo, Finland

The coordinator of TG88

Dr. Miimu Airaksinen

Research Professor, VTT Technical Research Centre of Finland

Introduction

Cities are a driving force in generating world's economic growth. All around the world, urbanization is a growing trend. Challenges rise as more and more people concentrated in the limited urban spaces, with outdated infrastructure, leading to a rapid increase in resource consumption and emissions. The principal challenges for cities, around the globe, are to deliver better services while being globally competitive, and meeting climate targets. Limited resources need to be managed in an efficient way. At the same time, societal development must be addressed and the focus put on people's wellbeing.

Pressure is growing to reduce our environmental impact, and there is a parallel compelling need for business to remain globally competitive. Expenditures on improving energy efficiency, modernizing infrastructure and on creating high quality living, and working environments, are enormous. At the same time, cities have limited financial resources for governance and services. The sustainable transformation of cities is only possible when it is done in a smart way. Smart systems and their integration need to be developed, not only to provide the services that people need but also to do so efficiently with minimum impact on the environment

Regarding the urban spaces as living ecosystems, the smart city design and planning, operation and management, needs to be done at the system level. Sub-optimization of individual city components will not lead to optimal performance of the all system. Multi-target optimization is not an easy task, but it becomes necessary as different components and systems are interlinked and interconnected – irrespective of where they are physically located.

Innovation in the form of 'smart city solutions' can deliver technologies, products and services that meet the dual challenges of reducing greenhouse gas emissions and delivering more efficient services. Cities worldwide are modernising and becoming poles of competitive strength.

The rapid development, and globalization, of information and communication technologies (ICT) can support the deployment of these solutions and their integration at system level. Applications as local small-scale energy production, as well as the transport solutions, for example, are the key enablers for cities becoming more resource efficient while better meeting the users' needs. It can be said that efficient ICT, where the Internet of Things has a central role, is a common dominator: tying together services, residency, mobility, infrastructure and energy.

Radical innovations and paradigm shifts are changing our whole city systems. Traditional sector-based industries and value chains are also changing, and completely new business models are starting to emerge. The AEC industry is not an exception, in this context, and has here a key role. The built environment, i.e. buildings, transports and utility networks, cannot remain only a passive platform. It also needs to be reshaped to make optimum use of the technology opportunities. The overarching goal is to provide good quality to live and work in cities based on resilient, sustainable, safe, resource efficient and connected products and services.

Objectives, scope and target group

In December 2013 CIB established a Task Group on Smart Cities. The aim of this task group is to compile the CIB community's vision and perspectives on the future of cities under the impact of the expected deployment of new technologies on the domains of distributed energy, virtual services, urban transport and; living/working opportunities. The goal is to provide pathways and recommendations for the AEC stakeholder's own action on the domain of smart cities.

To achieve this aim, this task group created a strategic roadmap for the building and construction related research needed for envisioned future smart cities. This document presents the visions and the roadmap providing the pathways to accelerate the adoption, take-up, development, and research of emerging and new technologies that may radically transform the built environment in the future cities.

The challenges and contributions we identified from the political, social, market, environmental and technological perspectives but also the values and their effect on different perspectives were considered in the workshops.

The main specific objectives were to:

1. Define CIB vision of smart cities
2. Define the priority themes for CIB in the smart city context
3. Develop the roadmap to achieve this vision
4. Develop recommendations for research and industry actions

Methodology

The roadmap work started with the conceptual framework, how we define smart city in the CIB context and what aspects are included in our frame. After framing the CIB context in smart cities the state-of-the art was defines and the identification of priorities and priority themes were defined. Highlighting today's state-of-the-art it was logical to set the vision how we want to see a smart city in the future. Setting the vision sets also the requirements for development strategy and research as well as industry needs to realise the vision. The chosen methodology follows the CIB roadmaps structure, framework illustrated in Figure 1 and they include a strategy for a research agenda on a specific topic.

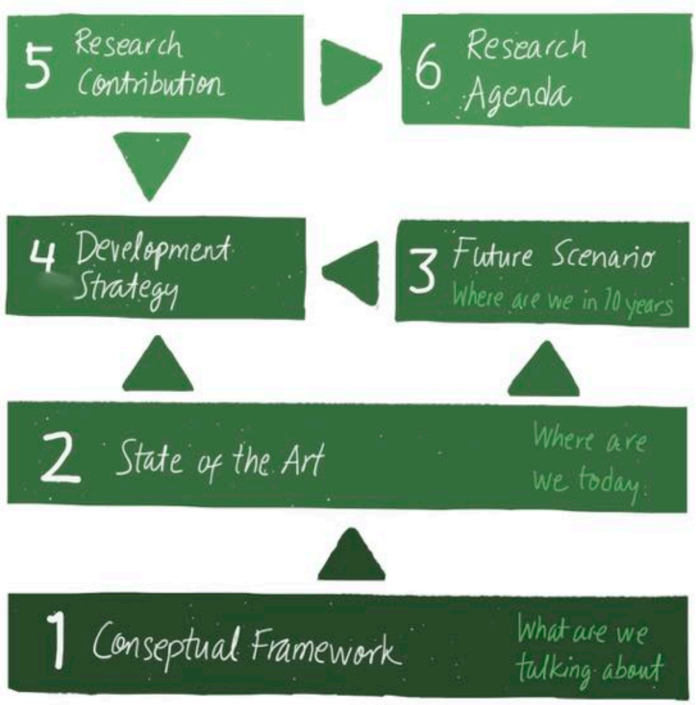

Figure 1: The structure of CIB roadmaps.

As the illustration indicates, a Research Roadmap should answer the following issues:

- Conceptual framework: the main issues; how those interrelate; by what is this all influenced; who are the stakeholders; the relevant areas of expertise; the characteristics of relevant systems; processes and technologies.
- State of the art: state of technology; best practices; international variations; perceived problems and challenges; needs for improvement; world's leading centres of expertise.
- Future scenario: the targeted state in ten years, stakeholders' opinions on required and envisaged future systems, processes and technologies, preferred future practices and skills.
- Development strategy: what is needed in terms of knowledge, information, tools, concepts and applications to enable the respective systems, processes and technologies to develop from the current state to the desired future state.

- Research contribution: how can research contribute to such Development strategy and what are the requirements for research to make that contribution.
- Research agenda: what is to be the agenda for research worldwide; areas of science and technology development; required sequences of development; priorities for research; international cooperation within the research community; cooperation between research and practice.

The working process of roadmapping was performed in three phases as indicated in Figure 2. First, the priorities for the work were set. Then the actual roadmap was done, and finally, actions defined based on the work.

Figure 2: Process for building a roadmap.

The interactive work process and schedule are shown in Figure 3 below. The first task group meeting and workshop was organised in Finland on February 20-21 2014. The workshop had 15 participants among the 22 task group members. The second meeting was organised as a webinar in June 2014 and the third workshop meeting was held in Washington on September 22-23 2014 with 17 participants.

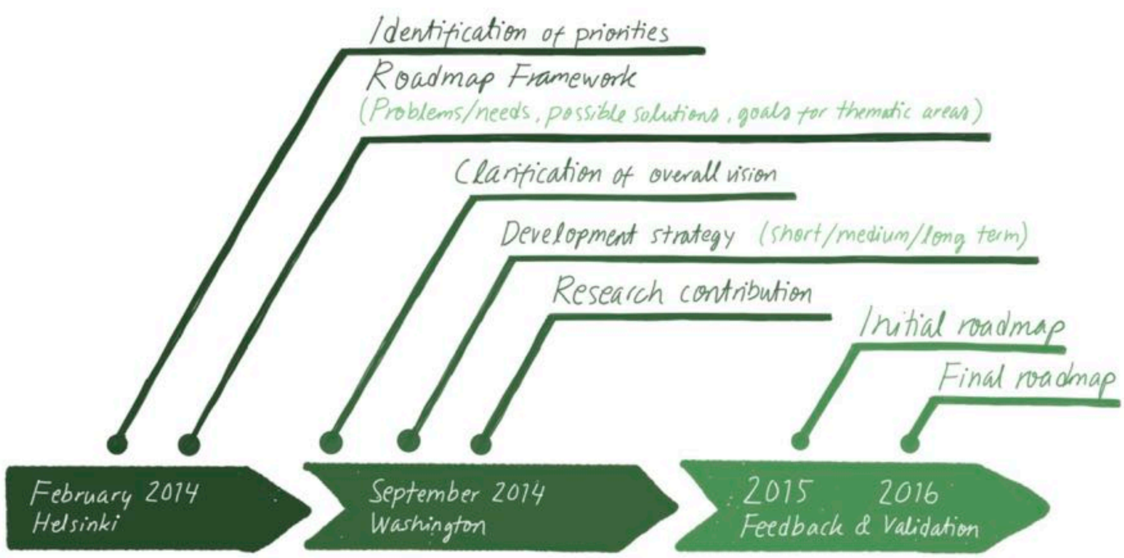

Figure 3: Schedule.

The objectives of the first workshop were:

- Objective 1: Identification of problem areas and setting key priorities (goals).
- Objective 2: Development of roadmaps for each priority area and identification of short, medium, and long term implementation actions.
- Objective 3: Definition of implementation actions for realisation of goals based on roadmaps.

In the first workshop each group started to draft reasons and solutions for possible problems were drafts in each group. In the end of that session a vision/goal for desired state was written. The workshop was divided into three parts: identifying the needs, deepening the analysis of the needs in thematic discussions and generating a vision for the identified themes. The participants were asked to group similar needs and to identify additional needs using the PESTEV frame (i.e. political, economic, social, technological, environmental and value related needs). For all of those, the change, actors and obstacles were identified.

The group results were compared and seven broad focus themes were identified for further analysis. Those were further grouped to form 4 groups: 1) Energy and buildings, 2) infrastructure, asset management, resources and waste, 3) land use, transport and mobility and 4) communities and users. In addition, several crosscutting themes were identified, such as resilience, interoperability, ICT, integrated planning and policy & governance.

The objectives of the third workshop in Washington were as follows:

1. Identification of most important sub-priorities in each main priority area, and
2. Setting short, medium and long-term targets for each priority area

The roadmap framework used for each priority area during the workshop is shown in Figure 4 below.

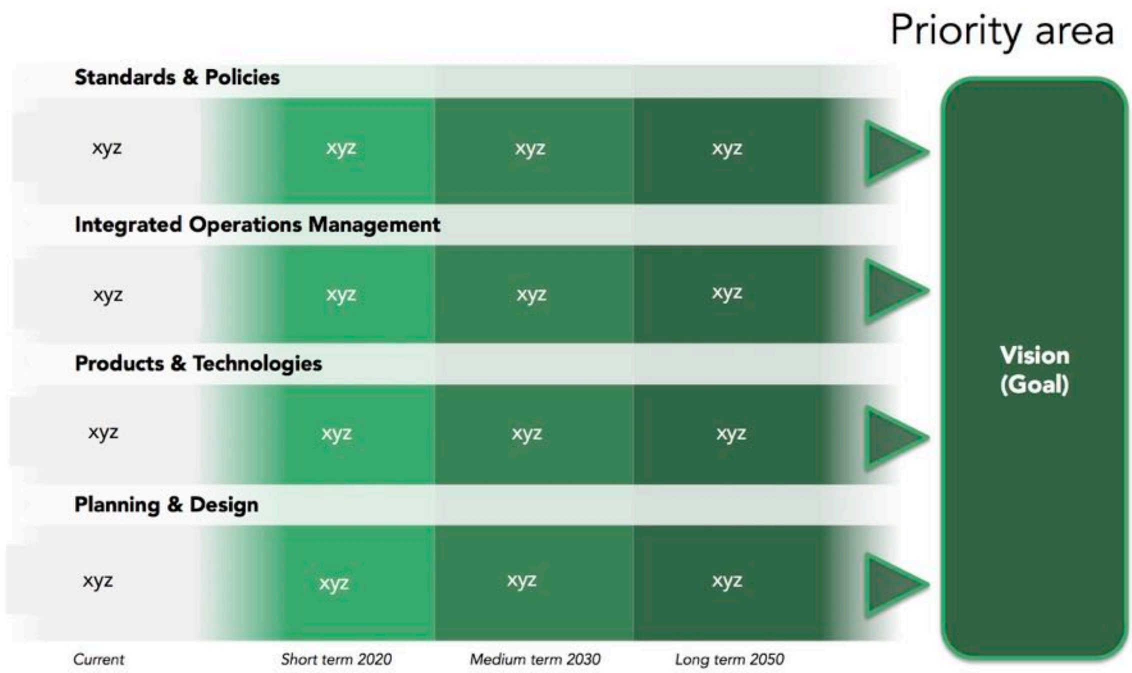

Figure 4: Roadmap framework.

Challenges and opportunities

Characteristics of city ecosystems

A city can be best viewed and understood as an ecosystem. Urban ecosystems are composed of the interactions between social, biological and physical components of a city[1]. The inhabitants of cities use natural resources in many forms by e.g. extracting energy, water, materials and food for the needs. The supply and demand, the flows and life cycle of those resources and their impacts should be analysed when developing a city and its different services. Analysing cities as ecosystems is important to understand the relationships between people, their activities and the environment and to thus solve problems of cities[1]. The core of urban ecosystem approach is in systems thinking – the humans and nature are analysed as an integrated whole, a socioecological system, not apart from each other as it is typically done.

Systems thinking is important also in smart city development in general, as the objective is to move from sectoral, separated and fragmented city development towards integrated and connected approaches. Smart cities emphasize the relations between urban flows on energy, material and people as well as governance and human behaviour. Further, the relations need to be explored in a holistic way to realise cities of high resiliency and sustainability. Therefore, the integration into, and interoperability between, urban systems is needed – alongside co-creation by, and involvement of citizens.

[1] Nilon, C., Berkowitz, A. and Hollweg, K., 2003. Introduction: ecosystem understanding is a key to understanding cities. In: Berkowitz, A. et al. (Eds.) Understanding urban ecosystems. A new frontier for science and education. Springer. P. 1-14.

The benefits of ecosystem functions for humans are known as ecosystem services[2]. The resources used in a city are typically manifold compared to the resources available in the geographical boundaries of the city and they originate from all around the globe. Cities should strive towards self-sufficiency to satisfy their needs with their own ecosystem services by reducing their demand, changing the consumption patterns and further developing own ecosystem services. Some more radical scholars claim that humans have already created so much harm to environment that the nature won't be able to provide the needed ecosystem services anymore unless we start to pay back the debt made by overusing the resources of the planet and develop practices of "restorative", "reconciliatory" and "regenerative" design that start from the needs and health of the nature[3] opposed to the "green design" practices that just slow down the pace of causing damage[4]. Such approach also opposes the prevailing human-centric worldview in which the simple purpose of nature is to serve humans. It aims at integrating the nature and people in a living system in which each element supports and is supported by the whole for long term viability.

Urban ecosystem services have been analysed from biophysical, economic and socio-cultural perspectives. Ecosystem services can be grouped in four categories: provisioning, regulating, habitat, and cultural and amenity services. The most important urban ecosystem services include food supply, water flow regulation and runoff mitigation, urban temperature mitigation, noise reduction, air purification, moderation of environmental extremes, waste treatment, climate regulation, pollination and seed dispersal, recreation and cognitive development and animal sighting. Which ecosystem services in a given city are most relevant varies greatly depending on the environmental and socio-economic characteristics of each site. In addition, urban ecosystems produce also some disservices. Ecosystem disservices have been defined as "functions of ecosystems that are perceived as negative for human wellbeing" and include e.g. trees emitting VOCs, microbes contributing to decomposing physical wood constructions and plants causing allergic reactions.[2]

The international smart city initiative City Protocol has developed a City Anatomy[5], an analogy to the human anatomy and its dynamic physiology, which serves as a framework for different parts of a smart city. It provides a hierarchically sound description and classification of all city systems, subsystems and interactions, thus analysing and mapping the interconnections between city systems. It describes the city ecosystem as three key system elements: a set of physical structures ("Structure"); the living entities that make up a city's society ("Society"); and the flow of interactions between them ("Interactions"). The Structure consists of three layers – "environment", "infrastructures" and "built domain" – and society is composed of "civil society" and "government". The interactions between the two are characterised by "functions", "economy", "culture" and "information".

The City Protocol's City Anatomy describes environment and infrastructures in the following way: "*The natural environment is formed by nature (plants and animals) and the three basic compartments, air, soil*

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[2] Gómez-Baggethun& Barton, D., 2013. Classifying and valuing ecosystem services for urban planning. Ecological economics 86, p. 235–245.
[3] Reed, B., 2007. Shifting from 'sustainability' to regeneration. Building Research & Information 35:6, 674-680.
[4] 7 group and Reed, B., 2009. The Integrative Design Guide to Green Building, Redefining the Practice of Sustainability. John Wiley & Sons, Inc, Hoboken, New Jersey. 432 pages.
[5] City Protocol Society, 2015. City Anatomy: A framework to support city governance, evaluation and transformation. Developed by TAFT "ancha". © City Protocol Society 2014. Co-chairs: V. Guallart & F. Giralt. 3 February 2015. Available at http://www.cptf.cityprotocol.org/CPAI/CPA-I_001_Anatomy.pdf

and water, interacting dynamically in a seasonally dependable way. The topography of the earth's surface is fundamental for siting cities. We have extracted minerals and materials from the soil throughout history, digging underground for the resources we use today, such as oil, gas, etc. Above ground are the plant structures, such as trees - and the area where animals move; and this is where farming was developed. Then we have water, which functions in a closed system, with clouds, rain, rivers, lakes, the sea, evaporation, in a continuous cycle. So all the aspects relating to the shape and quality of earth, air and water, which existed before cities were settled, and which we then organize within cities, are the environmental factors that we need to consider in the functioning of a city… The different infrastructures are connective structures that enable people to get the resources they need, especially from the environment, and bring them to the city or that enable the flows or cycles inside the city itself."[5]

A key issue related to socioecological city systems is resilience. Resilience, achieved by "adaptive capacity", determines how vulnerable a system is to unexpected disturbances and surprises that can break the control[6]. Climate change is feeding new and unexpected phenomena requiring more robust but flexible and self-recovering systems. Concrete threats to urban systems include natural disasters and other sudden shocks (storms, terrorism, collapse of vital technical infrastructure) as well as vast consequences of climate change (decreasing biodiversity in the ecosystems, repeated flooding, long periods of hot and arid summer seasons, distorted population structure, escalating migratory movements, and epidemic diseases). These challenges are very different from each other as some occur suddenly (epidemics) and have relatively limited duration (collapsed infrastructure) while some affect the society slowly and may be very difficult to change or to adapt to. The better we understand the functioning of cities as ecosystems and human activities as part of socioecological systems, the better we will be able to adapt to such extreme events and the better we will learn to mitigate such catastrophes in the long term[1,7].

Priority areas

The priority areas for the smart city roadmap were identified in the first workshop in February 2014 in Helsinki. The participants listed and discussed in three groups about choosing the priority areas. The main themes identified from the prioritisation of topics were structured into following groups:

- **Energy**: increasing the use of renewable energy, optimisation of the energy system and the management and balancing of energy supply and demand.
- **Buildings**: new solutions for renovation, living comfort and replication of building services and solutions.
- **Land use, infrastructure and asset management**: adaptive use and integration to existing systems.
- **Transport and mobility**: Easy and fast mobility, smart management systems, reducing the need and time for travelling.

[6] Holling, C., 2001. Understanding the complexity of economic, ecological and social systems. Ecosystems 4, 390-405.
[7] Moberg, F. et al. What is resilience? An introduction to social-ecological research. Stockholm resilience centre. Stockholm university. 20 pages. http://www.stockholmresilience.org/

- **Communities and users**: people participation, on-demand services, increasing awareness, trust and security, and good wellbeing.

The discussion included many cross-cutting themes, which are relevant for all priority areas. ICT solutions, interoperability and integrated planning and systems are essential elements in the smart city context. The discussion also strongly reflected cities' sustainability targets, including economic, environmental and social aspects. Especially efficient resources use and low carbon targets were considered as priority targets. One of the major changes considered was the development towards service-based economy. In addition, cities adaptability and resilience was highlighted, as well as policy and governance related issues with improved collaboration and communication. The summaries of individual group discussions are shown in following figures.

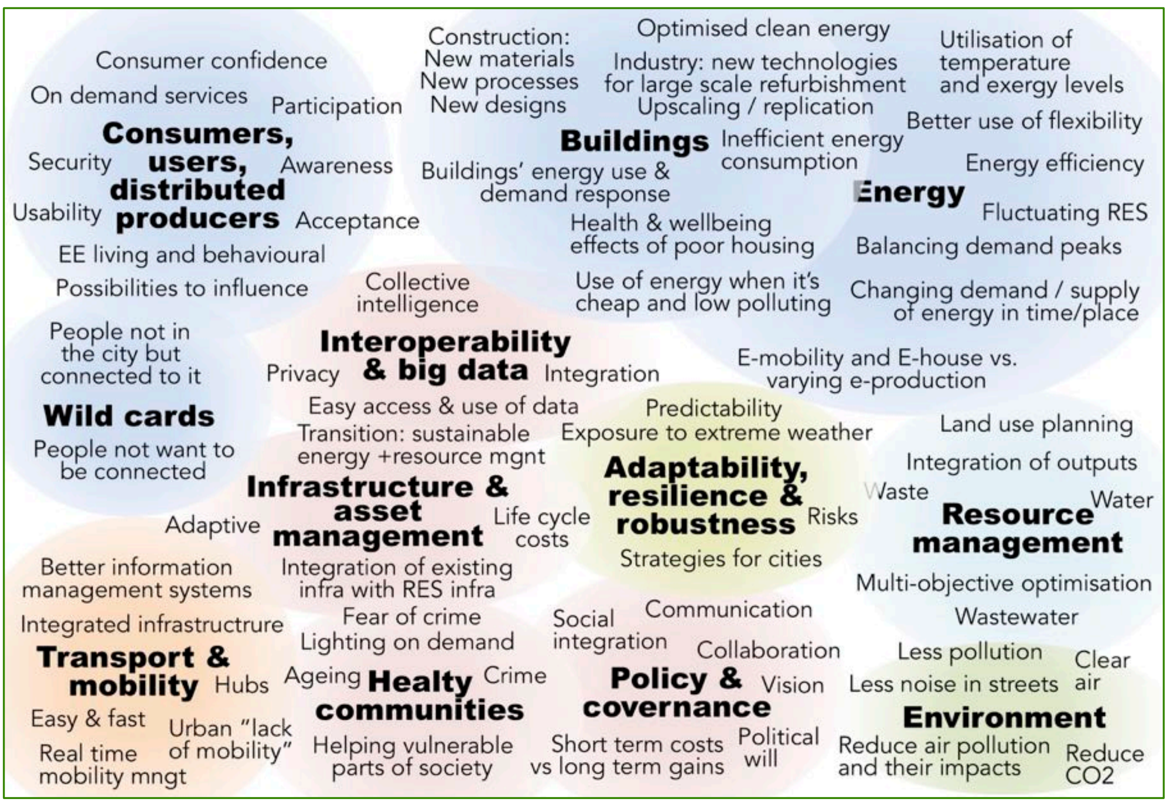

Figure 5. Priority topics for the roadmap as identified by group 1.

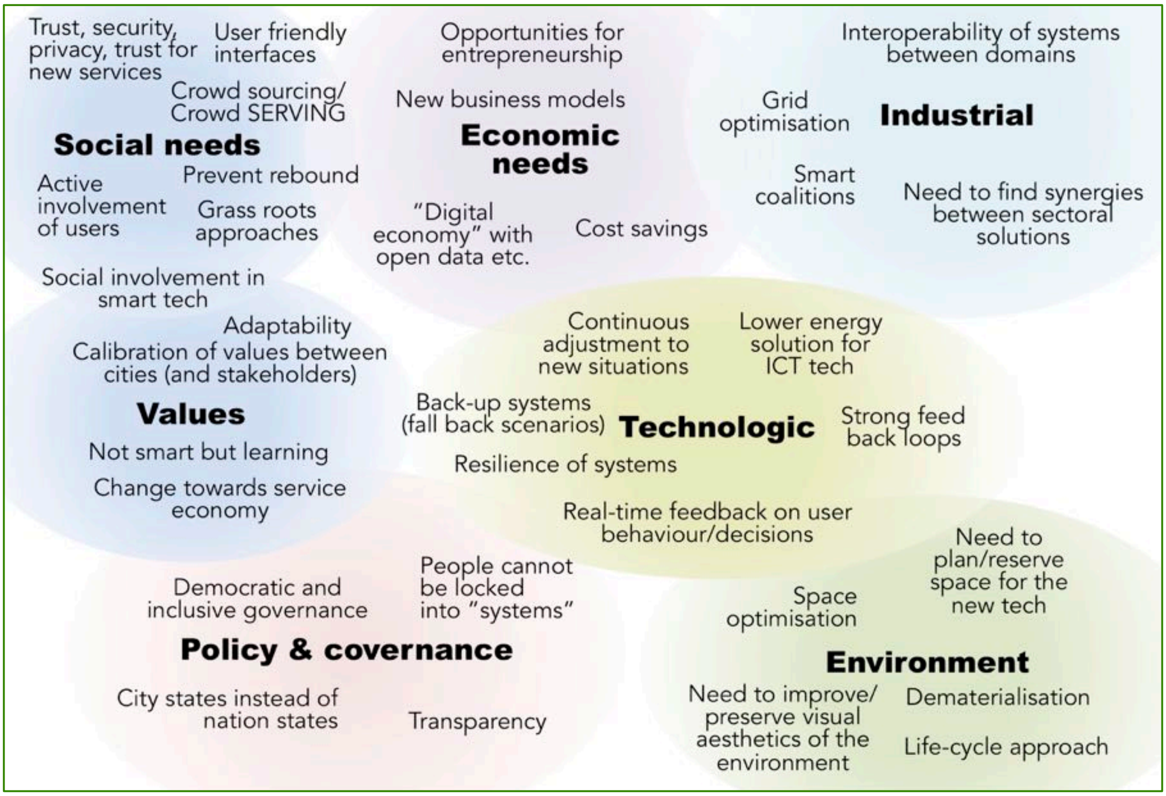

Figure 6. Priority topics for the roadmap as identified by group 2.

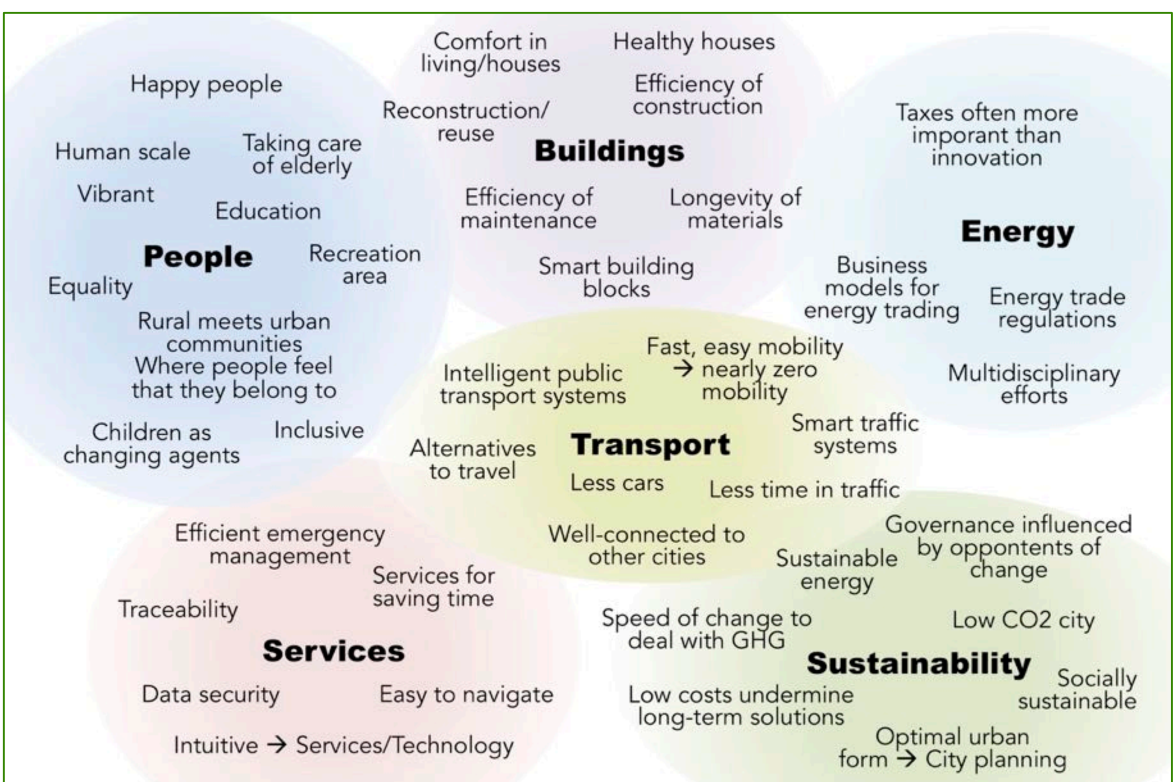

Figure 7. Priority topics for the roadmap as identified by group 3.

Challenges and opportunities

Urbanization had been rapid. Global urban population at 54% in 2014 is projected to rise to 70% by 2050. Currently only in Europe 78% of the citizens live in cities. Also, new cities have emerged,and hundreds are expected to be built in coming years. These upward trends are expected to be significant particularly in developing countries, where 90% of the additional 2.5 billion urban inhabitants and where muchof the growth of secondary and tertiary cities by 2050 are projected.

Cities are also engines of economic growth, accounting for 80% of the global GDP (85% in Europe). But they also consume around 75% of global primary energy and responsible for 70% of the global greenhouse gas (GHG) emissions. All sectors associated with urbanization (transport, building construction and maintenance, housing, waste management, energy, etc.) are registering trends that raise sustainability issues.

Rapid and unplanned urbanization has led to growth of slums, sprawl, housing and infrastructure shortages, social segregation, and exclusion. Accompanied by motorization, it has caused congestion and hazardous air pollution. Cities are where inequalities are most acute (one-third of urban dwellers in the developing world, for example, live in slums), where threats to culture and heritage are rising, and where the heavy concentration of people and assets poses high level of challenges and disaster risks.

Urbanization trends pose a need for strategic and innovative approaches to urban design, planning, management and governance. The accompanying trends in technolgies play a significant role in 21st Century urbanization as technolies are increasingly supporting business functions, city logistics and grids, transport, delivery of basic services, environmental management systems, government operations, data-driven industries like finance, and people-to-people interactions.

Globalisation has opened new markets and is requiring much more competitiveness from industries. The advanced and modern systems deliver new services and opportunities to growing wellbeing. But at the same, societies have become more vulnerable to human based criminality and also to natural based catastrophes. Climate change is feeding new and unexpected phenomena requiring more robust but flexible and self-recovering systems.

The concrete threats to the urban system include natural disasters and other sudden shocks (storms, terrorism, collapse of vital technical infrastructure), vast consequences of climate change (decreasing biodiversity in theecosystems , repeated flooding, long periods of hot and arid summer seasons, distorted population structure, escalating migratory movements, and epidemic diseases). These challenges are very different from each other as some occur suddenly (epidemics) and have relatively limited duration (collapsed infrastructure) while some affect the society slowly and may be very difficult to change or to adapt to.

Technologies have a crusial role and potential in address these urban challenges, presenting new opportunities and smart approaches for the global community to make cities inclusive, safe, resilient, and sustainable.

In CIB smart city work shops each theme group analysed the needs/problems from the perspectives of policy, markets, products & services and technololgies. In addition each group already started to draft reasons and solutions for possible problems. The group work result tables are presented below. Commonly the tables highlight the need for tecnolgies and services to support sustainability in cities and also the importance of technolgies to support sustainable choises in people every day life; i.e. making the sustainable choise the most convinient and easy choise without compromising wellbeing. The visions also highlight the new technologies for predictive, resilient and self-sustaining energy and resource management. In addition the vision states the transformation from internet of thing to internet of meaning, highlighting the importance to enrich the date to decision making to support city goals.

In the roadmap work each theme group analysed the needs/problems from the perspectives of policy, markets, products&services and technololgies. In addition each group already started to draft reasons and solutions fro possible problems. In the end of that session a vision/goal for desired state was written.

Workshop analysis: **Energy & Buildings**

? Problem or need	R Reason for problem	S Possible solutions	V Vision (Goal)
Policies			
• Distributed generation and its limits • Reliance on single energy source	• Lack of awareness • Legacy of design: central production	• Micro grids & islanding • Load balancing • Transactional energy: market & technology	• Clean, efficient and sustainable energy sources • Nearly zero energy buildings
Markets			
• Reuse of waste heat • Primary energy vs. delivered energy (process losses)	• Uncertainty • No ROI for environmental protection • Variable discount rate & time value for money • Costs & pay pack time	• Size-based sliding scale pricing & taxation	• Pricing policy that provides ROI on resilience, environment etc. • Dynamic energy prising
Products or services			
• Building stock inertia • Design to change user behaviour • Energy efficiency & losses	• Renovation need is huge	• Grid monitoring • Adaptive building management • User education • Real time feedback & pricing	• Smart grid & city • Adaptable and flexible structure design
Technologies			
• Resilience • Accessibility and affordability	• Lack of ROI for resilience • Fluctuating supply from RES	• Response market & mechanisms	• Holistic design • Novel building materials • Different design levels: Horizontal, vertical, temporal, 3D etc.

Figure 8. Analysis in Energy & Buildings.

Workshop analysis: **Infrastructures, Assets, Resources & Waste**

? Problem or need	R Reason for problem	S Possible solutions	V Vision (Goal)
Policies			
• Transition to sustainable energy & resource efficiency			• Self-managing multi-functional infrastructure for resource efficiency and zero waste.
Markets			
• Reduce life cycle costs • Building stock management	• Legacy of infrastructure and investment		• Smart energy management for water, waste and energy management / and smart technology
Products or services			
• Adaptive infrastructures • Integration of existing infrastructure with new infra	• Clean water scarcity		• Effective urban water and waste water management • Effective waste & resource management • Zero waste
Technologies			
			• Sustainable use of resources

Figure 9. Analysis in Infrastructures, Assets, Resources & Waste.

Workshop analysis: **Transport & Land Use**

? Problem or need	R Reason for problem	S Possible solutions	V Vision (Goal)
Policies			
• Too much land use for transport and infrastructure (parking lots)	• Locations not optimally planned	• Better management coordination: municipal to regional level	
Markets			
• Cities develop quickly • Resident dissatisfaction with land use	• Work opportunities higher in city → Urbanisation • Values (interests) of residents changing faster than development	• Better means for public participation in development process	
Products or services			
• Slow development and changes in transport & land use • Energy demanding solutions • Too much time	• Capital intensive development, different obstacles e.g. legality and public acceptance • Lack of public transportation & non-mobilised options	• Intelligent transport system • Retrofitting current systems to become more energy efficient and less fuel consuming + ITS	
Technologies			
• Optimal regional layouts is not yet understood/explored	• Non-multidisciplinary research and collaboration → sub-optimisation	• Support for initiatives towards multidisciplinary research and collaborations	

Figure 10. Analysis in Transport & Land Use.

Workshop analysis: **Community & Users**

? Problem or need	R Reason for problem	S Possible solutions	V Vision (Goal)
Policies			
• Set the standards for: data security, interfaces & requirements	• Lack of power/ involvement in decision making • Land use (crime & security)	• Open communication & governance • Creative consideration in urban planning • Decision making to local level	
Markets			
• Healthy & happy citizens	• Lack of jobs	• Mapping of human resources • Distributed facilities	• Health & wellbeing
Products or services			
• Citizen engagement	• Lack of education & career opportunities • Affordability of adequate healthcare	• Self monitoring → preventive health care • Service resilience • Better control on services	• Inclusive + equal + feeling part of the society
Technologies			
• Affordability of housing	• Lack of good quality buildings/homes	• Warning systems/ predictive monitoring of vulnerable people • Interactive infrastructure • Voting by email	

Figure 11. Analysis in Community & Users.

Trends, drivers and vision of the business environment

Cities are facing serious challenges stemming from global megatrends:

- Urban growth and urban sprawl: urban populations are estimated to grow by 2,3 billion over the next 40 years. Immigration causes problems in many parts of the world.
- Ageing population: the number of people over the age of 60 is expected to triple by 2050. This sets concerns of sufficient workforce.
- Global warming: cities consume 75% of world's energy and produce 80% of its GHG emissions.

Under these circumstances, cities are forced to adapt and improve the whole city system and its efficiency, for example develop new energy systems and tackle social issues. The philosophy of smart cities is to see challenges as opportunities and take advantage of other trends, such as

- Digitalization: the proportion of broadband access has exploded worldwide which enables more efficient and economical service provision and internet and remote retail and services.
- Automation and services: more and more jobs are carried out by machines and the trend has been since a long time from goods based manufacturing economy to service and solution oriented economy.
- Technological development: e.g. intelligent transport (automatic vehicles, electric cars) and smart grids give new opportunities for cities to think about their service provision.

On the positive side, also 85% of innovations happen in cities. Cities are driving forces in generating economic growth. Innovation in the form of “smart city solutions” can deliver technologies, products and services that meet the dual challenges of reducing greenhouse gas emissions and delivering more efficient services.

A key goal for many cities that want to be smart is to achieve better transparency in decision making through involvement and engagement of citizens in decision making by participative and co-creative approaches, providing data publicly (open data) and providing opportunities for bottom-up initiatives.

Industry requirements

The most visible part of the Smart City agenda is urban development and digitalised services. Also the industry has own and very interesting role. Many urban development projects are typically situated to the old industrial sites – to so called brownfields. Incomes from the plots sale (capex) can be a remarkable push in the restructuring of industry.

The Smart City agenda also challenge the industries to develop their resource efficiency and cleanness. These are areas, which are governed by national as well as international treaties. For industries, it is crucial to know early enough what changes are coming. Minor changes in requirements may lead to reorganisation of the value chain or ecosystem.

The digitisation of the industry is said to be The Fourth Industrial Revolution. This term refers to technologies and concepts of value chain organization. The Fourth Industrial Revolution aims to leverage differences between the physical, digital, and biological sphere. It integrates cyber-physical systems and the Internet of Things, big data and cloud computing, robotics, artificial intelligence based systems and additive manufacturing. Compared to previous industrial revolutions, the fourth one is evolving at an exponential rather than at a linear pace.

Digitalisation drastically modifies customer expectations, product enhancement, collaborative innovation and organisational forms. New technologies make assets more durable and resilient, while data and analytics change the way they are maintained.

Digitalisation promotes the service production often at lower cost. In order to achieve productivity leap by digitalisation, old-fashioned products or activities the exit. Artificial breathing with public funds would prevent the recurrence of the industry.

Next generation smart products will operate as parts of interconnected environments and what is increasingly called "systems of systems". In this environment connections to work without locking in suppliers, innovators and users to specific technology or platform it is essential to have common standards and interoperable solutions throughout the products and services life cycles: from APIs (Application Programming Interfaces) opening up the design, prototyping and testing possibilities, up to production process control systems and tools for aftersales operations. Shared data interfaces are also essential for gathering, transfer and processing of data from different sources in an interoperable manner and consequently the seamless flow of data across sectors and in vertical markets.

It is also urgent a reskilling of a significant part of the work force, including leaders and managers. The need for new, highly specialised skills is exploding, such as for big data analytics, cyber-security and cloud computing.

Barriers

There exists various barriers that can impede or restain the realisation of the development steps proposed in this roadmap. They are into following four categories: administrative and legal barriers, technical and infrastructural barriers, economic and market barriers and social acceptance and political barriers.

One of the most challenging ones is that cities have limited and often reducing financial resources for providing governance and various services. Often it is hard to understand the real benefits and costs of investments, and evaluate their life cycle impacts in the long term. Other common barriers for many smart city developments are related to systems sub-optimisation and unclear vision. It is typical that there are many stakeholders involved from different sectors and backgrounds, which makes the integration of processes and systems complex, and communication and collaboration need lots of efforts. Another common barrier is that the relationship between data monitoring and services and the privacy and security of users' data is not clearly regulated.

Table 1 on next page summarises some of the main barriers for the main targeted development areas and main cross cutting themes in this roadmap.

Table 1. Summary of main barriers for the targeted roadmap development areas and cross cutting themes.

	Administrative and legal barriers	**Technical and infrastructural barriers**	**Economic and market barriers**	**Social acceptance and political barriers**
Energy	Legal issues and lacking of new business models for local energy services and supply/demand matching. Development and changes are slow. Sub-optimisation.	Lots of actors makes interoperability and integration of processes and systems is complex. Limits of distributed energy (e.g. timing and fluctuation). Location affects to the accessibility and availability of RES.	High costs and long pay-pack times. Costs and efficiency still developing for some supply technologies, e.g. PV.	Legacy of design for central energy supply. Lack of common vision.
Buildings	Outdated regulations for renovation. Lack of policies for the integration of smart renovation measures. Retrofitting not integrated in district planning.	Lack of quality. Short term planning. Rare integration of smart products, services and technologies into wider city systems and tools. Huge renovation need. Building stock inertia. Maintenance reactive.	Doubts about ROI for investments. Smart renovation solutions not cost-efficient and focus on isolated buildings rather than district integration.	Lack of awareness and interest. Old habits.
Infrastructure	Decision making. Maintenance and renovation sub-optimised.		Long term investments vs. short term costs.	Lack of awareness and knowledge.
Mobility	Too much land use for transport and infrastructure (e.g. parking lots). Unnecessary trips.	Lack of public transportation and un-motorized options. Rarely linked to other city services.	Many cities develop uncontrollable.	Mistrust towards reliability of public transport.
Communities and users; citizens	Lack of possibility for involvement in decision making. Lack of information.	Security and privacy of data. Services, systems and interfaces that are not easy to use.	Affordability of housing. Lack of education and career opportunities.	Users resistance and mistrust towards new solutions.
Governance, policies, and land use	City decision making in silos. Development and changes are slow.	Sub-optimisation of the land-use. Inadequate evaluation of life cycle criteria.	Hard to see the impacts of the investment costs in the long term.	Dissatisfaction of people regarding the land use.
Interoperability and ICT	Data monitoring vs services vs privacy is not clear regulated	No common semantics and standardisation for communication and data exchange. Lack of open data.	Hard to calculate the benefits of investments.	Inadequate collaboration, communication and integrated planning.
Resource management; environment	Sub-optimisation.	Clean water scarcity.	Lack of ROI for environmental protection.	Competition for resources.

Vision

The vision of CIB smart cities was produced in the workshops. First four thematic visions were created for:

1. Energy and buildings
2. Infrastructures and asset management
3. Transport and land use
4. Community and users

The visions pointed our clearly the need for integrated approach and long term goals as well as citizen engagement. In addition visions highlighted the new technologies for predictive, resilient and self-sustaining energy and resource management. In addition the vision states the transformation from internet of thing to internet of meaning, highlighting the importance to enrich the date to decision making to support city goals.

Thematic vision: **Energy & Buildings** → **Near Zero Energy Building**

C What is the Change?	A Who are the actors?	O What are the Obstacles?
Political		
• National policies need changes • Legal problems • Ownership of grids	• Decision makers • Local & national level • Politicians • Voters	• Short term planning • Lack of compelling vision • Lobbying affect politics
Economic		
• Micro markets for selling energy (perhaps market could take the ownership of grids?)	• Companies • Regulators, Tax policy makers • Market structures • User, consumer	• Current markets are centralised • Investment money. E.g. lacking due to the lack of beneficiaries, or their diversion. Doubts about ROI.
Social		
• Acceptability of: demand response, pricing, and feedback→ technology to support this. • User behaviour. Social media	• End users • Construction companies	• "This is not my problem" attitude • Habits & cultural norms • Construction sector to change their attitude towards quality
Technical		
• Localisation: different solutions best for different countries • System integration	• Scientists • Engineers	• Quality and costs of construction • Materials: costs & efficiency, maturity. (e.g. PVs still under development)
Environmental		
• Less emissions • Clean sustainable energy • Energy efficiency	• Everybody • Regulators & government • Designers of buildings • Buildings' users	• Geological location: accessiblity & availability of RES
Values		
• Energy as a limited resource	• Non-governmental and environmental organisations, e.g. Greenpeace	• Short mindedness • Old habits • Free riders

Figure 12. Thematic vision for Energy & Buildings.

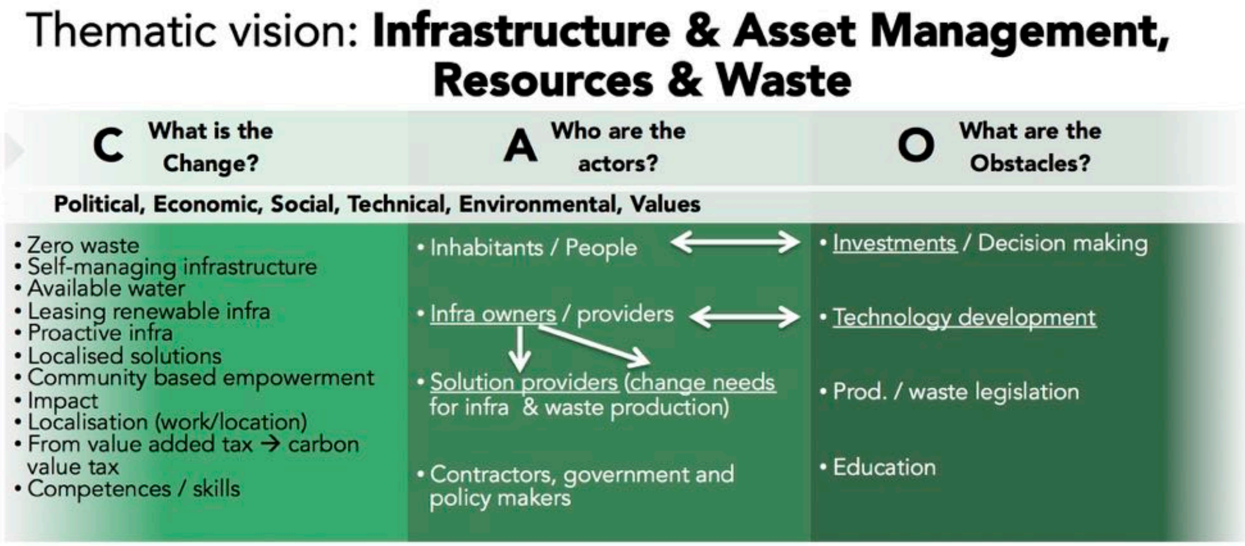

Figure 13. Thematic vision for Infrastructure & Asset Management; Resources & Waste.

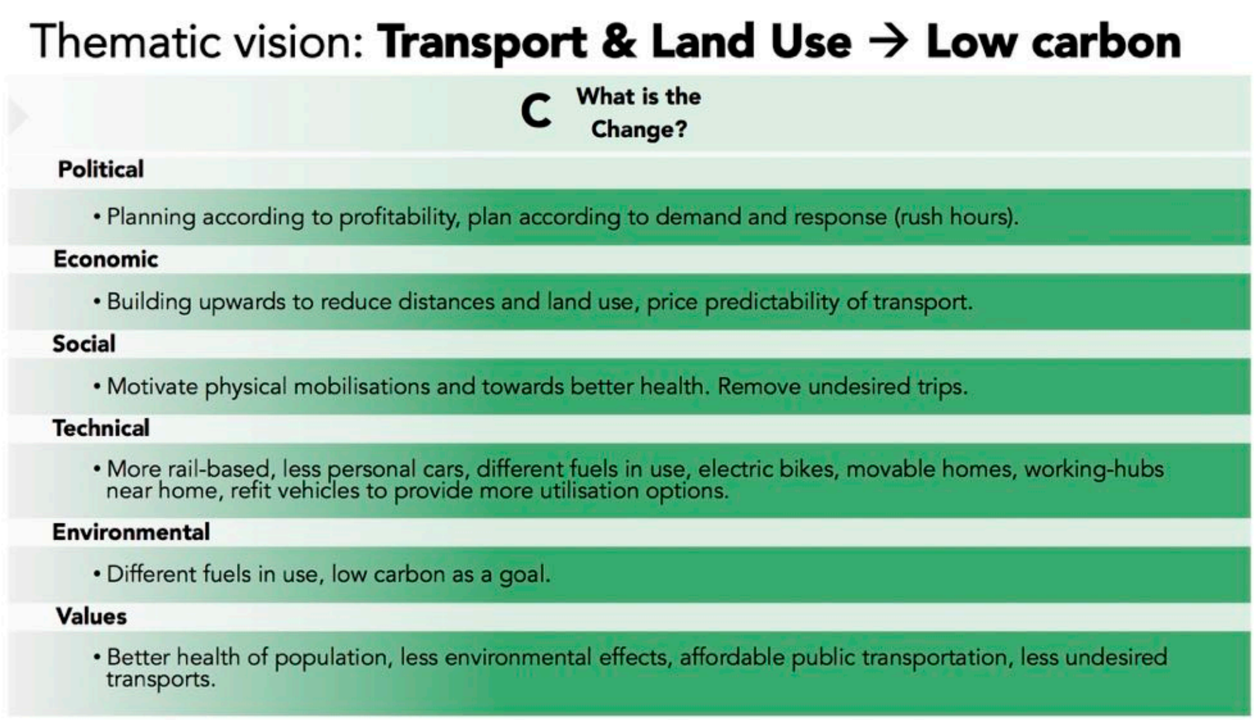

Figure 14. Thematic vision for Transport & Land Use.

Thematic vision: **Community & Users**

C What is the Change?	A Who are the actors?	O What are the Obstacles?
Political, Economic, Social, Technical, Environmental, Values		
• Sustainability at each level: Family, community, city, national, global • Get voice to quiet and weak ones • Many "equal areas" in the cities	• Academia, Multi-disciplinary research Evidence System understanding	• Political will/ ambition/ leadership • No support to the vision • Lack of understanding • Inadequate communication • Lack of collaboration/ shared vision • Unfriendly/melodramatic media/ publicity
• Flexible cities can redistribute jobs, services, buildings etc.	• Designers, researchers industry	
• People to choose the place where they live and work • No one owns a building/ house → upgrading buildings • Sharing/ being less selfish	• People/education/media Good pilots • Charity • Creating dreams Film makers • Religion/working groups/industry • Business policy • Local chamber of commerce • Regulators, local government	• Competition for resources • Complicated by cultural differences Special considerations Cannot have one size fits all • Vested interests/selfish perspective

Figure 15. Thematic vision for Community & Users.

The vision was created based on analyse from the perspectives of political, economic, social, technical, environmental and from the values perspective. The four thematic visions are show in the tables below. From the thematic visions following common themes could be seen:

- low emission
- sustainability
- integration
- many stakeholders
- flexibility
- resiliency
- real time
- user orientation and wellbeing
- personalised services
- economic viability

The CIB vision for smart cities was finally formulated to following:

CIB - VISION OF A SMART CITY

"Smart city is a dynamic ecosystem of citizens, authorities, companies and researchers that cooperate to develop products and services to foster innovation with the aim to develop an attractive, competitive and sustainable city. A smart city enables energy efficient and carbon neutral living, working and travelling without compromising the wellbeing and good quality of life."

Figure 16. Description for CIB vision of a smart city.

The Smart City roadmap

Overview

The roadmap is structured into following five main categories:

- Energy
  - Energy network management
  - District
- Buildings
  - New and existing buildings
- Land use and infrastructure interconnection and asset management
  - Land use and urban planning
  - New and existing infrastructure
- Mobility and transport
  - Mobility and Multimodal transport
- Community
  - Engagement of citizens + users
  - New governance models

Each roadmap section presents the specific vision and its requirements and needs, as well as relevant drivers, barriers and expected impacts. Then the development topics are suggested from state-of-the-art towards the vision in the short, medium and long term. These three development phases are defined (with indicative lengths) as follows:

- **Short term:** take up, piloting etc. implementation of existing, already developed solutions. E.g. actions, which help to get the already developed solutions in operation in real life cases. (1-2 years)

- **Medium term**: incremental development. E.g. adapting solutions, that are now used in other expertise areas, or that are currently used in industry etc. Also further develop of minor parts to an existing solution. (up to 5 years)

- **Long term**: actual research needed; radical development of solutions. (3-7 years +)

Energy

Drivers

Climate change drives cities to increasingly set targets and policies towards improving energy efficiency, increasing the share of renewable energy use and reducing environmental impacts. In addition, smart city developments, Internet of Things and Big data foster broad take-up of smart technologies, which can also support efficient management of energy systems in smart cities.

Vision

The vision is that energy supply is based on many energy sources, and it is simultaneously optimised and holistically coordinated. The share of distributed and renewable energy supply increases, and as a consequence the energy demand and (volatile) supply needs to be balanced with the optimal use of energy storage. Hybrid energy sources are used more efficiently with taking into account best suitable exergy levels for each energy supply and demand point. In addition, the planning of energy system is included early to the planning process both in the land use and building planning. The different energy systems need to be localised, as the choice of the best technological solutions vary in different countries, environments and locations. Energy and the services it is enabling (like indoor climate) are becoming more important, future users are buying e.g. “indoor air as a service”.

Needs and requirements

Key enabling technologies include smart energy management, demand side management and energy matching and balancing solutions. The multi-source energy system needs to be holistically coordinated, and the optimal use of energy sources managed. Interoperability and the integration of both systems and processes supports improving overall energy efficiency throughout the entire energy chain from energy supply to distribution, storage and demand.

Barriers

Current barriers are mostly related to legal issues and lacking of new business models for local energy services and matching. The energy system is operated by many actors (including both energy users and suppliers), which makes the integration of processes and systems complex. Moreover, municipalities are often struggling with assessing the costs, benefits and impacts of investments in the long term, but also with the lack of investment money.

Expected impacts

New business opportunities are expected to raise for the small-scale and local energy supply business, and also for offering new energy related services. The use of primary energy, and as a consequence the environmental impacts, will decrease.

Key stakeholders The key stakeholders are: energy companies, energy network operators, energy service providers, technology developers, and decision makers.

Energy network management

Roadmap for energy network management envisages optimised energy system that is designed and operated with a holistic coordination and integration throughout the entire energy chain from energy production, distribution, storage and demand. Both electricity and district heating and cooling networks are considered. The focus is put on improving the interoperability of the energy system, and taking a full advantage of open data opportunities, which both enable more efficient management of energy networks and systems.

State of the art

Existing energy management systems are usually individual, proprietary and designed for traditional energy networks where energy is distributed from centralised production plants and national electricity and gas networks to end-users. The data transfer goes usually only to one direction, without real two-way communication. The utilisation of distributed, local and multi-source energy supply is often seen as a challenging task, and the holistic coordination of city's energy system and e.g. balancing of local energy supply and demand is not much done in the practise, even though research projects exists (e.g. EU 7th framework programme projects IDEAS[8] and CITYOPT[9]).

Open energy data initiatives are on-going and development is fast. Open data is not yet much utilised in the management and optimisation of the energy network, mainly due to lack of relevant open data. Some research and pilots are on-going, e.g. an EU 7th framework programme project READY4SmartCities developed guidelines for opening, accessing and using open and linked data[10] and collected existing open energy data sets and ontologies[11].

Key research and innovation needs are:

Short term Methods, tools and solutions for **optimising the use of multi-energy sources** are needed, as well as **business and service models** for the optimal use of local energy sources and energy

[8] IDEAS: Intelligent Neighbourhood Energy Allocation and Supervision http://www.ideasproject.eu/; and e.g. Ala-Juusela, M., Sepponen, M. and Crosbie, T. (2014) Defining the concept of an Energy Positive Neighbourhood and related KPIs. Proceedings of 2nd EeB KPIs workshop, Sustainable Places, October 1-3, 2014, Nice, France. http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/SP14-Definition-and-KPIs-for-EPN_Revised.pdf

[9] CITYOPT: Holistic simulation and optimization of energy systems in Smart Cities. http://cityopt.eu/

[10] Guidelines for Linked Energy data generation and exploitation. READY4SmartCities project, 2015. http://www.ready4smartcities.eu/guidelines

[11] Online catalogue for ontologies and datasets about smart cities, energy and other related fields, collected by READY4SmartCities project. http://smartcity.linkeddata.es/

matching services.

Opening of energy system related data, such as anonymised energy consumption data would support **energy data interoperability** and linking of data[12]. However, data privacy, security and anonymization need to be taken care of, and issues related to data ownerships and authorisation to open the data.

Near future ICT developments can provide new business and service model opportunities for **the optimal management of energy networks**, e.g. through easing the optimal energy trading of distributed, volatile local RES energy production, utilising energy flexibility (in demand side management, storage use and production) to balance the difference between real time energy demand and supply, and /or to cut the peak loads.

Medium term

More efficient, integrated energy system planning would require interoperable data bases that enable **easy access, use, and sharing of various data**, e.g. urban plans, district heating network locations, transport route plans, GIS, building data, etc. Interfaces and standardised communication protocols between different meter data and algorithms are key steps towards enabling energy system integration.

The share of volatile, local renewable energy supply is increasing e.g. due to (nearly) zero and plus energy buildings. Optimisation and management tools are needed for real time energy balancing and matching between multisource energy supply, demand and optimal use of energy storages. The tools should take into account how to best utilise the different energy sources available at a specific time, and how to optimally use energy storage and flexibility in energy demand e.g. through demand side management. One example about utilising of the full potential for energy network optimisation (to maximise environmental and economic impacts) would be a need for real time energy price tariff levels and negotiation systems between buildings and energy networks. This kind of system could automatically negotiate which appliances in buildings are using energy at what energy tariff levels, and hence, the system would strongly support the optimal balancing of energy networks.

Long term

Interoperable, open and linked energy databases would support **optimisation and holistic coordination of energy networks**. Assessment methods and tools are needed for showing the energy network performance and for supporting decisions about the optimal energy network management (e.g. showing economic and environmental performance and what the impacts of different choices are). These tools should also support the collaboration among various stakeholders (e.g. energy producers, network managers, building and facility managers, energy brokers, end-users and possibly also e.g. municipal officials, such as city planners). Co-creative design environments and platforms could be one potential mean.

[12] Hukkalainen Mari et al, 2015: Innovation and research roadmap. Deliverable 5.6. READY4SmartCities – ICT Roadmap and Data Interoperability for Energy Systems in Smart Cities.

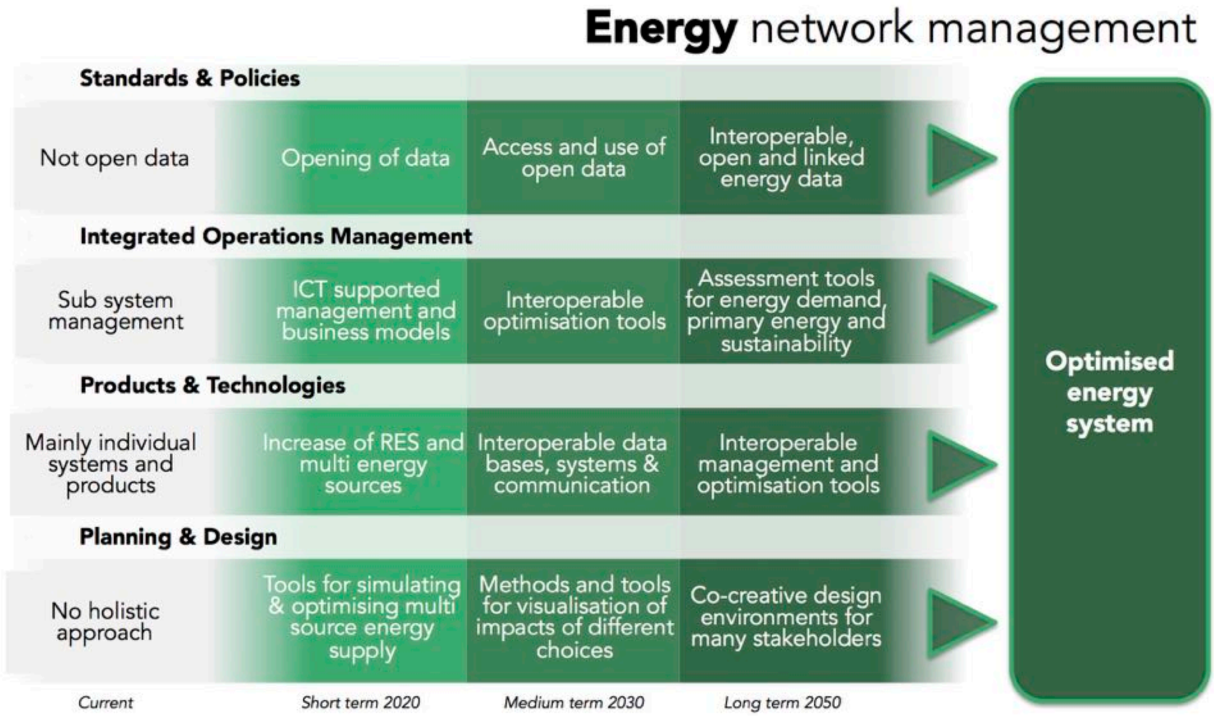

Figure 17. Roadmap for Energy network management.

Low carbon energy systems of districts

This roadmap section focuses on local, neighbourhood and district scale energy systems, including energy supply, distribution and storage, with the aim to minimise the carbon emissions from district energy systems. Electricity, heating, and cooling systems are considered. International climate targets and EU 2030 targets drive cities to increase the energy efficiency, use of renewable energy and reduce of environmental impacts.

State of the art

Energy supply is currently based on centralised energy supply mainly from fossil fuels. The use of district heating varies widely in different countries, advanced district heating and cooling solutions are widely used e.g. in Nordic countries. Recent guidelines for creating, publishing, accessing and using open and linked energy data are presented e.g. in READY4SmartCities guidelines[13]. Smart meters are existing already widely, but data from them is not yet utilised broadly e.g. for increasing the awareness and supporting energy efficient behaviour of users.

[13] Guidelines for Linked Energy data generation and exploitation. READY4SmartCities project, 2015. http://www.ready4smartcities.eu/guidelines

Key research and innovation needs are:

Short term

First priority is to develop **real time energy demand side management and optimisation methods, tools and services**, with the capability to predict the buildings' and districts' energy demand and available local energy supply and storage capacities, based on historical data, weather data, and predictions of the future energy profiles. Real time energy demand data from smart meters should be utilised more broadly in the **demand side management and real time optimisation** of energy use. This requires also developing standards and communication protocols to enable the communication between different meter/sensor data, system algorithms and users' interfaces.

Regarding planning and design tools, building information modelling (BIM) and similar district level **integrated modelling solutions** would support integrated design and simulation of energy systems, energy users and producers.

Medium term

Multi-criteria based optimisation of the district energy system would also support to operate and control the district energy system on the demand base, and as a consequence, to improve its overall sustainability.

Evaluation and benchmarking of life cycle analysis results for local energy systems are required for following the development and realisation of actions towards city's low carbon targets. **Holistic energy system planning** need to be supported by ***impact*** **analysis,** easy-to-understand **visualisation of the impacts** of different decision alternatives to support the communication of the choices to system planners, decision makers and other stakeholders.

Long term

Another development topic is the **integration and interoperability** of energy systems and their modelling and simulations, but also the **integration of the actual planning and decision making processes** with various stakeholders. This could be supported by multidisciplinary and multi-criteria based optimisation and management platforms that could support co-creative working among a wide group of planners, users and other stakeholders.

One of the long term research needs is to increase the support for collaborative and holistic design and operation of energy systems. Improvements to **assessing impacts** of energy system design alternatives are needed, as well as clear **visualisations** of these to support making decisions. The LCA and the impact assessment should include user behaviour aspects and preferences.

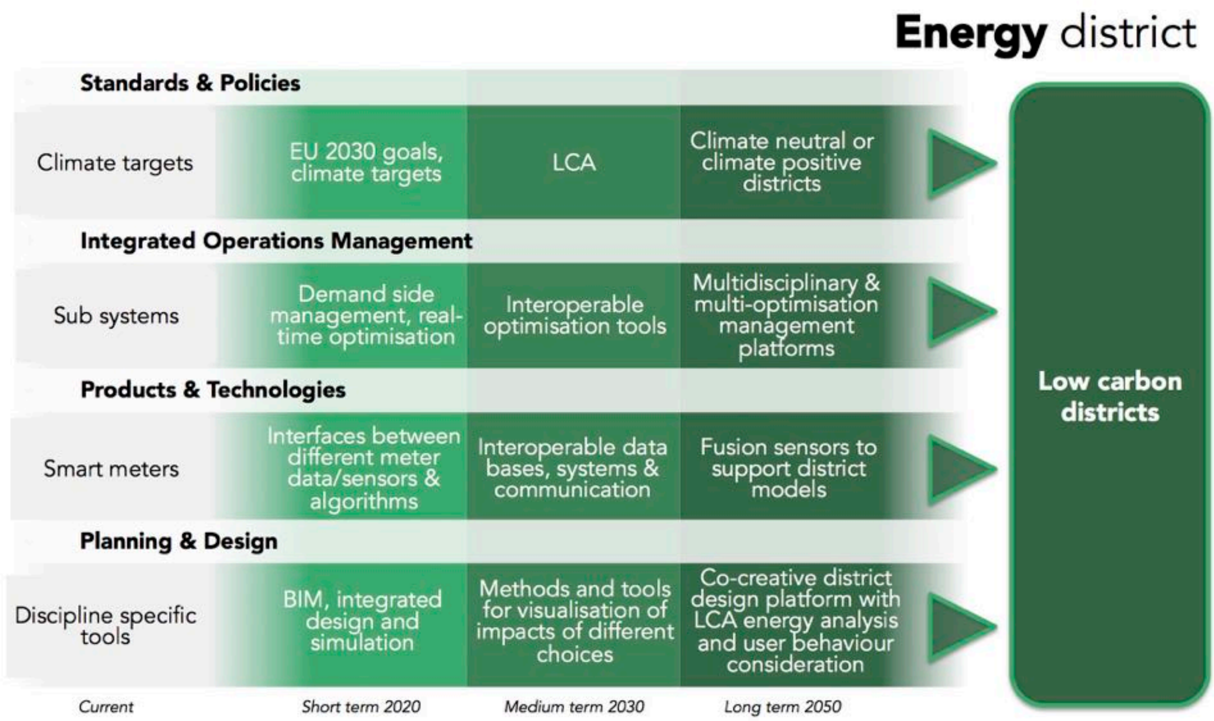

Figure 18. Roadmap for Energy district.

Existing and new buildings

Drivers

Extensive urbanisation is taking place on a global scale. The urban population is anticipated to rise to 66 per cent and 6,3 billion people by 2050. The increase in the urban population means both managed and controlled building construction and the agglomeration of unofficial living communities (slums), particularly in populous developing countries. In many countries, a large part of the future building stock already exists, but it is in a state needing renovation and has outdated equipment requiring modernisation.

Needs and requirements

Sustainable construction is a common goal in building construction. It entails not only energy and material efficiency, but also the approval of the resident population. The approval is particularly emphasised in cities, where population growth results in new buildings in the built environment. In populous areas, balancing the demand and supply of energy requires improving energy efficiency, lowering the peaks in energy demand, and utilising energy sources suitable for local conditions. Sensors and remote control play a key role in the balancing of the demand and supply of energy.

Vision

Building stock that is seamlessly integrated into the city systems.

Barriers	Planning concentrates on individual buildings. The planning of renovations and the selection of measures to be taken settle for outdated solutions. An eclectic mix or a total lack of building automation systems. Lack of remote monitoring and control.
Expected impacts	Comprehensive and accurate information on energy consumption, and enhanced energy management at the building and district level. Energy-efficient buildings and districts optimised over rest of the lifecycle. Development of standards providing full interoperability between applications.
Key stakeholders	Local authorities, urban planners, planners, construction companies, building service companies, building owners, facility managers, residents and energy services companies (ESCOs)

The building stock adapts to the needs of the society. Population growth in an area or an increasing business activity leads to new building construction. Old buildings need to be renovated or replaced by new buildings. The growth and construction needs are not distributed evenly; people and construction are accumulated to the cities. This is simultaneously both a challenge and an opportunity for improving the energy efficiency of the building stock.

State of the art

Today buildings form typically a closed system of their own. Investment costs are the decisive factor in the decision-making concerning the solutions of an individual building, not the building's life cycle costs, for instance. Processes and products developed for new building construction are applied to building renovation. Highly advanced concepts, building modelling, technical systems and control technology are used only in a limited amount of building projects. Buildings are monitored as separate units; bidirectional data transfer is minimal between centralised systems, and the buildings are not connected with each other.

Key research and innovation needs are:

Short term In the short term, the focus is on the digitalisation besides the new building construction but also renovation and maintenance of existing buildings. Modelling must first be made an everyday tool in all new construction and renovations projects. Additional components must be developed on top of the basic modelling concerning energy efficiency, first on the building and later also on the district level. The design of these additional components must take into consideration levelling out consumption peaks in energy use between buildings or on the district level. Means of improving energy efficiency that are more cost-effective than those currently in use must be developed for the renovation of the existing building stock. Mass customisation utilising modern methods of measurement (laser scanning), flexible production automation and quick installation methods should be developed for renovation work improving the energy efficiency of buildings.

Medium term In the medium term, the focus lies on the district-level networking of buildings. Networking requires data transfer formats and a district-level control system. Instead of focussing on individual buildings, it would be possible to even out the energy consumption between buildings on the district level taking the plan as a whole into consideration. For infill development, in particular, it would be possible to develop solutions where, for example, the energy saved through improvements in energy efficiency is used in the new buildings.

Long term In the long term, buildings in a district could share common goals that they would endeavour to fulfil with the help of common control systems (IoT). The districts would also be in contact with each other over a common city platform. Inter-building data exchange standards would be essential for integration.

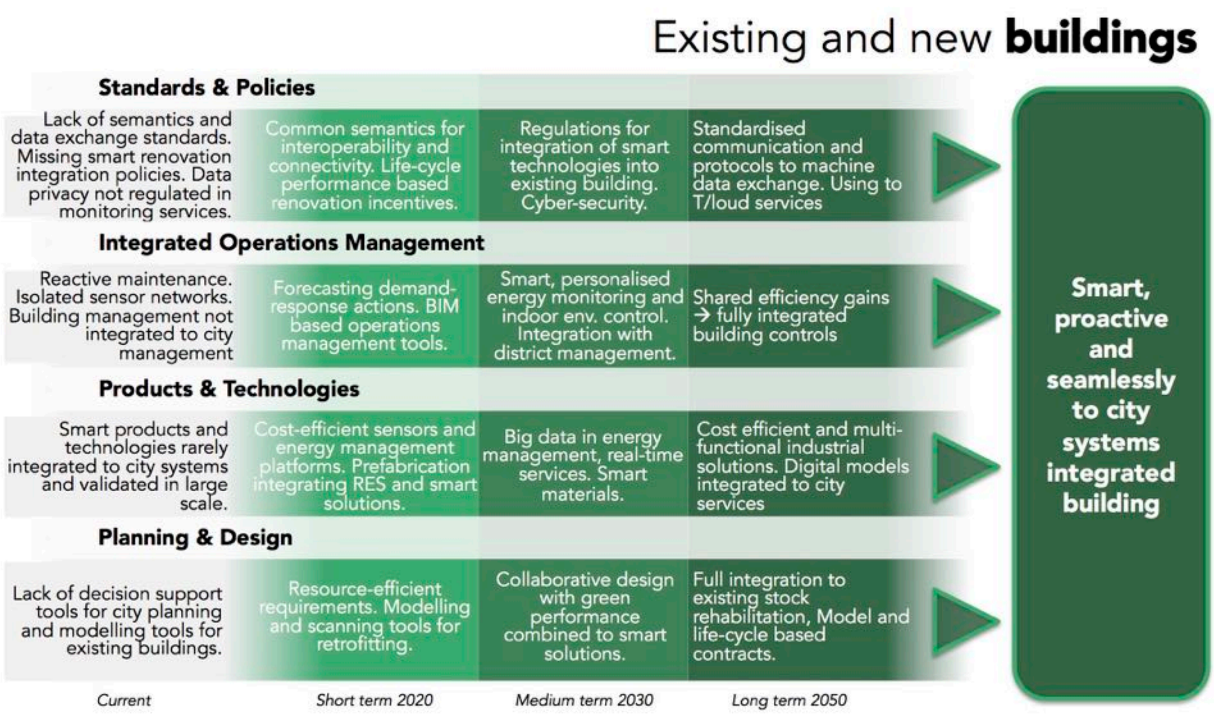

Figure 19. Roadmap for Existing and new buildings.

Existing infrastructure and new infrastructure (excl. energy infrastructure)

Drivers	Population growth is concentrated in limited areas. Were the construction of infrastructure to continue in the same ratio as has been the norm (business as usual), an inordinately large part of the ground surface would need to be reserved for transport routes. The construction and activities of population agglomerations place a burden on natural resources. For example, the amount of soil required for infrastructure construction is large, and arranging the water supply for the population agglomeration is challenging. Some of the existing infrastructure is very old and needs a thorough renovation. There are districts where the infrastructure is very easily disrupted by extreme weather conditions.
Needs and requirements	The production and use of infrastructure must be made more efficient through the utilisation of modelling technology in planning, construction and maintenance. A transition must be made from sector-specific optimisation to the development of the whole system, for instance, integrated structures. Infrastructure and building construction must also be tied closer together.
Vision	Resource-efficient infrastructure that is controlled in real time.
Barriers	Scarce financial resources of the public sector. Deficiencies in asset management. Different operational cultures and standards of the sectors. Path dependency due to prior choices. Monopolies.
Expected impacts	A more functional society. Better risk management. Savings in financial and physical resources.
Key stakeholders	The state. Municipalities. Private companies.

With the exception of buildings, all other built environment is counted as infrastructure. The core of a Smart City is infrastructure built for both local and global data transfer. In this Smart City roadmap, the data transfer infrastructure is left as an external factor, concentrating on how it would be utilised in the rest of the built infrastructure. The energy infrastructure plays such a key role in the Smart City agenda that it has been given its own roadmap. The topics remaining to be discussed here comprise the other structures of the communities, such as streets, roads, railways, seaways, air fields, and the water and sewer networks. These remaining structures can be divided into two groups. One group serves the districts, while the other group connects the districts with each other. The latter group includes airfields and seaways and, in particular, railways and roads crossing national borders. These differ from the rest of the infrastructure most clearly in that they are very strongly integrated so as to operate under common rules. Indeed, this Smart City theme concentrates on the internal infrastructure of the districts, or roads, streets and the water supply infrastructure.

State of the art

The infrastructure of a population centre can be quite old and be designed for a different use than what it is used for today. Typically, networks have been planned and built subsector-specifically. This is evident in, for example, the fact that there is no common nomenclature for network construction. The networks have been built over a long time period. The owners do not have complete information on the amount, location or condition of the assets under their management. Repairs are typically not made until disruptive defects appear. All defects are not repaired; in the water supply network, for instance, even major leaks are accepted, if the required amount of water can be delivered to the users.

Key research and innovation needs are:

Short term Common nomenclature to assist in modelling. Basic modelling, and the production and maintenance applications created to continue it. Modelling that brings together the different networks and house construction projects. Monitoring of the status, functionality and condition of the networks similarly to what is used in energy supply networks. Recycling of materials in the context of infrastructure construction, and utilisation of excess materials from other sectors in order to save valuable natural resources.

Medium term Closer connection between infrastructure and its use. Real-time and automatic data collection of the status of the networks with help of both sensors located in the networks and the users (such as sensors installed in cars). Combination of land use, networks and the use of the networks into common models, and simulation supporting the planning process. LCC/LCA more strongly involved in decision-making.

Long term Protocols that enable connecting information on the infrastructure to the city systems. Comprehensive design of the city service network, also taking into consideration the new construction, modernisation and renovation of infrastructure as part of the district development. LCC/LCA will be a special focus on the design of the service network.

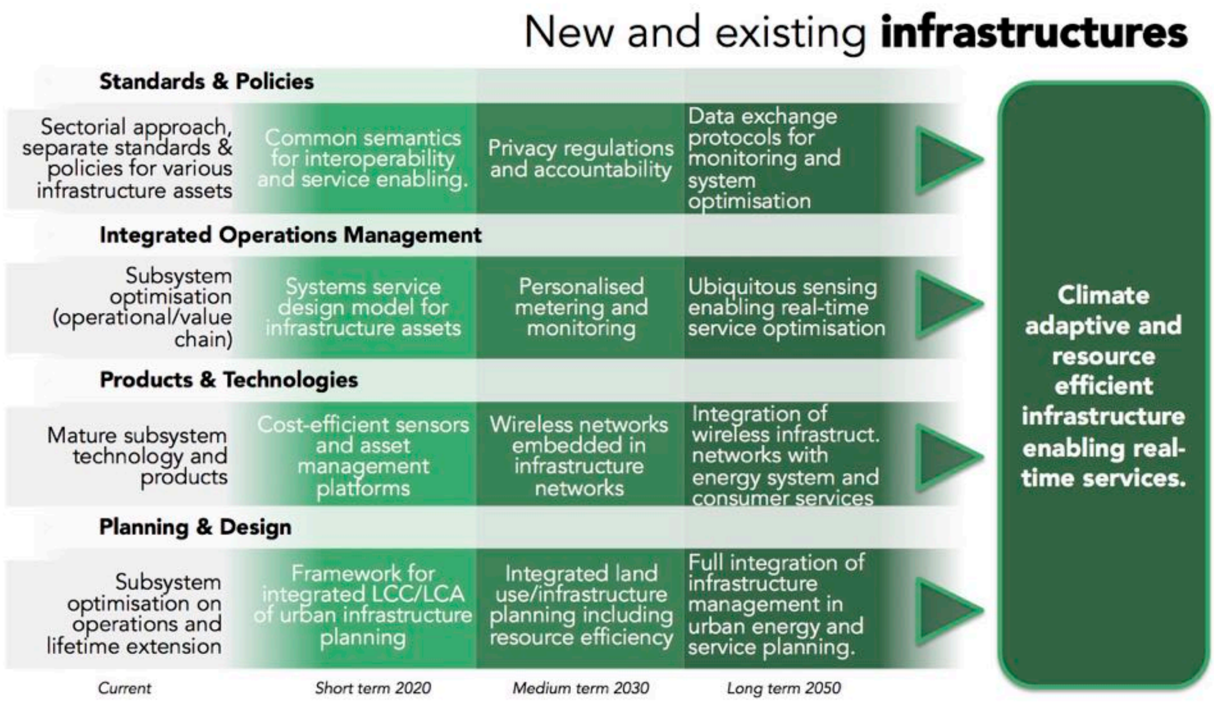

Figure 20. Roadmap for new and existing infrastructures.

Land use and urban planning

The target of this roadmap section is to increase the efficiency of land use via improving urban planning, which has a significant role in developing and modernising cities towards the sustainability targets. The goal of sustainable urban planning is to offer comfortable and sustainable living and working environment, which takes into account the cost-effectiveness.

Sustainable urban planning has strong links to the planning and operating of city infrastructure (e.g. energy networks, transportation, waste and water management systems), and the synergy benefits are targeted with the collaboration and coordination of these city systems. Urban planning can strongly support sustainable transportation system, among others by improving the efficiency of public transportation, enabling easily accessible un-motorized options and offering daily services nearby to reduce the need to travel. For example, when public transport systems are improved, the need for private cars reduces and less car parking facilities are required. The coordination and integration of city systems and services needs broad and open communication and collaboration among different municipality departments and officials, as well as with the private service and system providers and end users.

The land use development is highly capital intensive, and often it is hindered by legal issues and lack of public acceptance. The development periods in improving the efficiency and sustainability of land use are long, as the impacts of urban planning activities and land use improvements can be seen only in the long term and the changes are typically quite slow. One of the challenges is also the people’s dissatisfaction with the land use. At least partially this is due to the fact that the values and interest of people are changing faster that the land use development and modernisation can react to the change.

State of the art

Some cities are struggling with uncontrollable and too quick growth of the amount of citizens, which lowers the service limits e.g. for public transportation, and waste and water systems. One of the main reasons for the fast urbanisation is the fact that cities have better and more intensive working opportunities.

CIB roadmap workshop participants stated that the optimal regional layout is not understood and studied throughout. They considered that in many cities, too much land is used for transport and infrastructure, such as for parking lots. Partially this is due to fact that service locations and land use is not optimally planned regarding sustainability and low carbon targets.

Currently city planners use CAD tools and map applications for drafting land use plans. The needed base data exists in various databases in distributed locations and in different formats (existing city and regional plans, targets for the area, city's action plans etc.). Often city planners need to check this data manually, which requires lots of time. City planning and design tools rarely have possibilities to assess energy and environmental impacts inherent to the plan, and comparing different scenarios is time consuming. There exist some check lists and separate tools (e.g. based on spreadsheet calculation) for assessing the environmental impacts of city plans, but typically city plan options need to be manually inserted to these assessment tools. Often these tools are also complex and interpretation of results needs special expertise[14].

Key research and innovation needs are:

Short term: There is a need for new means to **support public participation** and offer easy possibilities to effect and **give feedback about the land use plans** during the urban area planning, design and development process. City planners need planning and design tools, which allow for quick and easy evaluation and performance estimation to assess the energy and environmental impacts of the land use plans. Tools should enable the comparison of alternative land use scenarios from the viewpoints of regulations, city plans and key performance indicators. Furthermore, it would be essential to provide clear and easy-to-understand visualisation of the expected impacts of alternative scenarios, which would ease the communication of plans and their impacts to decision makers and other stakeholders and hence, to support the collaboration and feedback collecting. Tools need to support the engagement of citizens and other stakeholders and handling of feedback from them (see also roadmap topic: Engagement of citizens).

Medium term: **Land use planning could be better integrated,** among others by improving the interoperability and data exchange for planning and design tools and databases. Tools also need to have an easy access and transfer to the various data sources, such as areal and city plans, GIS files, demographics, ground water area maps, renewable energy potential maps and data bases, city

[14] Hukkalainen Mari et al, 2015: Innovation and research roadmap. Deliverable 5.6. READY4SmartCities – ICT Roadmap and Data Interoperability for Energy Systems in Smart Cities.

system and network information (e.g. existing district heating and cooling networks), etc. This would support e.g. planning the land use so that less time is needed for travelling, e.g. by planning working-hubs near homes.

Long term

City models (similar to BIM) could in the long run support the better management and coordination of urban planning, from district to municipal and to regional levels. Solutions supporting collaboration within the different municipality departments as well as with other external stakeholders, such as construction and energy companies, end users and public transportation providers.

Standardization of data models, information exchange, interfaces and systems themselves) is needed for cross-organizational operations. Simulation could help urban planners to assess different scenarios. This would be some type of gamification involving real measured data. Support and initiatives are need for multi-disciplinary research and collaboration.

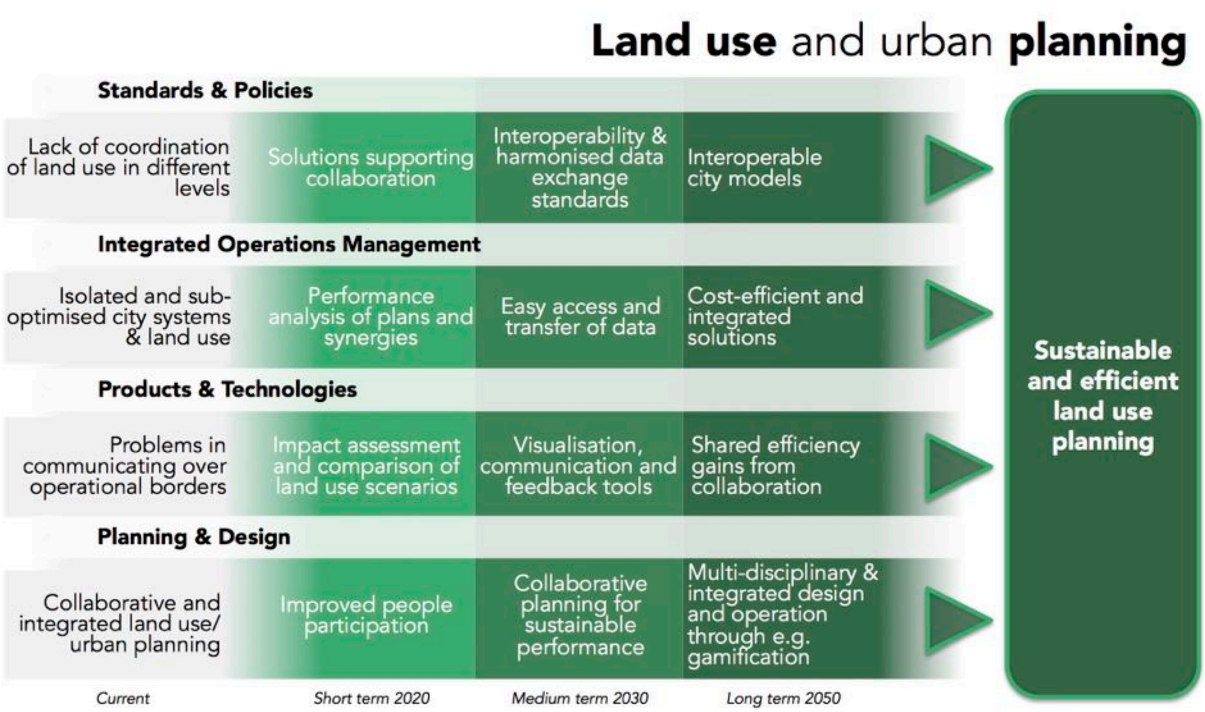

Figure 21. Roadmap for Land use and urban planning.

Mobility and multimodal transport

Drivers Energy consumption of transport accounts for some 25% at world level, road transport being the dominating sector. In the EU the share of transport is even bigger (33%). The EU has set the target (EU White paper, European Commission, 2011) for the reduction of 60% in greenhouse gas emissions (GHG). The aim to significantly reduce GHG emissions drives improved energy efficiency for moving people and goods - modal shift, people switching from private cars to public transport or to walking and cycling - and use of renewable energy.

ICT based technology, digitalization, internet of things, crowdsourcing and sharing economy among other drivers form a basis for entirely new service concepts. In digitalisation of transport, data integrates the functionalities of all conventional transport modes.

Furthermore, the automotive industry is developing new ICT based technologies such as cooperative intelligent transport systems (C-ITS) which means that vehicles are connected and communicate with each other and with the infrastructure. The next step will be automated vehicles and the automated transport system.

Needs and requirements

A wide sociotechnical change towards low carbon transport system and new transport policy thinking is needed.

The future mobility and transportation ecosystem could be organised according to the concept of Mobility as a Service (MaaS). MaaS is envisioned to provide high-quality and market-based transport services that meet the wide range of user needs. The MaaS ecosystem will be built upon the combination of transport, energy and communications infrastructures, transport services and data, and dynamic payment systems. Strong cooperation is needed with the public sector, business and users. Regulation is needed for ensuring transparent market conditions, fair market performance and securing the legal position of a user (as a consumer).

Automation is gradually increasing in the transport system. The key enabling technologies for automated driving are high quality and reliable environment perception systems at reasonable cost covering all circumstances, development of road infrastructure, accurate digital maps, positioning and communication technologies. The automated transport system needs to be developed for all users, not only for drivers of the automated vehicles. Furthermore, the transition period from partial automation to fully automation challenges the design due to the possible shortcomings for the human operator (falling out of the loop) or drawbacks for traffic efficiency. The legal and liability issues as well as data management and security need to be addressed.

Vision	Transport is a low carbon system in which transport and mobility needs of people are fulfilled by the Mobility as a Service concept. The transport system and the services built in the system support users to utilize different modes sustainably. Efficiency of using energy has been improved remarkably, and energy systems for transport are integrated into other infrastructures in terms of production, storage and delivery. The system is mainly powered by electricity, biofuels and hydrogen. Car driving, public transport, cycling and walking are in balance and users' personal mobility is based on 'use' rather than ownership. User-centric, on-demand mobility and freight services are provided based on a seamless, co-operative and sustainable transport ecosystem. Transport modes are utilised and combined into mobility services across geographical, modal and organisational borders. Logistics and users provide data, which travels with them from door to door. Cars and vehicles are driven automatically, and the automated systems ensure that transport is safe and efficient.
Barriers	Technically focused and detailed regulation of individual transport modes could prevent new business opportunities. Organizational issues may be a barrier, e.g. slow decision making procedures and lack of flexibility for new ways of thinking. Some technology development is still needed and the price of new systems could prevent wide deployment. For MaaS it may be challenging to find sufficient customer basis for viable business cases, especially in sparsely populated areas. Also, user acceptance may be lacking for increased use of public transport, use of renewable energy systems in transport, car sharing and even giving up driving the car in case of automated driving. Lack of evidence about the positive impacts can be a barrier for some development work and wide deployment especially public stakeholders.
Expected impacts	More efficient, sustainable and equitable functioning of the transport system is expected. Quality of life is improved in terms of mobility, improved safety and efficiency of traffic. CO_2 emissions are largely reduced. Fewer cars are needed due to better services in public transportation and increased car sharing. Less space is needed for parking because of increased use of public transport and automation. Car drivers can utilize the driving time for other activities.
Key stakeholders	Key stakeholders include automotive industry and its suppliers, transport and road authorities and road operators, transport service providers, telecom service providers, etc.

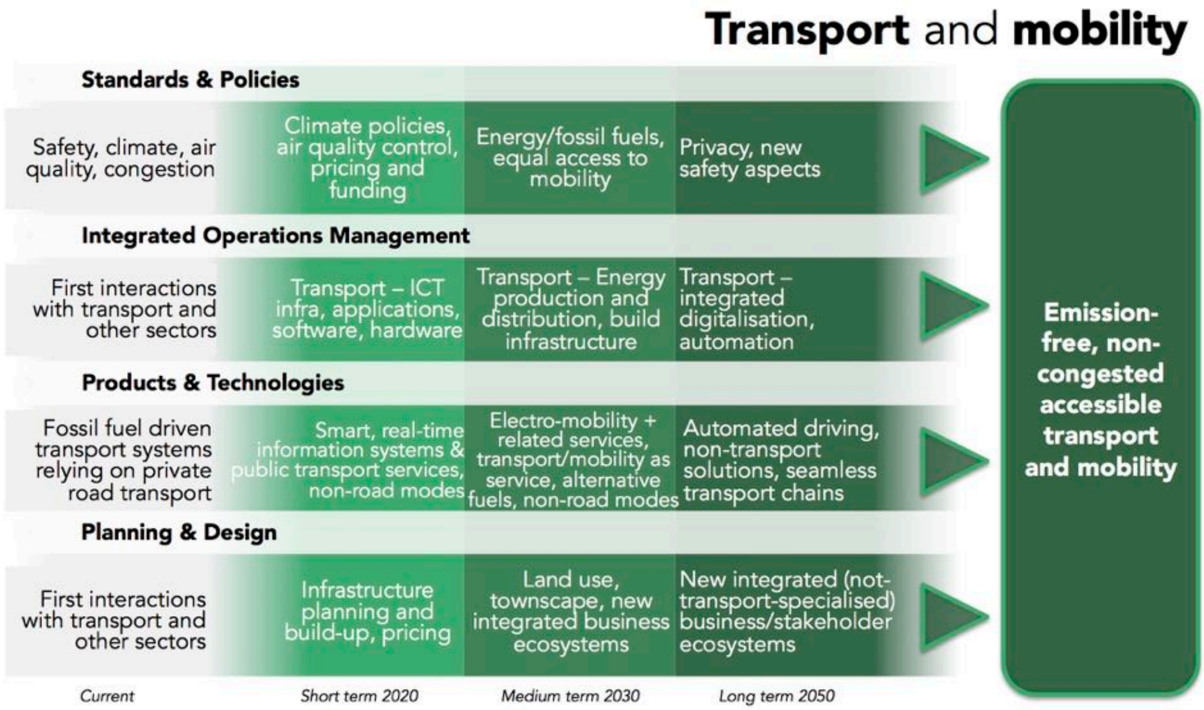

Figure 22. Roadmap for Transport and mobility.

Mobility services

Inefficient use of resources characterises the current transport system in many ways, e.g. in terms of fuel and energy efficiency, dependence on fossil fuels, capacity use of vehicles and dominance of motorised private transport. In a more sustainable future the transport sector could be reorganised according to the Mobility as a Service (MaaS) concept to provide on-demand services that seamlessly bring together the most appropriate transport chains across modes, transport operators and regions.

State of the art

Current transport systems rely largely on use of private cars, and access to different transport services is lacking and fragmented. Research, development and first demonstrations of various building blocks of the MaaS concept are underway, but efforts to refine technological solutions as well as business models are needed.

Key research and innovation needs are:

Short term Most urgent research efforts focus on developing the **conceptual side** of the overall MaaS opportunities as well as early service development. Further introduction of **ICTs** to vehicles, transport infrastructures and related functions such as booking, payment and travel planning are a key factor. **First practical demonstrations** and pilots of partial MaaS solutions should also target to capture user needs and user acceptance. Clean and sustainable energy sources and multimodal transport chains should be highlighted in developing MaaS offering.

Medium term	To establish a **stakeholder ecosystem** of MaaS, where a platform for transport operators and service providers to co-operate, is essential. Similarly, to involve users in this same platform and find operating and business models to connect the mobility demand and supply is of central importance. A **fully functioning MaaS system**, even if with somewhat incomplete service offering, should be available for user populations. **Data management**, privacy concerns and suchlike concerns need to be addressed.
Long term	Advanced **technological innovations** such as fully automated driving should be incorporated to the MaaS systems, and equitable **MaaS platform** should be available for all users and service producers in different regions and backgrounds. Integrated business and stakeholder ecosystems provide an interoperable playing field and **safe and secure** operations and data processes.

Automated road transport

Car industry and its suppliers are currently introducing automated systems and vehicles in road transport. In addition to industry several stakeholders are involved in the development projects on the area of automation. The levels of automation in road transport have been described starting from the level one (including intelligent systems providing real time information on the road) to the level five (fully automated transport system) with increasing coverage of tasks of the driver and circumstances with automation. There is a huge need of knowledge and research to enhance the use these new technologies in a sustainable way. Automated driving as a dramatic change can be compared to a new mode in transport system.

State of the art

Many systems, especially on level 1 (driver information systems) and level 2 (intervening driver support systems) are already available on market and in use in road traffic. These intelligent transport systems can be seen as first steps towards automated transport. Level 3 cars, which are driven without a driver in some conditions or areas, have been introduced and demonstrated. In level 3 the driver still has the responsibility to take over the control of the vehicle when requested. There are a lot of discussion and R&D activities going on to solve several issues related to more wide deployment of automated driving. The focus is in the legal and liability issues; technical development to cover the circumstances more widely; research on benefits and possible drawbacks in transport; human aspects etc.

Key research and innovation needs are:

Short term	More information is needed on the **impacts of automation** on traffic flow, traffic safety and mobility. Automation is going to change radically the driving task and research is needed to assess how the **human operator** is coping with the new situation. The effects need to be anticipated and understood on the transport system level including the **legal and liability issues**. For the technical development cost effective solutions are needed to increase accuracy of the **observations of the robot cars and vehicles in varying road and weather conditions**. The focus in short term is on partial and conditional automation. Demonstrations are starting in less complex situations or areas for cars. Truck platooning is starting in some European

highways.

Medium term **Large-scale filed tests** and demonstrations need to be organized regarding **partial and high automation** in highways but also urban and suburban pilots. The aim is to verify and get more information about benefits and drawbacks covering also in **mixed traffic** (vulnerable and non-equipped parties) situations. Effects on system level will be clarified and integrated with **city planning.**

Long term In long term high or **full automation** is expected. The effects need to be managed on **system level**. Changes is organizing mobility is assumed to result changes in e.g. land use and in activities of service providers and many stakeholders.

Community

Drivers The increasing interest of citizens to influence their surroundings together with increased use of internet and social media and availability of open data has led to a situation in which citizens are not only passive residents of a city but instead they have an active role as service co-creators and in providing feedback for the city. Also cities want to increasingly engage citizens in planning and development processes as this is a resource efficient way to reach an inclusive and vivid community.

Vision The vision is a city with healthy, educated and well-being citizens. The level of citizen engagement is high and efficient collaboration takes place among the public, private and the third sector. The citizens have an important role in developing their neighbourhood and a possibility to influence their living environment. Citizens also do not only behave as consumers of services but more as 'prosumers', hence changing the dynamics of business relations and pushing for development of new types of business models.

Needs and requirements An important prerequisite is the willingness of cities to involve citizens in various activities. This requires political target setting and decision making as well as development of functioning tools to enable efficient collaboration among different actors. Availability of open data spurs the development of new innovative services which can build on collaboration of entrepreneurs and citizens. New types of spaces need to be developed for new functions and new services, and various means are needed to encourage citizens to engage new sustainable activities.

Barriers

Even if cities are increasingly interested in providing citizens with opportunities to participate in decision making, lack of actions and tools to implement this attempt still constitute a major barrier. If the citizens feel that the city is not willing to involve them and provide sufficient amount of information, this might lead to frustration and passive or negligent behaviour regarding their surroundings. Also, even if businesses are eager to develop and embrace more innovative and co-creative activities, lack of open data and lack of other supporting functions by the city might cause a significant hindrance to this development.

Expected impacts

Citizens feel that they can influence their living environment and they have a strong interest to participate in neighbourhood development. New business opportunities and innovations based on open data, which might also be co-generated with citizens, will contribute to the economic welfare of the city as well as improve the well-being of the citizens. A new city ecosystem evolves, which supports social, economic and environmental sustainability of the city.

Key stakeholders

The key stakeholders are the citizens and decision makers but also private sector has a strong role in citizen empowerment.

Engagement of citizens and users

This part deals with issues regarding changes in service development and built environment, and the increase of environmental awareness of citizens. These development needs are seen as essential in reaching the goals of an open and inclusive community with high level of citizen engagement.

State of the art

In principle, cities are increasingly interested to engage citizens in decision making and to provide citizens with possibilities to impact their living environment. However, this willingness has not yet been realised to its full potential and therefore some needs should be carefully considered.

Key research and innovation needs are:

Short term

People are increasingly interested in collaborative activities and also to share their living environment with other people. **Policies allowing mixed use buildings** would increase the possibilities of residents to decide themselves what kind of functions they want to have available near their homes. Similarly, the traditional service business is in transition as citizens want to increasingly use services provided nearby and therefore functions such as **“people to people” services and co-operative service provision** are becoming more attractive. Also, as environmental awareness is increasing, people need to be provided with **spaces which enable environmentally friendly choices**, but simultaneously also enabling “easy living”. People need to be able to continuously receive information on the impacts of their behaviour, and for this a functioning **positive feedback** system is crucial.

Medium term As people want to increasingly influence their living environment, specific policies need to be adopted. Communities should not be developed with a top-down approach but instead, they should be seen as **"human scale learning communities"** in which both citizens and decision makers are taking new steps together, and learning from the results. Regarding design and use of buildings, residents should be provided with a possibility to collaborate in planning by **platform based design**. As demand for local services is increasing, a huge business potential exists in providing **on-demand services which are close to citizens**. Utilising collaborative service design is useful for businesses as in this way they receive precise information on current customer needs. As people do have a strong willingness to change but they lack information, collective **reward programs** would serve as a great motivation to take steps towards a new sustainable society.

Long term The goal of a society with empowered citizens who feel free to innovate and participate is **a dynamic, adaptive, resilient, sustainable and smart community.** The adaptability of the built environment plays an important role, and future **services should be integrated in built environment to make citizens' life easier. Multi-programmable spaces** are needed to enable provision of these local, on-demand, ad-hoc services. To facilitate environmentally friendly behaviour of citizens, **occupants should be aware of their footprints**, which can be enabled by **help of technology**. As already mentioned in the short term needs, a functioning feedback-loop is needed to enable residents to receive information on the impacts of their actions, and to be able to change their behaviour accordingly.

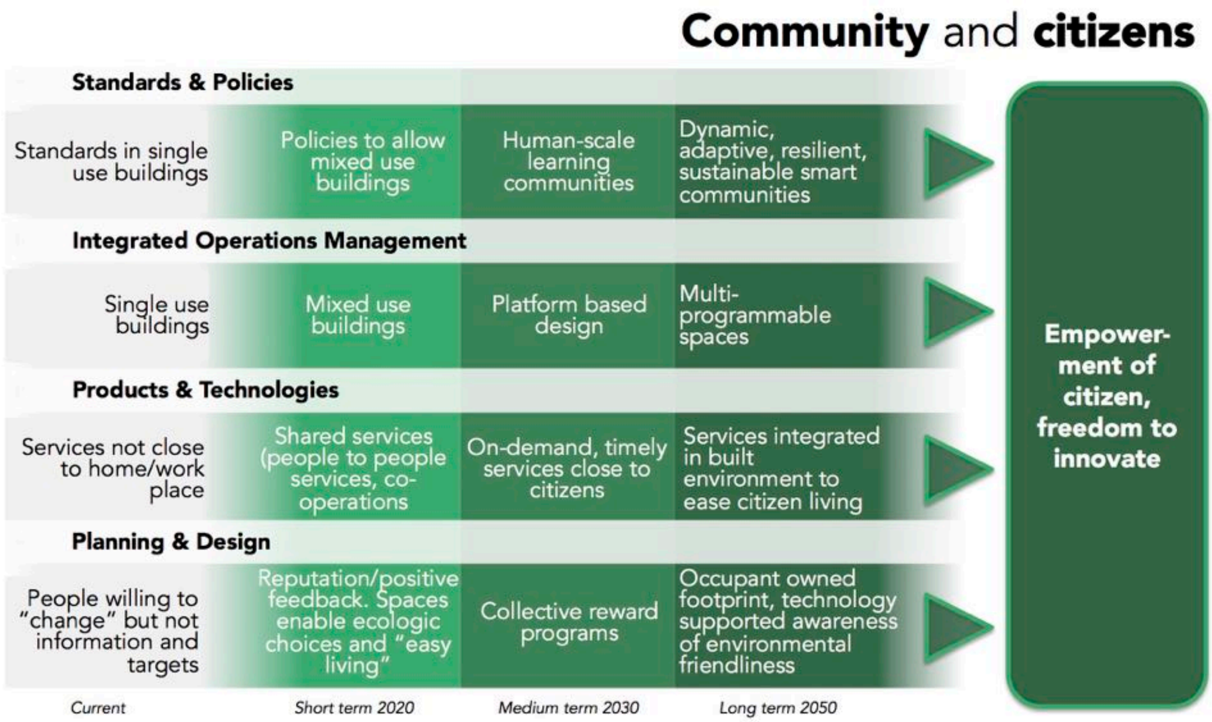

Figure 23. Roadmap for Community and citizens.

New governance models

Drivers

Development and application of information and communication technologies (ICT) in city environment evolves through interaction between various types of actors: private firms of various sizes and industries, city administrations, public authorities, municipal-owned enterprises (e.g. energy companies), citizens, interest groups and networks (e.g. software developer communities). None of these groups can unilaterally manage the development of a smart city. Rather, various governance arrangements are needed to coordinate activities between different actors.

Governance of collaboration between private and public sector organisations is often the key relationship in a smart city. Private firms are needed to innovate and implement new technologies and business models with large potential to solve urban issues. Public authorities, on the other hand, are often in control of urban infrastructure, public services (e.g. public transportation), and urban planning. They manage assets and service processes whose optimization and re-organization are the primary objective of many smart city solutions. In addition, the government sets the overall framework conditions for all business activities through regulation.

An effective smart city is one which can create favourable conditions for private firms to innovate and introduce smart solutions which have the potential to create social benefits, economic growth and environmental sustainability in an urban setting. However, purely market based developments are not likely to initiate fast deployment of a smart city. Engagement of city authorities and central government are required for a number of reasons. Public authorities set the general regulatory environment, govern large public infrastructures, provide public services, use large procurement budgets, hold large number of relevant data, and manage the overall urban planning processes.

Vision

Find appropriate governance arrangements, which align the public interest on social outcomes with the profit-seeking firms' capacity for technological innovation and effective operational implementation. Through appropriate governance practices public authorities can influence the smart city development towards societally desirable directions with lower environmental footprint, social inclusion, safety, democracy, and transparency. They can also aim to accelerate the smart city development in order to stay at the global forefront and gain local economic growth through early mover advantage from innovation.

Needs and requirements

An important prerequisite is the willingness of cities to involve citizens in various activities. This requires political target setting and making decisions as well as development of efficient tools to enable efficient collaboration among different actors. Availability of open data spurs the development of new innovative services, which can build on collaboration of entrepreneurs and citizens.

Barriers

Low predictability – Businesses give great value to an institutional environment with high degree of predictability. Assessing the return on investment and associated risks depends on the confidence firms have on the future development. Governance mechanisms which improve the predictability of the institutional environment include innovation-friendly intellectual property rights (IPR) regime and data ownership rules, and governance of privacy and data security. Also, regulation which is based on performance rather than obligating use of a particular technical solution. Clear and innovation-friendly regulation increases firms' willingness to invest in development and application of new smart city technologies and service models. They can also lower transaction costs between companies engaged in collaborative efforts.

Lack of collaboration – Smart city solutions typically require collaboration between various partners. To manage these collaborative partnerships specific governance models are needed. Collaborative innovation can be facilitated by providing innovation platforms, test environments and demonstration sites (e.g. designated urban districts). Intermediary organisations, such as research institutes, economic development agencies, consultancies, or think tanks are often instrumental in creating and facilitating projects with multiple partners. In operative deployment of smart city solutions, public-private financing arrangements can be used.

Inertia of technological interdependence – Under conditions of technological interdependence, which is typical in digitally networked applications and services, a chicken-and-egg problem often occurs. As products and technologies are highly interlinked between businesses, any single firm faces high risks with developing and introducing a new product if its success is dependent on products and technologies of other firms. Firms are tempted to wait for others to move, and in the absence of the first mover it is often the case that everyone prefers to wait. The chicken-and-egg dilemma thus arises. The city or central government can try to break the inertia and make an initiative by e.g. supporting collaborative innovation projects, providing innovation and demonstration platforms for collaborative experimentation, and using public procurement to trigger ecosystem development.

Adoption and upscaling – Moving forward from the R&D phase towards deployment of smart city solutions does not often take place in a straight-forward manner. Adoption and upscaling are often hampered by the complexity of urban systems, legacy of incumbent technology, and sunk costs to existing infrastructure. Pilots and demonstrations can lower risks and improve the fit with the socio-technical context. Overcoming this hurdle can be helped by establishing test sites with appropriate facilities such as available user base, links with developer communities and investors, and technical and financial validation services. A city government can also use public procurement to create demand for new smart city solutions. This can take place either through procurement of research and development (e.g. pre-commercial procurement approach) of a new solution or by being the first buyer of a product as it is first introduced on the marketplace.

Expected impacts

Direction and speed – Influencing the direction and speed of smart city development can be done by applying both 'soft' and 'hard' measures for governance. Hard measures include directing the smart city development by setting ambitious requirements by regulation and policy targets (e.g. climate targets). Soft measures include processes whereby visions and roadmaps are crafted, future developments are foresighted and scenarios built. Articulating future societal needs can activate and stimulate innovation of new smart city technologies and solutions. It can also help in understanding long term gains vis-à-vis short term costs. Moreover, these measures might also aim to alleviate the challenge of sub-optimisation typical in complex city contexts.

Democratic governance – City as a public space is subject to democratic governance. The influence runs through two principal channels: representative democracy through elected representatives (central, regional, local government) and direct participation in city planning and urban development. Smart city must contribute to political priorities set by the representative institutions. Demonstrating public value requires generating evaluative information about impacts of smart city projects and associated investments. Smart city solutions can also contribute to democratic governance by providing better information about city operations and increasing transparency. In the case of direct participation, smart city solutions can facilitate participatory planning and thus improve the quality of the built environment and public services. New participatory tools, such as augmented reality solutions applied in urban planning, can be instrumental in raising the quality of the urban environment as experienced by their residents, as well as improve the legitimacy of the urban development process by giving voice.

Learning effects and 'spillovers' – Unlike physical products, information has two important characteristics: it is non-rivalrous in use and non-excludable. As non-rivalrous good information can be consumed by many people at the same time, and it can be distributed to new consumers for very low marginal cost. At the same time, being non-excludable, it is not possible to prevent people who have not paid for information from having access to it, at least over longer time period. Knowledge thus easily 'spills over' from its creator to others. This is a problem for businesses developing and commercializing new technology. In contrast, for public authorities this can be a blessing, since by investing in knowledge creation and dissemination, there are increasing returns to investment through learning across the society and economy. There are thus important reasons to create information governance arrangements, which create favourable conditions for data dissemination and reuse. Open public data distributed via programming interface (APIs) can generate dynamic effects at the system level. On the long run, one can envision shaping of complete city information infrastructure based on a combination of open public data and proprietary commercial data linked together in a programmable web to empower real time smart services and operations.

Interoperability – Under high level of interdependence of smart city solutions there is a need to establish higher degree of interoperability across various technologies. On the short run, under the uncertainty of future standards and scalability, firms tend to prefer development of closed systems. There is thus a strong incentive for governments to facilitate development and deployment of open standards and interoperability. Cities are concerned of getting trapped in technology lock-in. They are also keen to encourage open competition and promote small and medium sized businesses. The most potent instrument is to leverage their large spending budgets by setting interoperability requirements in their public procurements.

Evidence base – Demonstrating the value for money on smart city investments is an important part of the overall governance framework. There should be demonstrable impacts on quality and productivity of public services, social wellbeing, and/or environmental sustainability. These benefits need to be assessed against costs and potential negative effects (e.g. social costs to particular groups). Moreover, application of a life cycle perspective is needed in order to evaluate the total cost-benefit over the ownership and contract periods. In addition, many cities would be interested to assess the impact of smart city investments on local economic development and eventually on job creation. Evaluation and impact assessment are thus needed.

State-of-the-art At present, smart city investments take place in the context of rather rigid public procurement practices where there is relatively little room for innovative solutions, total cost of ownership over the lifecycle, system level optimization, and attention to social and environmental impacts. New project delivery models for infrastructure development such as public-private partnerships (PPPs) are applied variedly in different European countries, thus reallocating risks between the public and private parties.

Recommended implementation actions

Cities are complex systems that are characterised by massive numbers of interconnected citizens, businesses, different modes of transport, energy and water systems, communication networks, services and utilities. Population growth and increased urbanisation raise a variety of technical, social, economic and organisational problems that tend to jeopardize the economic and environmental sustainability of cities. The rapid growth faced by several cities has generated traffic congestion, pollution and increasing social inequality. Therefore, the focus has been on the way new technology-based solutions, as well as new approaches to urban planning and living, can assure future viability and prosperity in urban areas.

The basis of developing systems has always been to move towards an optimum defined by multiple criteria. Economic aspects are often among the core criteria. Traditionally, an optimum has been reached with centralized solutions. Economy of scale has been achieved by systems with a distinctive point of control. The development of information and communication technology (ICT) has enabled the search for new kinds of optima. The outcome of the implementation processes in various systems is often called 'smart'.

Digitalisation has changed the meaning of geographical location. You can act locally but at the same time use resources in places you do not even know. Administrative borders can no longer be optimal borders for operations at the same time. In the current integrated and partially distributed systems, data can be gathered and analysed anywhere. This allows a much larger set of input data and much wider resources for assessment and conclusions.

The essence of being smart in modern society lies in acting locally but being networked outside one's own geographical location. The technological systems can only be managed if they are properly integrated. Technologies and ICT is the enabler that, when properly used for networking and integration, provides social, environmental and economic benefits for all. Cities all over the world see this as an opportunity for better quality of life.

The main cross-cutting recommendations in themes in the roadmap areas were following:

- Digitalisation, new technologies interlinked and interoperable systems allow multi-criteria optimisation which should be used whenever possible
- Resiliency, safety and security issues have high priority
- Integrated planning and management should be the baseline for future city planning and operation
- Since cities have many stakeholders the communication and tools for easy to understand communication is increasing.
- Take advantage of cross-disciplinary working and co-creation foster new innovations
- Importance of energy management at building and district level as well as the use of low carbon energies increases
- Future ownership and service models are changing, also traditional value chains are changing to new eco-systems
- Upgrading existing infrastructures and building stock is essential, new business concepts including new models for ownership are needed

The detailed theme specific recommendations are given in the figures below.

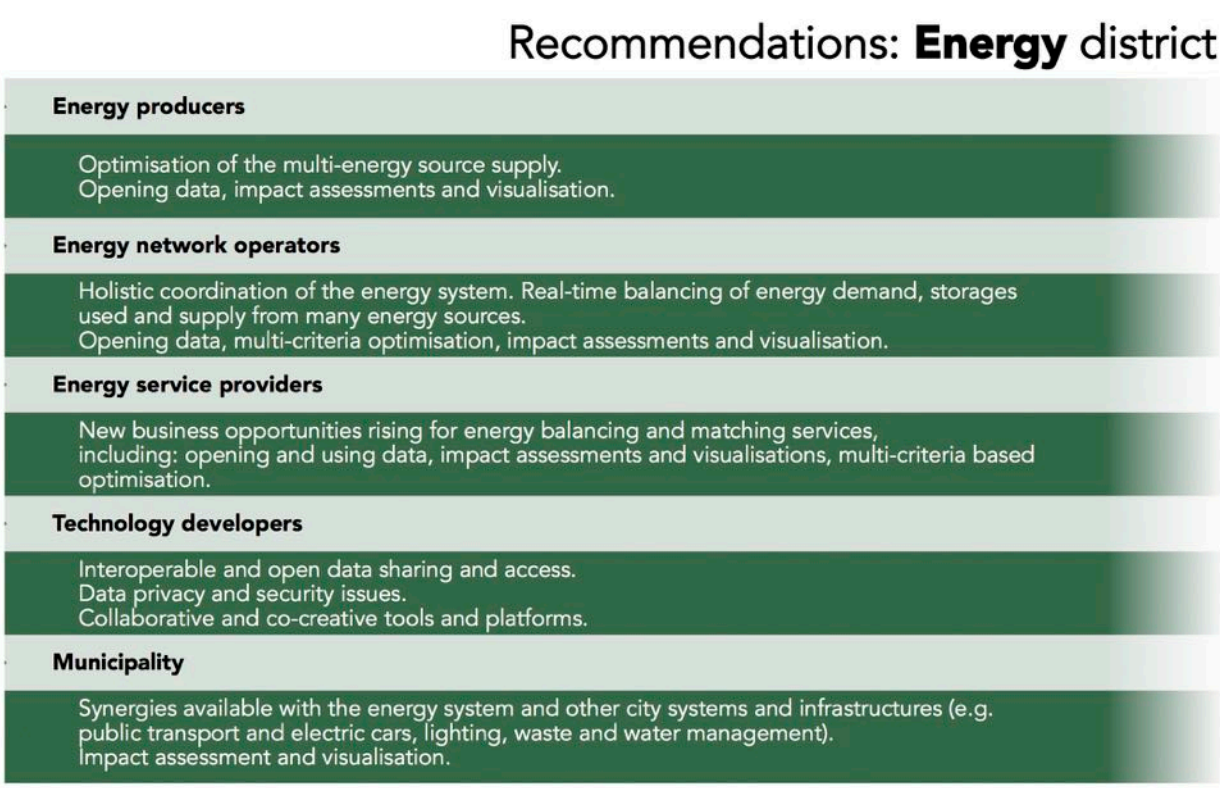

Figure 24. Recommendations for Energy district.

Recommendations: **Buildings, infrastructure, urban planning**

Owners of buildings and infrastructure

Opportunity on influence own investment and maintenance cost by taking advantage of new technologies during the entire life cycle.

Local authorities and urban planners

Connect housing construction & civil engineering projects and use densification as a tool in order to produce economically the built environment. Preserve the built environment's cultural values by renovating existing buildings. Co-creation with stakeholders.

Operators

Greater efficiency in service production by using accumulated information database (big data) in ERP.

Construction companies

Both renewal of existing business & products and entirely new products and services. Huge business opportunities.

Figure 25. Recommendations for Buildings, infrastructure and urban planning.

Recommendations: **Transport** and **mobility**

Transport users

Access to affordable on-demand transport and mobility services, customisable to personal needs.

Transport providers

Outreach to large user populations, business opportunity to collaborate with other service providers to offer transport chain services.

Authorities

Cost-efficient way to provide mobility to citizens with less negative externalities. Targeted steering measures and regulations are needed.

Society

Improved mobility of people, environmentally sustainable transport modes, fast adoption of technological advances and improved health of citizens.

Figure 26. Recommendations for Transport and mobility.

Conclusions

Cities are complex systems that are characterised by massive numbers of interconnected citizens, businesses, different modes of transport, energy and water systems, communication networks, services and utilities. Population growth and increased urbanisation raise a variety of technical, social, economic and organisational problems that tend to jeopardize the economic and environmental sustainability of cities. The rapid growth faced by several cities has generated traffic congestion, pollution and increasing social inequality. Thus, the focus has been on the way new technology-based solutions, as well as new approaches to urban planning and living, can assure future viability and prosperity in urban areas.

The essence of being smart in modern society lies in acting locally but being networked outside one's own geographical location (local but global). The technological systems can only be managed if they are properly integrated. **Digitalisation**, ICT and other technologies are enabling that, when properly used for networking and **integration**, provides social, environmental and economic benefits for all. Cities all over the world see this as an opportunity for better quality of life. Therefore, the smart city agendas will have a central place in urban development projects. While those projects are always huge investments, they also provide new business opportunities for different stakeholders.

Digitalisation is also able to change the way how cities are developed collaboratively together. There is a strong tendency in municipalities to place attention in **3D city modelling** technologies. A city model is a digital representation of the built environment, expressing terrain, sites, buildings, vegetation, infrastructure, and other planned objects in the region. The advantage of technology is semantics, each object is associated with additional details such as spatial data, providing constructive opportunities for a utilisation in smart city context. City models are able to scrutinize **up-to-date data** from many sources into one integrated environment to enhance collaboration between different stakeholders, such as authorities, municipalities, cities and experts from different domains. More effort is needed for interoperability and developing a process for bringing the industries together with the help of digitalization.

Smart city design, operation and management need to be done **cross-sectoral integrated** at **system level**. Sub-optimization of individual components will not lead to optimal performance of the system. **Multi-target optimization** is not an easy task, but it becomes necessary as different components and systems are interlinked and interconnected – irrespective of where they are physically located. Traditional sector-based industries and value chains are also changing, and completely new business models are starting to emerge. Radical innovations and paradigm shifts are changing our whole city systems. Typical examples are concepts like Mobility-as-a-service, indoor air as a service, office-as-a service, living-as-a-serves. Business models are more based on new service concepts, **X-as-a-service**. This will not only lead to new types on service business models but also to **new models of ownerships**.

Vitality and capacity for reinvention form an essential part of a Smart City. This means that the building stock and infrastructure must be flexible according to changes in the usage needs as well as the users. A Smart City also attracts new residents, and it must be able to grow eco-efficiently. Eco-efficiency involves recycling districts and buildings to new uses. Energy efficiency involves reducing the energy consumption of old buildings so that the energy demand of new buildings can be satisfied with the saved energy. In addition to other aspects of sustainability likes social and economic aspects must be taken into account. This will increase the importance of **integrated planning** and **district scale solutions**.

Choices made concerning a single building have only a limited impact. The impact can be **scaled up**, if the choices are made on the district level, instead. In district-level projects, it is possible to invest in innovations, product development and structural changes. With regard to energy efficiency, for example, district-level improvements and new construction solutions can achieve greater benefits than if they were implemented one building at a time.

Unlike in traditional building stock and other infrastructure, interactive data transfer is an essential part of Smart buildings. Where the consumption of energy or water is normally only metered passively, consumption in Smart buildings can be controlled so as to avoid consumption peaks. This is extremely important, if the pricing in buildings switches to cost correlation in the same way as in energy-intensive industry. The control option is extremely important when utilising renewable energy sources with uneven production depending, for example, on wind or sunshine. Connection of **smart buildings** and **electrical vehicles charging** infrastructure to smart **district management systems** is essential and gives huge **peak shifting and shaving potential without compromising users' wellbeing.**

Advanced technology and economy are not enough to make a building smart. At its best, a building could **promote the wellbeing** of its residents or the people working there. At its simplest, the high quality and healthiness of the indoor air can be ensured. Taken further, the building can, for instance, monitor the condition and safety of senior citizens and even give **active guidance**. At the district level, the quality of life of, for example, people with memory disorders could be improved by allowing them a wider living environment through new technology. In addition to guidance, smart systems can also actively **increase the safety and experienced safety** in buildings and district level, typical example being smart lighting systems.

Modelling is an absolutely necessary tool, as the initial data produced with it can be utilised in the simulation of functionality and solutions affecting energy efficiency. Modelling produces compatible data so that a common model of the district's building stock can be generated as part of the city model. Good building and district city models become virtual reality to help district optimisation but also to give visual information and feedback. In order to makes these systems working the **interfaces** between systems need to be **standardised** and **open data** should be promoted to create innovations. Further the large amount of data (big data) should be processed to information for different stakeholders. Namely the progress should be **form Internet of Things to Internet of Meaningful Things.**

Buildings are usually reasonably well documented, as they involve financial interests. They have registered users and owners, from whom the society collects property taxes. The situation is different with infrastructure. The public sector owns the majority of infrastructure, but does not necessarily know the amount, precise location, status or condition of its assets. Infrastructure is a mere cost item to its owners or local or central government. The information would, however, be necessary for both **asset management** and district development.

If the development project concerns an entirely new district, the infrastructure models and building construction models can be reasonably easily combined even today. This can be done at many different levels. At its simplest, it is a question of visualising the planning options. At its most demanding, the operations and traffic flows planned for the district are included, and the best solution for the overall system selected. The task becomes somewhat more laborious, if old building stock or old infrastructure is involved. Model-compatible data of these must be obtained by means of, for example, laser scanning and ground penetrating radars, if the original plans are not available. Complete modelling of the district is necessary when the objective is a comprehensive city model.

The main cross-cutting conclusion in specific roadmap areas were following:

- Digitalisation in enabling new services and innovation as well as more efficient systems
- Integrated and cross-sectoral planning and management is essential
- Cities have many stakeholders; value-chains and changing and new eco-systems are emerging
- Importance of energy management at building and district level increases as well as the increased use of low carbon energies
- New services, e.g. mobility as a service, building as a service, energy as-a-service, X-as-a-service are coming
- Importance of resiliency, safety and security is highlighted
- Upgrading existing infrastructure asks for new business concepts including new models for ownership

The essence of being smart in modern society lies in acting locally but being networked outside one's own geographical location. The technological systems can only be managed if they are properly integrated. ICT is the enabler that, when properly used for networking and integration, provides social, environmental and economic benefits for all. Cities all over the world see this as an opportunity for better quality of life.

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