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## Roadmap for ICT-based Opportunities in the Development of the Built Environment



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## Abstract

The built environment is a significant part of our national wealth. The built environment is the physical environment created by people. It consists of the buildings and all networks serving the flow of traffic, energy, water, waste and digital information, and the assemblies, equipment and (built) natural elements connected to them.

This publication presents a review of the development trends of the built environment that utilise information and communication technology. The focus is on buildings and construction. The review is presented in the form of four change roadmaps. The “Digital solutions” section presents the technologies related to the subject field and applied in it from the perspective of the built environment. The “Operation methods and processes” section presents the changes required and enabled by the new technologies in the operation methods and processes. The “Services” section presents the services enabled by digital solutions and changing operation methods and processes. The “Meta Roadmap” encapsulates the essential ideas of the other roadmaps.

The vision of development prospects in the built environment utilising information and communication technology is as follows: The technological foundation of the built environment utilising information and communication technology is based on well-timed sharing and utilising of information. Business is done through networks. This requires compatible processes and operation methods which can utilize commonly available interoperable digital information, such as, building information models and real-time information. These will fulfil the evolving needs of the user or customer and enable good usability and real-time services.

Current state-of-the-art solutions for information and communication technology in the built environment are mainly separate services. Progressive demand is limited and the suppliers and exploiters of ICT for the built environment are differentiated into narrow categories. The service providers offer niche services for specific purposes. Currently there are four state-of-the-art service entities: 1) planning, construction, operation and maintenance services; 2) remote services; 3) security services and 4) new health services. At the moment, the processes used by operators do not yet correspond to the requirements of information modelling applied in the ICT for the built environment.

Therefore, model information cannot be fully utilised in the planning and realisation of operations. Another area of change for operation methods is the development of commercialisation in both technological solutions and in the services packaging them.

In the short term, i.e. 1–5 years, the development paths in the information and communication technology of the built environment will lead towards the utilisation of an integrated information model which opens up new ways of connecting products and services. However, the application of information models requires that the integrated information models are understood and explained from the points of view of different operators. Products and services utilise user-oriented content production. The services of the built environment are produced with networked operation methods. In the short term, the essential factors will especially include the following four service entities: 1) information model services; 2) data collection, maintenance and management services; 3) information-based additional value services; and 4) the integration of services. The application of information and communication technology in the built environment emphasises the value of and services targeted at the whole life span of the product.

In the long term, i.e. 5–15 years, the formation of globally integrated operation models will start in planning and production, and large networks will produce services for the built environment. The end-user will be served in the whole design, planning and construction process by offering different mechanisms for visualisation, modularisation and giving feedback. In the long term, the following service entities will especially increase: real-time building information systems, services based on integrated information models supporting decision-making and operation, experience and health services and automated property assessment services. In the long term, a central factor supporting the change in operation methods will be the applications and tools designed for process management. In this respect, the key solution is found in the applications that utilise visualisation and information models and can officially be used as references for building inspections. New kinds of service providers may also be established for the services that exploit information models and integration.

The roadmap process helped to recognize five large development paths that will exploit information and communication technology in the future of the built environment. 1) The amount and exploitability of digital information in the built environment will increase. Tools must be developed for the management, analysis and effective use of information to support decision-making. 2) The development of information models, computation methods and computing performance enables more versatile virtual testing of products. 3) The digital and physical worlds are interconnected during the whole life span of a product. 4) Service-based software integration, situation-specific systems, social media and location technologies enable services that are automatically tailored according to users' needs in the built environment. 5) Information modelling of the existing buildings is a significant challenge that requires the development of appropriate methods and technologies.

## Foreword

In accordance with the policy of technical development for 2007–2011 confirmed by the Finnish Ministry of Trade and Industry in the autumn of 2006, part of the increase in budget funding for VTT will be directed at predicting market trends, emerging technologies and companies' competitiveness. This policy has also been taken into account in the result agreement between the Ministry of Employment and the Economy and VTT and in VTT's own strategy.

In its strategy, VTT emphasises the importance of developing forecasting operations. Appropriate forecasting operations support development of know-how, orientation of research and strengthening of the research center's own international competitiveness. VTT's research scientists already naturally monitor the changes in the operating environment related to their research work and the development of technology. Therefore, the research scientists are an exceptional resource in producing prediction data. Recognition of alternative development paths is important when planning research projects.

The built environment constitutes a remarkable part of our fixed national wealth. In a western society, people spend 80–90% of their time indoors. Of total energy end consumption within the EU, 41% is used in the housing and service sectors. VTT has been a central player in the built environment for decades. Together with companies we have developed technical equipment, systems and services. VTT has also played an important role in national technology programmes. Exploitation of information and communication technology in the planning, construction, use and maintenance of the built environment is increasing clearly. As the information on the built environment is becoming digitalised, construction moves from documents to modelling, construction operations start networking and sustainable development and environmental aspects become emphasised.

VTT decided to take a look at the future through systematic roadmap work. This publication described the results that have been reached through systematic information collection, recognition of technology forecasts and possibilities and with actual compilation of the roadmap. This publication can be considered VTT's current view on the near term development outlook for the markets and technologies of the built environment that exploits data and communication technologies. The publication focuses on building and construction – channels, connections and infrastructure is not discussed as extensively.

The project manager for the implementation of the roadmap project was Senior Research Scientist Satu Paiho with support from roadmap work expert Toni Ahlqvist and a core team consisting of experts from different areas. The team members were

Kalevi Piira, Janne Porkka, Pekka Siltanen and Pekka Tuomaala. In addition to the core team, VTT's research scientists Matti Hannus, Tarja Häkkinen, Leena Korkiala-Tanttu, Hannu Maula, Esa Nykänen, Veijo Nykänen, Kari Rainio, Tommi Rissanen, Sirje Vares, Olli Ventä and Charles Woodward participated in workshop work. In the finalisation stage of the work a feedback event for invited external experts was arranged in which Marko Kivimäki (Tekes), Kari Ristolainen (Senaatti-kiinteistöt), Ilkka Romo (Skanska Oy) and from VTT Toni Ahlqvist, Arto Kiviniemi and the undersigned participated. In addition, Heikki Haikonen (Tekla Oyj) commented on the manuscript. Research Professor Arto Kiviniemi also provided valuable comments to the manuscript draft. The supervisor of the work was Research Director Matti Kokkala.

We would like to thank everyone that participated in the work for their excellent input and the end result which we hope will also be utilised outside VTT.

Espoo, 22 August 2008

Matti Kokkala  
Research Director

Satu Paiho  
Senior Research Scientist



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## Abbreviations used

Ajax	AJAX (Asynchronous JavaScript and XML), or Ajax, is a group of inter-related web development techniques used for creating interactive web applications. AJAX is asynchronous, in that extra data is requested from the server and loaded in the background without interfering with the display and behavior of the existing page. (Wikipedia, Ajax (programming) 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Ajax_%28programming%29">http://en.wikipedia.org/wiki/Ajax_%28programming%29</a> .)
BACnet	BACnet – A Data Communication Protocol for <b>B</b> uilding <b>A</b> utomation and <b>C</b> ontrol <b>N</b> etworks. Official building automation standard (ASHRAE, ANSI Standard 135, ISO 16484-5).
bcXML	Building Construction Extensible Markup Language. XML format intended for electronic trading in the construction industry.
BIM	Building Information Model. The totality of the product data of a building. The totality of building information, digital product data, throughout the life cycle of a building. (Karstila 2007).
B2B	Business-to-business (B2B) is a term commonly used to describe electronic commerce transactions between businesses, as opposed to those between businesses and other groups, such as business and individual consumers (B2C) or business and government (B2G). (Wikipedia, B2B 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/B2B">http://en.wikipedia.org/wiki/B2B</a> .)
B2C	Business-to-consumer (B2C, sometimes also called Business-to-Customer) describes activities of E-businesses serving end consumers with products and/or services. (Wikipedia, B2C 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/B2C">http://en.wikipedia.org/wiki/B2C</a> .)
B2G	Business to Government (B2G) is a derivative of B2B marketing and referred to as a market definition of “Public Sector Marketing”. (Wikipedia, B2G 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Business-to-government">http://en.wikipedia.org/wiki/Business-to-government</a> .)
CAD	Computer Aided Design (CAD) is the use of computer technology to aid in the design of a product. (Wikipedia, CAD 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/CAD">http://en.wikipedia.org/wiki/CAD</a> .)

CAM	Computer Aided Manufacturing (CAM) is the use of computer-based software tools that assist engineers and machinists in manufacturing or prototyping product components. (Wikipedia, Computer-aided manufacturing 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Computer-aided_manufacturing">http://en.wikipedia.org/wiki/Computer-aided_manufacturing</a> .)
Cx/Commissioning	Life-Cycle Commissioning (LcCx) is a systematic building life-cycle process for assuring that new buildings and their system performances meet owner expectations and user needs, and existing buildings operate, function and are maintained optimally according to owner expectations and user needs.
C2C	Consumer-to-consumer (or C2C) electronic commerce involves the electronically-facilitated transactions between consumers through some third party. A common example is the online auction. (Wikipedia, C2C 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Consumer-to-consumer_electronic_commerce">http://en.wikipedia.org/wiki/Consumer-to-consumer_electronic_commerce</a> .)
EDGE	Enhanced Data rates for GSM Evolution (EDGE), Enhanced GPRS (EGPRS), or IMT Single Carrier (IMT-SC) is a digital mobile phone technology that allows increased data transmission rates and improved data transmission reliability. (Wikipedia, EDGE 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Enhanced_Data_Rates_for_GSM_Evolution">http://en.wikipedia.org/wiki/Enhanced_Data_Rates_for_GSM_Evolution</a> .)
e-Government	e-Government (from electronic government, also known as e-gov, digital government, online government or in a certain context transformational government) refers to the use of internet technology as a platform for exchanging information, providing services and transacting with citizens, businesses, and other arms of government. (Wikipedia, e-Government 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/E-Government">http://en.wikipedia.org/wiki/E-Government</a> .)
Flash-OFDM	Flash-OFDM (Fast Low-latency Access with Seamless Handoff Orthogonal Frequency Division Multiplexing) is a system that is based on OFDM and specifies also higher protocol layers. Flash-OFDM is also suitable for rural areas to replace traditional ADSL cable-based connections. (Wikipedia, Flash-OGDM 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Flash-OFDM#Flash-OFDM">http://en.wikipedia.org/wiki/Flash-OFDM#Flash-OFDM</a> .)

GIS	A geographic information system (GIS), also known as a geographical information system or geospatial information system, is any system for capturing, storing, analyzing and managing data and associated attributes which are spatially referenced to Earth. (Wikipedia, GIS 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/GIS">http://en.wikipedia.org/wiki/GIS</a> .)
GPRS	General Packet Radio Service (GPRS) is a packet oriented Mobile Data Service. GPRS can be used for services such as Wireless Application Protocol (WAP) access, Short Message Service (SMS), Multimedia Messaging Service (MMS), and for Internet communication services such as email and World Wide Web access. (Wikipedia, GPRS 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/GPRS">http://en.wikipedia.org/wiki/GPRS</a> .)
GPS	The Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. (Wikipedia, GPS 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/GPS">http://en.wikipedia.org/wiki/GPS</a> .)
ICT	Information and Communication Technology.
IFC	Industry Foundation Classes. An international specification for product data exchange and sharing for AEC/FM (Architecture, Engineering and Construction / Facilities Management.). IFC enables interoperability between the computer applications for AEC/FM. A subset of IFC is approved as ISO/PAS 16739. (Karstila 2007.)
JIT	Just-in-time (JIT) is an inventory strategy implemented to improve the return on investment of a business by reducing in-process inventory and its associated carrying costs. (Wikipedia, JIT 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Just_In_Time_%28business%29">http://en.wikipedia.org/wiki/Just_In_Time_%28business%29</a> .)
LandXML	XML file format for geographic imaging. Used in data transfer between some infrastructure sector planning software.

LOD	In computer graphics, accounting for <b>level of detail</b> (LOD) involves decreasing the complexity of a 3D object representation as it moves away from the viewer or according other metrics such as object importance, eye-space speed or position. (Wikipedia, LOD 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Level_of_detail">http://en.wikipedia.org/wiki/Level_of_detail</a> .)
MEMS	Micro Electro Mechanical Systems. These are also called microsystems and are components that combine several functionalities, for instance converting a mechanic deviation into an electronic signal (like in a pressure sensor or the launch sensor for airbags). MEMS components combine mechanic, fluidic, optical, acoustic, thermal and biological functions. Most common microsystem components are different micro sensors, such as capacitive pressure sensors, piezoresistive acceleration sensors and micro bolometers (an infrared sensor). (Wikipedia, MEMS 2007; more information on the subject [checked 19.11.2007]: <a href="http://fi.wikipedia.org/wiki/MEMS">http://fi.wikipedia.org/wiki/MEMS</a> .)
OpenGL	OpenGL (Open Graphics Library) is a standard specification defining a cross-language cross-platform API for writing applications that produce 2D and 3D computer graphics. (Wikipedia, OpenGL 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/OpenGL">http://en.wikipedia.org/wiki/OpenGL</a> .)
OS	Open source (OS) is a set of principles and practices on how to write software, the most important of which is that the source code is openly available. (Wikipedia, Open Source 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Open_Source">http://en.wikipedia.org/wiki/Open_Source</a> .)
PDA	A personal digital assistant (PDA) is a handheld computer (Wikipedia, PDA 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Personal_digital_assistant">http://en.wikipedia.org/wiki/Personal_digital_assistant</a> .)
PLM	Product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal. (Wikipedia, PLM 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Product_lifecycle_management">http://en.wikipedia.org/wiki/Product_lifecycle_management</a> .)

RFID	Radio-frequency identification (RFID) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. (Wikipedia, RFID 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/RFID">http://en.wikipedia.org/wiki/RFID</a> .)
SOA	Service Oriented Architecture (SOA) is a computer systems architectural style for creating and using business processes, packaged as services, throughout their lifecycle. (Wikipedia, SOA 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Service-oriented_architecture">http://en.wikipedia.org/wiki/Service-oriented_architecture</a> .)
STEP	Standard for the Exchange of Product Data. ISO-10303 Product data representation and exchange standard. (Karstila 2007.)
VRML	VRML (Virtual Reality Modeling Language, pronounced vermal or by its initials, originally (before 1995) known as the Virtual Reality Markup Language) is a standard file format for representing 3-dimensional (3D) interactive vector graphics, designed particularly with the World Wide Web in mind. (Wikipedia, VRML 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/VRML">http://en.wikipedia.org/wiki/VRML</a> .)
Wifi	Wifi (Wireless Fidelity, also known as Wi-fi, WiFi, Wifi or wifi) is the common name for a popular wireless technology used in home networks, mobile phones, video games and more. (Wikipedia, Wifi 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Wifi">http://en.wikipedia.org/wiki/Wifi</a> .)
WLAN	A wireless LAN or WLAN is a wireless local area network, which is the linking of two or more computers without using wires. (Wikipedia, WLAN 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Wireless_LAN">http://en.wikipedia.org/wiki/Wireless_LAN</a> .)
XML	An eXtensible Markup Language. XML is a language for defining and exchanging structured, computer-interpretable information. (Karstila 2007.)
3G	3G is the third generation of mobile phone standards and technology, superseding 2G. (Wikipedia, 3G 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/3G">http://en.wikipedia.org/wiki/3G</a> .)

- 4D                    4D = 3D + time, i.e. the linking of a time aspect to the building element and space objects of the 3D-model. The time aspect may describe, e.g., the installation date and time of a building element. Then 4D-simulation can be used to visualise the progress of construction in time. (Karstila 2007.)
- 4G                    4G (also known as beyond 3G), an acronym for Fourth-Generation Communications System, is a term used to describe the next step in wireless communications. A 4G system will be able to provide a comprehensive IP solution where voice, data and streamed multimedia can be given to users on an “Anytime, Anywhere” basis, and at higher data rates than previous generations. (Wikipedia, 4G 2008; more information [checked 7.4.2008]: <http://en.wikipedia.org/wiki/4G>.)

## Terms used

Agile software development	Agile software development is a conceptual framework for software engineering that promotes development iterations throughout the life cycle of the project. There are many agile development methods; most minimize risk by developing software in short amounts of time. Agile methods emphasize face to face communication over written documents. Agile methods also emphasize working software as the primary measure of progress. (Wikipedia, Agile software development 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Agile_software_development">http://en.wikipedia.org/wiki/Agile_software_development</a> .)
Augmented reality	Augmented reality (AR) is a field of computer research which deals with the combination of real-world and computer-generated data. (Wikipedia, Augmented reality 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Augmented_reality">http://en.wikipedia.org/wiki/Augmented_reality</a> .)
Bluetooth	Bluetooth is an industrial specification for wireless personal area networks (PANs). Bluetooth provides a way to connect and exchange information between devices such as mobile phones, laptops, personal computers, printers, GPS receivers, digital cameras, and video game consoles over a secure, globally unlicensed short-range radio frequency. (Wikipedia, Bluetooth 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Bluetooth">http://en.wikipedia.org/wiki/Bluetooth</a> .)
De facto standard	A method or similar practice which has achieved a position of being the “standard” practice, without being standardised by an official standardisation body. E.g. DXF-format in 2D-draughting data exchange. (Karstila 2007.)
Google Earth	Google Earth is a virtual globe program. It maps the earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS 3D globe. (Wikipedia, Google Earth 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Google_Earth">http://en.wikipedia.org/wiki/Google_Earth</a> .)



Green Building	Green building is the practice of increasing the efficiency with which buildings use resources – energy, water, and materials – while reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal – the complete building life cycle. (Wikipedia, Green Building 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Green_Building">http://en.wikipedia.org/wiki/Green_Building</a> .)
Integrated BIM	A Building Information Model whose information needs to be shared and thus warrants open international standards for information sharing (Kiviniemi et al. 2008).
KNX	Official building automation standard (EN 50090, ISO/IEC 14543).
LONWorks	Official building automation standard (ANSI, ASHRAE, IEEE).
NFC	Near Field Communication or NFC, is a short-range high frequency wireless communication technology which is a simple extension of the ISO 14443 proximity-card standard (contactless card, RFID). An NFC device can communicate with both existing ISO 14443 smartcards and readers, as well as with other NFC devices, and is thereby compatible with existing contactless infrastructure already in use for public transportation and payment. NFC is primarily aimed at usage in mobile phones. (Wikipedia, NFC 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Near_Field_Communication">http://en.wikipedia.org/wiki/Near_Field_Communication</a> .)
Second Life	Second Life (abbreviated as SL) is an Internet-based virtual world. A downloadable client program called the Second Life Viewer enables its users, called “Residents”, to interact with each other through motional avatars, providing an advanced level of a social network service combined with general aspects of a metaverse. Residents can explore, meet other Residents, socialize, participate in individual and group activities, and create and trade items (virtual property) and services from one another. (Wikipedia, Second Life 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Second_Life">http://en.wikipedia.org/wiki/Second_Life</a> .)

Semantic Web	The Semantic Web is an evolving extension of the World Wide Web in which the semantics of information and services on the web is defined, making it possible for the web to understand and satisfy the requests of people and machines to use the web content. (Wikipedia, Semantic Web 2007; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Semantic_Web">http://en.wikipedia.org/wiki/Semantic_Web</a> .)
Social media	Social media is an umbrella term that defines the various activities that integrate technology, social interaction, and the construction of words and pictures. This interaction, and the manner in which information is presented, depends on the varied perspectives and “building” of shared meaning, as people share their stories, and understandings. (Wikipedia, Social media 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Social_media">http://en.wikipedia.org/wiki/Social_media</a> .)
Zigbee	ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). (Wikipedia, Zigbee 2008; more information [checked 7.4.2008]: <a href="http://en.wikipedia.org/wiki/Zigbee">http://en.wikipedia.org/wiki/Zigbee</a> .)

# 1. Introduction

Technology roadmaps recognise, assess and promote development of cooperation projects within and between sectors in order to fill technology gaps and master the possibilities related to the technology (Emerging Industries 2001). Compilation of technology roadmaps is a flexible procedure that is used widely in industry to support strategic and long-term planning (Phaal et al. 2004). The approach offers a time-dependent structured and often graphical way of examining and communicating connections between growing and developing markets, products and technologies.

Kiviniemi (2007) researched the use of ICT and information models, in particular in the Finnish real estate and construction cluster as a part of Tekes' SARA technology programme (Tekes 2008). The survey was taken by companies that focus on technological development so the responses do not necessarily depict the average situation in the industry. Of the companies that responded, the exploitation rate of information model-based design/planning was 22% of the work volume. Eighty-four percent of the respondents estimated that information modelling will increase and 85% of designers see the increase of ICT use as one of the main investments in their company. The main problems in increasing the use of ICT was the continuous need for updating, incompatibility of software, high investment costs and the resources needed to educate the users. The main benefits in using ICT were data management and sharing, and in particular in the designer group, improved work quality. The main motives for increasing ICT use were maintaining or improving competitiveness and the wish to make technical work more efficient. For designers the wish to be a forerunner in the use of a new technology was also a significant motivation.

Similar IT solution development trend can also be detected internationally. In the Swedish IT barometer survey, the survey was sent based on statistical selection to the entire country and the respondents were architects, technical consultants, contractors, property owners, and goods manufacturers and vendors (Samuelson 2007). The survey provided information on the use of computers and communication equipment, the use of IT in three different CAD areas, project web and electronic trading as well as the future plans and strategies for IT use. One hundred percent of the respondents work in places with computers. More than 70% of the respondents had their own computers, e-mail addresses and access to Internet in the workplace. The use of CAD has increased, but was not significantly greater than in 2000. The use of information model-based CAD software has increased among architects and technical consultants. Project web and electronic trading are now wide-spread in the construction industry even though the usage rate is not very high yet. Plans in IT investments focus on tried and tested technologies in the companies' support functions and the leader at this point in time is mobile solutions.

Similar surveys have also been carried out in all Nordic countries and the Netherlands concerning the use of ICT and information models in the real estate and construction cluster (Kiviniemi et al. 2008). The results were similar to those separate studies in Finland and Sweden when there were enough respondents to make a reliable analysis.

This publication describes VTT’s view on the development trend of the built environment utilising information and communications technology (ICT), and it focuses on buildings and construction. The Roadmap for ICT-based Opportunities in the Development of Built Environment report touches on the roadmap survey related to building services previously done in VTT (Paiho et al. 2007). The roadmap has been compiled in a systematic process that has included a data collection phase, recognition of technology outlook and opportunities and the actual creation of the roadmap.

Figure 1 shows the structure of the project. The roadmaps have been recognised in phased workshop work. The first workshop dealt with drivers and technologies, and the second with markets and market actors. The working process and intermediate reports are presented in Appendix A. In addition, a lot of background material was used and a summary of these is presented in Appendix B. The publication draft made based in the workshops and background material was commented on by selected experts after which the final publication was edited.

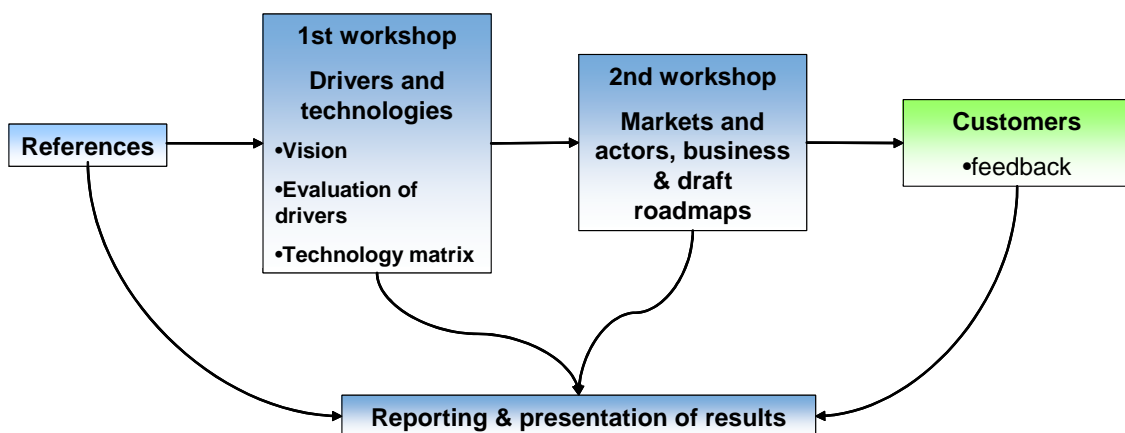


Figure 1. Roadmap project structure.

The structure of this publication is: Chapter 2 defines the topic and discusses the main change factors in the operating environment. Chapter 3 presents the roadmaps. Chapter 4 presents a few concrete examples of how ICT could be exploited in the digitalising built environment. Chapter 5 describes the conclusions.

## **2. Built environment utilising ICT**

### **2.1 Project definition**

The built environment constitutes a large part of our fixed national wealth. In this publication built environment is defined as follows:

The built environment means the physical environment created by humans and it consists of buildings, traffic networks, energy networks, water supply networks, waste management networks and ICT networks, and the assemblies, equipment and (built) natural elements connected to them.

This project includes the elements that exploit information and communications technology in design, planning, production, use and maintenance of the built environment. Such elements include applied technologies, changes in processes, operating methods and business models enabled by these technologies, and services based on the technologies in the built environment. The general vision is that the different parties in the real estate and construction industry (companies, customers, authorities, etc.) can share and exchange information needed in the planning, construction, use and maintenance of the built environment in an electronic format using internationally approved standards.

### **2.2 Change factors in the operating environment**

The project assessed possible change factors that affect the built environment utilising ICT. The basis for the work was change factors that touch on the subject area presented in other projects (Appendix B).

Major common change factors that clearly also affect built environment utilising ICT are:

- globalisation
- labour force issues.

These change factors have an effect in partially the same direction, when globalisation for instance changes work division and transfers jobs to countries with lower cost levels. The competition for skilled workers tightens, which on one hand requires more efficient industrial solutions, and on the other makes it even more tempting to have the work done elsewhere. A multicultural work force creates challenges for ICT as well. On the other hand extensive utilisation of ICT enables remote working.

The main change factors for the built environment utilising ICT were assessed to be:

- science and technology as a driver
- sustainable development
- commercialism, customer orientation (product customisation, long-term customer relations)
- innovative operations (new products, new business models)
- economic pressure (increasing time pressure, quarterly economy, price competition, etc.).

Table 1 lists the change factors seen as most central and issues related to each factor – either the main effects on the development of the built environment utilising ICT, or issues that should be taken into consideration when developing the built environment utilising ICT.

*Table 1. Main change factors and their possible effects.*

<b>Driver</b>	<b>Central effects on the development of the built environment utilising ICT</b>
Science and technology as a driver	<ul style="list-style-type: none"> <li>• knowledge management, biotechnology development, new materials</li> <li>• building information models are available</li> <li>• ICT effects everything: design, planning, construction projects, use, repairs, maintenance, renovations</li> <li>• virtualisation, visualisation, information sharing / web</li> <li>• measuring and modelling, sensor technology, ubiquitous ICT</li> <li>• ICT development enables larger and more versatile models – more aspects to the same model</li> <li>• open source development and other software infrastructure projects (cf. Google Earth) require compatibility</li> <li>• PLM implementation, things that support ICT implementation</li> <li>• The need for computer rooms decreases when the number of laptops increase. Large flatscreen TVs increase the need to move walls.</li> </ul>
Sustainable development	<ul style="list-style-type: none"> <li>• new energy production, demand for energy conservation and clean products and solutions increase, change in people’s attitudes (values change), taking climate change into account in everything</li> <li>• flexibility, accessibility</li> <li>• information management a central tool → better energy management, environmental thinking</li> <li>• life-cycle management, networked operations, material &amp; energy management, environmental awareness, service providers and users</li> <li>• connection between ICT and sustainable development (at a societal level) i.e. “the more ICT, the more sustainability”</li> </ul>

Commercialism, customer orientation (product customisation, long-term customer relations)	<ul style="list-style-type: none"> <li>• product families, mass customisation, conceptual approach, parametric models</li> <li>• functional requirements before technical requirements, requirement management and life-cycle management improve</li> <li>• new business / emerging of new players (e.g. monitoring services, maintenance services, life-cycle services), new methods due to efficiency thinking</li> <li>• requires full digitalisation in order to be cost efficient</li> <li>• competitive benefit, speed</li> </ul>
Innovative operations (new products, new business models)	<ul style="list-style-type: none"> <li>• new companies or companies that are willing to change, new earnings models, new products, processes and services</li> <li>• new operating methods increase the need to exchange information</li> <li>• custom-built, luxury is demanded</li> </ul>
Economic pressures (increasing time pressure, quarterly economy, price competition, etc.)	<ul style="list-style-type: none"> <li>• procurement processes change (design-build contracting, information models)</li> <li>• development of long-term planning and operations in the pressure of the quarterly economy</li> <li>• effects on higher efficiency in design, planning and construction <ul style="list-style-type: none"> <li>○ cost saving, predictability, manageability</li> <li>○ digitalisation helps, project templates, speed</li> </ul> </li> </ul>

Other change factors that affect the built environment utilising ICT were:

- changes in know-how
- control, security and safety
- networking (cooperation between parties)
- aging buildings and infrastructure
- segmentation, the needs of different customer sectors.

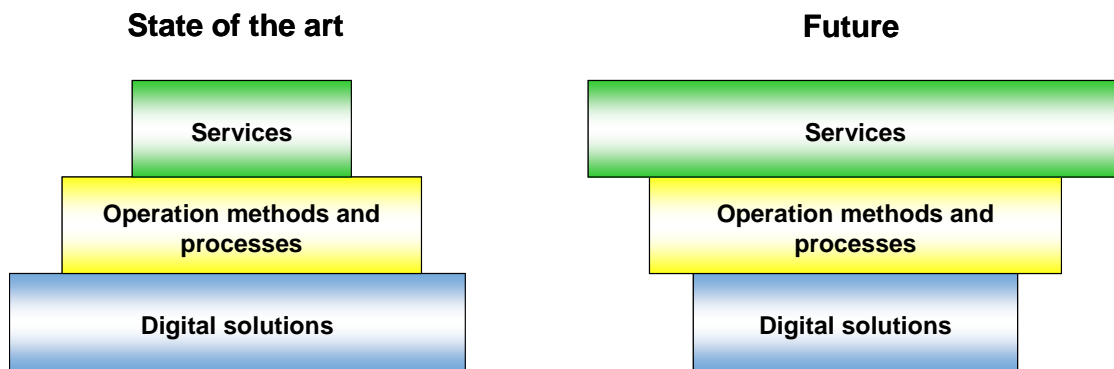
Table 2 explains other change factors that affect built environments utilising ICT and their effects. These factors are factors that arose during the project but they have not been classified as significant as the ones presented in Table 1.

Table 2. Other change factors and their effects.

Driver	Central effects on the development of built environment utilising ICT
Changes in know-how	<ul style="list-style-type: none"> <li>• use of new tools, disappearing traditional roles, young people are experienced ICT users</li> <li>• ability to create and use new solutions</li> <li>• education of builders lags behind</li> <li>• bulk work to China → specialisation, something that can be sold at a high price</li> </ul>
Control, security and safety	<ul style="list-style-type: none"> <li>• there is a need to make things easier</li> <li>• safe buildings which are easier to maintain, demand for new security technologies, the built environment becomes safer (median barriers, flexible poles, vehicle technologies, etc.)</li> <li>• development and spreading of asset management / decision making tools are becoming everyday things</li> <li>• ICT a central element; if managed poorly the feeling of control disappears</li> <li>• link/requirement for sustainable development</li> <li>• sensors and information networks already at building stage</li> </ul>
Networking (cooperation between the parties)	<ul style="list-style-type: none"> <li>• companies' need to seek new business arrangements</li> <li>• networking increases the need for electronic information exchange</li> <li>• combining know-how, large consortiums, increasing transparency, LCM, virtual products and companies</li> <li>• planning and bulk work is moving to China</li> <li>• requires smooth data transfer</li> <li>• large players and their networks must combine their skills – not necessarily that important for small players</li> </ul>
Aging buildings and infrastructure	<ul style="list-style-type: none"> <li>• development, increasing and valuation of repair methods</li> <li>• monitoring, data collection, mining, analysing, forecasting, decision making</li> <li>• more pressure to make repairs and maintenance more efficient (bridges, railways, etc.)</li> <li>• digital modelling of old building stock is difficult but must be done</li> </ul>
Segmentation, the needs of different customer sectors	<ul style="list-style-type: none"> <li>• large companies, knowledge-intensive new products for special sectors cf. luxury cruise ships (shipping industry)</li> <li>• as private wealth increases consumption habits change which generates demand for solutions and services directed at a narrow segment, unique solutions and luxury is demanded</li> </ul>



In addition to the above described general change factors the project was aware of a major trend changing the functional structure of built environment utilising information and communication technology (Figure 2). Currently there are a lot of different technical solutions and some methods and processes to utilise them, but only few services that exploit them utilising the full potential. In the future the situation will change so that the amount of services will be highest.



*Figure 2. Major trend changing the functional structure of built environment utilising information and communication technology.*

# 3. Roadmaps

## 3.1 Roadmap structure

The roadmap for the built environment utilising ICT consists of four roadmaps (Figure 3). The lowest level is Digital Solutions, which presents the technologies related to the subject field and applied in it from the perspective of the built environment. The middle level presents the changes enabled by new technologies in operating methods and processes. The top level presents the services enabled by the lower levels. The Meta Roadmap encapsulates the essential ideas of the other roadmaps. All roadmaps are change roadmaps, i.e. the situation of the first adopters in each review period.

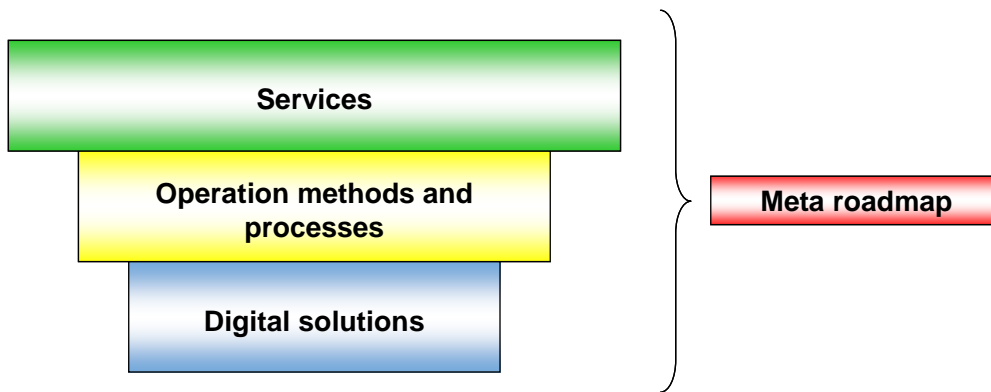


Figure 3. DigiBuild roadmaps.

## 3.2 Roadmap I: Digital solutions

**VISION:** Information is produced, shared and utilised between the real estate and construction cluster players at the right time throughout the life-cycle of the real estate and building. This offers added value both to end-users and the services that utilise the information.

The change roadmap for digital solutions is presented in Figure 4 and is here discussed in phases.

### Current situation (state-of-the-art)

Technological development (Figure 4) enables many kinds of operations and services for the built environment. The first roadmap classifies technologies into larger entities. During the development work *seven* currently crucial technology entities within *information production and utilization* were recognised as well as *seven* technology entities within *information communication*.

## **Information production and utilisation**

***Modelling, simulation and analysing technologies (1)*** take into account the extent of the built environment, the players and the phases of the construction life-cycle. Examples of technology solutions are CAD tools (Computer Aided Design), CAM (Computer Aided Manufacturing) and analyzing and simulation applications (such as temperature and energy consumption). Models for automatic content checking of information models are also being developed (so-called model checking). Currently advanced modelling solutions are used. However in addition to limited compatibility the heterogenic implementation is, viewed problematic by the industry. In modelling technologies the importance of information transferring and sharing will grow in the future.

Development of ***software technologies (2)*** offers new business opportunities. Modular systems offer the users the possibility to expand the purpose with different software modules. There are already software product families on the market where the content can be chosen flexibly with different expansion packs. The benefit of these solutions is the tailoring of the application according to need. Other significant software technologies are service-oriented architecture (SOA), agile software development and browser user interface development technology Ajax. One of the aspects of service-oriented architecture is Web Services techniques where the applications or services exploit services enabled by other applications using the information network.

***Mobile and positioning technologies (3)*** are mainly connected to mobile technologies which have been built to be used mainly in e.g. mobile phones and PDA terminals. These technologies include positioning technologies such as GPS (Global Positioning System) and GIS (Geographical Information System) solutions, mobile work and remote work systems through which, for instance, the borders between free-time and work are renewed and the possibilities for remote work develop (so-called mobile offices).

***Sensor technologies (4)*** are currently wireless at best. Their energy consumption and thus the need for maintenance has been constantly reduced, their reliability and durability are improving, they are starting to be mass produced and therefore affordable, they are constantly becoming smaller and their memory capacity is increasing. A central development direction is self-organisation of sensors in particular when forming sensor networks. Central sensor technologies on the sensor side are MEMS (microelectromechanical systems) and on the sensor network side Zigbee.

***Identification technologies (5)*** are related to identification of products and equipment, for instance in logistics applications. Examples of technologies used in identification are bar codes and RFID (Radio Frequency Identification) as well as visual tags (application of a mobile phone camera in identification).

*Scanning technologies (6)* are applied for instance in soil surveying and laser sensing of buildings. Solutions used in laser sensing include point cloud scans. The problem with point clouds is the large amount of modelling work as the only collected information is the coordinates of the measurement points and only visible parts can be processed. For instance, only the bottom of a pipe is measured. Another laser sensing solution is Lidar which means laser sensing from the air, i.e. so-called vertical sensing. For instance the City of Helsinki has Lidar material on the entire city.

*Smart materials (7)* include research and development work for instance in nanotechnology. Examples in the built environment include smart windows that alter the penetrating power of light and heat as the amount of sunlight changes. Managing the penetrating power of the window, for instance electronically (electrochromic window) develops the solution considerably. Also self-cleaning solutions have been developed for facades and windows.

The use of *open source technologies (8)* has increased in recent years. The market offers several platforms and solutions. In addition to individuals, an increasing share of companies are participating in the development work and instead of complete software solutions development work also focuses on tailoring. They enable flexible, problem-oriented solutions to questions through flexible solving methods. The main difference compared to commercial products is that there is no company responsible for commercial products and the central role is played by consultants that focus on problem solving and tell the companies what is possible and how the solution should be implemented.

## **Data communication**

The main challenge of *visualisation technologies (1)* is to combine static and dynamic information. Three main application areas were identified. In the first, *virtual reality*, the central feature is the vividness of the virtual model, which is affected considerably by the level of detail (ILOD) and used equipment solutions (such as PC-based and stand-alone computer systems) as well as the implementation environment (e.g. cave). Another visualisation solution is *augmented reality* that can be applied, for instance, when making 3D product catalogues where the virtual product can be viewed in an authentic environment. Virtual products are placed in a authentic environment using visuals tags or so-called markers. The third visualisation solution is *global 3D platforms* whose state-of-the-art level is currently represented for instance by Google Earth and Second Life. There are different types and levels of application technologies in use in virtual environments, such as VRML, 3D Studio, OpenGL and Ajax. Rapid development of the gaming industry has sped up the development of visualisation technologies.

**Short-range network technologies (2)** are used in implementing local services within a range of a few dozen metres. Solutions have been implemented with network technologies such as NFC (Nearfield Communication), Bluetooth and Zigbee. In connection with short-range network technologies a separate entity is sensor networks. They are implemented for instance with Zigbee technology that has become the official standard and whose biggest benefit is high fault tolerance.

Constant integration can be detected in **information network technologies (3)**. The main solutions currently are GPRS, EDGE, 3G, 4G, WLAN and Wifi. The need for Internet, other network solutions (such as corporate networks, grids, grid visualisation nodes) and mobile use may generate huge development steps in network technologies. An interesting solution at this time is Digita's free broadband connection that is based on Flash-OFDM (Fast Low-latency Access with Seamless Handoff Orthogonal Frequency Division Multiplexing) technology and has a very good range. An interesting future trend can also be seen in homes where the terminals that are being used are networking (such as digital television, mobile television, IP television) and promote convergence of information network technologies.

The central questions related to **data security technologies (4)** in terms of the built environment are related to security systems in different kinds of private and public buildings. Data security is a big challenge especially from a company's viewpoint as numerous users with varying user-rights are utilising different services. It is crucial to define in more detail who has the right to which information.

**Data sharing technologies (5)** are here defined as different data sharing channels, data sharing platforms and search engines. Examples of data sharing technologies related to built environment are model servers and project data banks that usually work on a file basis. Harnessing different kinds of science and development communities for application development may prove a central development engine for data sharing in the future. In the past decade the nature of programming has changed thanks to networked technologies and often the basis for an application can be development work performed by others as for instance different open source solutions can be downloaded from the web.

**Data transfer technologies (6)** include different kinds of data transfer formats. Different real estate and construction industry software programs use either their proprietary or open standard data transfer formats; often the dominating software vendor's format can become a so-called de facto standard. In general, open standards create both demand and supply which promotes networking and open cooperation. Because the array of formats used in the real estate and construction cluster is massive, conversion programmes between different software products and data transfer formats have been developed. Examples of different level data transfer standards are STEP (industrial

production), bcXML and IFC (buildings), LandXML (earthworks and route construction) and BACnet, KNX and LONWorks (building automation). One central development topic in data transfer is product libraries. Crucial in their development work is that the end result would be standardised and manufacturer-independent model structures. In the future it will also be possible to take into use product approval processes and model objects using approved, shared model structures described in product libraries. There are already some model-based product library solutions on the market.

*Electronic trading technologies (7)* are widely based on utilising existing technology solutions, such as data security, data network and data transfer technologies. From the viewpoint of the DigiBuild roadmap, the main challenge of electronic trading is to make the systems utilise product information portrayed for the construction industry, such as the as-built models (ProIT 2006) and to develop real-time reporting systems. Based on the above, evaluation methods that also cover use and maintenance in addition to design, planning and construction can be created.

#### **Short term (1–5 years)**

The short term prediction (1–5 year) is based on development trends detected in expert consultation, which in turn is mainly based on state-of-the-art technologies identified in the current situation. Their purpose is to develop digitalisation to better serve the users' needs.

**Information production and utilisation.** In the short term seven technology entities were expected to become more popular.

*Integrated information models (1)* have a significant potential which should be exploited when developing other applications to support building information modelling. Some development possibilities are life-cycle, simulation and analysis modelling technologies where the biggest challenge in the future is automation of the solutions. Data transfer between different software products is a central short-term development trend with the aim to converge information model technologies from file-based solutions to model server solutions. Integrated information models should also include product-specific information that is managed in the manufacturer's systems such as PDM systems (Product Data Management).

*New generation model servers (2)* is a development direction that is essential in the current situation. Current solutions are file-based, and their main problem is limited performance. One possibility of a solution to be developed in the future is a so-called view server approach which can create the desired, task specific views into the model information. The performance problem can be solved as the solution only uses the necessary part of the model (so-called 'model view'). One example of a partial model is

buildings' energy consumption; the calculation does not require knowledge of the details of all parts of the model, such as the colour of the walls.

***Reality modelling technologies (3).*** Examples of reality modelling technologies are creation of 3D models from photographs and algorithms with which objects can be recognised. Modelling is, in the short term, still at least partially manual work.

***Information utilisation and documentation technologies (4).*** These technologies use different utilisation methods for existing data, such as data mining applications and collection of tacit knowledge. There is a need to develop applications to transfer information that may be lost when generations change – there should be a way to transfer tacit knowledge from older to younger.

***User interface technologies (5).*** Developed user interfaces, interaction technologies that control the user when necessary are particularly on the rise. The use of different multimodal tools such as the data gloves is also increasing. Different types of training applications to make the implementation of new technologies and application technologies easier are also connected to user interfaces.

***Biometric and multimodal identification technologies (6).*** In biometric identification a person is identified by measuring the user's physiological or behavioural-related features. In multimodal identification, for instance, fingerprint and facial identification are combined. The main application areas for these technologies are security, safety and protection.

***Mobile indoor positioning technologies (7).*** These solutions enable positioning applications indoors. The data can, for instance, be connected to blueprints of the building, virtual models and the applications based on the building information model.

## **Data communication**

***Reporting and communicating systems (1).*** A central question in the short term is related to the identification of structures and systems that are suitable for control. For instance, simulation methods used in the planning phase can be used when verifying the condition of structures, collected data on the actions predicted by the simulation methods can be compared, and diagnostic methods that utilise the results of the comparison can be developed. Structure monitoring technologies can be used, for instance, in real estate and infrastructure reporting applications, as well as in signing off maintenance tasks. A central short-term development area is illustrative reporting technologies and presenting data with different types of visualisation tools etc. It is also important that a real-time reporting system is developed, so that data transfer and

reporting methods are linked into a seamlessly updated entity. In the short-term the role of sensor technologies becomes emphasised. For instance, RFID solutions are used to manage material flows. Different automated tools, workforce and storage control and maintenance techniques are also applied on construction sites.

***Open development communities (2).*** This refers to the execution of different types of solutions through a global network. The basis for development work is often development work done by someone else. It is predicted that the importance of open source applications will increase in the future, and decrease the gap to commercial software. Currently development is still carried out in limited development communities but already in the short term solutions developed by companies will increase.

***Open standards and interfaces (3).*** Here it is important to determine the product data model that supports the products' life-cycle and meet the data needs. Open standards and open interfaces between applications will be taken widely into use already in the short term.

***Social media and user involvement strategies (4).*** Social media applications are tools for communication and data sharing that apply the web 2.0 approach. Social media solutions are already used in different industries but currently they are not being utilised in the construction sector. In the short term, for instance, collection of user feedback and end-user data with social media tools is likely to become more common.

### **Long term (5–15 years)**

Long term prediction is especially hard when the assessment target is ICT systems and solutions. Usually the service life of software products is not even as long as the review period, which means that the assessment is made based on solutions that do not even exist yet. Long term expert opinions take a stand on considerable and central problems detected in the industry.

### **Information production and utilisation**

***Service-based application integration (1).*** Companies will demand flexibility from digital solutions in the future, as well as operational reliability. Therefore the applications will need service interfaces that serve different sectors and parties. Jointly agreed on interface standards and open source solutions are exploited in service interface development where applicable. In terms of development, it is crucial that the solutions enable flexible service utilisation. Service-based application integration generates new types of business models for software technologies.



*Context controlled systems (2)* that are fault-tolerant and able to utilise insufficient information. The systems are able to react to the environment in which they are used (ambient intelligence). One form of context control is presenting the same information from different viewpoints depending on who the user is.

*Smart reality digitising technologies (3)*. These are applications that can be used to model existing structures smartly and hierarchically. They need sufficient definition precision and easy implementation. Currently there are, for instance, on-going discussions about how to model the existing building stock.

*Customer-based solutions and decision support systems (4)*. These solutions offer the user the possibilities to gain access to information in the desired and required format. There are different types of reporting options that support decision making where the data has been processed into the required form.

*Self-configuring solutions (5)* can automatically configure to systems with a plug-and-play principle, e.g. in accordance with the profile of other equipment, software or the user.

**Data communication.** Three main development trends were recognised in data communication in the long term.

*Real-time information systems (1)*. The recognition of the main problem areas, development of monitoring and reporting systems and their control is crucial.

*Long term data storage solutions (2)*. The aim is to have systems where the stored data will be available at least 50 years from now. This requires the storage systems to be reliable, generic and upgradeable.

*Semantic web technologies (3)*. In a way this is the second coming of artificial intelligence. The technology required to implement semantic web already exists. In terms of built environment the semantic web contains, e.g. building information models.

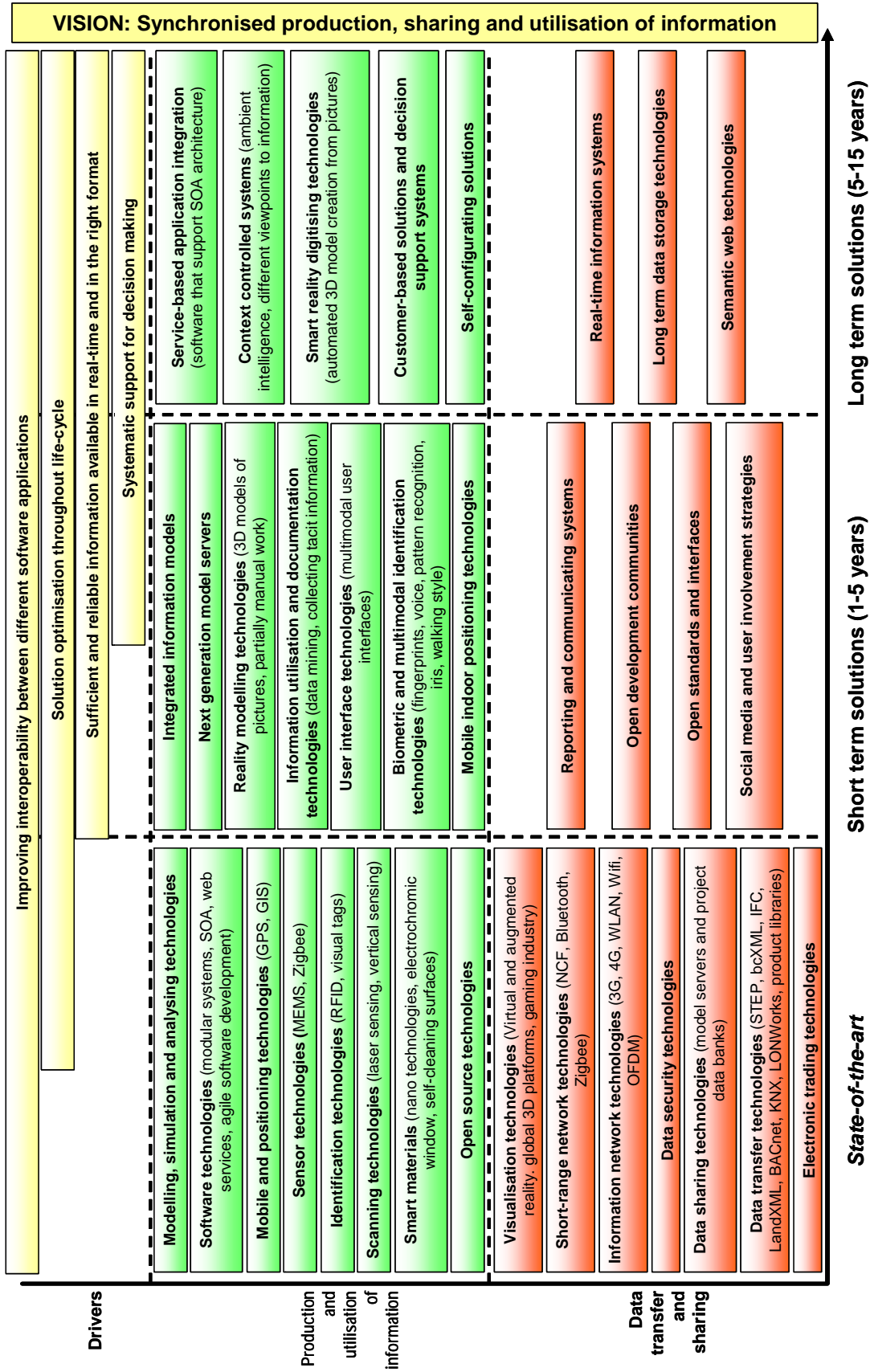


Figure 4. Change roadmap 1: Digital solutions.

### 3.3 Roadmap II: Operating methods and processes

**VISION:** Business operations are open, transparent and networked. This requires that the use of processes and operating methods based on the application of digital data are compatible.

The change roadmap for operating methods and processes is presented in Figure 5 and is discussed here in phases.

#### **Current situation (state-of-the-art)**

**Drivers.** The central starting point for drivers is currently that large actors – real estate owners, such as Senate Properties, constructions companies, such as YIT and Skanska, municipalities and software vendors – control the development direction with their actions. This structure has both positive and negative features: on the one hand certain development directions shared by large market players develop, but on the other hand the support from large players for some development directions can cause deadlocks and prevent new development directions from emerging. This means that the focus of large players and main customers are visible as a certain kind of “must” that needs to be answered. Players’ larger partnership networks are also central drivers.

Cost efficiency in production and development work is a central driver these days. In this case the key is the profit generated from the product in the short term, not the long term development needs or renewal of the product portfolio. Development work in the construction industry in particular is focused on safe development: development ideas can be taken to prototype stage but products are not often taken to the market. The situation is partially the result of meagre project resources for different types of construction industry projects. On the other hand, the problem is that in a broad sense the critical mass of the development industry for the built environment has not yet reached a size where there is a demand for new and possibly groundbreaking solutions.

**Markets.** The current market situation emphasises status quo thinking. Progressive demand is limited. In one-family houses, designers are not always even aware of progressive solutions because there is not enough information available. On the other hand there are not always products that would meet progressive demand either. The basis is that large players dominate the markets and their main interest is to guard acquired benefits. In addition, companies’ attempts to change operating methods are easily met with a landslide of negative feedback from different locations in the value network.

The construction industry is also conservative and sectored by nature. The central context for applying new solutions is the European market situation. The European

markets in the construction sector are small and closed. The same product cannot, due to national regulations, be offered to different national markets because e.g. climate conditions and regulations may vary immensely. The operating methods are based on established practices. A bottleneck for digitalisation in Europe is that ICT is not seen as a central production factor as it is for instance in the US. In addition, competition in Europe is more closed, and due the fragmentation the markets are smaller than in the US. Opening up competition in Europe is difficult. A technology that would open up markets, such as product libraries, might change the situation in Europe. Functioning international product libraries based on an open data transfer standard would be crucial for the industry. A company could use the library to sell product information impartially and independently of the manufacturers (an “Amazon” of the construction industry). The problem here is agreeing on international definitions of product information.

**Changes in operating methods.** Operating methods are relatively slow to change when it comes to the built environment. Implementation of information and communication technologies is slow and in this sense the learning process is challenging. Currently information model-based design, mainly 3D planning is however growing more popular on demand from large players. Even though information model technology is already applied to some extent, the parties’ processes do not yet utilise the potential of information models and therefore all the benefits of information model technology are not visible. The benefits of information and communication technology become most visible if the parties’ processes also support the efficient use of the technical solutions.

Information model-based planning (BIM, building information model) is still in its infancy and requires productisation. Information models could be utilised, for instance, in planning building maintenance and renovation – the information model can alert when the different parts of the building require repairs and in what order the repairs should be made. Information model-based maintenance log is this kind of an application.

**Technologies.** In current technologies that support change in operation methods, the weakest link is data transfer between different software applications when utilising digital data that can consist of e.g. an information model or real-time data. Some interfaces between the software applications communicate currently relatively well but new types of solutions have not yet been extensively implemented into systems. Therefore the players are using a large number of solutions that are difficult to steer towards a common information model. The current state-of-the-art sensor technology in built environments is passive and remote read sensors. These are already tested, for instance, in concrete damp measuring.

## **Short term (1–5 years)**

**Drivers.** In the short term the large players' channelling effect on development will continue, and cost efficiency remains as the key element. Long term planning carried out with strategy and simulation models is likely to become emphasised. A central short term driver is also that the role of consumers and end-users will become emphasised in the construction industry. The activation is already visible in consumer products. It is predicted that the field for activation will start expanding towards other industries and services. Activation of consumers goes hand in hand with companies' aim to expand their operations and gain customer loyalty.

In the short term consumer networking around certain themes enabled by social media and user driven solutions will also increase. This means that critical mass can develop around a certain theme virtually. Such emerging themes in the construction industry can be, for instance, a healthy house and a passive house. These kind of solutions can also be promoted with regulations and legislation. For instance, in energy solutions a certain part of the energy could be required to be produced with solar panels. These emerging themes will bring new product possibilities for companies.

**Markets.** In the short term the consumer's role is emphasised in market development. This is visible as mass-customisation of construction products. One market innovation could be "visualisation services for laymen" with which consumers could customise products. Another market innovation could be a type of test drive system for apartments (cf. model houses) where the purchase decision would not be made simply based on brochures and a couple of showings. The development is heading towards visual information model solutions.

In the short term network-like operation methods and market-oriented thinking become emphasized in the construction and real estate cluster and in producing built environment. The idea of branding and added value will become central in business models as well. An example of a networked operating process is "transillumination" of product manufacturing, which means that the manufacturing and structure of the product can be viewed virtually and openly.

In addition, risk financing and business angels are needed in the construction industry to increase resources both in implementing pilot projects and in taking the inventions created in the pilot projects to the market. Execution of larger and international projects also becomes a central development need in the short term. The European market situation, which is highly conditioned by public finance, is different compared to the situation in e.g. the US. On the other hand, in European politics execution of change is more rigid and the benefit may be that weak ideas never get implemented.

**Changes in operating methods.** In the short term the wider benefit viewpoint becomes emphasised in changes to operating methods. In order for new operating methods based on digital solutions to be taken into use, the players should understand the benefits from changing the processes. Organisations' existing power structures often prevent changes to operating methods. In owner-run companies changes to operating methods may be slightly easier. One idea may be to "test drive processes", i.e. process simulation where the benefits generated by a change in operating methods could be tested. This test drive and changing operating processes in general naturally require tools developed for operation planning. One such tool could be a workflow management system that would be a flexible base for process planning with a user approach. In this kind of system the processes should be modular and industrialised. Flexibility should be available in process interfaces in particular and the planning system should be highly fault-tolerant.

One basis for changes to operating methods in the short term is developing the channels of data transfer between different systems and between practices developed at different times and different organisational stages. This means that new operating methods should be able to internalise old, good and still relevant operating methods so that what still works needs not be remade and relearned. This requires an extensive system innovation approach: the built environment, digitalisation and organisations should be seen as a sum of extensively planned practices that have been formed in the long term, and that should be taken into consideration when promoting change to operating methods. Solutions that structure operating methods should thus be timeless, i.e. relevant practices should remain the same even when technologies change. The systems should also include handling of planning and real-time data. Currently real-time and design/planning data are highly separated but combining these views could generate completely new services.

A change in operating methods requires a lot of new kinds of education. The education should be process-oriented and aim at understating large systemic entities. Basic level training in information and communication technology is also required, as well as education to steer away from old operating methods. In order to develop new operating methods new concepts, terms and definitions should also be developed.

**Technologies.** The central development in technologies that support changes to operating methods is, in the short term, combining and comparing virtual models and reality. For instance, in excavation contracts mixed reality solutions can be increasingly exploited to support and make information from the real situation more effective. In the short term sensor networks will also be utilised more extensively in ICT applications for the built environment.

## **Long term (5–15 years)**

**Drivers.** In the long term a new driver will be consumers that learn to demand options and customised products. Cost efficiency maintains its role as an important driver for operations.

**Markets.** Mass-customisation will become a central principle of production. Production operations will become globally integrated so that large networks produce services for the built environment. A globally integrated cooperation model is created in design and planning, which some parties are already implementing. New players will appear on the market of built environment. As an example we can mention a vendor that offers virtual real estate services for monitoring and guarding of buildings.

**Changes in operating methods.** In the long term, a central factor supporting the change in operation methods will be the applications and tools designed for process management. The tools should be highly visual so that a clear visual picture on the company's processes and the share and stages of a certain function in these processes is available on the workstation. One should get a situation assessment of which processes are ongoing and which are not. In this sense control compares to a technical process control room that manages the processes of the organisation and the organisation networks. In network management the applications should clarify the role of each party as part of a certain process. There are already applications for these types of solutions in logistics, for instance tracking packages with RFID.

Another expected change in operating methods in the long term is connected to modelling the benefits and flows in networked operations. This is an operating model for virtual organisations where the aim is to model the incentives of company network players with the aim of moving from partial optimisation to full optimisation. Making processes parallel and commensurable can be illustrated, for instance, with business games. The aim is to make the benefits and profits of operations clearer to the players of an open value network. Basic research for these types of solutions is already done by several Finnish parties.

The third long term change factor is related to process simulation. Special simulation games could be used to model and train new processes. New simulation solutions try to simulate processes across company borders and connect simulation to non-recurring processes. Learning and predictive systems should be included in simulation models – they may work better in construction projects than traditional simulation.

**Technologies.** In the long term, a central technology that drives changes of operating methods is model server or data storage where the data and data processing are

separated. These information models are also mobile, so they can be flexibly applied in construction projects. Flexible application is enabled by automated information transfer between the information model and local situation. For example, the location of a pile can be adjusted based on local knowledge. In the long term, central technical solutions are in particular connecting the data transfer interfaces. This enables flexible construction of databases that combine both the history information in the register, and earlier collected data. In the long term, sensors become more common as a basic technology for building projects. Here passive, powerless and cost efficient sensors can be embedded into any space, for instance, in bathrooms and other spaces where moisture conditions should be monitored. Sensor networks can also be utilised in sensor network-based condition surveys.



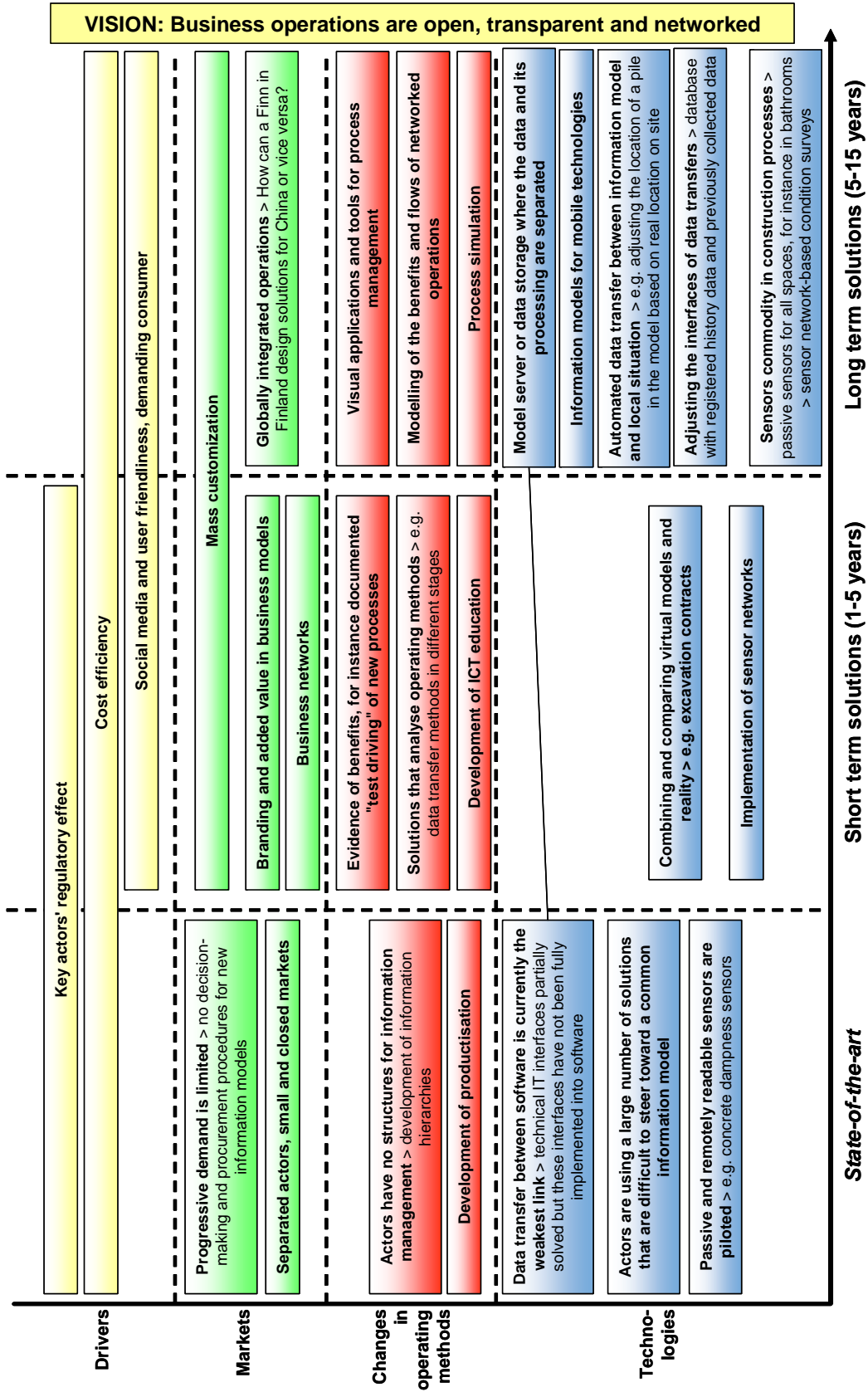


Figure 5. Change Roadmap 2: Operating methods and processes.

### 3.4 Roadmap III: Services

**VISION:** The importance of services will grow. Easier data handling creates and enables new services that are end-user friendly, easy, discreet and up-to-date for different user groups.

The roadmap for services is presented in Figure 6 and is here discussed in phases.

#### **Current situation (state-of-the-art)**

**Drivers.** The current central drivers in digital built environment services are security threats and development of measurement technologies (e.g. MEMS). Similarly the need to improve productivity and financial pressure as well as more efficient production will become more strongly emphasised.

**Markets.** There are services that exploit digitalisation in narrow niche sectors.

**Services.** Currently service provisions in the construction environment are narrow and directed at particular target groups. Services can be divided into six broader entities.

***Design, planning and contracting services before occupancy (1).*** The state-of-the-art factors of this entity are modelling services, (CAD) design and planning, checking services for model content and structures, and model checkers which can be used to identify the deficiencies in planning operations.

***Usage and maintenance services (2).*** These include remote maintenance services, measuring services (such as findings on a buildings subsiding based on a sensor network) and energy certificate services. Use and maintenance services can also be connected to services delivered to workplaces related to either private life or work, such as having daily shoppings delivered to the work place or masseur or barber services at the workplace.

***Visualisation services (3)*** can be related both to exploitation of static and dynamic information.

***Remote services (4).*** This includes, for instance, remote work services (for example, remote booking meeting rooms or arranging a meal), electronic food orders and remote healthcare services.

*Security services (5).* Security services include home security services including fire safety and break-in security, different types of water damage services, surveillance service and environmental safety services.

*New healthcare services (6).* These include different safety bracelets and sensor carpets.

### **Short term (1–5 years)**

**Drivers.** In the short term the central service driver is the aging population using aging buildings and aging infrastructure. Another factor that affects the production and determination of the built environment is the society's reactions and creation of regulations in issues related to the climate change. Technology solutions are increasingly enabling ubiquitous ICT which will support aging population continue living at home. The ICT services in the built environment can aim at certain needs and be correctly timed (JIT, Just in time).

**Markets.** Services are developed for different target groups, parties and networks (e.g. B2B, B2C, C2C, B2G, e-Government) utilising different virtual and networked operating models.

**Services.** In the short term, the following four service entities will become essential:

*Modelling services (1)* cover existing buildings and information model-based design and planning services for new constructions which will increase in the near future. Models will include new features like authority inspections and accessibility assessment straight from design which creates new needs for model service development. Another form of model services can be, for instance, publicly available database-based information from which the product specific data, such as maintenance instructions, can be used directly in the used media. A common product information format would enable an information brokerage service through which data from different sources could be distributed to be read and processed with different software applications.

*Data collection, maintenance and management services (2).* The central need in these services is connected to productisation and processing during the building's life-cycle. Potentially there are several service types. Services are needed to combine data derived from different sources, services to use the combined data for different purposes, service to ensure easy availability of data, services to process the combined data, to generate versions, to chart judicial responsibilities and to archive the data.

*Information-based added value services (3).* Analysing services can be related to simulation in terms of different operations and life-cycle stages. Another service is

information model-based maintenance and asset management. Analysing services will also include different types of remote diagnostic services, measuring services, position data services, condition services and design-build services. Analysing services for flood prediction and defining different functionality criteria for built environment will also be developed. There can also be services where different analyses are combined to a comprehensive package.

A central change in the analysis in the short term will be connected to the fact that analysing services involve predictive and forecasting informative features. These could for instance, be energy services, with which one could manage electricity consumption so that the user of the building would only have commitment or guarantee of a certain usage level. The system optimises the use of electricity within the chosen framework by removing electricity from a certain part of the building as needed. The service can also notify when it is most favourable to use sauna or wash laundry. Energy services could also include dynamic tariffs, which notify when the price of electricity exceeds a certain level and recommend alternative heating or electricity consumption options.

*Service integration (4)*, which can, for instance, be carried out by a networked virtual company. The service entity works on a so-called one-stop basis that includes an integrated user interface and overall management of the building. The integration service can also manage construction stage logistics. A house server can act as the implementation platform of integration services.

### **Long term (5–15 years)**

**Drivers.** In the long term the central service driver is also the aging population using aging buildings and aging infrastructure. Another factor that affects the production and determination of the built environment is the society's reactions and creation of regulations in issues related to the climate change. Technology solutions are increasingly enabling ubiquitous ICT which will support the service needs of the aging population. The ICT services of built environment can aim at certain needs and be correctly timed (JIT, Just in time). Productivity, cost-efficiency and effectiveness still play an important role.

**Markets.** Services are still developed for different target groups, players and networks (e.g. B2B, B2C, C2C, B2G, e-Government) utilising different virtual and network-like operating models.

**Services.** The services that will emerge in the long-term can be defined as four main entities.

***Real-time property information systems (1).*** This refers to an integrated system that combines measurement, cost, utilisation, consumption, maintenance, spare parts, condition, structure, etc. information into a managed whole. A real-time reporting service entity can handle, for instance, analysing of bathrooms in the same way as a car is analysed for service needs. If the system detects, for instance, water damage it will automatically shut down the water inflow. If, on the other hand, the system detects mould formation somewhere it will automatically contact the maintenance organisation. The real-time reporting system is controlled remotely through the web or mobile connections. The real-time system can also be applied in the construction stage. In this case the system combines automatic management of realisation data and construction control. The system will tell, for instance, how excavation should be done, or how pipes should be installed.

***Service based on integrated information models that support decision making and use (2).*** Services that support decision making and use applied multivariable decision-making systems. Several examples of these services can be recognised. The first one could be virtual environments for end-users. In this case the system could be used, for instance, to monitor the operations of a real and modelled system simultaneously. Such a system is already in use in, for example, nuclear power plants. Another example is a new type of stakeholder, a facilitator, who takes the user's needs towards implementation. The need for a facilitator grows because the customers' know-how compared to the possible solutions will narrow and demand for experts in procurement within a certain sector will be created.

***Experience and healthcare services (3).*** The experience services include, for example, different digital culture and art services, virtual walls and virtual travel. Colour therapy as well as water and temperature experiences can also be executed in bathrooms or in a "condition and experience room". An analysing toilet is also an example of new healthcare services.

***Automatic property assessment services (4).*** This service entity can include, for instance, assessment on the building's condition compared to the price, consumption information and information on different rating systems (e.g. LEED® Green Building Rating System).

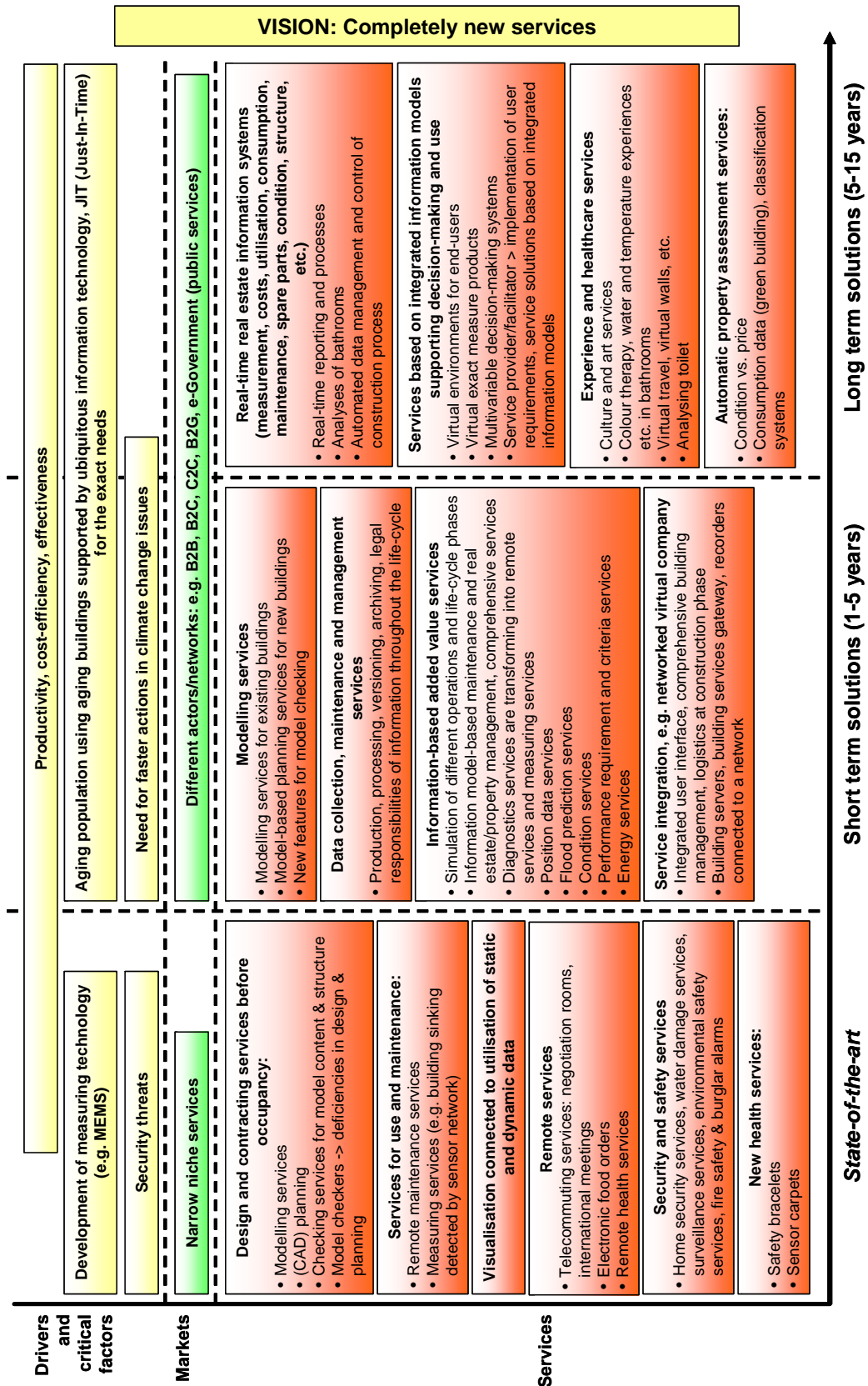


Figure 6. Change roadmap 3: Services.

### 3.5 Meta roadmap: Development paths of built environment utilising ICT

**VISION:** The technological foundation of the built environment utilising ICT is based on well-timed sharing and utilising of information. Business is done in transparent networks. This requires compatible processes and operation methods which can utilise commonly available interoperable digital information, such as information models and real-time information. These will fulfil the changing needs of the users and customers and enable good usability and real-time services.

The meta roadmap on the situation of first adopters is presented in Figure 7 and is here discussed in phases.

#### **Current status (state-of-the-art)**

**Drivers.** Currently the central drivers for built environment utilising information and communication technology are improvement of productivity, economy and efficiency. Efficiency and productivity are emphasised in particular in the operations of organisations, and increasingly also in the operations of the public sector. Another central driver is improving compatibility between different software products. In the short and long term this driver will strengthen as a background factor in ICT development. Supporting interoperability is strategically crucial for the industry because it helps to remove data transfer problems and improve productivity. The optimisation of solutions in relation to the changing needs of the built environment's life-cycle is also strongly connected to the ICT for built environments. The importance of this driver is also likely to increase in the future. Currently a central driver in the ICT for the built environment is development of measurement, sensor and network technologies, which enables more versatile applications in monitoring of the built environment, and as part of the infrastructure and control systems of the built environment. Another central driver in the current situation is security threats that are related in particular to monitoring the condition of the infrastructure, the physical safety of the built environment (e.g. break-ins) and data security.

**Markets.** The current market situation in information and communication technology of the built environment can be described in terms of progressive demand still being limited. Progressive demand is a central issue for the development of ICT for the built environment because these are solutions that are not yet widely used, require significant investments in the beginning and will replace many solutions that are currently in use. The situation is partially a result of the fact that producers and exploiters of the ICT for the built environment are differentiated into narrow categories. This differentiation is also promoted by sector specific education and training systems that do not discuss

about the problems related to system integration or approaches that would combine the producers and exploiters. The limited progressive demand and educational content has led to a situation where service producers offer narrow niche services only for limited needs.

**Services.** Six current central ICT state-of-the-art service entities in the built environment have been identified (see Roadmap III, section 3.4). The first one is *design, planning and contracting services before occupancy*. The second is *use and maintenance services*. There are already relatively progressive services available currently in both of the above categories. The services operate, however, on a niche basis: design, planning, contracting, use and maintenance are mainly separated services and they are not, for instance, based on a common information model. *Visualisation services* can be related to utilising different types of information. *Remote services* can, for instance, be different system monitoring tasks, remote work services, electronic food orders and remote healthcare services. In *security and safety services* monitoring and guarding services that exploit ICT are already used quite widely. Other security and safety services include home security services including fire safety and break-in security, different types of water damage services, surveillance service and environmental safety services. In the near future security services may also refer to data security. *New healthcare services* are new types of home and remote care concepts which can be based, for instance, on a safety bracelet or sensor carpet.

**Operating methods.** At the moment, the processes used by operators do not yet correspond to the potential of modelling applied in the ICT for the built environment. This leads to a situation where model information cannot be fully utilised in the planning and realisation of operations. Another area of change for operation methods is the development of commercialisation in both technological solutions and in the services packaging them. ICT for the built environment is in the future increasingly tied to different service concepts and this development requires a wider understanding of productisation.

**Technologies.** The ICT for the built environment are based on solutions for data production and utilisation as well as data transfer and sharing. Current state-of-the-art solutions are related to modelling, simulation and analysing technologies, mobile and location technologies, software, sensor, identification and scanning technologies, smart materials and open source technologies (see Roadmap I, section 3.2 for detailed descriptions). In data transfer solutions the key role is held by visualisation, information network, data security, information sharing and data transfer technologies as well as electronic trading technologies (see Roadmap I, section 3.2).



## Short term (1–5 years)

**Drivers.** The central short term drivers for built environment utilising information and communication technology are already partially visible. Productivity, economy and efficiency will be central drivers both in the short and long term. Another currently central driver, improving interoperability of software products, will increase its importance in the short and long term. Similarly optimisation of solutions in relation to the changing needs of the built environment's life-cycle will become more important in the short and long term. In the short term we also recognised new, increasingly important drivers. These are an aging population in aging buildings and adapting to climate change.

**Markets.** There are development paths on the market that open doors for development of integrated information models. Concepts based on integrated information models can combine products and services in a new way. Another development path that will become emphasised in the short term is user-based content development, which will also increase in the services for the built environment. In the short term the operating methods of networking will become emphasised in the construction industry. In the short term, services are developed for different target groups, players and networks. The aforementioned development paths will lead to a situation where companies that produce services related to ICT for built environment will operate as part of value networks based on information models. The ability to bring out new products and services, and the ability to adjust the company's competences to this value network structure are central competitive factors in the future for companies that produce solutions for the built environment. From a development viewpoint the markets have a problem in the fact that the ownership and use of buildings is highly separated, and real estate often forms portfolios whose manager is not necessarily interested in developing the use of the building or its economic efficiency in the long term. Climate change can be a driver that also affects the owners' attitudes.

**Services.** In the short term the following four service entities are important (see Roadmap III, section 3.4). *Modelling services* cover existing buildings and information model-based design and planning services for new constructions which will increase in the near future. The models will also enable new functionalities like authority inspections and accessibility assessment directly from the plans. *Data collection, maintenance and management services* are essentially related to the production and processing of data during the building's life-cycle. In order to be realised these types of services also require input from the public administration and centralised control and uniformity in different municipalities' requirements. Potentially there are several service types. Services are needed, for instance, to combine data from different sources, to ensure easy accessibility of data and to process combined data. *Information-based added value*

*services* include analysing services that produces added values. Analysing services can be related to simulation in terms of different operations and life-cycle stages. Analysis services also include different types of remote diagnostic, measuring, position data, condition and design-build services. *Service integration* can, for instance, be carried out by a networked virtual company. The service entity works on a so-called one-stop basis that includes an integrated user interface and overall management of the building.

**Operating methods.** In the short term, customisation throughout the life-cycle of the product is emphasised in changes to operating methods. This means that service concepts will increasingly emphasise long term aspects, and also adjust these long term options to the customer needs. Therefore, companies' business model will change in the future: instead of the old way of a product that is sold once, long term concepts are sold which mix material products with intangible services that support the product. This does, however, require a change to current practices in which the property owners avoid committing to builders and suppliers in terms of life-cycle services. There has also not been required expertise among builders and product suppliers. One example of an implemented concept in building services is, however, elevators that currently are sold so that the concept includes the actual elevator as well as related maintenance and repair services. In the short term the understanding of the benefits of integrated information models from the viewpoint of different stakeholders is also emphasised. The stakeholders must understand the benefits from changing the processes in order to take new operating methods based on digital solutions into use. One idea may be to test drive processes, i.e. process simulation where the benefits generated by a change in operating methods could be tested. The third central development path leads towards solutions with which the parties can seamlessly and in real-time monitor project information.

**Technologies.** Solutions for data production and utilisation are based on utilisation of integrated information models, new generation model servers, industrial modelling, information utilisation and documentation, user interfaces, biometric and multimodal identification technologies and mobile indoor positioning (see Roadmap I, section 3.2). In data communication the solutions are based on reporting and communicating systems, open development communities, standards and interfaces as well as social media and application of solutions based on user involvement (see Roadmap I, section 3.2).

### **Long term (5–15 years)**

**Drivers.** The main long term drivers in the built environment utilising information and communication technology are mainly the same as in the short term.

**Markets.** A globally integrated cooperation model is created in planning which some stakeholders are already planning. Mass-customisation will become one of the central

principles of production. Production operations will become globally integrated so that large networks produce services for the built environment. The end-user is tied to the whole design and planning process by offering different mechanisms for visualisation, modularisation and giving feedback.

**Services.** Services arising in the long term can be defined in four entities (see Roadmap III, section 3.4). *Real-time real estate information systems* refer to an integrated system that combines measurement, cost, utilisation, consumption, maintenance, spare part, condition, structure, etc. information into a managed whole. A real-time reporting service entity can for instance handle analysing of bathrooms in the same way as a car is analysed for services. *Services that support decision making* apply multivariable decision making systems. At least two examples of such services can be identified: virtual environments for the end-user, and new types of stakeholders that customise products according to users' needs. *Experience and healthcare services* can be executed in different ways, as an example different digital culture and art services, virtual walls and virtual travel can be mentioned. *Automatic property assessment services* can for instance include assessment on the building's condition compared to the price, consumption information and information on different rating systems. Even though people have an emotional approach to buildings and homes in particular and they are mainly assessed on other basis than technical data it is still important to have this type of information to support decision making.

**Operating methods.** In the long term, a central factor supporting the change in operation methods will be the applications and tools designed for process management. In this respect, the key solution is found in the applications that exploit visualisation and information models, and can officially be used as references for building inspections. With visual applications a clear visual image of the company's processes and the share and stages of a certain function in these processes is available on the workstation. The exploitation of information models in product design, planning, implementation and use is based on utilising virtual measuring accuracy. New kinds of service providers may also be established for the services that exploit information models and integration.

**Technologies.** The solutions for data production and utilisation are in the long term based on service-based application integration, context controlled systems, smart digitalisation of reality and customer-based decision making supporting and configuring solutions (see Roadmap I, section 3.2). Data communication solutions are based on real-time systems, long term data storage and semantic web (see Roadmap I, section 3.2).

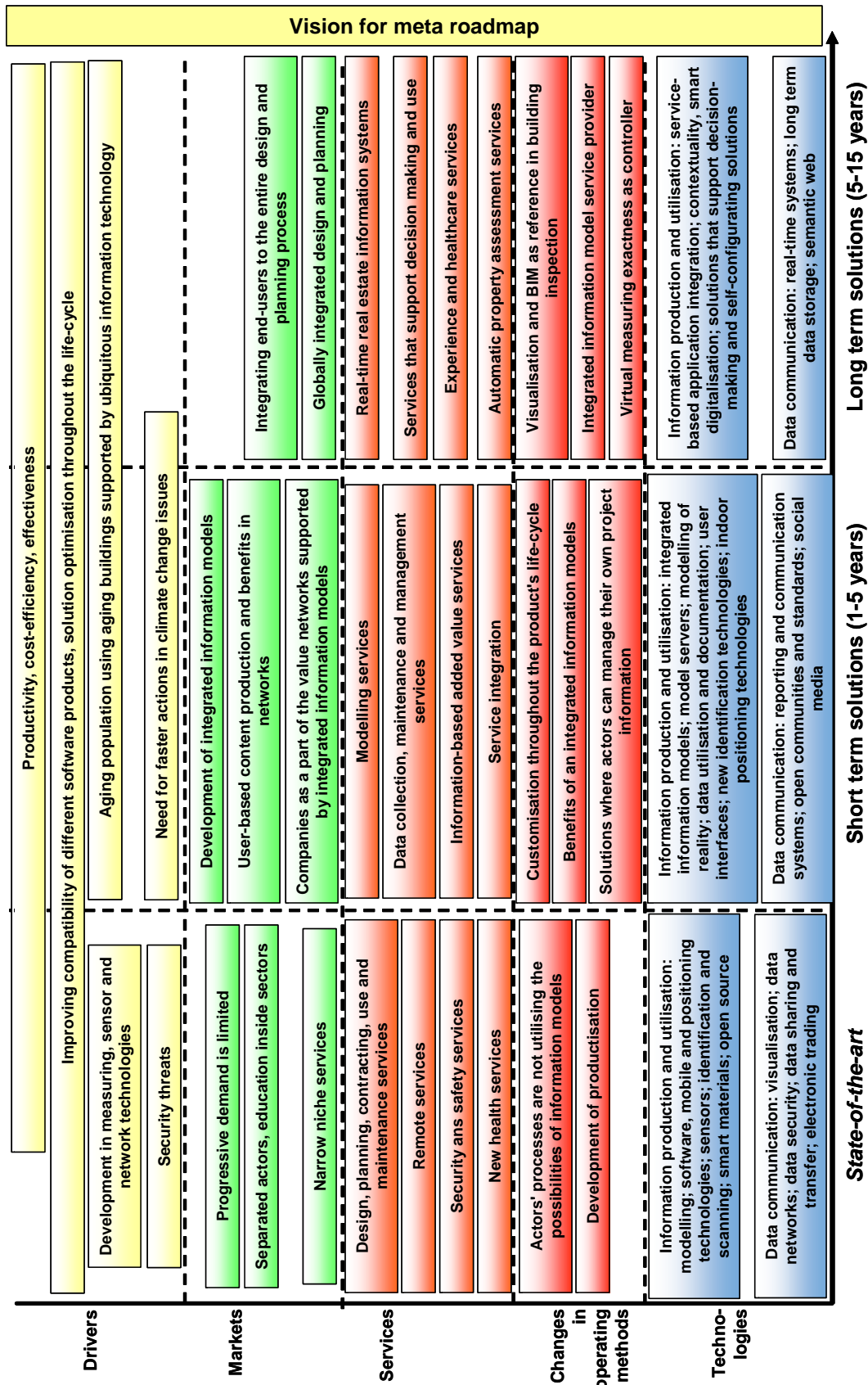


Figure 7. Meta change roadmap.

## 4. Service and action examples

This chapter presents some concrete ideas and examples of how ICT could be exploited in the digitalising built environment.

### Case: Web portal to market services and processes

The informative and easy-to-use portal is directed at the needs of consumers and construction industry professionals. The services offered by the portal are used over the Internet (Figure 8) and they are so simple that potential customers can start using them as a self service. The service tray, however, also includes advanced services and their use requires expert support from e.g. VTT. These expert services include recognition and visualisation of consumer needs, technical and financial comparison of alternative solutions and dialogue between the customer and supplier.

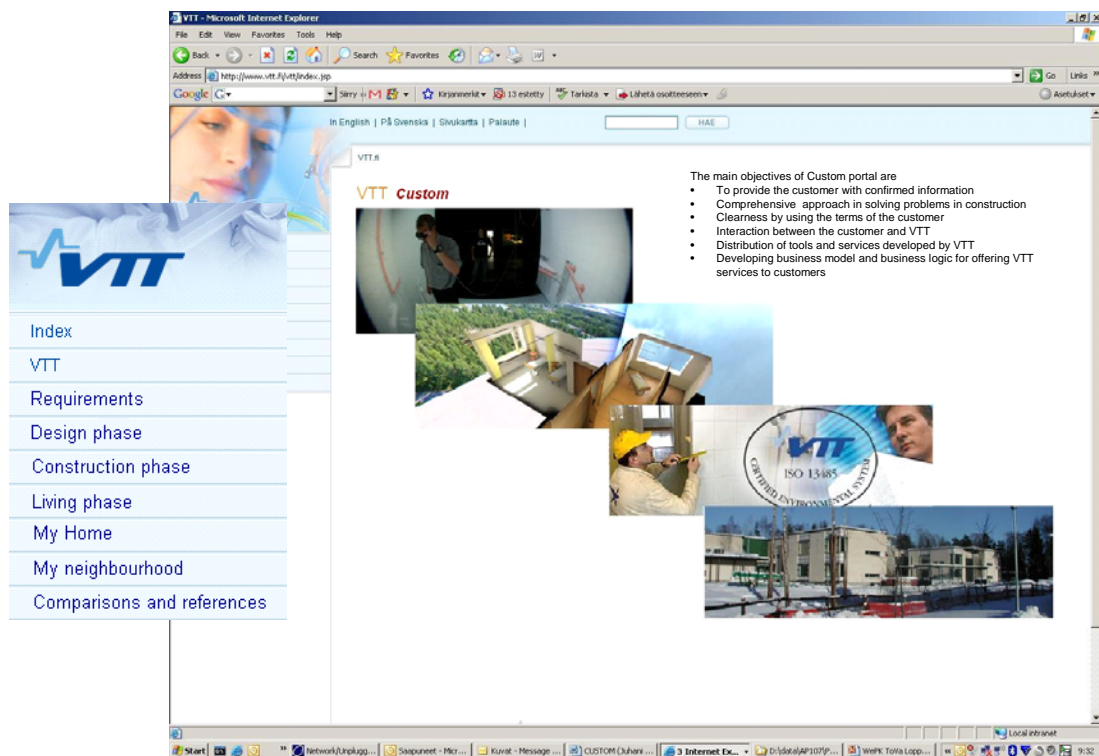


Figure 8. Web portal for analysing and comparing alternative solutions in the building sector, and for dialogue between consumers and construction industry professionals.

#### Property owners and end-users

- get impartial and clear information to support their decision making
- recognise potential product suppliers and service providers
- get concrete predictions on the management of weather conditions, energy consumption and life-cycle costs.

### *Service providers*

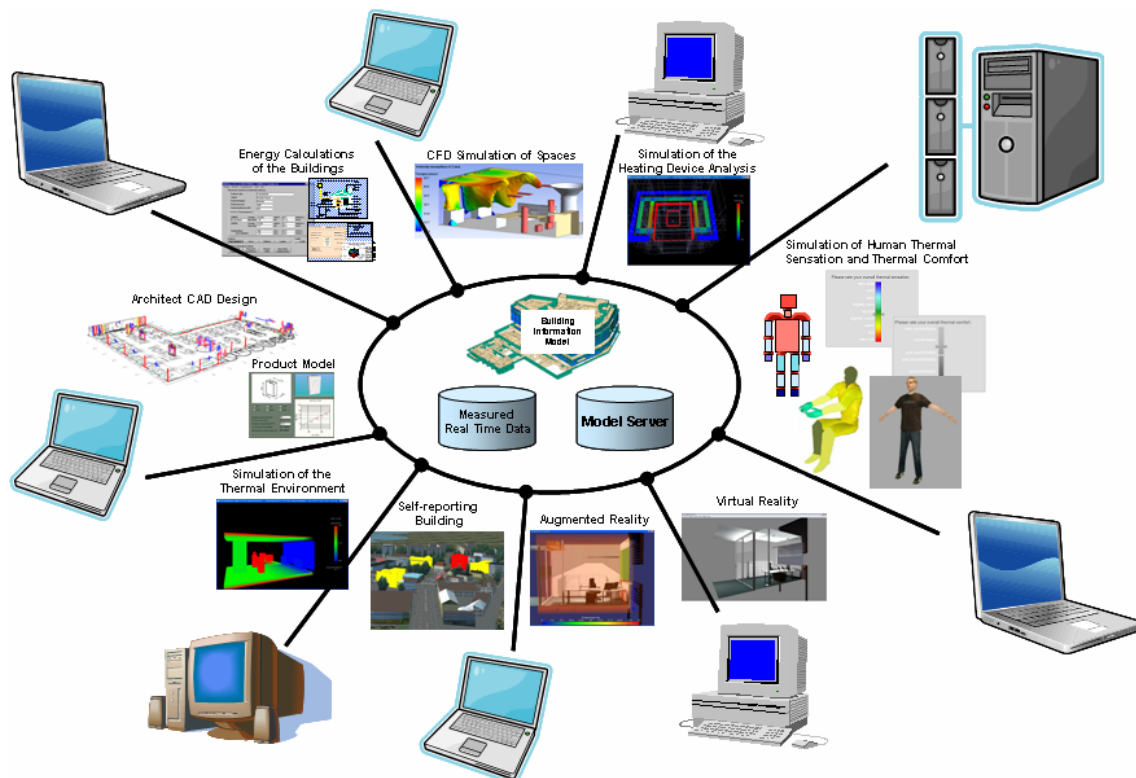
- can cost effectively offer their services in heavily growing supplier markets
- get new and impartial information about the newest development trends in the real estate and construction industry
- ensure their own role on the emerging network markets.

### *Material and product suppliers*

- can offer certified information about their product for decision making during design, construction and use
- get extensive information about customer needs to develop their operations
- can develop their own operating methods for networked business operations.

### **Case: Virtual Building Environment**

This example describes some factors related to the building's life-cycle that affect the sharing and utilisation of digital data and information between different applications and for the needs of different parties. Figure 9 illustrates different applications and needs related to data sharing and utilisation.



*Figure 9. Sharing data and information between different applications.*

A lot of different information is created and needed during the life-cycle of a building. It is essential that all applications and parties do not need to know everything. Different applications and parties need only parts of the integrated information models. For instance when calculating the energy consumption of a building information on the colour of the walls or shape of door handles is not required. Thus different applications and parties only need view of the database and not all integrated information.

Similarly different calculation applications need simplified information on the building's geometry which would require tools for simplifying geometric data.

A construction projects is a joint project between different organisations. Checking gates are needed inside the organisations to manage different versions, validate updates and ensure the correctness of information. This would be a so-called building secure operation.

Building maintenance requires its own view of the information models. Maintenance services should have feedback loops to the maintenance company's other objects. If, for instance, the change interval of light bulbs is unusual in one object the maintenance company should consider whether there is a reason behind this that could be fixed. It is also crucial for maintenance services that history and other similar data is transferred to the new company when the maintenance provider is changed.

*Service:* The data management, revision and collection for the needs of different applications, users and parties described above could be handled, for instance, by a virtual company. This would be a service company that would operate in the sector of *digital data management throughout the building's life-cycle*.

## 5. Conclusions

### 5.1 Summary on roadmaps

The vision of development prospects in the built environment utilising information and communication technology can be summarised as follows:

The technological foundation of the built environment utilising information and communication technology is based on well-timed sharing and use of information. Business is done through networks. This requires compatible processes and operation methods which can utilise commonly available interoperable digital information, such as, information models and real-time information. These will fulfil the changing needs of the users and customers and enable good usability and real-time services.

Current state-of-the-art solutions for ICT for the built environment are mainly separate services. Progressive demand is still limited and the suppliers and exploiters of ICT for the built environment are differentiated into narrow segments. The limited progressive demand and education has led to a situation where service producers offer narrow niche services for limited needs. Currently there are four state-of-the-art service entities: 1) design, planning, construction, operation and maintenance services; 2) remote services; 3) security services and 4) new health services. At the moment, the processes used by operators do not yet utilise the potential of information models applied in the ICT for the built environment. This leads to a situation where the benefits of information models cannot be fully realise in the design, planning, construction and maintenance operations. Another area of change for operation methods is the development of commercialisation in both technological solutions and in the services packaging them.

In the short term (1–5 years) the development path of information and communication technology in built environment will lead towards exploiting integrated information models. Concepts based on integrated information models enable new ways to combine products and services. However, the application of information models requires that the integrated information models are understood and explained from the points of view of different operators. Products and services utilise user-oriented content production. The services for the built environment are produced with different networked operation methods. In the short term, the essential factors will especially include the following four service entities: 1) information model services; 2) data collection, maintenance and management services; 3) information-based additional value services and 4) the integration of services. The application of ICT for the built environment emphasises the value of and services targeted at the whole life span of the product. This means that service concepts will increasingly emphasise long term aspects and also adjusting these long terms options to the customer needs.



In the long term, i.e. 5–15 years, the formation of globally integrated operation models will start in planning and production, and large networks will produce services for the built environment. The end-user will be served in the whole design, planning and construction process by offering different mechanisms for visualisation, modularisation and giving feedback. In the long term, the following service entities in particular will increase: real-time real estate information systems, services supporting decision-making and operation, experience and health services and automatic property assessment services. In the long term, a central factor supporting the change in operation methods will be the applications and tools designed for process management. In this respect, the key solution is applications that utilise visualisation and information models and can officially be used as references for building inspections. New kinds of service providers may also be established for the services based on integrated information models.

## 5.2 Future challenges

This section includes thoughts that were voiced in the workshops, and to which resources should be focused in the future in digitalising the built environment.

It is crucial to *gain better control of the built environment for instance through digitalisation*. In this context the highly different life-cycles of digital information and buildings or properties must be considered. It must be defined how the information will be accessible and how design/planning and real-time data and the related models will be combined. How will version handling and updates be handled? It must also be decided who will have the access to the building or real estate information and how it can be used.

*Simulation and visualisation software* are needed to which all stakeholders can create new information and all can take a stand to. The implementation solutions could be for instance collaborative (web-based) tools that enable the customer's involvement in the design and planning process. The approach must be wider than merely the construction and operating environment. Simulation and visualisation environments should shift from “design for maintenance” thinking also towards “design for information maintenance” thinking. This would mean that the information structures should also be saved and stored.

*New solutions* are also needed for *change in the use of the building and towards the end of the building's life-cycle*. These solutions mobilise users to bring forth information about the use of the building and its systems and detected defects. In this case *the end-user would have a view of the house* and he/she could easily give feedback. It is also important to recognise the *real needs of the end-user and customer*. The final payer may be left aside, if engineers develop devices and applications for each other. It is essential

what information the end-user needs to increase his/her knowledge. An operating method where different stakeholders could access information that is essential to them must be developed. *Information and communication technology* can also be utilised in *building demolition and material recycling*. For instance a model on how a building is to be torn down and how recycling is taken into account in the demolition could be developed.

*Industrialisation of the construction industry* is a necessity. Industrially pre-manufactured products and solutions and processes that support them are needed. There should be template solutions where an individual house or partial solution can be configured. *Information model-based tools* are needed to support industrialisation. These help plan processes and monitor the realisation of the design in the field. In addition *development of information architecture deliberation* and *the management method of information model-based construction projects* are needed. Also the evolving roles between the designers must be redefined.

*Education and training* must be rethought. The “now I am ready” approach should be changed into a *process of continuous learning*. For instance a *Building Informatics* training programme could be established where the main thing would be a shift from the 2D document world to the 3D information model world. Similarly extensive *educational and training packages* should be developed for the industry. There could be, for instance, a demonstration room or environment where companies could demonstrate their applications or train potential users. There should be a data accumulation mechanism in the demonstration room which could be applied and that would enable commenting from the end-user.

### **5.3 Main development paths**

At the end of the publication the following five elements, which based on the roadmap process can be considered the main future development paths of built environments exploiting ICT, are presented:

1. The amount and exploitability of digital information in the built environment will increase. The precondition for exploiting the potential is that tools, operating methods and processes for data management, analysing and efficient decision support are developed.
2. The development of information models, calculation and simulation methods and computing performance will enable more versatile virtual testing of products. Technical features and products’ usability can be tested and verified before manufacturing and use. In this case different parties, including the end-users, can be involved in the test use.

3. The digital and physical world will be interconnected during the whole life span of a product. The information related to the product and its handling techniques will become part of the product: product information, measuring, control, adjusting, simulation and usage history are connected to the product. This will affect the development of both ICT and products.
4. Service-based software integration, context-aware systems, social media and location technologies will enable services that are automatically tailored according to users' needs in the built environment.
5. Information modelling of the existing building stock will be a huge challenge. It requires development of methods and technologies. However, it is a mandatory task since the progress through new construction only would take approximately 50–100 years.

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# Appendix A: Working process

## The objectives of the DigiBuild roadmap

The objective of the “DigiBuild (Open Integrated Digital Built Environment) Roadmap” is to make a technology and market roadmap on the built environment exploiting ICT that includes a VTT wide view.

The data collection stage and the recognising of the technology outlook connected to making the roadmap were carried out in workshops. The roadmap was made using the VTT format.

## Building the roadmaps – workshop work

The “DigiBuild Roadmap” project was carried out in three stages (Figure A1). The first stage was analysis of background material where the core team of the project made an extensive analysis of roadmap and prediction projects within the field (Appendix B). In addition, more common extensive prediction projects were analysed. Based on the analyses, central change factors that affect roadmap work were recognised and a preliminary list on societal drivers was compiled.

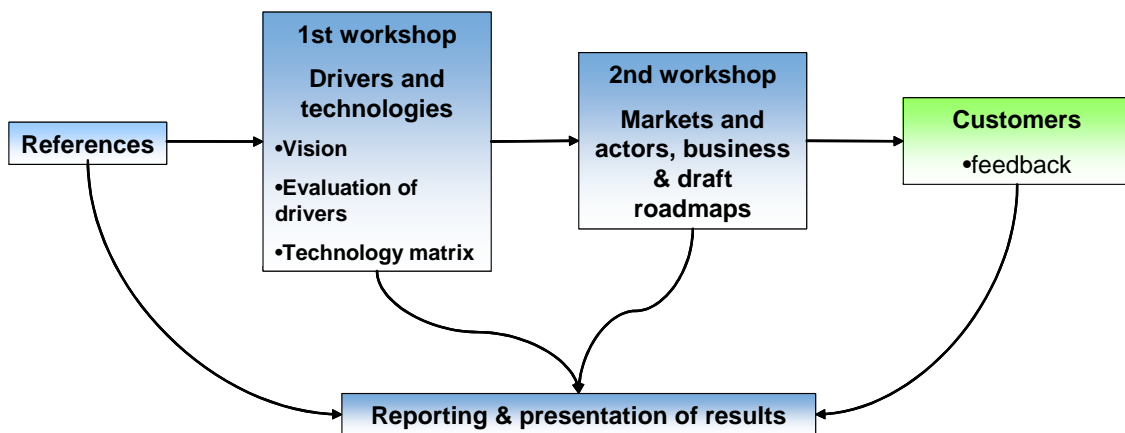


Figure A1. Roadmap project structure.

### First workshop: drivers and technologies

The actual workshop work started by analysing and assessing the predetermined vision presented next.

**VISION:** Companies in the real estate and construction industries shall be able to share and/or exchange electronically the information needed to design, build, operate and maintain buildings – and built environment in general – using internationally accepted standards.

For instance the following comments were made on the vision:

- The following should be added to the vision
  - customers and public authorities
  - stakeholders.
- The vision should also cover infrastructure, i.e. it should be visible as a word in the vision.
- A PLM approach should be part of the vision. The need of data copying and compatibility should maybe be taken into consideration because laborious “hand copying” is still required in data transfers between different systems.
- How is the virtual organisation visible in the vision? For instance 20 years ago the topic was “soft buildings” and “soft plans” that would be compatible, easily adjustable and flexible. However, they are not yet that in reality.
- Digitalisation is an opportunity for companies to become organised and execute projects in a new way. This is a new business dimension.
- Life cycle engineering could be visible in the vision.
- It may actually be that all companies do not really want an open integrated environment because they want to dominate the market.
- The vision could define the group to whom the vision belongs and what everyone does. This way there are no “locks” in the vision.

In the second stage of the first workshop societal drivers were assessed. Driver assessment was based on the driver list prepared by the core team based on its background analysis, which had been made based on the drivers presented in the background material (Appendix B). At the same time the drivers were prioritised based on the future of the digitalising built environment in order to form a picture of general changes. In connection with the prioritising the main drivers were deepened by describing the essential future challenges caused by the drivers.

In the third stage of the first workshop central technologies in terms of the future of the digital built environment and issues that affect the technological development were recognised with a technology matrix. The core team built a generic way to specify built environments exploiting ICT that was used as a basis for the work. This meant that the topic was divided into the following three areas:

1. Digital solutions
2. Operating methods and processes
3. Services.

The topics were analysed in relation to three defined technology maturity stages. The first maturity stage applied in workshop was current state-of-the-art applications. They were defined to mean the best current applications that are already in use among leading players and companies. The second technology maturity stage was emerging technologies. Emerging technologies referred to technologies that will be taken into use in the near future (1–5 years) and replace state-of-the-art technologies or take operations in a new direction. The third definition referring to the maturity stage of technologies was technologies in R&D phase. They were defined as follows: technologies that are currently in the research and development phase but whose effects cannot yet be properly predicted, and whose potential implementation will take place in the long term (5–15 years).

### **Second workshop: roadmap ideas**

Based on the results of the first workshop roadmap ideas were compiled to be processed in the second workshop. There were three main ideas and they followed the division of the first workshop: 1) Digital Solutions, 2) Operating Methods and Processes and 3) Services. The aim was to sharpen the elements of the roadmap ideas and define the connections between the different elements. The purpose was to develop the roadmap ideas as far as possible towards the final roadmaps.

The vision connected to each roadmap idea was considered or specified. Because the roadmap ideas had slightly different structures specifying questions were also asked regarding them.

The roadmap idea for Digital Solutions was considered from the following viewpoints:

- What is the relation between the presented digital technologies to possible future service concepts? What kind of technologies should be developed to enable a particular service?
- What are the strong links and main connections between the technologies?
- What are the most applicable development paths of the digital solutions?
- What are the possible transition factors of the digital solutions?

In the Operating Methods and Processes roadmap idea group work focused in particular on operating methods' change process and possible networking of the parties and new parties. The roadmap idea was considered from the following viewpoints:

- What are the main changes in operating methods and processes that will follow from application of digital solutions?

- How far does technology control the processes?
- What new business opportunities or service operations does the change in operating methods cause?

The Services roadmap idea group focused on defining the vision and sharpening of business viewpoints. The roadmap idea was considered from the following viewpoints:

- Which services and operations could have business opportunities? For what purpose?
- Which stakeholders or networks are potential exploiters of the services?
- What kind of new players or service providers can arise? There are market vacuums in the current situation that offer room for new parties and operating methods, for instance data management or modelling.

Based on the updates made to roadmap ideas the final roadmaps were compiled as well as a meta roadmap that summarises the partial roadmaps. The structure of the meta roadmap followed the general structure presented in Figure A2.

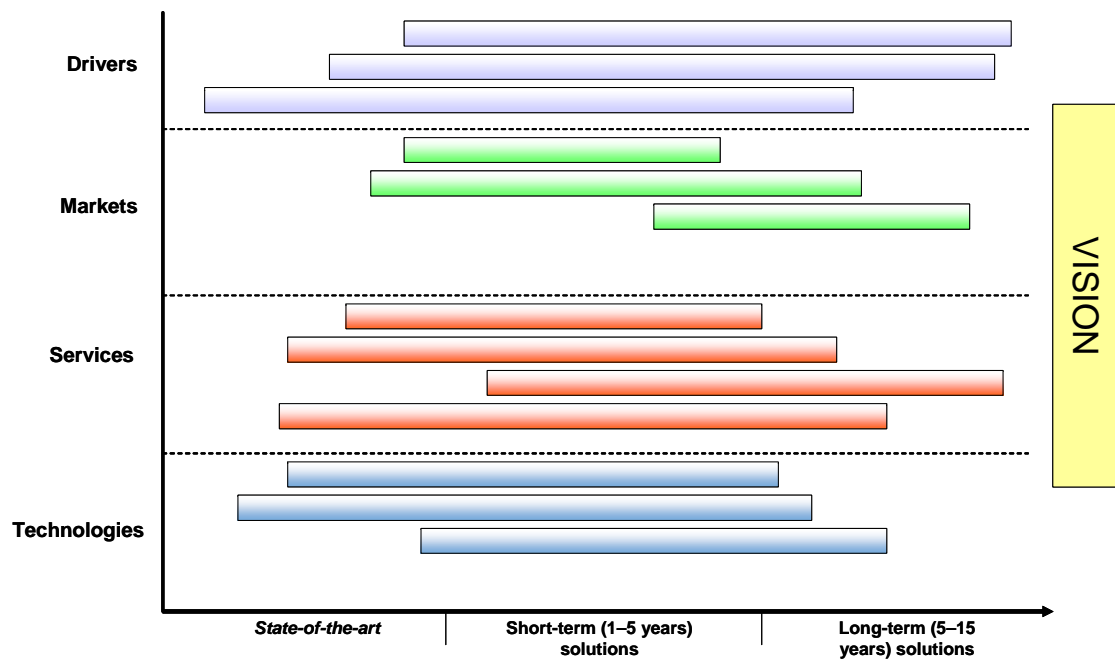


Figure A2. General structure of the meta roadmap.

At the end of the second workshop a free-form discussion on the future challenges of built environments utilising ICT was held. Each workshop participant had a chance to say where he/she would invest 10 or 100 million euro within areas of the DigiBuild theme if he/she could freely choose the main development targets.



## Appendix B: Summary on background materials

Extensive background material was utilised in the project. The material was divided into two parts: change factors and roadmaps. Table B1 lists the headlines of the material analysed that is presented in more detail later.

*Table B1. Division of background material.*

Change factors	Roadmaps
<ul style="list-style-type: none"> <li>• FinnSight 2015</li> <li>• NeoClusters</li> <li>• Rakesa</li> <li>• Roadcon</li> <li>• Vision 2010</li> <li>• Expert workshop arranged at VTT</li> </ul>	<ul style="list-style-type: none"> <li>• Building services roadmap</li> <li>• Coconet</li> <li>• EXERGAME</li> <li>• Fiatech</li> <li>• MOSAIC</li> <li>• Moses</li> <li>• PATH (2 versions)</li> <li>• PeBBu</li> <li>• Rakesa</li> <li>• Roadcon</li> <li>• Strat-CON</li> <li>• TUPAROAD</li> <li>• Vomap</li> </ul>

### Change factors

At the beginning of 2005 the Academy of Finland and Tekes launched the **FinnSight 2015 Prediction Project** (FinnSight 2006). The aim of the project was to examine future know-how needs in science, technology, society and economic life. Prediction was carried out in ten panels, in which experts from research and industry brought diverse competences and broad views to the discussions. In total 120 top experts participated in the panel work and, including their networks, the views from several hundred experts were utilised in the prediction. Table B2 shows the general change factors presented in FinnSight 2015 prediction and change factors in the information and communications sector that were seen as most likely and most important.

*Table B2. General change factors and change factors of the information and communication sector presented in the FinnSight 2015 future report.*

<b>General change factors</b>	<b>Change factors in the information and communication sector</b>
<ul style="list-style-type: none"> <li>• Globalisation</li> <li>• Population changes</li> <li>• Science and technology as a driver</li> <li>• Sustainable development</li> <li>• Changes in know-how</li> <li>• Changes in work and people's mental resources</li> <li>• Changes in the cultural environment</li> <li>• Control and safety</li> </ul>	<ul style="list-style-type: none"> <li>• Globalisation, becoming more common and comfort orientated</li> <li>• Technical convergence of mediums</li> <li>• Growth in entertainment and experience industry</li> <li>• Web-based society</li> <li>• Finnish know-how and education</li> <li>• Opportunities in Russia</li> <li>• Increase in computing power and capacity</li> <li>• Increase in software complexity</li> <li>• Ubiquitous information and communication</li> <li>• Interaction between humans and machines</li> <li>• ICT and biotechnology</li> </ul>

The **NeoClusters** project analysed the trends in the real estate business and the new opportunities offered by clustering in buildings and technology business (Kanerva & Paloheimo 2005). In the first stage the project focused on domestic real estate and ICT markers. In the second stage the project made a comparative analysis of the current trends in the US markets, investigated the trends and best practices in Asia, and presented some R&D ideas. The following were seen as central trends

- globalisation, the growing role of Asia
- new strategies in old industrial countries: customer orientation, service business, networking & new and wireless ICT applications.

The **Rakesa** report recognised the central change factors, goals and objectives of the construction industry that will direct the industry and the digitalisation of construction inspection operations in particular (Sutelainen et al. 2007). Table B3 shows the main change factors in the construction business and from the viewpoint of municipalities' construction inspection mentioned in the Rakesa report.

*Table B3. Main change factors in the construction business and from the viewpoint of municipalities' construction inspection mentioned in the Rakesa report.*

<b>Main change factors in the construction industry</b>	<b>Main change factors from the viewpoint of municipalities' construction inspection</b>
<ul style="list-style-type: none"> <li>• statutory requirements to increase municipal cooperation (PARAS legislation)</li> <li>• statutory obligation to use competent and sufficient expertise is extended</li> <li>• information society development</li> <li>• change in society's age structure</li> <li>• construction projects are becoming increasingly demanding</li> <li>• change in norms</li> <li>• increasing share of renovation work</li> </ul>	<ul style="list-style-type: none"> <li>• tighter municipal economy</li> <li>• change in municipal structures</li> <li>• increasing inspection tasks of different authorities</li> <li>• considerable increase in annual accumulation of archive documents</li> <li>• difference in archived materials between municipalities</li> <li>• customers' increasing expectations and skills</li> <li>• customers' new service needs</li> <li>• increasing role of third parties</li> </ul>

The **Roadcon** project found that ICT is essential in the construction sector to manage multiphase and fragmented project implementation in design, planning and execution as well as taking into consideration the developing demands of the environment and technologies (Hannus et al. 2003). ICT enables interactive planning and demonstrating of execution in the future. It:

- promotes automation, integration of different parts and communication between different parties as well as control resources
- enables functional demonstration between the executors and users
- increases possibilities of environmental analysis of buildings, financial income and quality of life
- enables life-cycle analysis of buildings.

**Vision 2010.** The central organisations and companies in the real estate and construction cluster decided in the autumn of 2000 to start a project to recognise the joint development trends that stretch to 2010. At the same time these actors decided to create a common vision 2010 for the entire cluster based on these trends. The first report (Kiinteistö- ja rakennusklusterin visio 2010, 2001) presents the vision 2010 of the real estate and construction cluster and the global trends on which the vision is based.

After an extensive interview round and as a result of expert work five important global trends were outlined in the project as a basis for the visions. These trends which were seen to change the future of the industry most are:

- Customer relationships grow into partnerships
- Technology renews the operating environment
- Ownership and support functions are changing
- Environmental values become emphasised
- Investments and business operations become more international.

In the fourth report of the vision group (Kiinteistö- ja rakennusklusterin visio 2010, 2005) a strategy update from the viewpoint of know-how and information management was made to the vision. The following change trends are found to have sped up or become strengthened after the joint vision was set in 2001–2005:

- Internationalisation is accelerating and growing deeper
- Services are increasing and becoming networked
- Information management is becoming an increasingly important success factor
- The importance and energy and eco-efficiency is becoming emphasised.

Table B4 summarised the change trends in the construction sector’s operating environment within the next 5–10 years that were recognised in the **Expert Workshop arranged at VTT** (Kohvakka et al. 2005).

*Table B4. Changes in the building services and real estate sector within 5–10 years (Kohvakka et al. 2005).*

<ul style="list-style-type: none"> <li>• Price competition</li> <li>• Increasing time pressure</li> <li>• Saving of energy and the environment become emphasised</li> <li>• Carefreeness</li> <li>• Need for security</li> <li>• Preparation for severe weather phenomena</li> <li>• Differentiating needs of different customer sectors</li> <li>• Competition for customer interface control</li> <li>• Accelerating market change</li> </ul>	<ul style="list-style-type: none"> <li>• Legislation/standards change quickly</li> <li>• Globalisation</li> <li>• Subsidiary economy</li> <li>• Commercialisation of the real estate sector</li> <li>• Networked operating methods and partnership models</li> <li>• Life-cycle models</li> <li>• Operating methods of the municipal sector in transition</li> </ul>	<ul style="list-style-type: none"> <li>• IT development enables shortening of the time span between planning and execution or even continuous planning during execution</li> <li>• Wirelessness</li> <li>• Products that react to user presence and actions</li> <li>• Smart products</li> <li>• Combination of product model technology and smart products</li> </ul>
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# Roadmaps

This section discusses the earlier roadmaps that affected the work.

## Building services roadmap

Building services create customised, user-oriented and controlled conditions for the various activities taking place on real estates and related premises (Paiho et al. 2007). These include e.g. transmission of water, heat, energy, light and information. Electronically controlled and managed safety and access services and services based on the movement of other material, electrons, sound waves, etc. Building services consist of technical systems, equipments and services.

Paiho et al. (2007) presented in roadmap format a view on the future development of building services. The roadmaps describe the main technologies, the products and solutions based on these, crucial market situations and the drivers that affect the operating environment.

The building services roadmap consist of six roadmaps (Figure B1). The meta roadmap is an umbrella under which the more detailed thematic roadmaps are presented. There are four sub-level roadmap themes and five actual roadmaps. The first roadmap is for building services systems and equipment. The second theme is ICT and software, consisting of roadmaps for networked building services and building services life-cycle design processes. The third sub-level roadmap analyses the interfaces from building services to both buildings and their infrastructure. The fourth sub-level roadmap examines the future development trends for the business models and service concepts of building services.

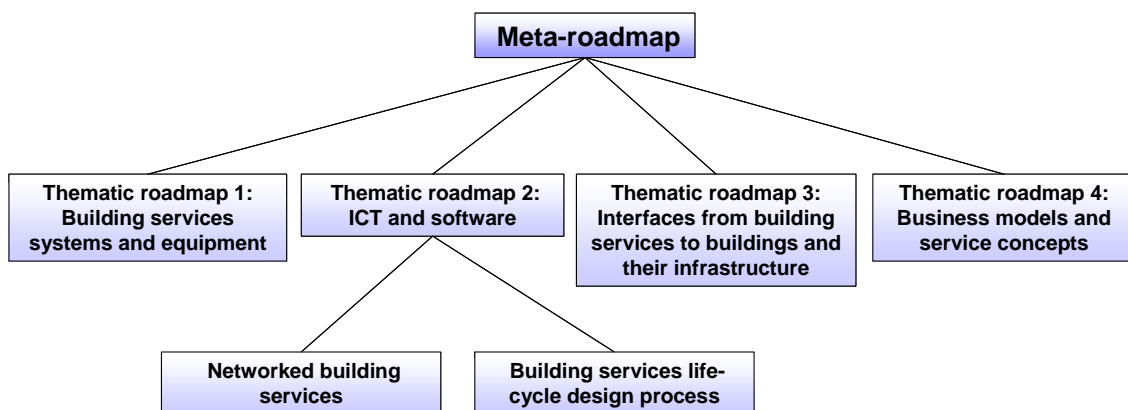


Figure B1. Structure of building services roadmaps.

Currently building services is mainly based on technology-led independent solutions produced by different suppliers from which different designers compile building-specific systems. The different equipment does not communicate and they are seldom compatible. Building services markets are fragmented into highly specialised areas. The operating principle of the market is mainly based on partial optimisation. The service business models are not very developed.

In the short term (1–5 years) in particular modular building services technology, low-exergy technology, low energy construction, product modelling and other ICT and measuring and sensor technologies will become emphasised in building services. In products and solutions differently packaged and conceptualised user-oriented services, undisturbed repair solutions, integrated user interfaces and other integrated solutions will become emphasised. In building services marketing development and offering of different service concepts will be emphasised.

In the long term (5–15 year) applications of product model technologies, low-exergy technology, integrated infrastructure and utilisation of sensor networks and new materials are emphasised. Product solutions focus on integrated and user-oriented services that are compiled by collecting necessary information from wireless devices and that are supported by discreet and adaptable user interfaces. Turnkey solutions and service entities are the central operational ideas on the markets. A business model that generates competitive advantage is based on management of the buildings serviceability and productivity of premises.

### **Coconet – context-aware collaborative environments for next generation business networks**

Coconet (<http://coconet.telin.nl/>) was a project in EU's IST programme, where the project coordinator was the Dutch Telematica Instituut and the core team consisted of Fraunhofer (Germany), IBM's Haifa Laboratories (Israel), VTT, University of St. Gallen, MCM Institute (Switzerland), Pleyma Unternehmensnetzwerke (Germany), Siemens SPLS (Germany) and Mondragon Innovation and Knowledge (Spain).

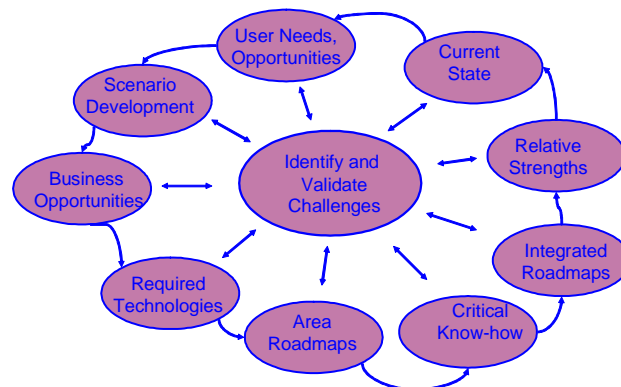
Coconet's objective was to develop a strategy and roadmap for research and technology development for development of context-aware collaborative environments in next generation business networks (<http://coconet.telin.nl/>). The main general targets were (Södergård & Schaffers 2004)

- to identify the research challenges in the domain of context-aware cooperation in work and business
- to assess Europe's competitive position and potential in this respect

- to develop a strategic roadmap for applied research of high industrial impact, driven by visionary scenarios
- to define a R&D agenda and strategy for 5–10 years
- to involve key players in Europe, build a constituency through scenarios and workshops, establish consensus in feedback with stakeholders
- to create a breeding ground for developing ideas and proposals for innovative, large-scale and business supported projects in EU's sixth framework programme.

The focus of the Coconet project was in combining personal and collaborative support systems while developing cooperation environments for the processes of several players. The challenge, in particular from companies' viewpoints, has been to combine corporate systems to better support functions carried out alone and in groups. The aim has been to develop ambient intelligence like context-aware collaborative systems that work better in networked functions and that would be more flexible and better suited for tailoring than existing systems (<http://coconet.telin.nl/>).

The project consisted of three two-day roadmap workshops (<http://coconet.telin.nl/>). The first workshop analysed trends and development paths based on four scenarios dealing with context-aware environments. The aim of the first workshop was to create a frame for creating the roadmap and to recognise the central elements of the roadmap that were technologies, applications and the components of the user environment. The central factors of the roadmaps are presented in Figure B2.



*Figure B2. Elements of the Coconet roadmap (Södergård & Schaffers 2004).*

In the second workshop the recognised elements were deepened and they were processed further by identifying the bottlenecks and future challenges of context-aware operating environments. Based on the recognised elements' challenges, in particular in R&D operations, were identified. In the third workshop the visions, scenarios and identified R&D challenges were combined into roadmaps. Figure B3 shows the creation process of Coconet's scenario-based roadmap.

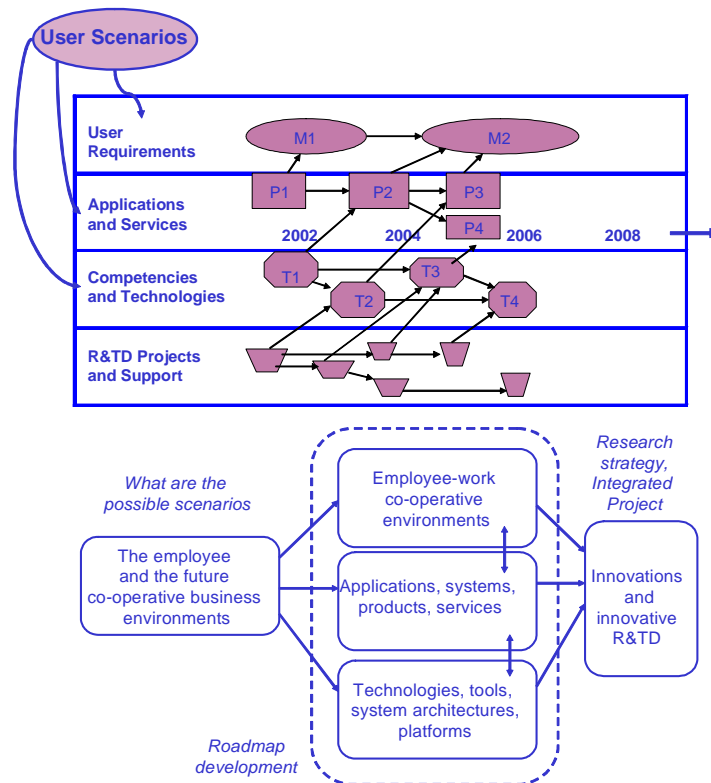


Figure B3. Structure of Coconet's scenario-based roadmap (Södergård & Schaffers 2004).

## Technology Roadmap for Exergaming, EXERGAME

VTT's EXERGAME project studied how young people's exercise hobbies could be increased by combining gaming with mobile terminals (e.g. mobile phones) with active exercise (Ala-Siuru et al. 2006). The same data communication, identification and other developed user interface technologies can be used in implementing ICT-based building services solutions (smart house functions, maintenance automatics, etc.).

As an example of such technologies is PointMe pointing technology (Figure B4) that can be exploited in many future user interface applications. The sections marked with yellow in the figure are existing technologies, the grey areas show developing technologies and the green area shows the targeted status. According to this figure pointing can be executed with e.g. RFID tags, lasers, infrared technology, barcode scanners or cameras.



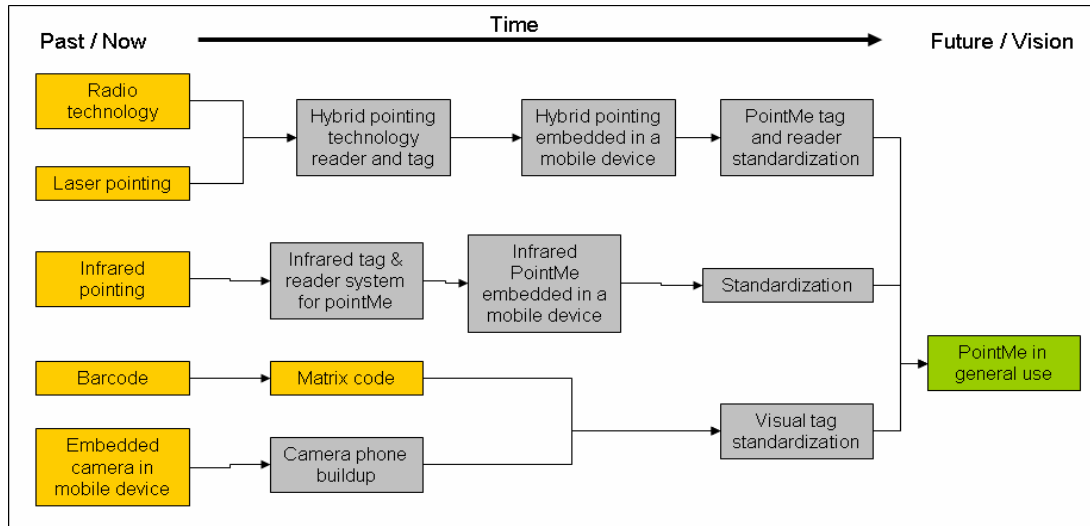


Figure B4. Critical path for PointMe pointing technologies.

### Fiatech report

The purpose of the report is to provide a summary understanding of some of the ICT likely to have a significant impact on the construction industry in the foreseeable future: what they are and how they are likely to have an effect (Wood & Alvarez 2005). The report discusses nine different developing technologies or application technologies:

- construction simulation technologies
- RFID for construction materials management
- wireless communication networks
- mobile user interface devices
- technology training tools to make implementation of new technologies and application technologies easier
- automated tools, workforce and storage control and maintenance techniques on construction sites
- sensing technologies, sensors and wireless sensor networks
- material logistics management technologies
- subsurface mapping technologies.

Each technology and its applications was analysed

1. from a technology viewpoint: what is the technology or technique that enables the application and what is its maturity level, how is the technology applied and what does the application do.

2. in terms of the work process: which construction site processes can the application technology affect, how is the process handled currently and how would it be done if assisted by this new application technology.
3. in terms of the potential benefits: how would the user benefit from the work process changed by the technique or technology (increase efficiency, lower work costs, etc.)
4. in terms of financial drivers: what kind of financial benefits does the new technique or technology bring and are the potential benefits sufficient to encourage investments in the new technique or technology.
5. in terms of technical limitations: which technical issues can limit wide commercialisation of the application technology, what type of changes are still required for the technique or technology to be ready for application in the construction industry.
6. in terms of commercial limitations: which commercial aspects must be developed in order for the application technology to be ready for extensive application in the construction industry.

The report is a comprehensive general description of emerging information and communication technologies and their effects on the construction industry are analysed well. The report mainly focuses on the construction process; the entire life-cycle of buildings is not discussed much.

### **Roadmap for Implementing Mobile Workplace Innovation in Life-Cycle Management Sectors, MOSAIC**

This roadmap (Fernando & Huovila 2005) was developed in the MOSAIC, i.e. Mobile Worker Support Environments, project financed by EU's sixth framework programme. The aim of the roadmap is to describe and facilitate innovation development and further processing within mobile work in different engineering sectors. The compared industries in the roadmap are the automotive, aerospace and construction industries.

In the MOSAIC roadmap processing of mobile work is divided into three parts: First the three chosen sectors (aerospace, automotive, and construction) are considered from a business and product development perspectives in order to identify business drivers and process needs for mobile technologies. The second section presents visions and future scenarios for mobile collaborative engineering environments. The visions and outlook are used to define the research challenges of the actual roadmap in section three. Based on the visions, future outlook and research challenges the roadmap defines the potential barriers and opportunities of the change processes.

According to the roadmap the main development opportunities and challenges in the real estate and construction cluster are:

- enabling and offering mobile services throughout the building's life-cycle to meet the users' changing needs
- lowering the life-cycle costs of real estate and buildings, while maintaining good performance taking into account sustainable development of the environment
- maintain, develop and transform the existing building stock to meet the social and cultural needs of communities and citizens of the knowledge society.

The construction industry has become highly information-intensive and managing the information in a decentralised field of players is highly challenging. Development of an integrating software platform for the construction industry is an important future requirement. The software platform must be based on a standard information model, with which the workforce, processes and tools can be combined into a functioning entity. A standard software platform could for instance improve cooperation between different parties and enable simultaneous product and manufacturing planning, as done in the automotive and aerospace industries. Mobile technology, combined with an integrating software platform is seen to have a great effect in the construction industry, for instance, in making logistics more efficient, monitoring workers and improving profitability. (Fernando & Huovila 2005.)

The biggest barriers for mobile technology becoming common in the construction industry are, according to the roadmap, the lack of mobile tools and funding for system development and insufficient reliability and security of mobile technology or information systems. In addition, human resistance to new technology or new work methods and the lack of business models that support cooperation between parties are factors slowing down the change. (Fernando & Huovila 2005.) Based on the development requirements in the construction industry and factors that slow down the development the MOSAIC roadmap defines a research agenda for mobile technology development and exploitation from the viewpoint of the construction and real estate industry. The research agenda is divided into four blocks: current and short-term (0–3 years), medium term (3–5 years) and long-term (5 →) research challenges. Figure B5 is a graphic presentation of the research agenda of the MOSAIC roadmap.

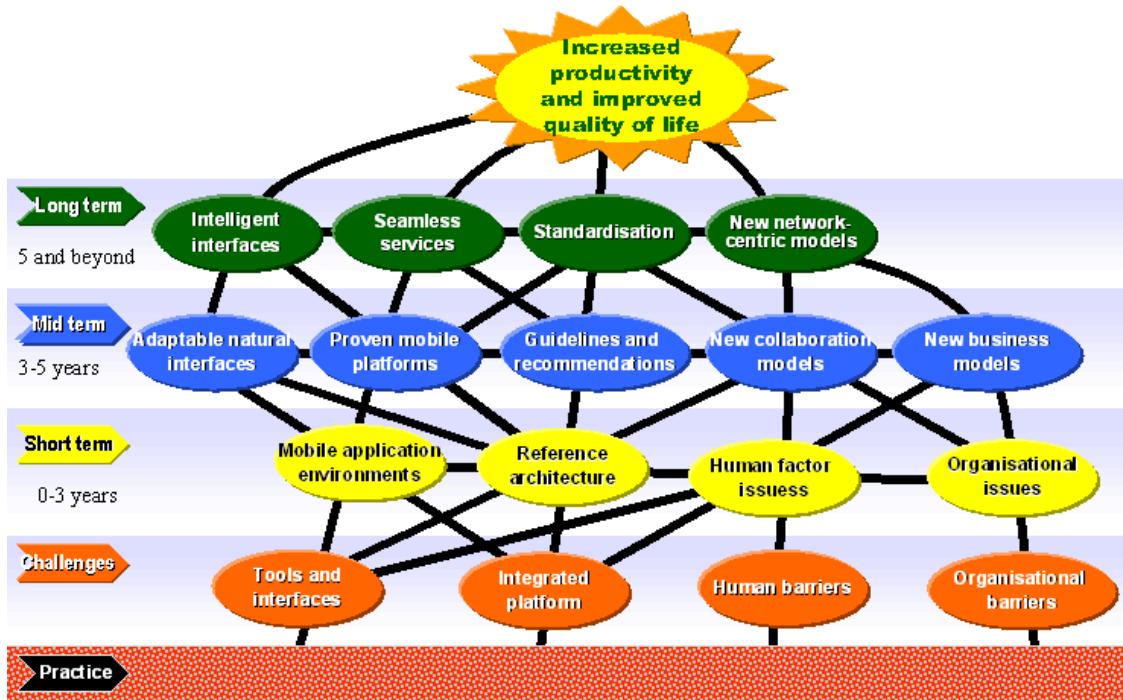


Figure B5. Graphic presentation of the roadmap of the MOSAIC project (Fernando & Huovila 2005).

### Moses, Mobile services' roadmap in the construction and traffic sector

The aim of the Moses roadmap is to support the dialogue and development work between VTT and companies in development and implementation of mobile technology for the construction and traffic sectors (Moses 2002). Mobile services are viewed as a central future development area where R&D efforts will be considerable. The objective has been to find out what VTT must do in order for R&D of mobile services connected to the built environment to become a business for VTT.

The work made 8 thematic roadmaps on the following subjects: building production (business and processes), service concepts for the use of buildings (use and maintenance, security, care, new services, and user needs), traffic and logistics.

The report presents for instance the following change trends and drivers:

- Customer needs become more complicated
- Networked win-win-win services develop
- Transparency increase in the demand-supply chain
- Information becomes digitalised
- Added value is created in the user's processes
- The environmental aspects become emphasised

- Information becomes real-time-based and independent of place
- Mobile service selection increases
- Customers' requirements levels grow (the so-called demanding customer)
- Understanding on the needs of the parties increase and it is linked to production
- Quality control in the supply chain becomes more effective
- Systems and equipment exchange information
- Services are produced based on needs.

The presentation format of the roadmap is a clear and visual diagram and has the same format in all themes. The diagram is divided into four parts that present the current situation (state-of-the-art), future vision (ideal situation when everything works, expected timeline is not stated clearly), challenges and opportunities in the operating environment (technology trends, changes to industry structures, etc.) and VTT's possible actions in the short, medium and long term.

### **PATH (Partnership for Advancing Technology in Housing) roadmaps**

PATH (Partnership for Advancing Technology in Housing) is a programme based on cooperation between the private and public sector in the US with the aim to develop and support "next generation" American housing solutions and create markets for these. The aim is to improve for instance the quality, durability, environmental efficiency and reasonable pricing of future housing. The main three targets of the programme are:

- to determine the needs for improved housing technology development and provide relevant strategic services
- to develop new housing technologies
- to disseminate new and existing technological information.

The objective of PATH technology roadmapping is to identify technology areas for immediate technological research in home building to serve as a guide for research investments by government and industry. The roadmaps define the main areas for research and development in and provide the home building industry with a strategic plan for future technology development. PATH's steering group initiated the roadmapping process in 2000. So far roadmaps related to the energy efficiency of old buildings (three parts), exploiting new technologies in construction, industrial production of houses, exploitation of information technologies in construction and prefabricated frame-based construction have been completed. The timeframe of the roadmaps is relatively short: it typically stretches approximately to the year 2010.

All of PATH's roadmaps have the same structure: First the current status is described and the target status is defined. Then the actual roadmap describes the strategies with

which the target status will be reached. The strategies are presented as concrete action proposals and they are divided based on their importance into three groups. The importance is defined based on how quickly the execution of the strategy must be initiated. Each strategy is divided into subtasks and actions that are placed on a timeline.

The following is a more detailed description of the roadmaps related to exploitation of new technologies and information technologies in construction.

#### PATH – Technology Roadmap: Whole House and Building Process Redesign

According to the roadmap (NAHB Research Center 2002a) the aim is to build better prefabricated houses faster and at a lower cost. The concrete objective is that in 2010 planning and construction is so efficient that a house can be erected in 20 days. This would decrease costs so that as much as 90% of the population could afford owner-occupied housing. Design, planning and construction is made more efficient by utilising new and innovative products, systems and processes and by increasing education and training.

The roadmap report depicts the current situation of housing construction in USA. Because a home is more than just a place to live and is increasingly becoming a way to identify oneself, houses are being customised more to suit the owners taste. Housing prices have also clearly risen. The home building industry remains highly fragmented and the number of contractors has increased considerably. Overall management of the construction process is an enormous challenge: The subcontracting chains are long and the number of stakeholders is vast. Tools and systems that would improve productivity are not used much. Comprehensive system thinking is, however, on the rise.

The roadmap lists several things that risk realisation of the visions. According to the roadmap, construction does not sufficiently take into account how costs could be cut and how buildings could be made more durable and energy efficient. The general view is that consumers demand unique houses. Apparently consumers actually do favour large and special houses, and shun prefabricated houses. Secondly, there are clear shortcomings in the education level and professionalism of the workforce. Thirdly, building inspection is reserved towards new technologies and materials and contractors are also unwilling to exploit them. Fourthly, small contractors in particular are dependent on subcontractors and are not able to control the construction process well. Fifthly, industry's change resistance and inability to cooperate cause problems. Sixthly, the quality of houses could also be improved. Most of these problems are familiar in Finland as well.

The roadmap presents five central strategies:

- manage the change process: accelerate acceptance of innovative home building technologies
- change the approach: create an environment that facilitates systems solutions
- industrialise the home building process
- improve the constructability of houses
- move the home building process into the factory.

The main thing in managing the change process is to make implementation of new innovative building technologies more efficient. The aim is to create a process workgroup whose tasks are change process management, development of a precise framework to make implementation of new technologies more efficient (e.g. for analysing new innovations), communication of information to the industry and other parties, developing tools for monitoring and collecting feedback and institutionalisation of the change management process approach (e.g. by ensuring that it is visible in sector education and training).

In changing the approach, the main thing is to create preconditions for comprehensive systemic solutions. First of all the aim is to chart the situation elsewhere (e.g. in Europe) and define the goals and develop an example that summarises the construction of a systematic approach (e.g. FutureHome). The next task is to apply comprehensive systems in research and product development and create skill centres whose task is to develop and study technologies and promote the industrialisation of housing construction.

In industrialisation of the construction process the central tasks include application of factory production processes that have been proven to work in other industries, and utilise automated robot production technologies in factories. In improving constructability the aim is to make installation of mechanic systems more efficient (heating, ventilation, electricity, etc.), develop integrated mechanic systems and productise housing construction (e.g. by developing new materials and better working methods). In transferring the building process to the factory the aim is to develop standardised prefabricated element types and sizes and standardised connections, improve and make transportation of construction elements more efficient, develop better techniques and tools for assembling the elements on site and make education and training more efficient. Most of these operating models that support improvement of cost efficiency and quality can also be applied to Finland.

## PATH – Technology Roadmap: Information Technology to Accelerate and Streamline Home Building

The vision of the roadmap (NAHB Research Center 2002b) is availability of information when and where needed by participants in the home building process so they can perform their jobs more accurately, efficiently, and on time.

The challenges and barriers of extensive use of information technology in housing construction according to the report are:

- fragmentation of the industry
- use of subcontractors
- building on site.

The roadmap lists four strategies to promote the exploitation of information technology in housing construction:

1. Develop a common language that enables people, processes, and information technology tools to communicate across the residential construction process.
2. Streamline the regulatory process, which means increasing efficiency in permitting, plan review, site inspection, and product approval using information technology.
3. Build a non-commercial information portal, which will provide a source for objective, reliable, and technical information about home building for builders, trade contractors, and consumers. This will allow users to make informed decisions about products, materials, systems, and processes.
4. Create production management systems from concept to closure, which enables linking of information technology tools and data within and across companies. This will improve the efficiency of managing the housing production process from start to finish to not only make today's management approaches work more smoothly and accurately, but also to lay the foundation for more productive ways of doing business.

### **Performance Based Building (PeBBu) R&D roadmap**

The Performance Based Building network was financed by the EU's fifth framework programme's operational whole Competitive and Sustainable Growth. The network was in operation from 2001 to 2005. The aim of the roadmap compiled by the network was to establish a comprehensive application of the performance approach in practice, and make it one of the key enabling principles to move the building, construction and real



estate industry into a client-focused, knowledge-based and services-based industry, characterized by sustained innovation and excellence. The time horizons of the roadmap stretched to 2010, 2020 and 2030 (Foliente et al. 2005).

According to VTT's Pekka Huovila, the performance approach in construction refers to an operating method where at the selection stage the functional requirements of the end product are described instead of technical solutions. Performance requirements are, according to Huovila, a required feature that is presented without specifying the technical solution.

The vision of the PeBBu roadmap is that if the performance concept is used routinely and applied comprehensively within the construction and real estate industry, it will deliver value to present and future stakeholders, deliver sustainable outcomes and is transformed into a knowledge and services-based industry, characterised by sustained innovation and excellence (Foliente et al. 2005). The roadmap describes what kind of choices lead to the desired outcome and it emphasises that, in addition to reactive (regulation-based) strategies, proactive (performance definition-based) strategies should also be used.

By 2010 the aim is to:

- develop a comprehensive database that applies to factors related to building performance, performance requirements, tools for assessing performance and technical solutions
- develop methods to chart user needs and requirements
- develop next-generation, compatible planning and assessment tools (i.e. computational models and computer software)
- assess the benefits and costs of the approach based on experiences from implemented projects
- develop methods related to procurement management
- collect information on users' experiences and operations using qualitative and quantitative methods
- develop objective methods to assess performance.

By 2020 the aim is to:

- develop an "open" ICT-based system for integrated analysis of performance and based in it nD models that cover the entire life-cycle of the building
- develop real-time monitoring systems for performance and indoor conditions
- better anticipate technology development and changes in user needs and requirements

- develop methods that can be used to assess the benefits of a performance-based approach for different parties
- further develop quantitative performance criteria
- create increasingly complex, systematic performance models
- generate new educational material.

By 2030 the aim is to create an integrated selection of nD models and assessment tools for building procurement and management throughout the life-cycle, develop as “thin” and transparent performance-based regulation systems as possible, and ensure that the construction and real estate industry would strive towards top expertise and continuous learning as a information and service oriented industry.

The PeBBu roadmap has an exact focus: it clearly defines the targets of performance thinking for different time spans and strategies to reach these targets.

### **Construction inspection’s digitalised target operating model from the building’s life-cycle viewpoint, Rakesa**

The aim of the Rakesa project was to develop municipalities’ construction inspection’s services and operations through electronic business, archiving and issue management (Sutelainen et al. 2007). The objective of the project was to develop joint information technology and content specifications for electronic data reception, authority processing, issue management, storage and service. The implementation is based on networked operation, data communication networks and multichannel network services. The basis was the delivery process of municipalities’ construction inspection and service production.

The central solutions recognised in development of construction inspection are related to the operating and service models and exploitation of new technologies:

- service recommendation for construction inspection
- increasing customer orientation
- digitalisation of construction inspection documentation
- distinction and specialisation of work division
- solutions for electronic issue management
- electronic customer and authority services
- process digitalisation and streamlining
- automation of routine tasks
- automatic exploitation of existing information in service and authority processes
- authorisation of third parties
- service prioritising and pricing

- utilisation of new operating models (customer-producer model, service centres, etc.)
- utilisation of multichannels
- joint data pools
- standardisation of databases and interfaces.

The preliminary study created an overall image of municipalities' construction inspection. The overall picture charted the following subfactors:

- stakeholders
- building life-cycle and customer process
- customer segments
- municipalities' construction inspection services
- new electronic solutions and operating methods
- technology and data pools.

The Rakesa preliminary study created a vision on the digitalised operating model for construction inspection (Sutelainen et al. 2007). The targeted operating model covers building life-cycle related services that utilize and create information related to the built environment. The customer interface for the targeted operating model was a portal that consists of information services and an electronic desktop.

*Information services* enable that the stakeholders related to the building's life-cycle have access to a centralised and up-to-date service that includes general information, guidelines and advice regarding the built environment. Information services play a key role, for instance, when a person considers building, is looking for a site, compares residential areas or collects information and guidelines connected to a building site.

*The electronic desktop* is the electronic workspace for the builder, building professional and construction inspection. The desktop controls the construction projects during the design, planning and construction phase in tasks related to collection of source data, design, planning, preparation of the building permit and application of the permit as well as inspection during construction.

Comprehensive architecture that supports development of information management refers to a description of operations, information architecture and information system and technology carried out using uniform description methods. Description of the entity from the viewpoint of construction inspection and recognition of architecture sub-areas is crucial (Sutelainen et al. 2007). The Rakesa preliminary study defines an architecture supporting electronic business, issue management and archiving for the targeted operating model. Figure B6 shows the main basic registers and systems related to the targeted operating model.

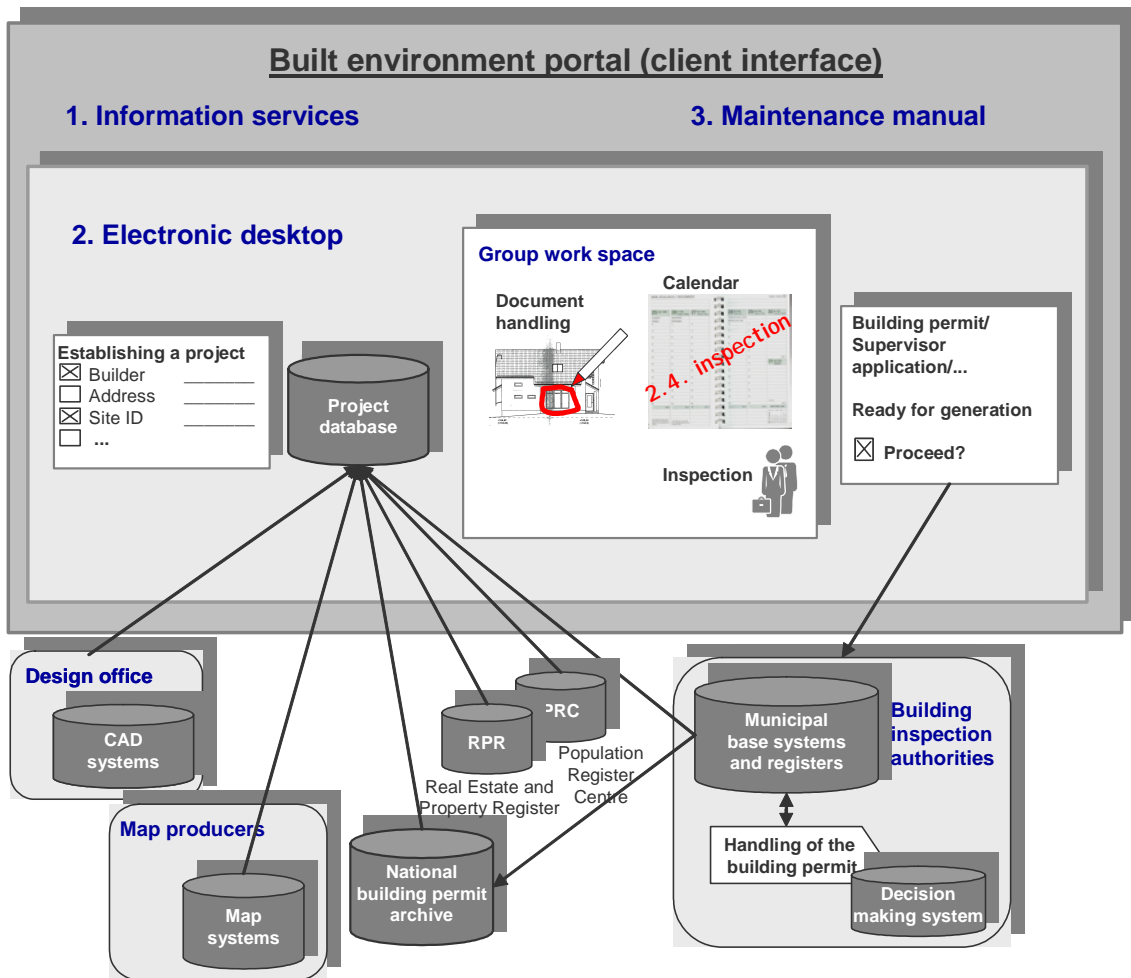


Figure B6. Main basic registers and systems related to the targeted operating model (Modified from original source: Tietoenator's presentation material 2006).

The Rakesa preliminary study also includes a phased roadmap which will be used to make progress from the preliminary study through technology project to publication of an electronic desktop of the building during its occupation stage. The roadmap also presents links to other main development projects in the public sector.

### ROADCON, Construction ICT Roadmap

The main goal of the ROADCON project was to develop a vision of utilising ICT in the construction sector (Hannus et al. 2003). Figure B7 presents a vision of the use of ICT in building construction sector within 10–20 years.

The construction sector is heterogeneous and fragmented as well as labour-intensive and dependent on different domain experts (Hannus et al. 2003). The company size is small and companies mainly specialise on local market demand. Operations are highly project-dominated and divided into small subcontracts. Subcontractors often work

together for the first time. Buildings are nearly prototype-level contracts and they are used for 25–50 years and are modernized from time to time to meet the requirements of that moment in time. The sector is highly regulated with standards and provisions. A lot of new building firms are created because the capital needed is small and there is basic information available on operations.



Figure B7. ICT vision in building construction sector within 10–20 years.

### Strategy to promote ICT in construction industry

#### Effectiveness:

- global competition, effectiveness, operations and standards
- emphasising the consumer's and society's environmental awareness and quality instead of costs and schedules as previously
- extensive coverage in different levels of the society.

#### Business processes:

- Cooperation collects the best expertise together regardless of the organisation or its location

- ICT is the common media in communication, joint use between individuals and communities within the limits of legislation and design standards
- Physical and virtual operations supported by ICT and operating environments become more human
- Business processes support utilisation of experience in project planning and lifecycle thinking
- Business processes increase the use of standardised processed and products
- Business processes enable systematic design, planning and implementation of technical solutions throughout the construction project
- Business processes serve customer needs in selection of different product options
- Business processes support life-cycle thinking in terms of the building.

#### Applications and systems:

- Applications help users make choices. This improves decision making, communication, cooperation and coordination.
- Applications and systems are generic solutions that support generation of critical mass throughout the construction sector.
- ICT applications are user friendly, open, web-powered, paid based on use, or possibly sponsored, and user support is sufficient.

#### Structure:

- automated and smart products that are suitable everywhere: chips, tags, sensors
- all products and development information available to all stakeholders in the latest version and in a specific place
- systems learn from their use and users' behaviour, and are, if necessary, automatically updated; maintenance and user support arranged
- web-based (NGI = Next Generation Internet) and semantic information structure for all communication.

#### ICT and standards:

- all information commonly available for all equipment, always and safely; special focus on mobile use
- systems learn from their use and users' behaviour and are, if necessary, automatically updated; maintenance and user support arranged

- smart software that supports the needs of the construction industry and which users can develop flexibly; good user support
- product information, processes and other data can be downloaded to other applications
- open standard that can be quickly and flexibly developed.

## Embedded ICT system in intelligent buildings

### *Current situation in buildings*

Buildings contain many different monitoring and maintenance systems that are becoming more versatile. They are currently based on vendor-specific technologies using “dumb” devices, proprietary software platforms and wired connections and protocols. Monitoring, maintenance and services are done by specialised companies, each responsible for different systems.

### *Vision*

All systems in buildings share common platform and network and support the same protocols (Figure B8). Secure external connectivity via the internet enables remote and mobile monitoring, diagnostics, operation and self-reporting. Ubiquitous access to all building information from design and planning to use and maintenance history is available to all stakeholders. Wireless and powerless sensors support interactive spaces providing personalised, location and context aware services.

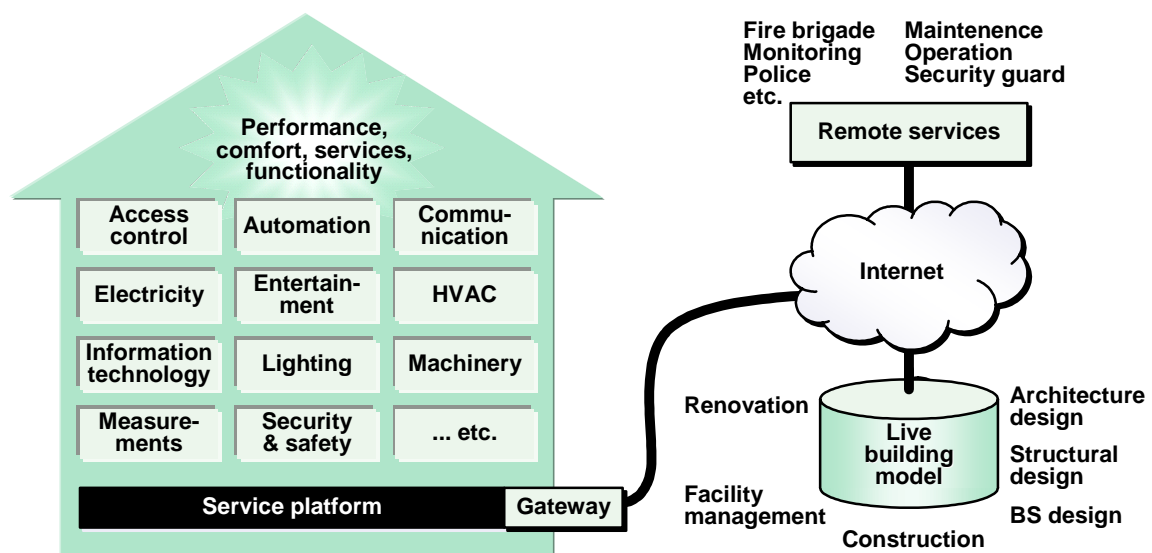


Figure B8. Smart building functions.

Figure B9 shows the roadmap of a smart building where time is presented on the y-axis. The lowest section (Use) shows the solutions that already exist and are available commercially and used by the leading industry. Next (Take-up) presents existing technologies that are taken into use, demonstrated or will be in use within 0–2 years. Results in development stage (Develop) and clearly definable or directly available in 3–5 years are presented in the middle. Themes that need research and prototypes are presented next (Research) and they are expected to be on the market within 6–10 years. The highest level shows emerging R&D opportunities (Emerging) where the review period is over 10 years. The “suns” in Figure B9 depict visions and the black lines show alternative paths to reach the vision.

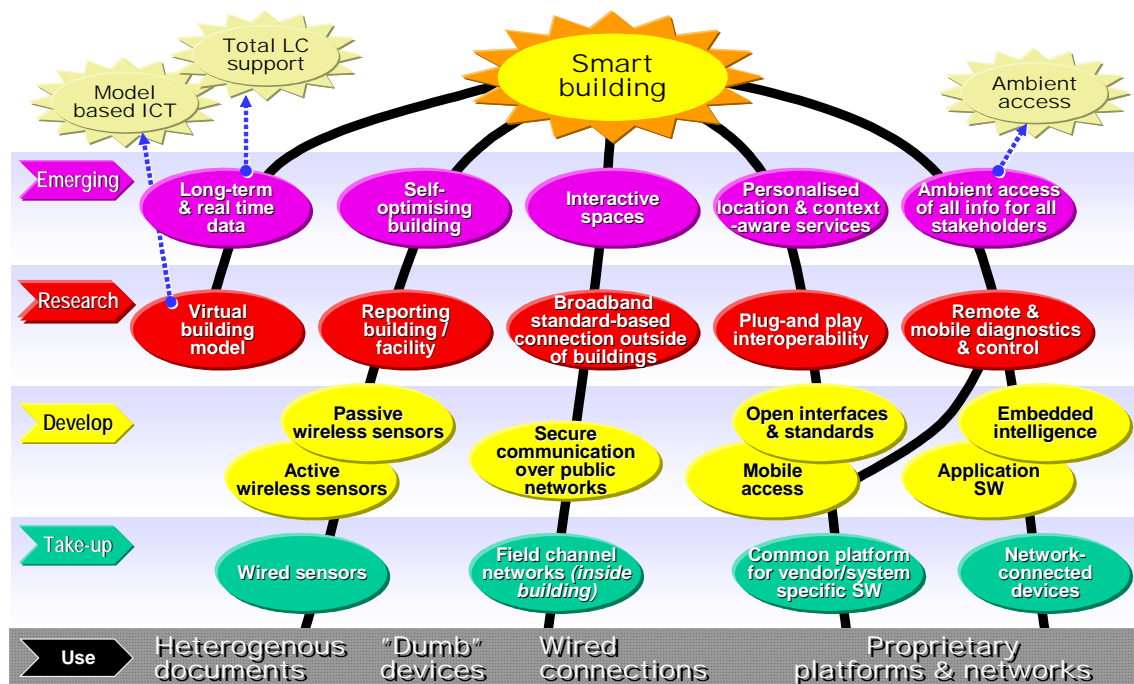


Figure B9. Roadmap for smart buildings.

## Strat-CON

The Strat-CON project had three scientific goals (Zarli et al. 2007):

1. improve, justify and if necessary further develop the ICT vision and roadmap presented in the ROADCON project
2. recognise a group of strategic measures to implement the above mentioned vision
3. implement strategic measures and present instruction for implementation.



When developing ROADCON's (Hannus et al. 2003) roadmaps and identifying strategic research topics Strat-CON applied four thematic areas:

- processes: business and production models
- products: digital modelling of products and smart construction
- projects: interoperability of ICT systems; ICT support in collaborative work
- enterprises: taking possession of project experiences and utilising them in new business models enables by ICT.

While ROADCON was research and development-based, Strat-CON was industrial-based. Strat-CON roadmaps were developed keeping business drivers in mind. Figure B10 shows Strat-CON's thematic division and the related eight main themes.

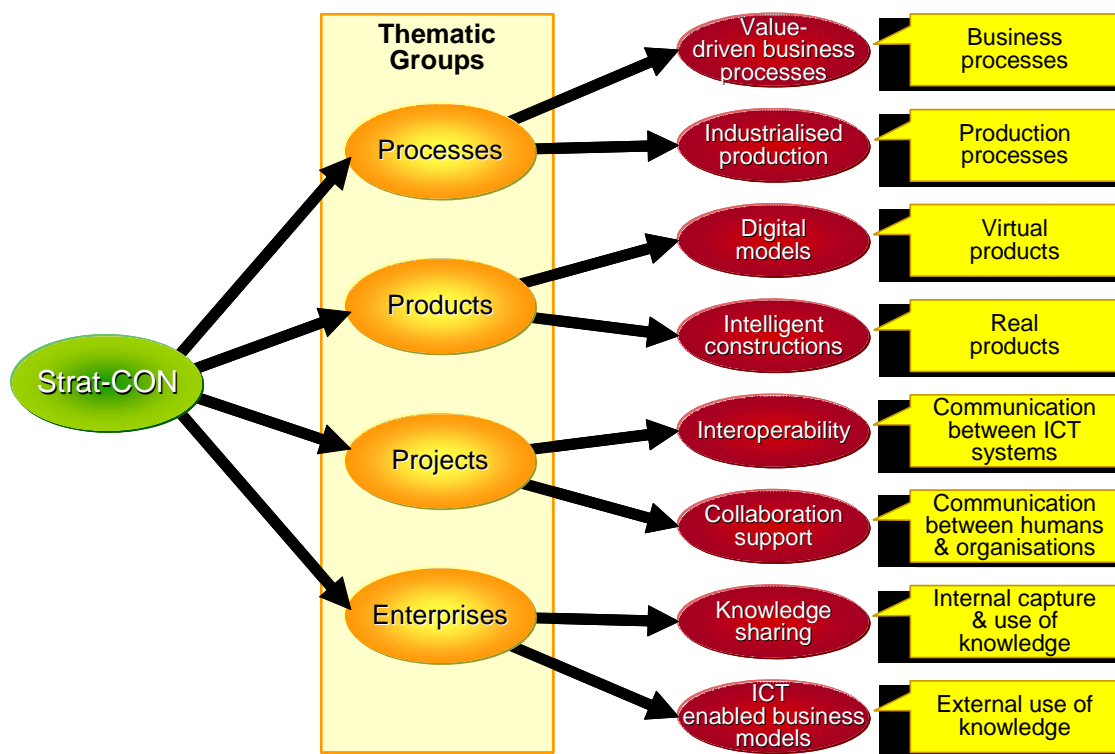


Figure B10. Strat-CON's thematic groups and strategic research priorities (roadmaps).

### Serving home automation of the future – analysis of current situation, scenarios and roadmap (TUPAROAD)

Serving home automation of the future – analysis of the current situation, scenarios and roadmap is a report made in Tekes CUBE programme in 2003 (Ala-Siuru et al. 2003). The purpose of the study was to chart the current status and development outlook of Finnish home automation. Based on the study, VTT in cooperation with other

companies built a home automation demonstration for the 50th anniversary exhibition for the Finnish Society of Automation at Heureka Science Centre. The execution utilised the latest technology (wireless data transfer, smart sensors, motion control, RFID, automatic regulation of lighting based on the situation and mood).

The prediction period for the TUPAROAD roadmap was five years (2003–2008). The most exact realisation of the prediction has been wireless broadband services and applications and, for instance, in new buildings data transfer cabling. In addition, the estimated increase in need for home surveillance and security electronics is becoming reality. On the other hand the growth in home control systems predicted for 2006 has not materialised considerably. Partly TUPAROAD was too optimistic, for instance in terms of context-awareness development into a part of home applications which have not materialised (still at research stage) nor are the user interfaces of devices and applications multimodal. According to the device technology prediction (“further in the future”) of the TUPAROAD roadmap future technologies include personal area networks, optical networks for consumers, fully voice controlled terminals, bendable organic displays, environment intelligence, awareness of social context, absolute integrated indoor and outdoor localization, “digital me” and digital paper. Digitalisation of home technology is however, inevitable; the increase in the number of digiboxes mentioned in TUPAROAD roadmap is already evident.

### **VOMap – development roadmap for virtual organisations**

The VOMap roadmap was executed in 2002–2003 in the EU’s IST (Information Society Technologies) programme. The project coordinators was the Portuguese Uninova (Institute for Development of New Technologies) and the members of the project’s core team were Fraunhofer (Germany), The University of Amsterdam (the Netherlands), CAS Software Oy (Germany), Virtuelle Fabrik (Switzerland), CeTIM Centre for Technology and Innovation Management and VTT (<http://www.uninova.pt/~vomap/partners.htm#Coordinator>).

The aim of the VOMap roadmap was to walk the path from emerging collaborative networks formed in the 21st century self-organising ad hoc operations towards sustainable collaborative networks that would work based on well planned structures, models and tools as well as repeatable infrastructures (Camarinha-Matos & Afsarmanesh 2003, p. 5). The VOMap roadmap was directed at strategic science and research levels. The aim was not to recognise a future path connected to a certain technology or product but to define a strategic research program for virtual organisations (Camarinha-Matos & Afsarmanesh 2003, p. 3). The summarised project vision for 2015 was the following: “In 2015 most enterprises will be part of some sustainable collaborative networks that will act as breeding environments for the formation of dynamic virtual organisations in response to fast changing market conditions.”

The building of the VOMap roadmap was done in five stages (Camarinha-Matos & Afsarmanesh 200, p. 7–9). In the first stage a gap analysis was made to make a detailed characterization and essence of the baseline in comparison to the vision, in particular in terms of strengths and weaknesses. In the second stage a plan of action was formed with which the current status and vision could be combined. The actions were called transition steps and they were recognised on five different levels. Socio-economic changes, management, infrastructures, support services and theories, and models. The steps were at this stage generated with an ad hoc procedure. In the third stage the planned actions were verified and validated based on two criteria. The first criterion was to check how the resulted proposed actions “contribute” to fulfil the vision. The second criterion was to check how “feasible” these actions are, considering the two facets of the baseline, i.e. the positive and negative factors. Based on these a qualitative value for the actions was formed. In the fourth stage a time plan on the implementation of the planned actions and other factors that affect the implementation such as resources and stakeholders. In the fifth stage the actual roadmap was built. Central in creating the roadmap was to identify the interaction between the different tasks and connections on five levels (socio-economic changes, management, infrastructures, support services and theories and models) and consider their importance in particular in respect of their timing. When the interactions between the different levels had been identified, the roadmaps were combined into a larger entity. Figure B11 shows the roadmap of the VOMap project.

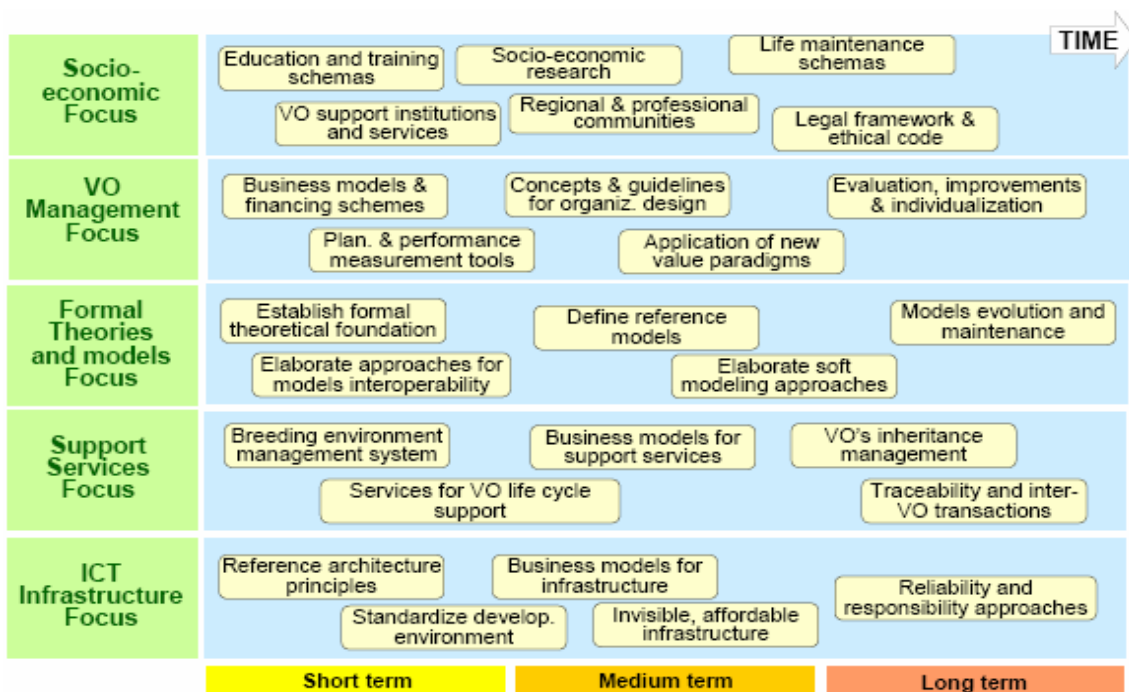


Figure B11. VOMap – roadmap for development of virtual organisations (Camarinha-Matos & Hamideh 2003, p. 28).

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<p>Title <b>Roadmap for ICT-based Opportunities in the Development of the Built Environment</b></p>		
<p>Abstract The built environment is a significant part of our national wealth. The built environment is the physical environment created by people. It consists of the buildings and all networks serving the flow of traffic, energy, water, waste and digital information, and the assemblies, equipment and (built) natural elements connected to them.</p> <p>This publication presents a review of the development trends of the built environment that utilise information and communication technology. The focus is on buildings and construction. The review is presented in the form of four change roadmaps. The "Digital solutions" section presents the technologies related to the subject field and applied in it from the perspective of the built environment. The "Operation methods and processes" section presents the changes required and enabled by the new technologies in the operation methods and processes. The "Services" section presents the services enabled by digital solutions and changing operation methods and processes. The "Meta Roadmap" encapsulates the essential ideas of the other roadmaps.</p> <p>The vision of development prospects in the built environment utilising information and communication technology is as follows: The technological foundation of the built environment utilising information and communication technology is based on well-timed sharing and utilising of information. Business is done through networks. This requires compatible processes and operation methods which can utilize commonly available interoperable digital information, such as, building information models and real-time information. These will fulfil the evolving needs of the user or customer and enable good usability and real-time services.</p> <p>Current state-of-the-art solutions for information and communication technology in the built environment are mainly separate services. Progressive demand is limited and the suppliers and exploiters of ICT for the built environment are differentiated into narrow categories. The service providers offer niche services for specific purposes. Currently there are four state-of-the-art service entities: 1) planning, construction, operation and maintenance services; 2) remote services; 3) security services and 4) new health services. At the moment, the processes used by operators do not yet correspond to the requirements of information modelling applied in the ICT for the built environment. Therefore, model information cannot be fully utilised in the planning and realisation of operations. Another area of change for operation methods is the development of commercialisation in both technological solutions and in the services packaging them.</p> <p>In the short term, i.e. 1–5 years, the development paths in the information and communication technology of the built environment will lead towards the utilisation of an integrated information model which opens up new ways of connecting products and services. However, the application of information models requires that the integrated information models are understood and explained from the points of view of different operators. Products and services utilise user-oriented content production. The services of the built environment are produced with networked operation methods. In the short term, the essential factors will especially include the following four service entities: 1) information model services; 2) data collection, maintenance and management services; 3) information-based additional value services; and 4) the integration of services. The application of information and communication technology in the built environment emphasises the value of and services targeted at the whole life span of the product.</p> <p>In the long term, i.e. 5–15 years, the formation of globally integrated operation models will start in planning and production, and large networks will produce services for the built environment. The end-user will be served in the whole design, planning and construction process by offering different mechanisms for visualisation, modularisation and giving feedback. In the long term, the following service entities will especially increase: real-time building information systems, services based on integrated information models supporting decision-making and operation, experience and health services and automated property assessment services. In the long term, a central factor supporting the change in operation methods will be the applications and tools designed for process management. In this respect, the key solution is found in the applications that utilise visualisation and information models and can officially be used as references for building inspections. New kinds of service providers may also be established for the services that exploit information models and integration.</p> <p>The roadmap process helped to recognize five large development paths that will exploit information and communication technology in the future of the built environment. 1) The amount and exploitability of digital information in the built environment will increase. Tools must be developed for the management, analysis and effective use of information to support decision-making. 2) The development of information models, computation methods and computing performance enables more versatile virtual testing of products. 3) The digital and physical worlds are interconnected during the whole life span of a product. 4) Service-based software integration, situation-specific systems, social media and location technologies enable services that are automatically tailored according to users' needs in the built environment. 5) Information modelling of the existing buildings is a significant challenge that requires the development of appropriate methods and technologies.</p>		
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The built environment constitutes a significant part of our national wealth. Utilisation of information and communication technology in the design, construction, use and maintenance of the built environment is clearly increasing. As the information on the built environment is becoming digitalised, construction moves from documents to modelling, construction operations start networking and sustainable development and environmental aspects become more clearly emphasised. This publication presents VTT's view of the development trends of the built environment that utilise information and communication technology. The focus is on buildings and construction. The views are presented as change roadmaps.

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