Classification: Public

ROADCON

Construction ICT Roadmap

Authors:

Matti HANNUS	**(VTT)**
Marcelo BLASCO	**(BBRI)**
Marc BOURDEAU	**(CSTB)**
Michel BÖHMS	**(TNO)**
Grahame COOPER	**(University of Salford)**
Fikry GARAS	**(Garas Consulting Ltd)**
Tarek HASSAN	**(Loughborough University)**
Abdul Samad KAZI	**(VTT)**
Jarkko LEINONEN	**(VTT)**
Yacine REZGUI	**(University of Salford)**
Souheil SOUBRA	**(CSTB)**
Alain ZARLI	**(CSTB)**

Issue Date	30 September 2003
Version	4.4
Deliverable Number	D52
Task Numbers	WP5: T5100/5200
Status	Final

Aknowledgements

The support of numerous people to the roadmap preparation is acknowledged with gratitude. Only some but not all of them can be listed here:

- Vincent Cousin (Processus & Innovation, Fr) provided the “Digital Site” detail level roadmap.
- Various inputs to the roadmap were provided by e.g.: Régis Bonetto (CSTB, Fr), Markku Jokela (Granlund, Fi); Christophe Gobin (GTM-Construction, Fr); Mervi Himanen, Pekka Huovila, Arto Kiviniemi, Kalevi Piira, (VTT, Fi).
- The Virtual Construction Platform group (VCP) of the European Network of Construction Companies for Research and Development (ENCORD) provided advice on industry priorities and feedback on the evolving roadmap.
- The project officer and the review team of the European Commission: John Nolan (EC), John Mitchell (Graphisoft, Hu), Yrjö Matikainen (RIL, Fi), Joao Mena De Matos (EDC, Nl) made various suggestions during the roadmap development.
- Over 50 experts in various EU countries prepared 79 RTD topic suggestions [listed in Appendix 2]: Marcelo Blasco (BBRI, Be); Foroutan Parand (BRE, UK); Adele Seniori Costantini, Adele Seniori Costantini (CSPO, It); Alain Anfosso, Régis Bonetto, Marc Bourdeau, Bruno Fies, Eric Gaduel, Celson Lima, Souheil Soubra, Rémi Vankeisbelck, Benoit Vinot, Alain Zarli (CSTB, Fr); François Giraud-Carrier (DERBI, Fr); Vincent Cousin, M.F. de Jonge, Adina Jägbeck, Wolfgang Katzer, Jeff Stephens, Riitta Takanen, Wilfred van Woudenberg (ENCORD); Bimal Kumar (Glasgow Caledonian University, UK); Gudni Gudnason (IBRI, Is); Vitaly Semenov (ISP RAS, Ru); Juan Pérez (Labein, Es); Bernard Ferries (Laurenti, Fr); Alastair Watson (Leeds University, UK); Tarek Hassan, Dino Bouchlaghem (Loughborough University, UK); Thomas Olofsson (Luleå University of Technology, Se); Anders Ekholm (Lund Institute of Technology, Se); Juan Manuel Mieres Royo (NECSO, Es); M. R. Beheshti (TU Delft, Nl); Peter Katranuschkov, Karsten Menzel, Raimar Scherer (TU Dresden, De); J.P. van Leeuwen (TU Eindhoven, Nl); Yuhua Luo (University of Balearic Islands, Es); Ziga Turk (University of Ljubljana, Si); Danijel Rebolj (University of Maribor, Si); Benachir Medjdoub (University of Nottingham, UK); Mustafa Alshawi, Ghassan Aouad, Laura Campoy-Gomez, David Chadwick, Grahame Cooper, Elaine Ferneley, Yacine Rezgui, Marjan Sarshar, Ian Wilson (University of Salford, UK); Matti Hannus, Kalle Kähkönen, Antti Lakka (VTT, Fi).
- Numerous proposers of "Expression of Interest" (EOI) to the IST program in 2002; out of 13.000 EOIs we identified and analysed 56 EOIs related to ROADCON.
- Participants in several national and European workshops organised by ROADCON.
- Many members of the ROADCON Support Group: altogether 500 persons, from 300 organisations in 30 countries around the world.
- Partners of several European RTD and IST roadmap projects provided information related to ROADCON.

Executive summary

ROADCON is one of the nearly 30 "strategic RTD roadmap" projects on "New Methods of Work and Electronic Commerce" launched under the IST programme by the European Commission in 2002 as preparatory actions towards the 6th Framework Programme.

The aim of ROADCON was to develop a vision for agile, model-based / knowledge driven construction and to prepare a roadmap towards achieving that vision.

Based on consultations with experts from both research and industry a number of trends were identified as the main drivers for change in the construction sector. These trends were linked with industrial requirements on one hand, and opportunities offered by evolving ICT technologies on the other hand. All combined, a vision for future ICT in construction was defined and can be shortly formulated as follows:

"Construction sector is driven by total product life performance and supported by knowledge-intensive and model based ICT enabling holistic support and decision making throughout the various business processes and the whole product life cycle by all stakeholders"

Realisation of the vision requires advances in several key technology areas which are summarised in figure 1 below. The roadmap, described in this report, suggests steps in these technologies towards the vision.

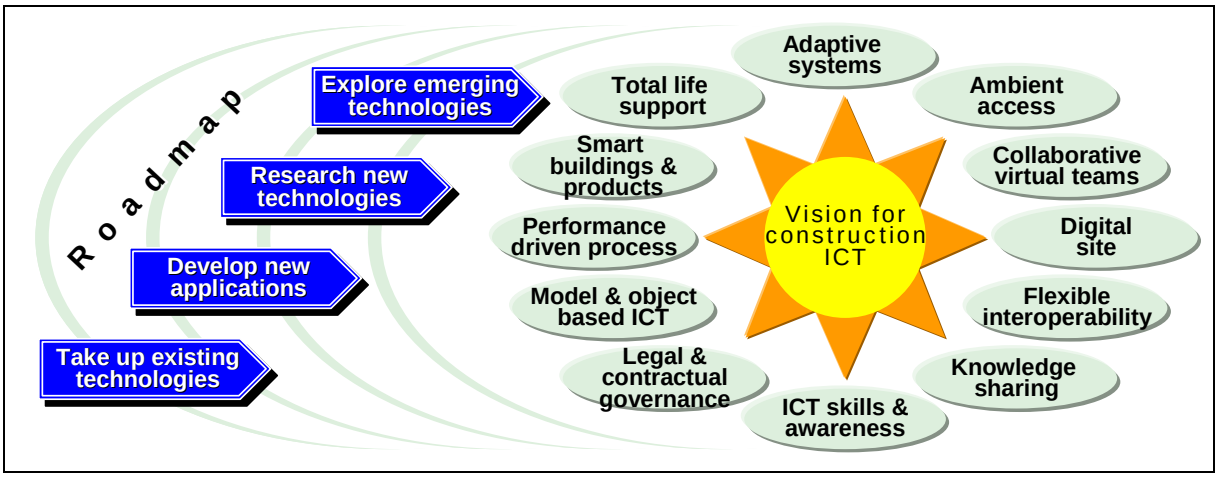

Figure 1. Roadmap towards the vision of ICT in construction

For each technology area, a "subroadmap" has been defined to indicate potential migration steps and RTD from the current state towards the envisioned future state. Each "subroadmap" is illustrated in this report as a simple diagram and explained showing RTD steps in different time spans from current state to take up, further to development, research and exploring emergings needs and opportunities.

The main observation from roadmapping in ROADCON is that the several trends and opportunities related to ICT are to a large extent generic i.e. applicable to several industry sectors. Some of the core ICT priorities for the construction sector are beyond the available expertise within the sector. The challenge for RTD in construction is to identify the opportunities to collaborate with and use results from other sectors while focusing its own resources on sector specific issues.

Table of contents

Executive summary **3**

1. Introduction **5**
1.1 Overview 5
1.2 Objectives, scope and target group 5
1.3 Methodology 6
1.4 Experiences and lessons learned 9

2. Industrial needs and drivers **10**
2.1 Characteristics of construction sector 10
2.2 Trends, drivers and vision of the business environment 10
2.3 Industry requirements for ICT support 11
2.4 Barriers for ICT 13

3. Opportunities offered by ICT **14**
3.1 ICT as an enabler of business improvements 14
3.2 ICT trends 14
3.3 Opportunities for construction 16

4. The roadmap **22**
4.1 ICT vision for construction 22
4.2 Envisaged ICT tools, systems and platforms 24
4.3 Top level roadmap 27
4.4 Detail level roadmaps 28
4.4.1 Adaptive and self-configuring systems 28
4.4.2 Ambient access 30
4.4.3 Collaboration support for distributed virtual teams 33
4.4.4 Digital site 35
4.4.5 Flexible interoperability 37
4.4.6 ICT skills and awareness 40
4.4.7 Knowledge sharing 42
4.4.8 Legal and contractual governance 45
4.4.9 Model based ICT 48
4.4.10 Performance driven process 50
4.4.11 Smart buildings and embedded systems 54
4.4.12 Total Life Cycle support 56
4.5 Implementation mechanisms and instruments 60

5. References **61**

6. Abbreviations **63**

Appendices **65**
Appendix 1: Related IST roadmap projects 66
Appendix 2: Suggested RTD topics 70
Appendix 3: Expressions of Interest 75

1. Introduction

1.1 Overview

The ***Executive Summary*** presents the general summary of this report.

Section 1 ***Introduction*** presents the overall aims methodology of this report.

Section 2 ***Industrial needs and drivers*** is mostly based work in ROADCON WP3 that has been reported in more detail in the deliverable [D3].

Section 3 ***Opportunities offered by ICT*** is mostly based work in ROADCON WP4 that has been reported in more detail in the deliverable [D4].

Section 4 ***The roadmap*** presents the results from ROADCON WP5: " Construction ICT Roadmap". It presents the vision as the synthesis from industry requirements (section 2) and ICT opportunies (section 3). The strategy towards the vision in terms of phased RTD actions is presented as several "subroadmaps" on key technology areas. It also gives a short summary of the main instruments for the suggested RTD.

1.2 Objectives, scope and target group

As part of preparations directions for the 6th Framework Programme (FP6) the European Commission launched several “strategic RTD roadmap” projects in mid 2002. The ROADCON project was initiated as an Accompanying Measure under the IST programme. Its objective was to develop a vision of ICT support in the construction sector and form a strategy for future research and development towards the vision.

The proposed Strategic RTD Roadmap focuses on new and emerging ICTs. However, it also indicates opportunities to the industry to take up existing technologies. Because of limited time and resources the main focus of ROADCON has been on issues that are relevant for industry-wide collaboration between various actors rather than on issues which mainly influence internal activities of a single company only. The main focus is shown at the right side of figure 2.

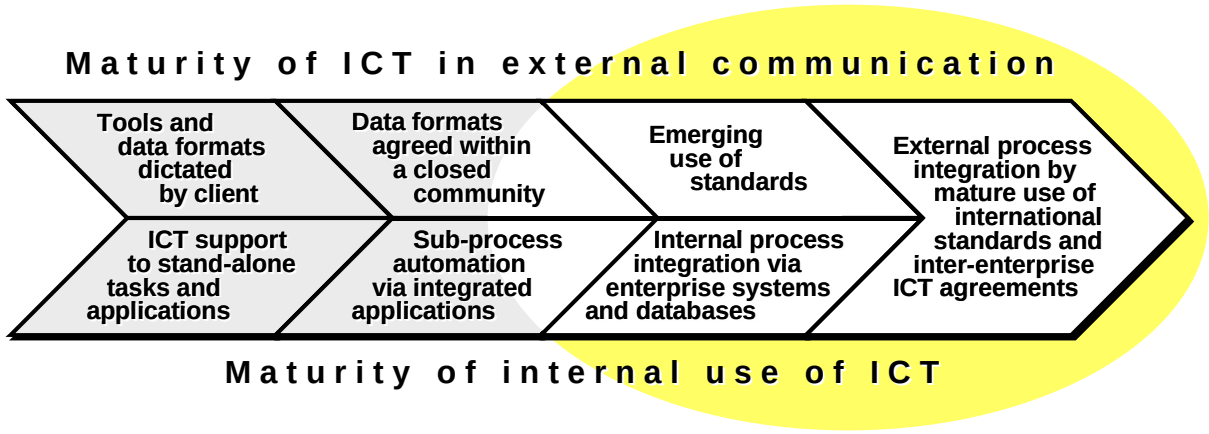

Figure 2. Main scope of the roadmap (modified from [USPI-NL 2002])

The target audience of the roadmap is the RTD community within the construction sector: research organisations, ICT and business developers within the construction sector, ICT developers and RTD funding organisations.

1.3 Methodology

Information sources - The roadmap presented in this report is based on the wide experience of the consortium members in related RTD, assessment of industry requirements [Deliverable D3], analysis of ICT trends and opportunities [Deliverable D4, Böhms & al. 2003], consultations with stakeholders [e.g. ENCORD and the ROADCON Support Group] throughout the EU and surveys of various RTD proposals [Appendix], a number of other "Technology Roadmaps" e.g. [IMTI 2000] etc. During the ROADCON project very little information was available from other parallel roadmapping projects but we expect several synergies between them.

Common communication framework - In contacts between industry, researchers and ICT developers there is often a feeling of lack of mutual understanding. Industry often feels that researchers have their feet high up in the air and that the ICT vendors do not pay enough attention to their needs. Researchers are pressed to focus on innovative and emerging technologies. ICT vendors are driven by immediate market opportunities. ROADCON has tried to understand and integrate the different views and expectations of many stakeholders groups and reach a common ground for discussions about strategic directions. For this purpose the ROADCON consortium adopted a common framework, illustrated as the "thinking cube" in figure 3. The figure shows the positioning of the prime focus of the various Work Packages of ROADCON and the industrial stakeholders. This report addresses the roadmap dimension (depth, WP5).

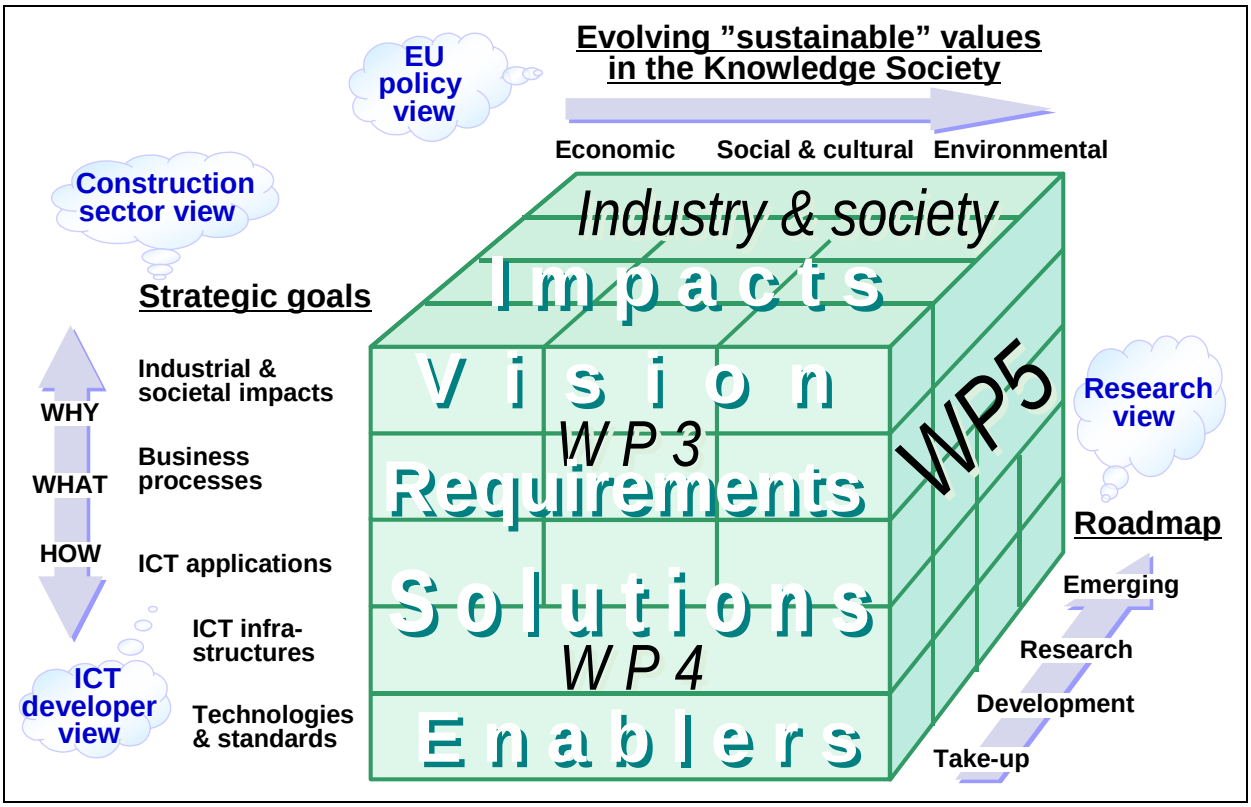

Figure 3. The ROADCON "thinking cube";

With this model we were able to address:

- The shifting values in the emerging knowledge society. This view reflects the political and industrial expectations on the impacts of ICT. It has strong influence on decisions to

provide public as well as private funding for RTD activities (the horisontal dimension of figure 3). These high level strategic priorities need to be well understood.

- The inter-relationships between anticipated impacts, business processes, ICT applications, ICT infrastructures, technologies and standards. A key here is to show and understand the interdependency of the interests of different stakeholders. As an example, the industry is mainly interested in potential business process improvements and expects support from various ICT applications and systems. Thereby the industry's vision is closely related to impacts, their requirements are related to business processes and ICTs are seen as (potential) solutions. However, the strategic goals of other stakeholder groups may be on different levels of a recursive why-what-how hierarchy. As an example, the ICT developers who try to meet their industrial clients' expectations need to focus, not only on required applications, but also on the underlying ICT infrastructures and enablers (the vertical dimension of figure 3).
- The view of strategic RTD planning is shown by the third dimension (depth) of figure 3. RTD activities need to be planned for different time spans. Commercially available technologies are ready for take-up e.g. in trials and pilot projects. Maturing technologies need to be further developed and adopted for specific application purposes and user needs. Research is needed to find new ways forward e.g. by prototyping. Finally, emerging new technologies and business priorities need to be explored. All this needs to be done in a holistic manner without gaps in the evolutionary process. New technologies should not be introduced to industry in a premature stage.

About roadmapping - During the last few years "roadmapping" has gained increasing popularity in strategy planning in various areas. Especially in the US there have been several large "technology roadmap" efforts involving various industries. However, so far there are no commonly established systematic methodologies and tools. It should be noted that there are many categories of "roadmaps" for various purposes. Some of them go into quite detail level, even to the level of project task definition and scheduling, in areas like product development, manufacturing and marketing. ROADCON and the other IST roadmap projects represent a new type called "strategic RTD roadmap". There are very few, if any, pre-existing roadmaps of this type that could be used as reference models.

About the approach in ROADCON - We have deliberately tried to:

- describe high level the strategies, the "big picture", for realising the main trends,
- provide easily understood illustrations of the roadmap as simple diagrams in order to enable easy dialog between stakeholders; therefore complex interdependencies are hidden,
- emphasize the desired functionality of future ICTs without overloading the reader with various specific technologies that are deemed potential for the realisation.

Consequently we have deliberately avoided:

- using construction industry specific views and terminology in order to enable synergy with other communities, and
- suggesting detail level RTD actions (projects).

Only after the publication of the various other IST roadmaps it will be possible to identify the best approaches. The available information so far indicates that many IST roadmaps have used very different methodologies. On the other hand there is probably a lot of synergy regarding some of the main trends and RTD priorities.

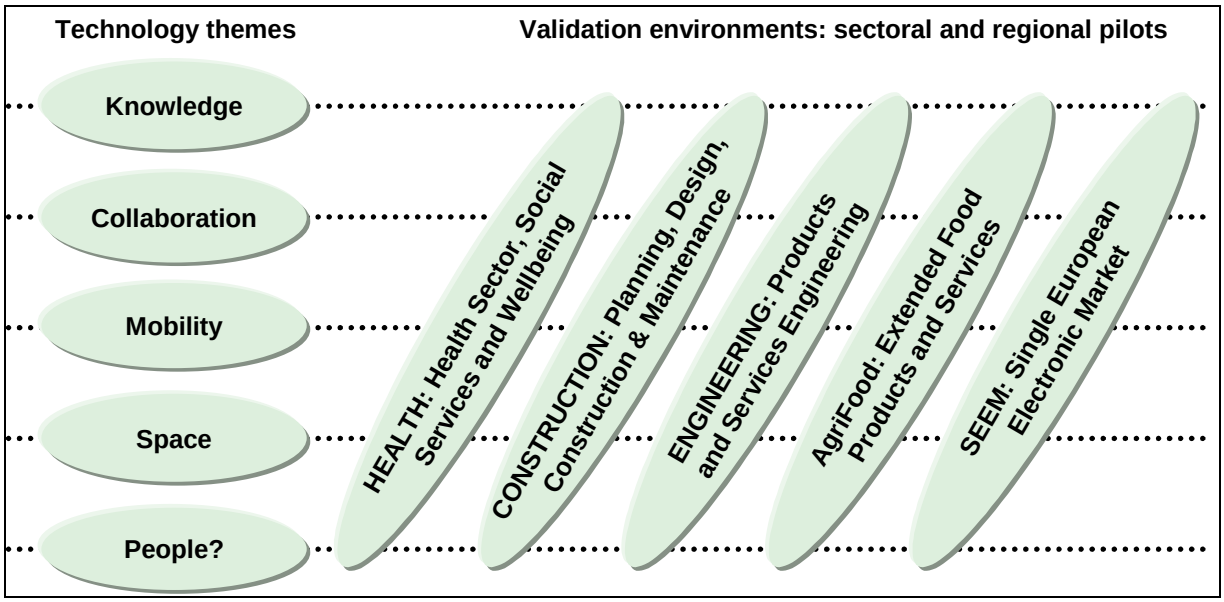

Figure 4. An example of a potentially emerging approach to structure future European RTD? (Modified from EC communication about "Ambient Intelligence @work", Family of ERA Communities relating to Ambient Intelligence and New Working Environments, June 2003)

About the structure of roadmap for construction - It is very common in the construction community to focus on (a) process stages and (b) stakeholder roles as the main dimensions of strategic planning, RTD etc. We did not do so when preparing this roadmap for the following reasons:

- The stage/stakeholder view leads to focus on specific ICT applications that are relevant for limited target groups only. Furthermore, these applications are typically developed by commercial players like software companies driven by immediate market needs.
- We see that a main role for publicly supported RTD is to promote integration of the construction processes. This requires focus on issues like inter-company communication, coordination, collaboration and interoperability of ICT systems by means of standards and application of some new technologies.
- Assessment of related studies in other sectors, and European research in general, clearly showed that there are several identifiable ICT-related "megatrends" that influence most industrial and business sectors. Construction sector depends on ICT solutions from vendors who prefer to provide generic tools that apply to larger market segments.
- It is not realistic that a single sector like construction, in spite of its size, could have the capacity and competence in many ICT related areas where lots of RTD is done by other communities. Bringing together these fragmented communities gives huge opportunities that the 6th European Framework Program (FP6) is aiming to exploit. It now seems that several emerging large RTD efforts will have a matrix structure combining (a) RTD on horisontal technology issues and (b) implementation & validation in several vertical industry sectors (figure 4).
- FP6, which has now started, was known to shift towards large scale efforts like "Integrated Projects" that combine expertise from many disciplines. The trend is to shift from incremental to more radical improvements and major impacts. We did not expect that many construction industry specific initiatives would be implemented within FP6. Unfortunately this expectation seems to be realising now in FP6. Therefore it was crucial to identify RTD priorities which are not only relevant to the construction sector but also

common with other sectors. Figure *4* below shows and example of how major European RTD efforts might be structured in the future.

1.4 Experiences and lessons learned

The preparation of strategic RTD roadmaps has proven to be, not only in ROADCON but also in other IST roadmap projects, a challenging and difficult task.

Many persons outside the ROADCON core consortium have made contributions to the roadmap by providing RTD topic suggestions, industry strategy documents, comments and feedback. We have also identified and analysed the construction related Expressions of Interest that were submitted to the IST call in June 2002 [listed in Appendix]. In addition, the consortium itself has been able to gain from its own substantial experience in this area.

The general conclusion is that most received suggestions focus on incremental development of specific, and often fragmented, problems. Capturing "the big picture" and visionary long term trends is very difficult indeed. Probably the best way would be (would have been) a process where a small group of "visionaries" develop the roadmap and expose it to a larger audience for crical review in several iteratice cycles. Within the available time and resources this has been only partially reached . The ROADCON consortium is looking forward to continue such iteration with stakeholders even after the formal completion end of the project.

2. Industrial needs and drivers

This section is mainly based on information from the public ROADCON deliverable D3 "ICT Requirements of the European Construction Industry: The ROADCON Vision".

2.1 Characteristics of construction sector

The construction industry exhibits characteristics that differentiate it from other industrial sectors. These are summarized below:

- The sector is heterogeneous and highly fragmented, depending on a large number of very different professions and firms, which are mostly small in size, tend to respond to local market needs and control only one element of the overall building process.
- Construction is one of the most geographically dispersed sectors with marked regional differences.
- Construction is highly project oriented. Any ICT used within a project must be deployable and profitable to all / several partners.
- Each construction project, whether to create a new facility, or a renovation/repair project is a prototype. The final product tends to be very durable, lasting 25-50 years and longer, and represents one of the few non-transportable industrial products. When construction facilities become obsolete they are most often repaired, modernised and sometimes radically transformed to suit new requirements rather than disposed of and replaced with new, which is more typical for manufactured products.
- The sector is highly regulated. Regulations and standards are more rigorous in construction than in most other sectors of economy, with the involvement of several levels of governments (local, provincial, national).
- The entry-level for new contractors is relatively low because the need for operational capital is small and the necessary basic knowledge is commonly available.
- The sector is very labour intensive, with high mobility of the workforce and growing skills needs as construction technology becomes more sophisticated. The duration of contracts is often linked to the length of the site construction phase.
- Business relationships are temporary and often short-term, bringing together partners who may never work together again.

2.2 Trends, drivers and vision of the business environment

Given the ever increasing international competitiveness and complexity of buildings that have to meet continuous economic, societal, environmental and technology requirements and challenges, the ROADCON project advocates that ICT (Information and Communication Technologies) are in the future to be the key enabler and instrument to support leading edge, innovative and powerful solutions targeting the main issues that the Construction sector is facing today.

Furthermore, ROADCON is promoting the vision of model-based, knowledge driven, ICT in the construction sector as the main enabler for realisation of important societal, environmental, industrial, and business priorities. The underpinning idea in future use of ICT is computer-interpretable (model-based / semantic-driven) information that will enable:

- enhanced automation, integration and communication in Construction;

- functional applications supporting the versatile needs of the construction industry and users;
- increase the impact of construction on sustainability, including economical growth, employment, and the quality of life.

2.3 Industry requirements for ICT support

The industry is in need for solutions that enhance the practice in general while giving equal consideration to people, processes and technology. The following requirements have been highlighted during the wide consultation organized by ROADCON:

- ***Brief formulation:*** solutions to support the capture of requirements from the client, end-users, and other relevant stakeholders.
- ***Project management (including risk management):*** solutions to assist in the efficient and effective use of various resources needed to deliver and operate a building / facility (including human resources, supply chain, financial aspects and costing), solutions to manage risk and control the occurrences of contingencies.
- ***Decision support:*** solutions to assist in process and product compliance with regulations across the building / facility lifecycle, selection of best design, construction and facility operation options (in the large), selection of sustainable product components achieving best performance and buildability.
- ***Knowledge sharing:*** solutions are expected to provide easy access to relevant information while improving the decision-making process.
- ***Communication and collaboration:*** solutions to facilitate communication and collaboration between geographically dispersed actors (including in different time zones).
- ***Assets management:*** solutions are required to better manage the asset of the facility during the exploitation while improving its global impact on the environment.

Based on the above general requirements captured through the organized ROADCON workshops, questionnaire analysis, as well as a list of over 300 requirements captured from existing surveys, reports, RTD projects and visions in the Construction sector, five priority areas have been identified with the potential to solve the ICT related problems of the Construction industry, namely: (1) Knowledge Management, (2) Legal and Contractual aspects Management, (3) Quality and Performance Management, (4) Total lifecycle Management, and (5) Human Resource Management. These are detailed below:

Knowledge Management

- Improvements in all aspects of ICT training, including Continuous Professional Development, currently delivered within the construction sector.
- Improve access to relevant information and knowledge throughout the leifecycle (standards, regulations, models, specifications, products and processes);
- Develop decision support (knowledge-driven) systems.
- Promote the use of best practice databases.

Legal and Contractual Aspects Management

- Assess legal implications resulting from the introduction of ICT solutions to traditional practices, and adapt and develop the legal framework.

- Acceptance of the legal accountability of all Information Communication Technology transactions.
- Develop standard systems for assigning and defining contractual liabilities.
- Definition of the liabilities of the partners in relation to accessibility of electronic data.
- Assess and address IPR, Security, Privacy, Ownership implications resulting from the introduction of ICT solutions to traditional practices.

Quality and Performance Management

- Improve the decision-making process in the selection of best options.
- Refine assessment methods and performance indicators.
- Develop support systems and tools.
- Improve monitoring and measurement of project progress and performance.
- Adopt high sustainability standards (eco-labelling, certification, performance-based standards, etc.) related to protection of environment, saving of natural resources, health and safety, safety of workers, etc.
- Develop procedures to effectively manage productivity and quality (including conformance to performance standards).

Total Lifecycle Management

- Promote the adoption of a total lifecycle approach, including all management aspects at various stages of the product lifecycle, including pre-construction, construction and post construction (e.g. development management, project management, resource management, design management, etc.).
- Improve decision-making.
- Promote inter (between different companies) and intra (within the company) company integration.
- Improve communication and collaboration.
- Improve process efficiency and effectiveness (including feasibility, planning and scheduling of activities. This includes means to analyse and measure productivity, analyse risk, allocate resources, plan sites etc.).
- Support the development of long-term business relationships between stakeholders.
- Anticipate the expected changes and impact on traditional Construction management philosophies (including procurement methods and approaches) of the rapid introduction of ICT (including rapid development of eTendering and eProcurement).

Human Aspects Management

- Change the cultural attitude of the industry to ICT.
- Change the personal attitude towards cross-cultural ICT based collaboration.
- Improve Trust and Social Cohesion in the workplace.
- Identify and address organizational and personal barriers to the adoption of ICT.
- Anticipate the expectations of the emerging generations.
- Support universal accessibility, flexibility, and equality of opportunity.
- Address health and safety issues.

Expected benefits

ICT is instrumental in achieving many key improvements in the construction sector. The expected benefits to key stakeholders are summarised on a high level in figure 5.

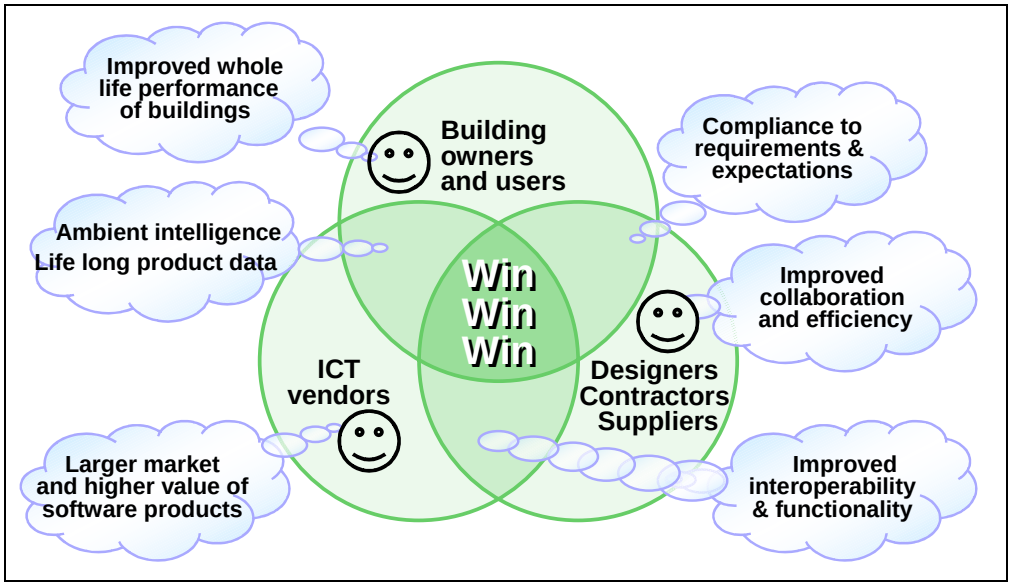

Figure 5. Benefits to key stakeholders

2.4 Barriers for ICT

The following barriers to the adoption of ICT solutions have been identified:

- There is no global actor to enforce the use of standards and ICT on projects.
- Lack of a legal framework to enforce and regulate the use of ICT.
- General end-users (practitioners) ICT maturity and preparedness for change. There is a general need for cultural change in the Construction industry. While the potential gains anticipated through proper adoption of ICT are desired, the necessary changes are resisted.
- Lack of long-term partnering between actors that could result in proper ICT strategy adoption and ICT infrastructure adoption.
- Lack of IT strategy in most Construction organizations (composed of a majority of SMEs with less than 20 employees).
- Robustness, flexibility and scalability of existing ICT solutions (most of which are non-construction specific).
- Interoperability problems due to the complexity and diversity of the Design and Construction process that requires multi-dimensional solutions highly likely to involve ICT solution from several vendors.
- ICT solutions tend to be expensive with low immediate return on investment (the industry is mainly project orientated). Licencing conditions are not feasible for multi-participant projects.
- Lack of adapted solutions for site-based work (high performance nomadic and mobile solutions).
- Lack of visibility and convergence between numerous research and development initiatives, compounded with national issues and interests.

3. Opportunities offered by ICT

3.1 ICT as an enabler of business improvements

This section is mainly based on information from the ROADCON deliverable D4 "ICT-Related Trends & Opportunities for the Construction Industry Sector". State of the art in ICT in key areas is summarised in figure 6.

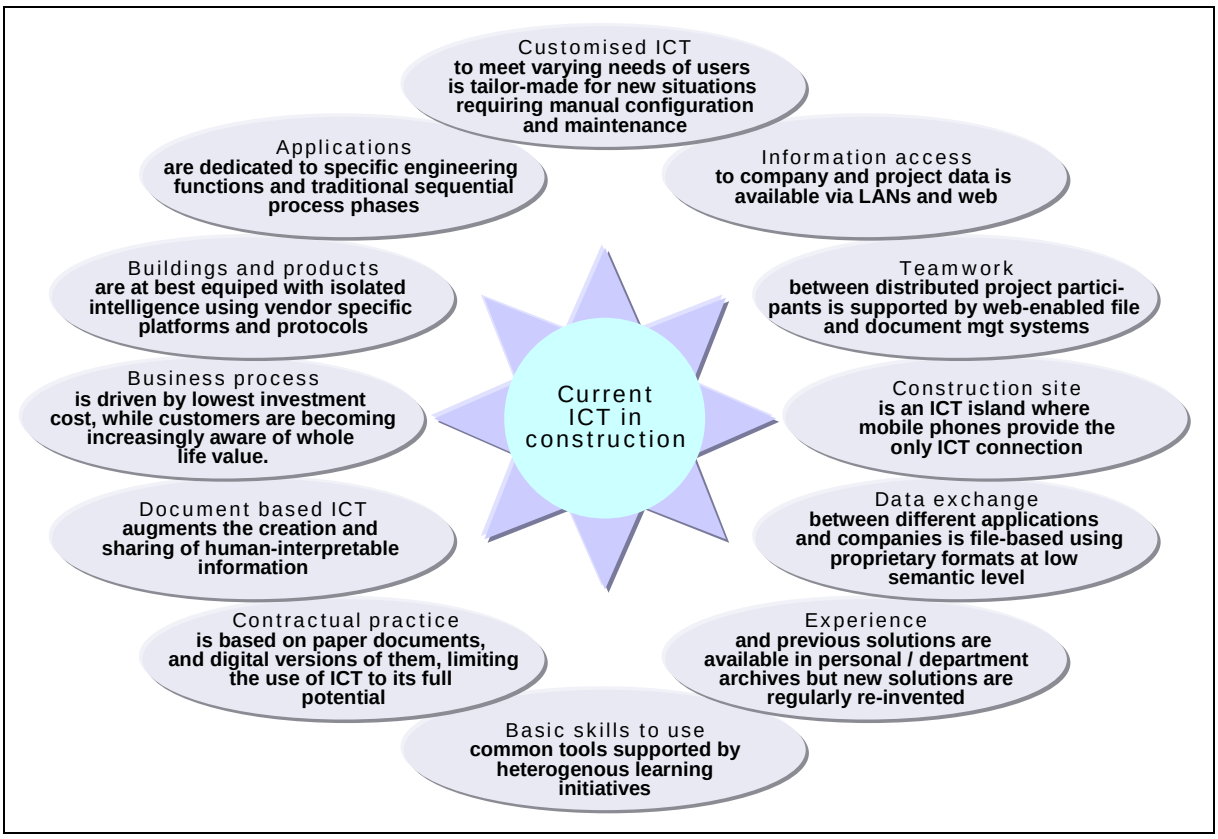

Figure 6. Current ICT
(compare with vision in figure 10)

From an industry point of view ICT is an enabler that allows industry to achieve desirable benefits via its business processes. As the industry is maturing the business drivers tend to shift from basic cost, quality and time towards “higher” level goals such as customer perceived value, whole life performance and sustainability. These trends have clear implications to the expected ICT support. At the same time changes in business processes are also catalysed by the evolving ICT opportunities.

3.2 ICT trends

Derived from the "thinking cube" in figure 3 the below figure 7 illustrates how ICT supports the evolving business processes and priorities. This simplified figure does not suggest direct relations between various items that have quite complex interdependencies.

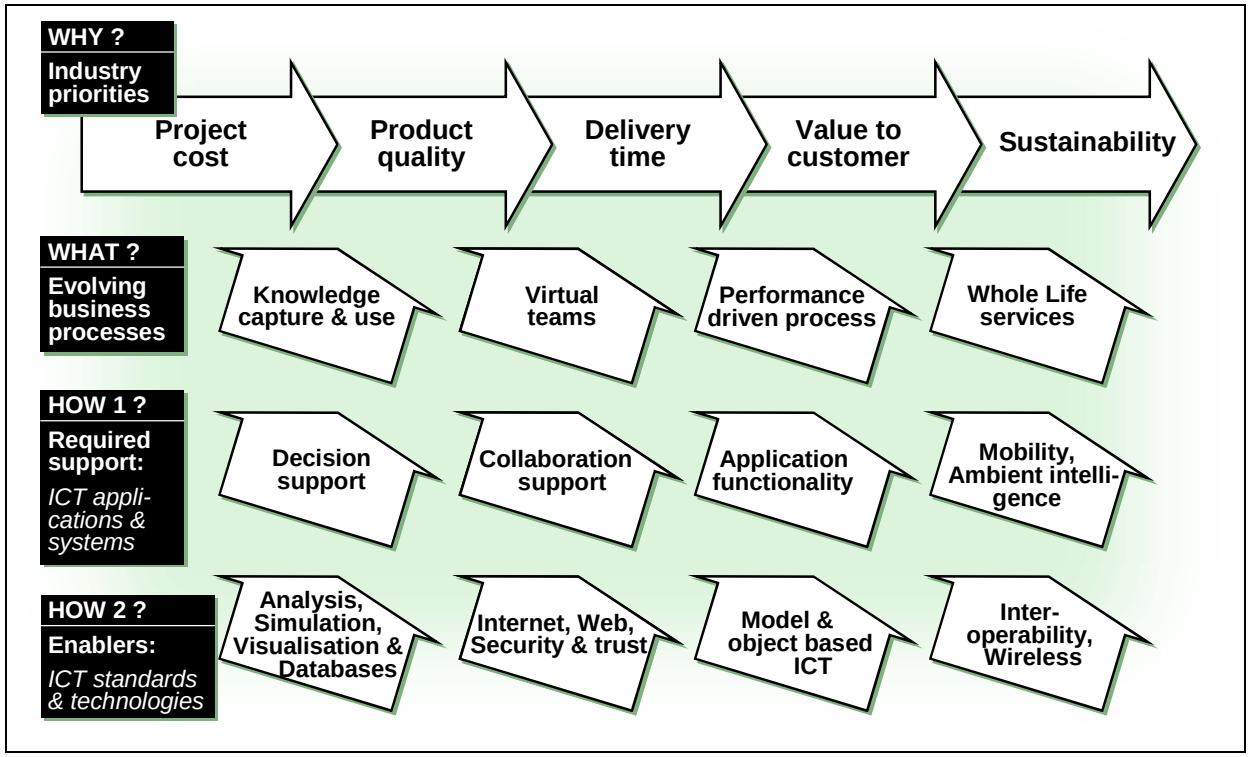

Figure 7. ICT support to business drivers

ROADCON has identified a number of trends that drive ICT developement in this area. Table 1 below list 22 trends grouped on different "Strategy levels" (see figure 3).

Table 1. Trends effecting ICT in construction

Strat. level	Trend
Impact	**Globalisation:** Global competitiveness, impacts, operations, standards etc. **Sustainability:** Shift towards (new) intangible values like customer & society perceived value and environmental sustainability beyond the (old) tangible economic values like cost, time and quality. **Wide coverage:** Considering impacts not only for a company but also for individuals, business partners & stakeholders, industry, society and the environment as a whole.
Business processes	**Collaboration:** Distributed virtual teams combine best competences regardless of organisational or geographic boundaries. **Contractual & legal governance:** ICT becomes the pervasive media for communication, coordination and collaboration between individuals and companies fully supported by the legal and contractual framework. **Human centered:** Both physical and virtual (ICT-supported) processes and working environments become more tuned for humans and less focused on technologies. **Knowledge sharing:** Enhanced and systematic re-use of past experience and best practice from projects and product life cycle performance within and increasingly also between companies. Less re-inventing. **Industrialisation:** Increasing use of standard processes and products / components. **Performance-driven:** Systematic compliance of technical solutions to whole life

	functional & performance requirements. **Service orientation:** Offering of holistic solutions to customer needs combining knowledge-intensive services with products. **Total life cycle support:** Business processes and supporting systems become more focused on total product life cycle.
ICT applications and systems	**Enhanced functionality:** Applications really targeting and supporting the end-user in their current work context. Better support for decision making, communication, collaboration and coordination. **Generic tools:** Use of robust sector-independent ("generic") solutions instead of sector-specific tools. Improved critical mass and cross-sector interoperability. **ICT provision mechanisms:** Instead of only selling & buying licences ICT solutions become available via various new business models like open source, web services, pay-per-use, sponsoring etc.
ICT infrastructure	**Embedded ICT:** Automated and intelligent products, buildings and infrastructures. Chips, tags, sensors "everywhere". **Information sharing:** All product and process information available to all stakeholders, over the whole life cycle in the latest version from one logical source. **Web-based:** The Internet and the future Next Generation Internet (NGI) or Semantic Web will be the information infrastructure backbone for all communication.
ICT enablers: technologies & standards	**Ambient access:** All information and communication accessible via the most appropriate device, anywhere, anytime in a secured way. Mobility is a prime issue. **Adaptive / flexible systems:** "Self-learning" from their own use and user behaviour, and adapting to new situations without manual configuration, maintenance and support. **Model based:** Smarter software (applications and information) that "understands" the building objects of interest and can support the users in more intelligent ways without manual interpretation and re-entry. Better support for user specific views in the actual work context. **Object orientation:** Integration of functionality and data, product and process information in "objects with behaviour". **Open standards:** Rapidly integrated ICT solutions built up from multi-vendor components.

Out of these (22) trends, some can be regarded as key trends from the ICT point of view. We select to emphasise the following ones: (1) Knowledge Management, (2) Model-based, (3) Information/Knowledge Sharing, (4) Object Orientation, (5) Open Standards, and (6) Web-aware. Combining these six key ICT trends we state that the future of ICT in construction is essentially towards: "**Model-based and Object-oriented (Company/Market) Knowledge & (Project) Information Management and Sharing via Open Standards over the Web**".

3.3 Opportunities for construction

In this chapter we introduce five key ICT opportunities that enable the key trends listed in the two bottow rows of Table 1 (ICT Solutions and ICT Enablers:

1. Semantic Web (SW) for the Model-based trend
2. Web Services (WS) for the Object Orientation trend
3. IAI IFC for the Open Standards trend (for "specifications")

4. ISO 12006-3 for the Open Standards trend (for “definitions”)
5. XML (-based technologies) for the Web-based trend

The idea is that the top two Change Levels (Impacts and Business Processes) are indirectly enable and/or supported by the ICT-enabled bottom two layers.

Semantic Web Opportunity

The Semantic Web is the representation of **data** on the World Wide Web. It is a collaborative effort led by the World Wide Web Consortium (W3C) with participation from a large number of researchers and industrial partners. It is based on the Resource Description Framework (RDF), which integrates a variety of applications using XML for syntax and URIs for naming.

The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.

The current web based on HTML-pages is typically for human communication. Computers or other devices have no way of interpreting this information. The semantic web structures the information making it also accessible and comparable for software applications. XML can be used to express this information but more is needed to define its semantics. For this OWL is offered: Ontology Web Language. This language can be used to define the objects that will be communicated.

OWL can be seen as the “STEP EXPRESS” for the web (not yet like UML since functionality definition is missing). With OWL we can describe both data structure and actual data together with their interrelationships (“type relations”). OWL provides us with a very flexible way to organically describe both structure and content.

One of the design principles is that there is no central structure (like with IFC) that controls all progress. Many schemas and/or ontologies can live together evolving and using each other over time. Not agreeing one specific ontology of course gives rise to the need of more intelligent software (e.g. agents) that recognise patterns and map different views on the fly. These agents can be seen as a kind of smart search engines.

The semantic web can do what ISO STEP technology never did; the built-up of enough critical mass (even beyond specific sectors) to share a common syntax and grammar making the data structure and content interoperable and integrateble. IAI IFC and ISO 12006-3 semantics can be brought into this framework in the form of high potential ontologies that can be reused by many applications in a more flexible way than existing today.

Web Services Opportunity

“Web Services” are seen by many people as the next internet hype. They offer a web-based way of having software functionalities use/call each other over the web. Whole applications (like on application servers) but also only access to certain data stores (like distributed APIs) but most likely something in between: a module or component with really added value (added “business logic”) that is worth to reuse in some context (inter-, extra- or intranet). At the moment of writing there is however a great controversy of whether web services are really web-based in their nature. One of the key design principles of the web is that every resource is directly accessible. Scripts like ASP were already violating this principle but with web services it is again easy to hide resources behind some functionality. In OO-context this hiding was always brought as an advantage: you need a transaction around your data to keep it in consistent state; in the flexible internet world this approach might be too rigid.

It is hard too predict whether web services will really provide a breakthrough. Still we will briefly describe its component parts. Web Services are essentially a combination of three specifications that all share an XML-syntax:

- UDDI – Universal Description, Discovery and Integration of Web Services (kind of yellow pages or meta-service: who provides?). This specification is now in version 3, more info: http://www.uddi.org/).
- WSDL – Web Services Description Language (what service is provided?). A working draft of version 1.2 is available at http://www.w3.org/TR/wsdl12/.
- SOAP (over HTTP) – Simple Object Access Protocol (the envelope: how is it communicated?). The Candidate Recommendation version 1.2 is available at: http://www.w3c.org/2000/xp/Group/ - drafts.

Harmonized sets of these three are kept in sync via basic profiles provided by the WS-I (Web Services Interoperability Organization) (http://www.ws-i.org/) initiated by Microsoft and IBM. Currently they developed a draft Basic Profile version 1 (22. January 2003).

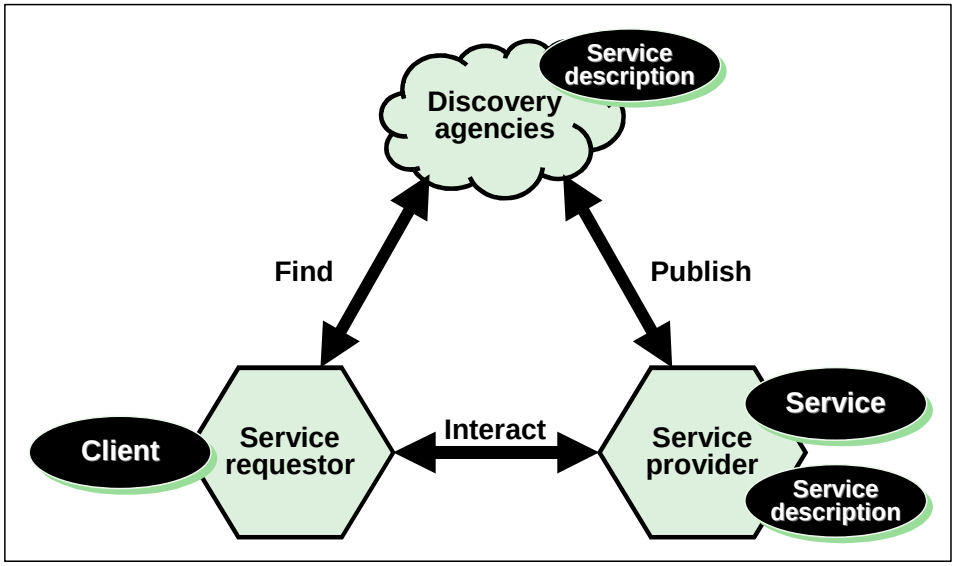

Figure 8. Web Services

In figure 8 we find a general web services architecture. Finding, Publishing and actual Interaction take place over “the wire” typically a SOAP/HTTP stack of protocols.

With the Web services technologies, application servers get a new type of channel for information exchange, adapted to Internet communication, as based on XML. For instance, the SOAP (Simple Object Access Protocol) protocol, which is the RPC protocol for Web services, allows the invocation of (applications') objects over the Internet and through the firewalls, which is a big difference with CORBA IIOP or Java/RMI, protocols typically unable to cross firewalls. Because defined and transported through an XML-based format, SOAP messages are exchanged just like documents between different computers, and over standard protocols like HTTP and SMTP. Moreover, the economical development model of Web services brings to enterprises standardized means to mutualise any type of exchange thanks to both great simplification and speed of interconnections and collaborative work. This is a key-point in a context requiring to provide flexible and lean organizations with state of the art communication, especially taking into account the specificity of the building sector, above all its unique network of SMEs.

Platforms which provide the grounds for such new environments are typically Microsoft .NET or SUN ONE (for Java), or light architectures that are Open sources. As regards Web services by themselves, standard specifications and frameworks are still required anyhow. Indeed, if protocols for services dealing with communication and transport (SOAP for Web services invocation, WSDL for technical description / interfaces of Web services) are now well specified, there are still a lot of expected progress to come in the 2 or 3 upcoming years on protocols for repositories (e.g. UDDI, DSML), orchestration (e.g. XLANG, WSFL), business process (e.g. BPML4WS), user interactions (e.g. WSCM), that provide with technical services, or on protocols for business services, e.g. RosettaNet, ebXML, BTP or UBL for instance.

Web services are perceived as future powerful instruments of deployment of new enterprise applications with a substantial business logic, i.e. one can publish any application over the Internet like a Web service with the description of its interfaces (via WSDL), ways of publishing and finding it as a resource (through UDDI), providing means for remote requests (through SOAP), and co-ordination (through workflow protocols, e.g. WSFL). These should allow ease of access by other Web applications, and simplify future EAI (Enterprise Application Integration). However, it also clearly appears that this is not enough, and link is required with the so-called "Semantic Web", which should provide future structures for dealing with business-oriented concepts in a specific (construction) domain or context: XML as a way to deal with structured information (with types in XML schemas), Dublin Core and RDF(S) for meta-information management, Semantic dictionaries (e.g. DAML, OIL, OWL, etc.), and ultimately conceptualisation of business domains through ontologies: future is to rely on Business-oriented ontologies for the Construction industry, that are to be Web-enabled, and IFC-connected.

For ROADCON “Web Services” are for “functionality” like what the “Semantic Web” is for “data” on the web. Combined (WS/SW) in the right way they will form the future backbone of any ICT Infrastructure providing the agreed basis for construction data and intelligence management, transfer and sharing.

IAI IFC Opportunity

The IAI (International Alliance for Interoperability) mission is: ‘To provide a universal basis for process improvement and information sharing in the construction and facilities management industries, using Industry Foundation Classes (IFCs)’. The first Chapter of the International Alliance for Interoperability was set up in North America in June 1995, the UK Chapter in January 1996. Other Chapters cover German-speaking, French-speaking and Nordic countries, Iberia, Japan, Singapore, Korea and Australasia. Industry Foundation Classes are a practical tool for information sharing, using object technology; they are information-rich, swiftly transmitted and not limited to any one software vendor or system.

Latest Developments (April 2003): IFC 2x 2nd Edition

The main advantage in IFC 2x 2nd Edition (“IFC2x2” for short) is that the concept is changed: instead of containing the complete model itself, IAI has fixed the ‘core’ as platform and defined a way to extend this core IFC model with standards from specific disciplines. Main extensions of provide by IFC2x2 in the area of:

- Drafting extensions (XM-4)
- HVAC extensions (BS-7, BS-8, CS-4)
- Structural extensions (ST-1, ST-2, ST-3, ST-4)
- Facility extensions (FM-1, FM-8)

Release schedule of IFC 2x2:

- Beta version March 2003
- Final version Published 14-5-2003 in Washington (also the first IFC 2x2 applications will be demonstrated).

The idea is that Model Servers will be the best choice for hosting IFC data in the future. There are plans to harmonise the interface (API) to such a model server, they call this the SABLE project [SABLE]. This common interface should be defined in such a way that it is independent of the IFC version used (especially useful for the new version 2x2 that uses the 'platform concept'). Such a model server is essential if multiple users have to work on THE SAME data using different ICT applications.

In short, model servers seem especially in combination with the new IFC 'platform concept' a big step in the right direction, nevertheless in practice the 'platform concept' will show its gain for end users but most end users will not directly use the model server technology.

Bringing IFC to ISO

IFC moved a step closer to full international endorsement as a common language in construction when, at the end of last year, ISO/CD PAS 16739 IFC 2.x Platform specification was registered as a draft international standard (DIS). This means that at the end of the committee draft (CD) stage, the International Organization for Standardization (ISO) approved this publicly available specification (PAS). During the ensuing enquiry stage, it will be circulated as a DIS to all ISO member bodies (national standards organisations such as Standards Australia) for voting and comment. Although this draft standard is not one that building industry practitioners would necessarily refer to, it is still significant

IFCs are a practical tool for sharing information electronically. They provide for the development of applications that can swiftly transmit information that is not limited to any one software vendor or system. Commercial applications implementing IFC releases 1.5.1 and 2.0 have been available for several years. With the latest release IFC 2x specification, IAI certification is now being awarded under a more stringent (two-stage process) system. The first stage establishes whether a set of test files, supplied by the vendor, is IFC-compliant. This is followed by a six-month pilot project period, at the end of which end-users involved in the pilot give their approval. With wider use of these IFC standards, the industry can look forward to more customised applications for improving information sharing between project stages and industry partners.

ISO 12006-3 Opportunity

ISO DIS 12006-3: *Building construction – Organization of information about construction works – Framework for object-oriented information exchange*. This draft international standard (DIS) developed within ISO TC59/SC13/WG6 specifies an information model (or meta-schema") which can be used for the development of Vocabularies (their term for "ontologies") defining concepts of interest and their relationships for the construction industry, in a language independent and computer interpretable way. Vocabularies based on the standard should provide common, cross-language definitions which can be referenced from classification systems, information models and object libraries.

According to the New Oxford Dictionary a concept from a philosophical point of view is "an idea or thought which corresponds to some distinct entity or class of entities, or to its essential features, or determines the application of a term (especially a predicate), and thus plays a part in the use of reason or language." A Vocabulary consists of both types of concepts: (classes of) entities and predicates, where predicates are associated with entities to formulate its

essential features. In ISO PAS 12006-3 entities are called Subjects or Activities and predicates are called Properties. Other predicates describe special types of Relationships between entities, such as Type-of relationships and Part-of relationships.

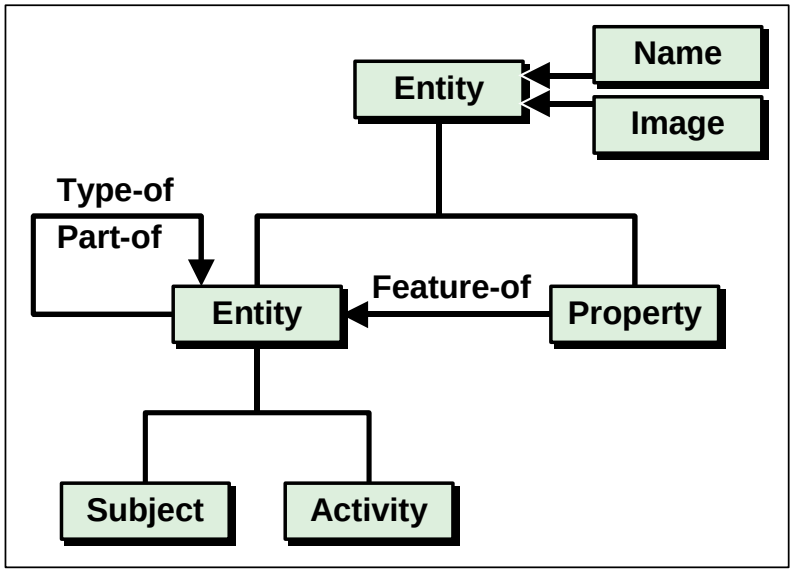

Figure 9. The global meta-schema

ISO PAS 12006-3 allows concepts to be named and described by any number of names and descriptions, in any language. Hence the terms in the Vocabulary are just pointers to the concepts. Moreover, sometimes a concept can be better described in a graphical way with the help of an image. The definition of the concept lies in its associated features, only concepts of the predicate type have a lexical definition.

On the international level the IAI XM7 project is active, which is aiming at the harmonization between an international Vocabulary and IFC2x2 Property sets. Similar efforts have started in Norway, in the BARBI project [referenced in ROADCON D4]. This will add a new semantic level to the IFC Property Sets: instead of using locally defined properties these property sets could then use standardized properties, taken from the vocabulary.

XML (-based technologies) Opportunity

eXtensible Mark-up Language (XML) will be the used format (syntax) for structured data on the future web. Based on XML many other XML-based technologies were developed like:

- eXtensible Schema Definition (XSD), a language for defining the structure of XML files,
- eXtensible Stylesheet Language (XSL), a language for mapping an XML file to another syntax (XSL) or to another XML file (XSLT). This specification also covers internal manipulation (XPath and XQuery) of XML files.
- Resource Description Framework (RDF) and Ontology Web Language (OWL) for defining semantics (meaning) of XML files,
- Web Service Description Lange (WSDL), Simple Object Access Protocol (SOAP) and Universal Description, Discovery and Integration of web services (UDDI) for defining all aspects of Web Services (see more info at the Web Services opportunity).
- And many more (XLink, XForms, X3D, etc. etc.)

More and more the specifications by the W3C become the standard. They are often successful because of their relatively fast development process and inherent flexibility.

4. The roadmap

4.1 ICT vision for construction

Construction sector is characterised by collaboration between many stakeholders who work together in projects for limited periods of time. Other key characteristics are the complexity and long life cycle of products. Therefore it is only natural that the current use of ICT is fragmented serving specific tasks, stakeholders and life cycle stages. The main challenge for the construction sector is to achieve a holistic and integrated ICT support.

ROADCON has formulated the vision for future ICT in construction as follows:

Construction sector is driven by total product life cycle performance and supported by knowledge-intensive and model based ICT enabling holistic support and decision making throughout the process by all stakeholders.

Figure 10 shows ICT related aspects of the vision. The comparision between the current state (figure 6) and the vision (figure 10) is shown in table 2.

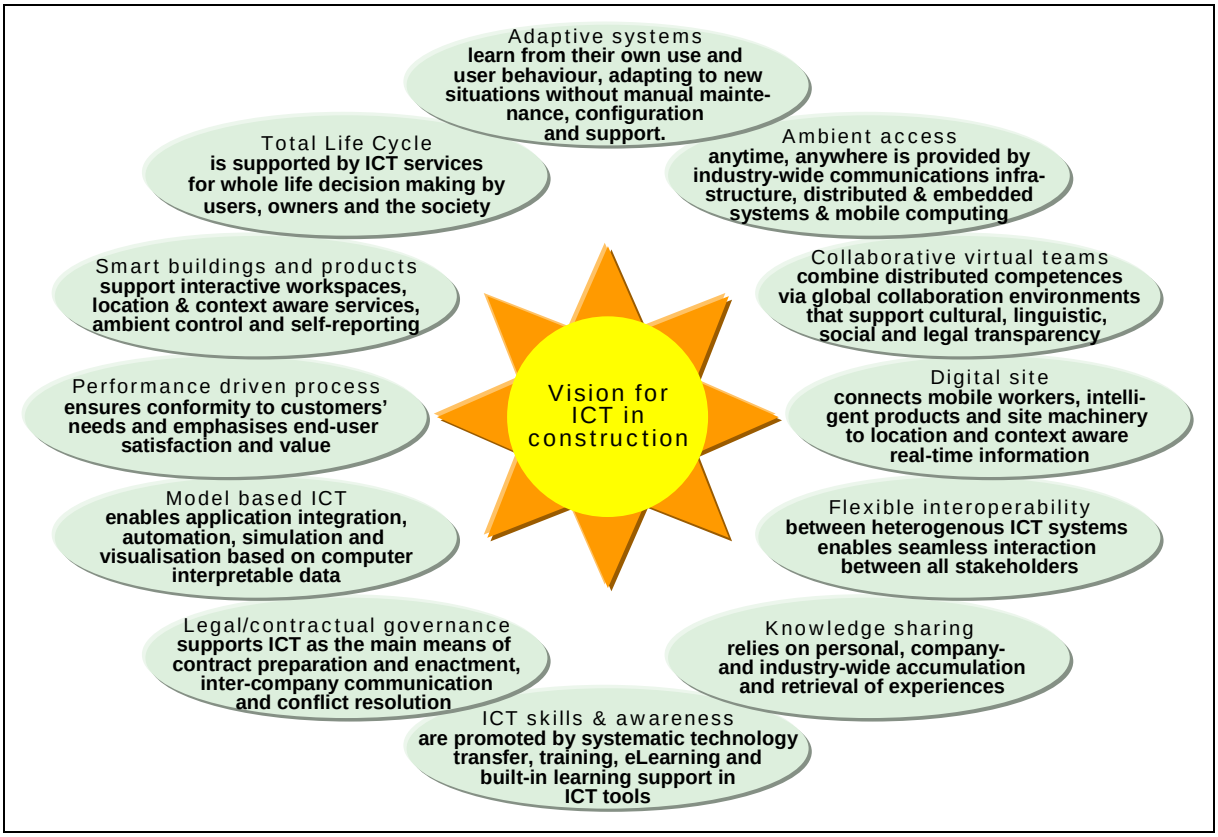

Figure 10. Vision for construction ICT
(compare with current state in figure 6)

Construction sector makes use of available ICTs and does not have much influence on the basic ICT development. Thus the ICT opportunities in construction are similar as in other industry sectors. However, the priorities for applying ICT will reflect the characteristics of the construction sector. The sectorial differences become more clear at detail levels.

Table 2. From current state towards the vision in construction ICT

Current state (figure 6)	**Vision** (figure 10)
Customised ICT is neded to meet varying needs of users. Tailor-made solutions for new situation require manual configuration, maintenance, and support.	**Adaptive systems** learn from their own use and user behaviour, and are able to adapt to new situations without manual configuration, maintenance and support.
Information access to company and project data is available via LANs and web.	**Ambient access** anytime, anywhere regardless of physical location: office, construction site, home etc. Provided by industry-wide communications infrastructure, distributed and embedded systems, ambient intelligence and mobile computing.
Teamwork between distributed experts in participating companies is supported by web-enabled file and document management systems with basic team collaboration support (”project web sites”).	**Collaborative virtual teams** combine distributed competences via global collaboration environments that support cultural, linguistic, social and legal transparency. Distributed team members collaborate across organizational, geographical and time boundaries as if they were co-located.
Construction site is an ICT island where mobile phones provide the only ICT connection.	**Digital site** connects mobile workers, intelligent products and site machinery to location and context aware real-time information and services.
Data exchange between different applications and companies is file based mainly using proprietary formats at low semantic level.	**Flexible interoperability** between heterogenous ICT systems enables seamless interaction between all stakeholders. ICT tools and systems of different enterprises are interconnected very rapidly in unforeseen conditions.
Basic skills to use common tools are supported by heterogenous learning initiatives	**ICT skills & awareness** are promoted by systematic technology transfer, training, eLearning and built-in learning support in ICT tools.
Experience and previous solutions are available in personal and departmental archives but new solutions are regularly re-invented in every project.	**Knowledge sharing** relies on industry-wide sharing of previous experiences, best practices and knowledge within and, increasingly, between organisations.
Contractual practice is based on paper documents, and digital versions of them, limiting the use of ICT to its full potential.	**Legal and contractual governance** supports ICT as the main means of contract preparation and enactment, inter-company communication and conflict resolution.
Document based ICT augments the creation and sharing of information which still requires human interpretation and re-entry.	**Model based ICT** enables system integration at high sematic level, context awareness, automation, simu-lation, user specific views and visualisation based on computer interpretable data.
Business process is driven by lowest investment cost, while ustomers are becoming increasingly aware of whole life costs, perceived value and intangible assets.	**Performance driven process** ensures conformity to customers’ needs and emphasises end-user satisfaction and value.
Buildings and products are at best equiped with isolated intelligence using vendor specific platforms and protocols.	**Smart buildings and products** support interactive workspaces, location & context aware services, ambient control and self-reporting.
Applications are dedicated to specific engi-neering functions and traditional sequential process phases. Sub-optimisation is the norm.	**Total Life Cycle** is supported by ICT services for whole life decision making by users, owners and the society.

Model-based, semantic information is at the core of the vision and has fundamental impacts on various uses of ICT. Some of them are illustrated in figure 11 below.

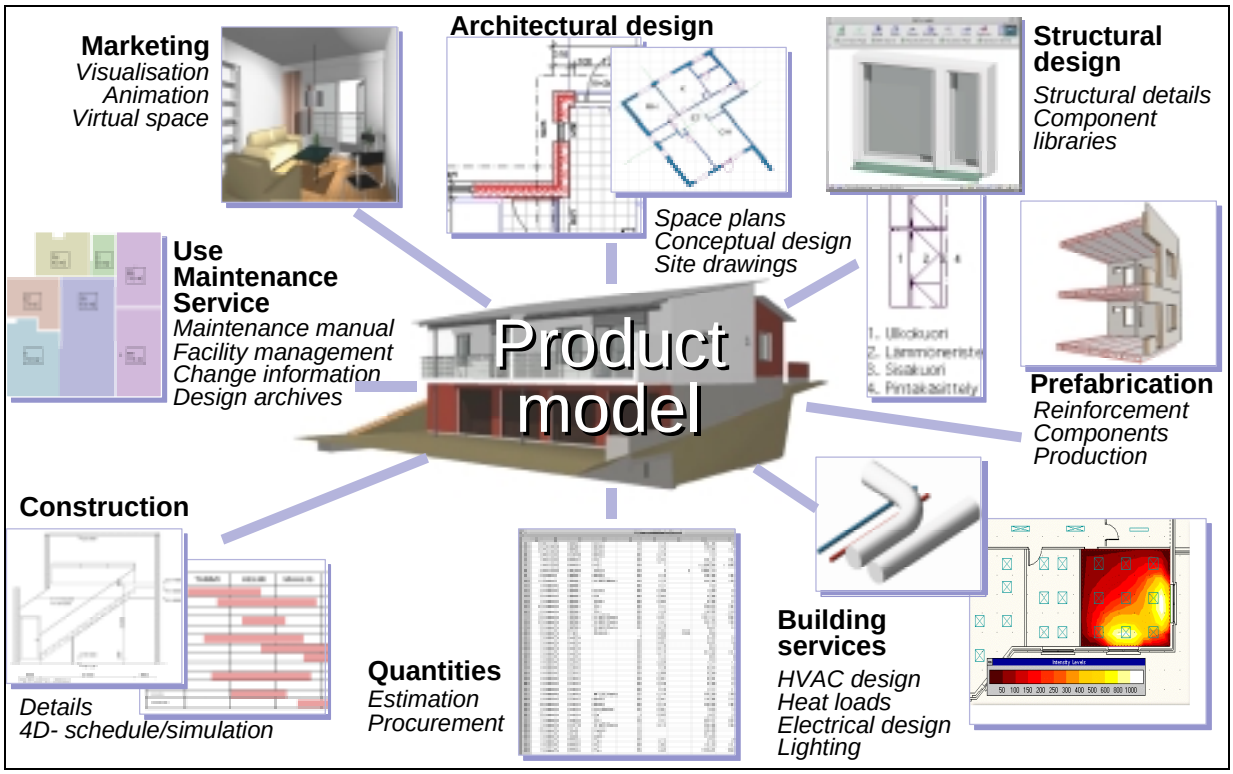

Figure 11. Building model supporting various engineering applications

4.2 Envisaged ICT tools, systems and platforms

Intensive inter-enterprise collaboration and information sharing is a fundamental characteristic of construction. Figure 12 shows a high level view of a target ICT architecture in a multi-enterprise environment. In this figure the ICT system components are grouped on 7 layers (Globemen 2003).

The figure shows the logical and functional architecture while the physical architecture can be implemented in numerous ways.

The topmost 3 layers in figure 12 describe the internal ICT environment of a company. Iterfaces to external systems are concentrated on the 3rd layer. Otherwise an organisation has a high level of autonomy to decide what kind of ICT solutions it uses.

The middle (4th) layer is basically the Internet and related protocols and standards. This is especially the case in construction where dynamic business relationships make commonly available and standardised communaction means (i.e. the Internet) highly preferable compared to any proprietary ICT network solutions.

The 3 bottom layers describe the inter-enterprise collaboration platform. It consists basically of services and shareable information that are accessible via standardised interfaces (APIs). In the context of ROADCON the most basic services are document and product model management. These can be complemented by a variety of additional services as needed. The services in this layer can be provided e.g. by external service providers (e.g. of “project web sites”) or by the collaborating companies themselves.

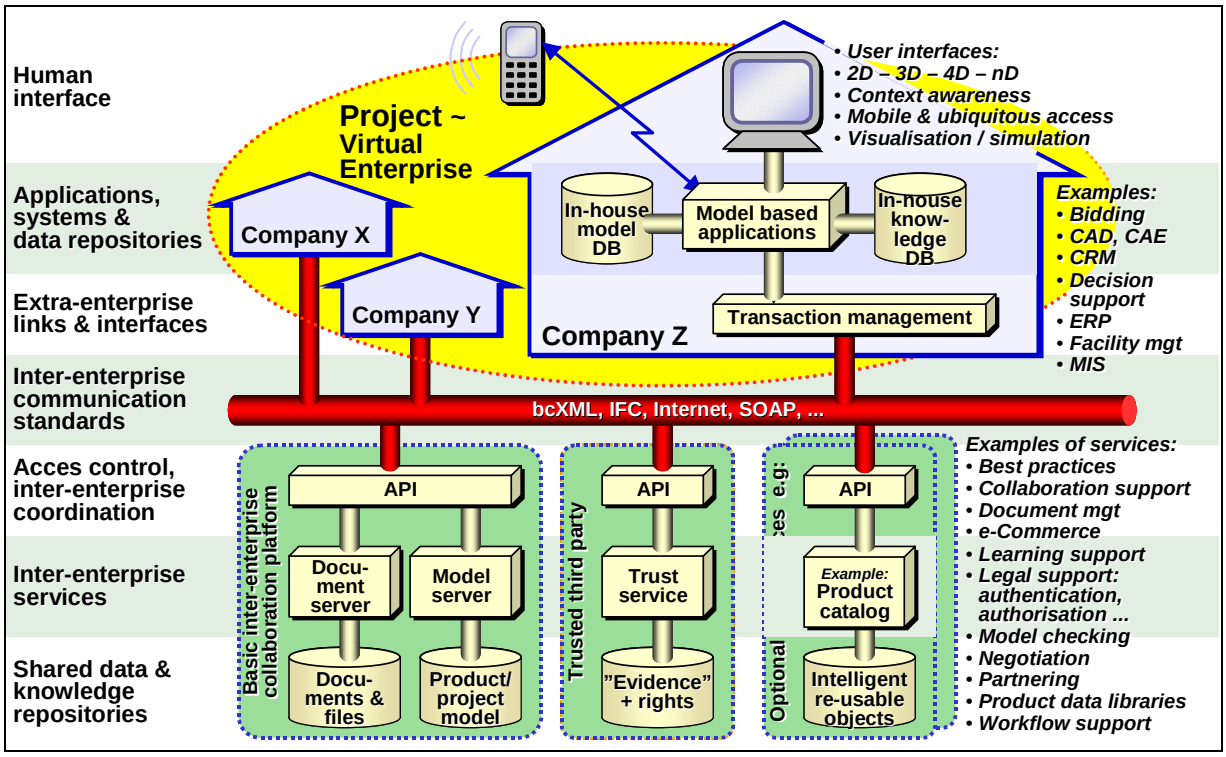

Figure 12. Target ICT system architecture for collaborative processes in construction

Human interfaces

The human interface is what a human user sees and interacts with. Traditionally the user interface was typically part of each ICT tool or system. The trend is to separate them. General purpose web browsers are increasingly used at this layer. In this simplified figure we do not show support for business logic as a separate layer and regard it as part of applications. The user interface provides:

- user specific view e.g. 2D – 3D – 4D –5D – nD,
- context awareness,
- mobile & ubiquitous access,
- visualisation of analysis/simulation results etc.

Applications & systems

This layer provides tools and databases that are available within an organisation but are not accessible to other organisations.

A large number of end-user tools can be identified:

- Analysis, Automation, Bidding, CAD, CAE, CRM, Decision support, Design, Engineering, ERP, Estimation, Evaluation, e-Commerce, e-Negotiation, e-Work, Facility mgt, Knowledge mgt, Learning, m-Work, MIS Simulation, Smart buildings, Web services, ...
- The applications are related to construction process stages: Inception, feasibility, Requirement specification, briefing, Design, Estimation, Tendering, Scheduling, Resource planning, Procurement, Site management, Hand-over, Facility management, Renovation / refurbishment,…
- The applications are also related to actor roles: Architect, BS/HVAC eng., Contractor, Consumer, Consultant, Estimator, Information service provider, Manufacturer, Owner, Project manager, Public authority, Structural Engineer, …

It is anticipated that for the foreseeable time companies will prefer to "own" applications and systems for daily core activities. This covers "outsourcing" to external service providers on a long term basis. It is less likely that mission critical applications and systems would be changed for each project.

Extra-enterprise links and interfaces

Inter-enterprise interface: In order to achieve cross-company interoperability at project level it is necessary that in-house systems are provided with an open external interface. This layer will provide controlled transaction and communication with other organisations. In most companies hardly more than a firewall exists today. Ad hoc means like email, collaborative web sites etc. are frequently used for inter-enterprise communication. The main problems are that individual employees are expected to learn and use varying external systems directly (with web browsers) and the organisation has very little control of in- and out-going information flows. It is envisaged that much versatile support will be provided in the future in order to integrate internal and external workflows in a transparent manner while assuring security.

Proper implementation of this layer will protect a company from being imposed e.g. by a dominant customer, to use other ICT tools than those that it is familiar with. Some functionalities at this layer are:

- Encrypting, Digital signing, Filtering, Firewall, Event logging (audit trail), Messaging, Packaging, Transaction management etc.

Inter-enterprise communication technologies and protocols

At this level the construction sector must mainly rely on publicly available networks (the Internet) and open standards:

- bcXML, IFC, Internet protocols, …
- Underlying standards for distributed systems are e.g.: IFC, LDAP, PDM schema, SOAP, STEP, UDDI, XML, WSDL, ... etc.

Access to inter-enterprise collaboration platform

A main issue here is management of role-based access. Companies working together in a project will have contract-based rights and obligations. Typically each company assigns corresponding roles to its employees. The same persons will have different roles (i.e. rights) in different projects. The inter-enterprise collaboration platform should enable role-based access in a transparent manner.

Web services

Key services are: document/file management, collaboration support, product model management and trust management.

These can be complemented by a variety of additional services as needed e.g.: Best Practices, e-Commerce, e-Contracting, e-Learning, e-Litigation, e-Market places, e-Negotiation, Notification, Partner & supplier databases, Product & material data libraries, Schedule / process / workflow synchronisation, Standards-compliance checking etc.

Shared repositories

This layer simply provides the persistent storage of the data which is shared between collaborating companies. A key issue is persistence beyond project duration.

4.3 Top level roadmap

This section introduces the “roadmap” i.e. the strategy towards achieving the vision that was presented in chapter 4.1.

Figure 13 below shows the high level ROADCON roadmap. This figure is simply a combination of the Current State (figure 6) and the Vision (figure10). Each path (road) in it is described in more detail in a number of "subroadmaps" in the following section.

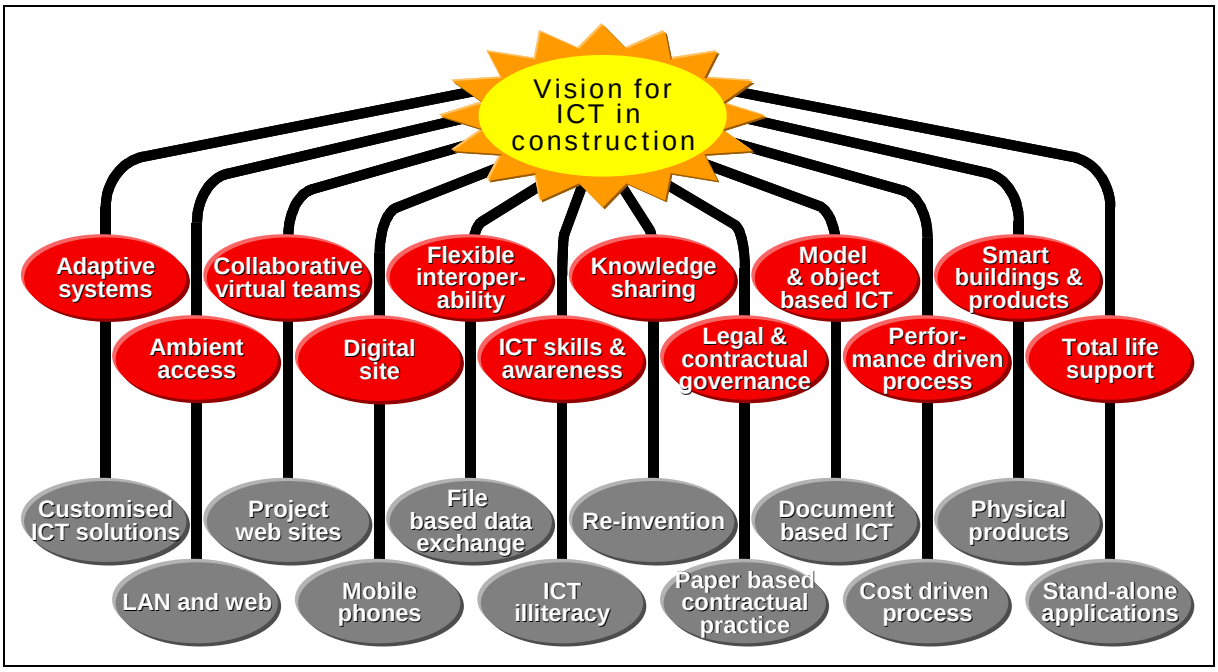

Figure 13. Top level roadmap from current statetowards the vision

The "subroadmap" diagrams divide the suggested steps into different time spans, and show alternative routes how to proceed depending on specific priorities of the stakeholders. RTD topics are positioned in the innovation life cycle. The tentative time to exploitation of results is given as an indicator of the time frame:

- ***Take-up*** - Adopt, deploy & demonstrate mainly existing technologies (0-2 years).
- ***Development*** - Clearly defined RTD to achieve exploitable results (3-5 years).
- ***Research*** - Prototyping is required to find the way forward (6-10 years).
- ***Emerging*** - Exploring RTD needs and opportunities for potential solutions (11-20 years).

It should be noted that these illustrations are simplified and in reality many RTD issues are interlinked in a very complex way. These interrelations can not be captured by simple diagrams which are meant to provide a high level view, the "big picture", on the directions for future RTD in construction. Some interdependencies are shown in the detail level roadmaps (subroadmaps) where some key ICTs appear as enablers for different parts of the overall vision. Otherwise the interdependencies of the many suggested RTD actions are not presented in this report. The notation used in the roadmap diagrams is presented in figure 14 below.

The roadmap diagrams provide a view at a given point of time (now): Mature ICTs can be deployed immediately. Application development is needed for exploitation of available technologies. Research is needed on new technologies and the potential of emerging technologies needs to be explored.

Over the time each specific technology needs to taken systematically through its different innovation stages: Emerging => Research => Development => Take-up => Impact.

Naturally, as time goes on, the maturity of each technology evolves and new technologies emerge. Also the vision will evolve. Thereby the vision is not likely to be achieved in the form that we now see it. The roadmap gives a sustaining direction in this dynamic landscape of rapidly evolving technologies.

It is usually not possible or feasible to cover the whole innovation cycle in one RTD action only. Synchronisation between interdependent actions must be planned in order to assure that the expected final impact will be achieved. Past RTD has often suffered from gaps in the innovation process whereby the path towards take-up and impact has been broken. The roadmap provides basis for synchronisation of different, inter-related RTD actions towards a consisten whole.

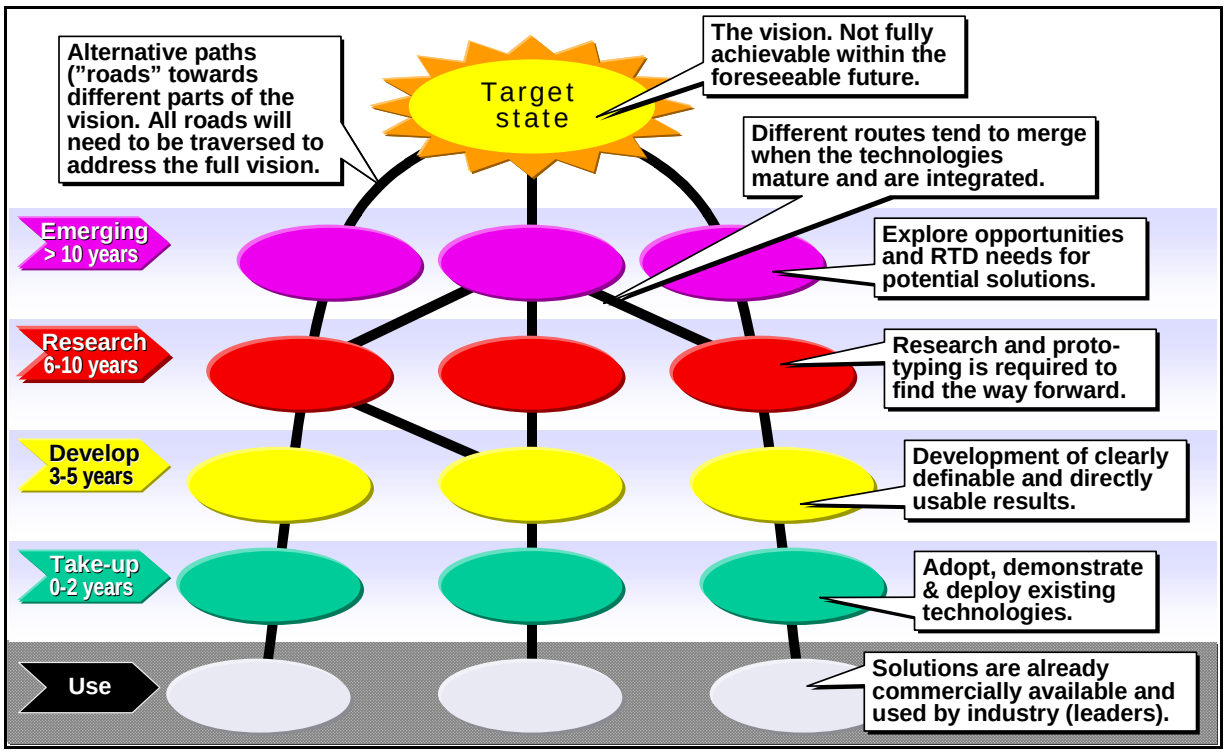

Figure 14. Graphical notation of the roadmap diagrams

4.4 Detail level roadmaps

4.4.1 Adaptive and self-configuring systems

Current state:

- Customised ICT to meet varying needs of users is based on large, monolithic applications that require manual configuration for specific uses, maintenance and support.
- Tools are available for filtering and searching information, but the relevance has to be determined by the end user, resulting in a great deal of "noise".
- Users must specify everything at the symbolic and syntactic levels rather than at the semantic level, resulting in time and energy being spent on "translation" tasks.

Vision:

- Component-based ICT systems learn from their own use and user behaviour, and are able to adapt to new situations, locating and incorporating new functionality as required.

- Information is made available, on a "push" basis, to individual users, prioritised according to the user's interests, which are determined from their roles, previous history of information use, and the urgency and importance of the situation, through whatever medium is most appropriate at a given time
- Users are given early warning of areas that may require attention, based on pattern recognition and uncertain reasoning (e.g. fuzzy or probabilistic logic, or neural nets).
- Systems automatically keep track of the social and knowledge networks of their users, suggesting appropriate references and contacts that may be useful in a given situation.

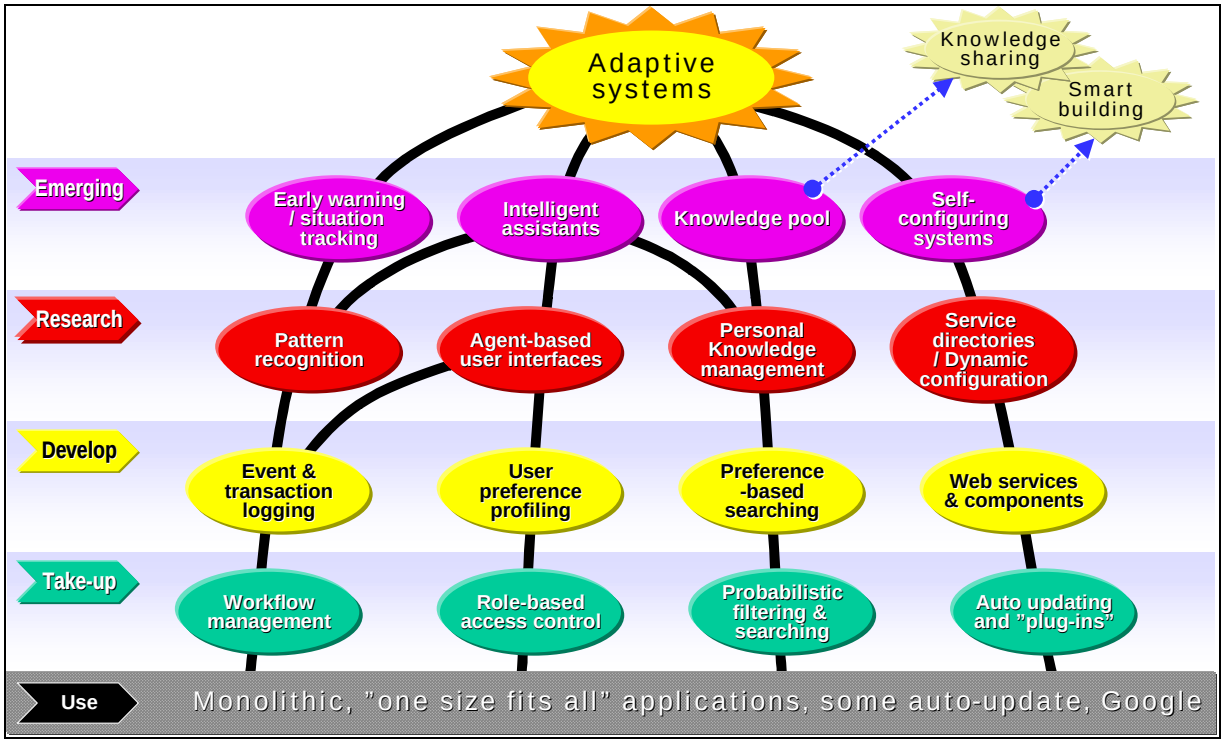

Figure 15. Roadmap for Adaptive systems

Scenario: System detects that a known constraint has been potentially violated in the real-time as-built information for an ongoing construction project. Informs the site manager, who takes the decision to stop work temporarily on this part of the site. System informs the project manager (in his car), the architect (out at another site) and structural engineer (in his office), with a high priority level. System retrieves all relevant model objects and regulations, sets up an online meeting by consulting the diaries of the participants, locates an available structural engineering model server, books time, and arranges access through the GRID for the meeting. The architect and structural engineer discuss the implications, running scenarios on the model server, and agree a modification. Some finite-element calculations are required, so the system finds, downloads and incorporates a suitable software component, negotiating prices between supplying systems within pre-arranged limits. Change costings are calculated automatically and forwarded to the project manager for approval. Production views are generated for the site manager and sent to the site.

Technologies in industrial use

- Monolithic applications based on "one size fits all" approach. Manually configured for a given situation, with limited data interchange.
- Keyword based information searching.

Ready for take up

- Workflow management based on predefined workflows, with appropriate applications made available as needed.
- Role based access control with single sign on (e.g. through pluggable authentication modules).
- More intelligent searching based on ontologies, thesauri, etc. and probabilistic approaches.
- Some software updating and configuration management through "auto –update" and "plug-ins" auto-downloaded as needed.

Develop

- Event and transaction logging
- Individual "roaming" profiles, allowing configurations to follow users, relating to a wide variety of applications.
- Searching based on defined individual preferences, augmented by the user over time through limited learning capabilities.
- Access to, and interworking between, applications through web service definitions.

Research

- Use of pattern recognition to identify and prioritise key issues to be addressed, and to identify relevant information.
- Agent-based user interfaces adapt to suit user preferences and profile inferred from usage habits.
- Personal knowledge store maintains information on where relevant information can be found, known useful services and people.
- Software services located in real time through directory services and used as required.

Emerging

- Situations are automatically tracked and significant events flagged up.
- Intelligent assistant maintains a view of the users responsibilities, finds needed resources as required and priorities events and tasks, making relevant services available as needed.
- Knowledge is pooled within systems supporting communities of practice, adapting in real time as new information is added.
- Component-based ICT infrastructures configure themselves n real time as needed, adopting new functionality through downloaded components found through directories.

4.4.2 Ambient access

Current state: Information access to company and project data is available via wired networks (LANs and Internet). For mobile workers, mobile Internet through GPRS allow some but limited communications (e.g. emails, access to some Internet services). WIFI hot spots allow to connect to Internet in some places with higher bit rates. Mobile services dedicated to construction workers are very limited in scope and functionality.

Vision: Availability of ICT support, applications and data, anywhere, anytime, regardless of physical location: office, construction site, home, etc. ICT systems intimately integrated with everyday environments and supporting people in their activities.

Ambient access stems from the convergence of 3 key technologies:

- ubiquitous computing;

- ubiquitous & secure communication;
- intelligent user-friendly interfaces.

Scenario: The personal computing system is reduced to a highly wearable personalised communication device (PCD, e.g. wristwatch). On the construction site, the site manager vocally orders his PCD to display a simulation of the moves on the work site planned for the coming days, with the exact perspective from where he is standing. With special organic lens, he can view the simulation placed in the real scene. By taking into account the weather forecast, the system warns him that the casting of a concrete slab should be postponed (because of bad weather), and consequently the supply chain organisation should be revised… On the other hand, the PCD allows a building user to unlock a door, to move around in an ambience that is shaped according to his needs and preferences. A series of multi-service vendors offer complete packages of services linked to the PCD that tailor the user's environment according to his preference. Embedded agents in the PCD and intelligent home devices are in continual negotiation with agents associated to service providers such as maintenance companies, shops, travel agencies and so on.

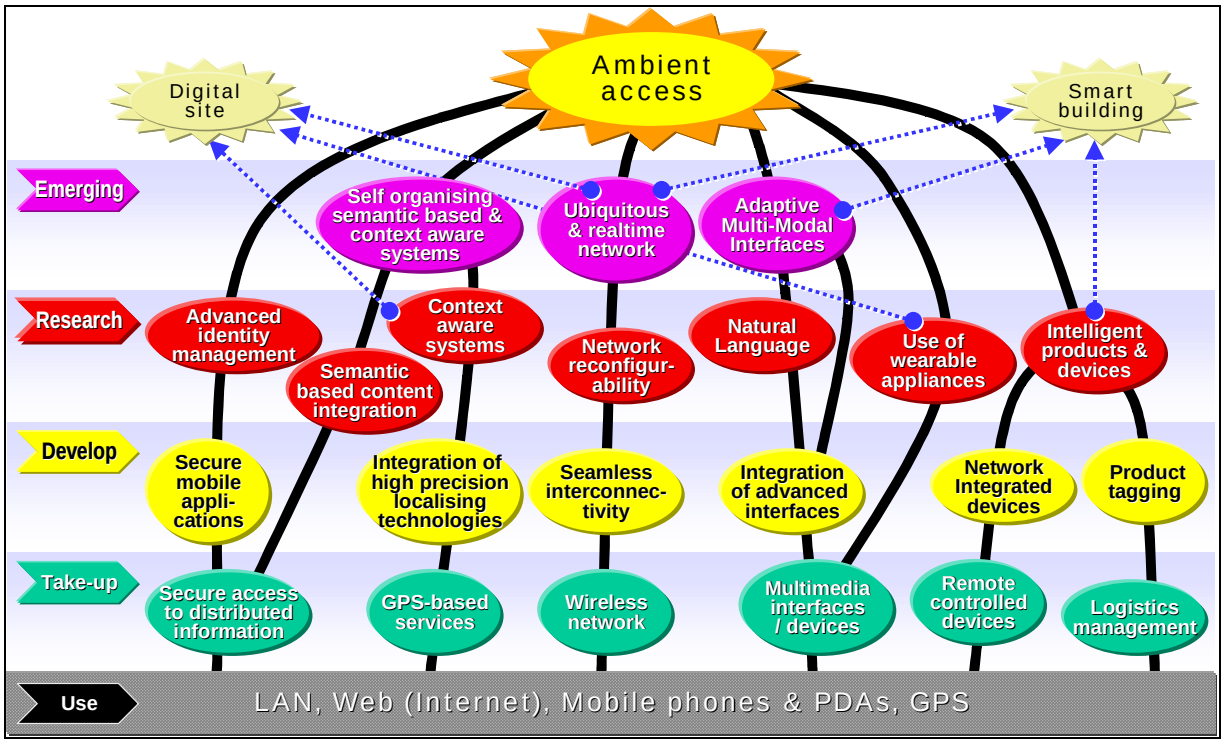

Figure 16. Roadmap for Ambient access

Technologies in industrial use

- Today ambient access relies on the use of technologies based on Internet, local area networks using computers, mobile phones and PDAs. Some advanced but specific applications are available, e.g.: digital identification on PDA, voice command for dialling on mobile phones.

Ready for take up

- Secure access to distributed information: adapt, deploy and assess today technologies such as SSL (secure data transmission), PKI-based encryption and digital signature (authentication).
- GPS-based services: explore and adapt current technologies and tools developed for GPS.

- Wireless network: investigate, classify the appropriateness of various wireless technologies and devices (related to GPRS, BlueTooth, WI-FI, etc.) according to various construction scenarios and context of deployment.
- Multimedia interfaces: promote the generalised use of various types of interfaces, including simple voice interfaces and standard multimedia displays (text, graphics, video). This is related to handheld devices (like PDA, PC tablets, …) to be promoted and used in mobile construction activities.
- Remote controlled devices: investigate the use of such devices (HVAC, lighting, audio-video equipments…) in the built environment.
- Logistics management: investigate and assess mobile technologies and services, as regards the improvement of performance of construction projects. This should especially allow improved overall co-ordination of projects, material and component handling, through linking construction site information to project and resources management.

Develop

- Secure mobile applications: specify and develop such applications based on third generation mobile communications systems, related to e.g. authentification and payment.
- Integration of high precision localising technologies: move from GPS-based services so as to provide advanced location based services (best current accuracy of GPS is between 3 and 5 meters).
- Seamless interconnectivity: identify and specify new services for Construction, based on the 3rd generation of mobiles and the Internet Protocol IPv6.
- Advanced interfaces: evaluation, adaptation to the Construction processes, and integration of such systems (currently developed in research centres and laboratories), including speech recognition interfaces, rollable & foldable displays, head-mounted display devices, and holographic applications (this last point both at level of *Develop* and *Research*).
- Use of network integrated devices (such as home appliances and site equipments) : develop new applications seamlessly and dynamically integrating through the network any autonomous device, based on its universal ID, its dedicated API, and its capacity of active / reactive behaviour.

  > *Note: the 2 previous developments (advanced interfaces, network integrated devices) must in turn rely on advances on powerful and miniaturised components, which are not of direct influence on the ROADCON roadmap, but indeed have indirect consequences. This is why they do not appear on the figure.*

- Product tagging: development and deployment in Construction of solutions and services for dealing with security tagging, RFID (Radio frequency identification) tags microchips, and optimal source tagging integration, leading to overall improved traceability for materials, components, etc.

Research

- Advanced Identity Management: based on a follow-up of the progress in current research in this field (typically related to biometrics), identify and assess the potential of integration of these technologies in services dedicated to Construction.
- Semantic based content integration (including data fusion): specify and develop algorithms and solutions that will achieve syndication of information from a semantic point of view leading to a seamless integration of data from disparate and multiple data sources.

- Context aware systems: identify, specify and develop services to support personalisation and context data processing, therefore being able to interpret information on the user and his environment in order to provide seamless information access and gathering, as well as value-added information dependent on the context.
- Systems relying on network reconfigurability: based on current research on 3.5G communication networks, dynamic bandwidth control and dynamic network reconfigurability, develop solutions and systems exploiting general communication media with support for a broad spectrum of communication types, along with independence of topology and protocol.
- Natural Language: develop enhanced applications, both for spoken and written languages, based on the latest results of research on natural language processing, the aim of which is to design and build software that will analyze, understand, and generate languages that humans use naturally (using e.g. knowledge-engineered techniques, machine-learning techniques, etc.)
- Use of wearable appliances: integrate and/or adapt in new services and solutions currently emerging new multi-form wearable appliances, allowing "wearable computing", with embedded circuitry, one-handed input device, and wearable display and receivers.
- Intelligent products and devices: specific and develop enhanced products characterised not only by improved features (e.g. optimising the equation quality/duration/cost) and capabilities (e.g. smart buildings), but also shipping with e.g. fully digitalised, unique and personalised, universal electronic cards or digital mock-ups, which will manage the information structuring and integration for the product, and will allow traceability of all parts of the final end product (so as to provide all guarantees of quality and safety to the client), and long-term memory of end products for maintenance, enhancement, refurbishment, and even improving the demolition process (in terms of potential reuse of parts of the building).

Emerging

- Self organising semantic based and context aware systems: identify, specify and develop services to support self-configuration and context-based adaptation, especially to access information anywhere at any time → ***achievement of Ubiquitous (smart) computing***
- Ubiquitous and realtime network : develop solutions and systems exploiting the 4th Generation Broadband Mobile Network that will provide the best interactive and intuitive collaboration / communication services than any alternative networks, including high-level security, better QoS, mobile and audio / video conferencing enabled, improved wireless data protocols, etc. → ***achievement of Ubiquitous & secure communication***
- Adaptive Multi-Modal Interfaces: identify, specify and develop systems allowing context-based multiple modes of interaction, augmenting human to computer and human to human interaction, adapting to the devices, user preferences and contextual conditions, and available / accessible to all → ***achievement of intelligent user-friendly interfaces***

4.4.3 Collaboration support for distributed virtual teams

This chapter describes shortly a few core issues identified by ROADCON. For more information we refer to other roadmap projects that address this theme in more detail, primarily: COCONET (Ribak A. & Schaffers H. *eds.* 2003) and Future Workspaces [Appendix 1].

Current state: Teamwork between distributed experts in participating companies is supported by email and basic web-enabled document management systems (”project web sites”). Quite sophisticated tools/systems to support distributed teamwork are already commercially available. However, the business models of ICT vendors are targeted mainly for internal use by one company and its supply chain. Business models are missing for the provision of these tools and related services to temporary inter-enterprise teams.

Vision: Distributed team members collaborate across organizational, geographical and time boundaries as if they were co-located. Single global virtual workplace for all project and business applications including the construction site.

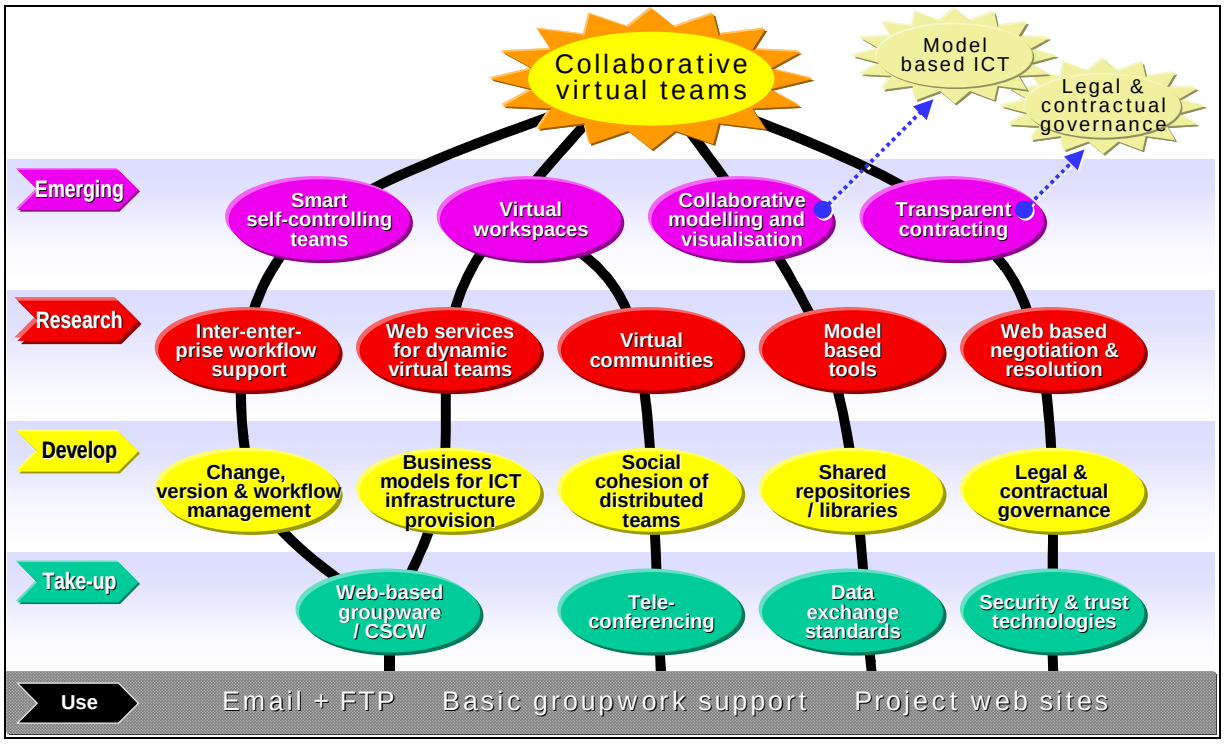

Figure 17. Roadmap for Collaborative virtual teams

Technologies in industrial use

- Email and FTP.
- Web enabled document servers, "project web sites", for exchanging and storing files.
- Some basic groupwork support services like calendars, discussion forums, email distribution lists, partner contact information etc. Use of more sophisticated groupware is limited by licencing conditions: the dominant business model of pricing systems based on the number of "seats" is not suitable for temporary short term projects with several and dynamic partners.

Ready for take up

- Tools for Web based groupwork support: Computer Supported Collaborative Work, (CSCW), Customer Relationship Management (CRM), Document management, Product Data Management (PDM), Workflow Management (WfM) etc.
- Teleconferencing with audio and video using medium to high speed data connections.
- Data exchange standards.
- Security & trust technologies.

Develop

- Tools for change, version & workflow management.
- Business models for ICT infrastructure provision to temporary, distributed, cross-organisational project teams.
- Social cohesion of distributed teams, supporting the emergence of communities of practice, perhaps through shared/distributed authoring using tools such as WIKI and the maintenace of emerging, specialized ontologies.
- Legal and contractual governance and agreements on practical procedures for ICT based collaboration e.g. model contracts.

Research

- Inter-enterprise workflow support for partially defined and ad-hoc processes.
- Web services for dynamic virtual teams.
- Virtual communities using sophisticated applications based on WebDAV (Web-based Distributed Authoring and Versioning).
- Model based tools for all engineering applications.
- Web based contract negotiation, enactment and conflict resolution.

Emerging

- Smart and self-controlling / self-managing teams.
- Virtual workspaces.
- Collaborative manipulation of shared models using e.g. GRID-based communications. Use of advanced visualization to develop and communicate abstract (non-physical) information and concepts.
- Transparent contracting.

4.4.4 Digital site

Current state: Only the site offices are partially equipped in Internet services such as e-mail and connection to general web services or specific project web sites. Site workers are, at the foreman level, equipped with GSM mobile phones and VHF radio terminals. A few sites are fitted with cameras linked with project or company web sites to serve as progress pictures for advertisement to clients and public. Some deep foundation sites and critical bridges components are fitted with sensors in surveillance networks operated 24 hrs a day and interconnected with central data acquisition platform through radio terminals. Some soil treatment sites have implemented fully automated electronic control and operation loop for injection works. A few foremen, particularly in the maintenance sector, are equipped with radio or GSM interfaced PDAs that give them the opportunity to receive instructions and record work done as a link in a seamless administrative process from order receipt to invoicing. Paper-based transmission of partial information is yet generally the norm.

Vision: A completely digitalised work place where intelligent terminals on machineries and individuals give all site stakeholders ubiquitous context-based, geo-referenced and permanent access for all stakeholders, whether on- or off-site, to all site- and project- generated knowledge and information flow in the global project supply chain. This digital work place will assist every site worker to perform his duties or work and drive machineries in the most efficient way further to having taken the most knowledgeable decision in order to obtain a targeted result expressed in economical or sustainable terms.

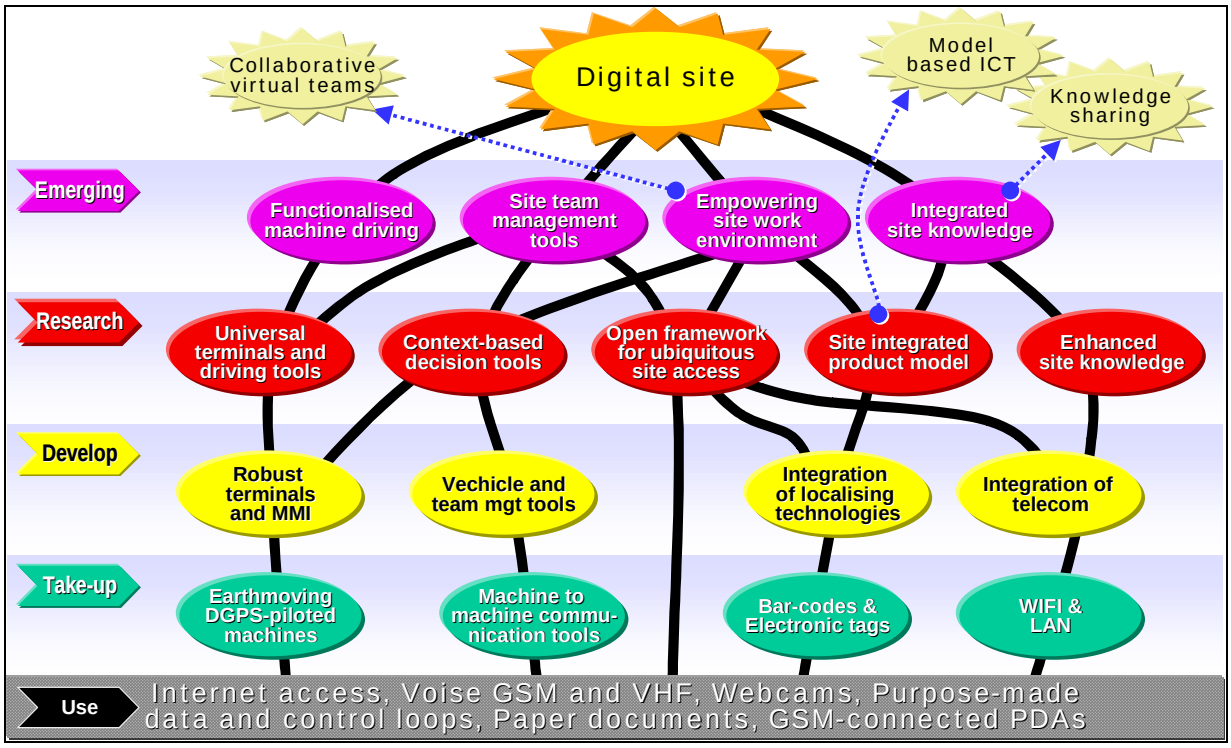

Figure 18. Roadmap for Digital Site

Technologies in industrial use

- Voice based telecommunications with GSM and VHF radio, for the mobile user, fixed telephone and HF radio for fixed facilities
- Data transmission of files and E-mails with Internet site connections for fixed site facilities
- Snap-shot images from sites from webcams installed in fixed positions overviewing site facilities, interconnected with project web sites.
- GSM-connected PDAs for back office work in maintenance and services applications
- Purpose made process control loops with electronic data exchange
- Fax and paper-based transmission mostly used

Ready for take up

- Assistance for piloting cutting tools of some earthmoving equipment according to product models and based on DGPS signals
- Information sharing for production of several machines working in road construction sites
- Use of WIFI on site as telecommunication technology
- Bar-coding and electronic –VHF tagging for controlling the supply chain

Develop

- Tools for management of constituted site working teams with fleet of machineries
- Robust technologies fit for site working environments (heat, cold, vibrations, dust, rain, storms, interferences, hazards etc.)
- Integration of site-fir telecommunication technologies of all dimensional scales
- Integration of radio-based, DGPS and tracking technologies for universal and ubiquitous geo-referencing

Research

- Open source framework for integrating all sensors and intelligent terminals, geo-referenced services and management and work performing functionalities as well as all types of data standards, media, telecommunications and localization technologies
- Knowledge management technologies and tools to transform and integrate all newly site developed information and data into the overall company, project and general knowledge
- Identify and make explicit all site parameters having influence onto sustainability issues.
- Context-based decision making tools, including calling of experts in emergencies or critical situations, but living high level of initiative to user
- Integration, interoperability and interfacing of product model and site management and production tools
- Comprehensive but light and robust, universal, multi-functions and multi-media site terminals

Emerging

- Assistance to piloting tools, and to driving machines in a seamless chain with product model in order to achieve site and company objectives in terms of economy and sustainability
- Similarly assistance to piloting and managing site operations or teams
- Ubiquitous and context-based work environment ensuring permanent access and interaction to site, project, company and general knowledge giving the possibility to site users for knowledgeable and empowering decision making
- Site knowledge is a key component integrated in the total project knowledge

4.4.5 Flexible interoperability

Current state: Integrated multi-vendor ICT systems within companies hardly exist. The same is true externally for the communication between ICT applications of different companies being actors that need to cooperate in the construction life-cycles and supply-chains. Typically ICT applications communicate if at all, point-to-point based on incomplete, proprietary (vendor- or user-dependent) inflexible interfaces at a low semantic level where often only the syntax aspects are agreed. 90% of all data exchange is done manually, needing a lot of non-essential human (interpretation) effort and introducing many errors in the process. This is especially true for "data"-communication. The situation is even worse for reuse of "functionality" or services.

Vision: Ability to interconnect ICT tools and systems of different enterprises very rapidly in unforeseen conditions. The general assumption is that there will never be one ICT Vendor who can deliver all software functionalities in the best possible (optimal) way. Each vendor has to concentrate to be good in his core business/expertise/competence. As a result, a complete ICT system will always be multi-vendor, consisting of software modules from different vendors. These different software modules address however for a large part the same kind of information hence have to communicate about the same objects.

Assuming further the application of external software (not in-house developments only) for the right critical mass, it is not difficult to see that agreements on communication between software application/components is vital on a scale larger then a specific company. Especially in construction where projects always involve external communication, open standards are

therefore crucial. What kind of openness is actually needed depends heavily on the actual integration scenario and the level of intelligence, table 3.

Table 3. Rationales for openness

Interoperability Level	**Rationale** (internal need)
Closed *(no interfaces)* Open proprietary • ICT Vendor-dependent • ICT User-dependent *(incl. fixed end-user networks)* Open Standard *(allowing flexible networks)* • National • European • World-wide	ICT Vendor has to stick to his core business / competence. No one ICT-Vendor can deliver full optimal ICT solution for the end-user. ”One-stop-shop” scenario is doomed. Always multi-vendor solution (best-in-class ICT application portfolio) requiring open communication for integration. Need for Open ICT Infrastructures based on Open ICT Standards and Technologies. Open Standard: explicit and agreed on a certain scale.

Depending on the scenario you have to agree one form of syntax, semantics or both for information, functionality or both. Defining these things in a neutral way is exactly the goal of many current standardization initiatives in Construction ICT.

The wider the scale of agreement the better. That’s why an international standard is preferred above a say European or even national standards. However, international standards take a long time to develop (need a lot of consensus) and are no guarantee for a good standard (often too much democracy resulting in bad compromises). In that sense there will always be a mix of national, European and worldwide standard with interoperability problems of their own.

Another view on flexibility is the idea that people will easier reach consensus and actually use the standard if the standards themselves are more flexible. Not rigid schemas but easily accessible, adaptable and extendable specifications. Ontology approaches especially the web-based ones are seen as a key opportunity here.

Scenario: For the scenario we distinguish between four streams relevant for flexible interoperability that complement, strengthen and fuel each other:
1. ICT Technology
2. Data management / meta-data
3. Data exchange / data
4. ICT Functionality

One observation is that we expect more and more web-based-ness in our solutions. More and more we come to expect from a common ICT Infrastructure: Next Generation Internet with a Next Generation Web on top of it. This next generation web is characterised by a higher level of semantics (model-based Semantic Web) and tight integration with functionality (Web Services or aggregations of them). This way rigid monolitic ICT applications and interface schema specifications will be replaced by flexible, distributed components working on also distributed ontologies and content organized according to these ontologies.

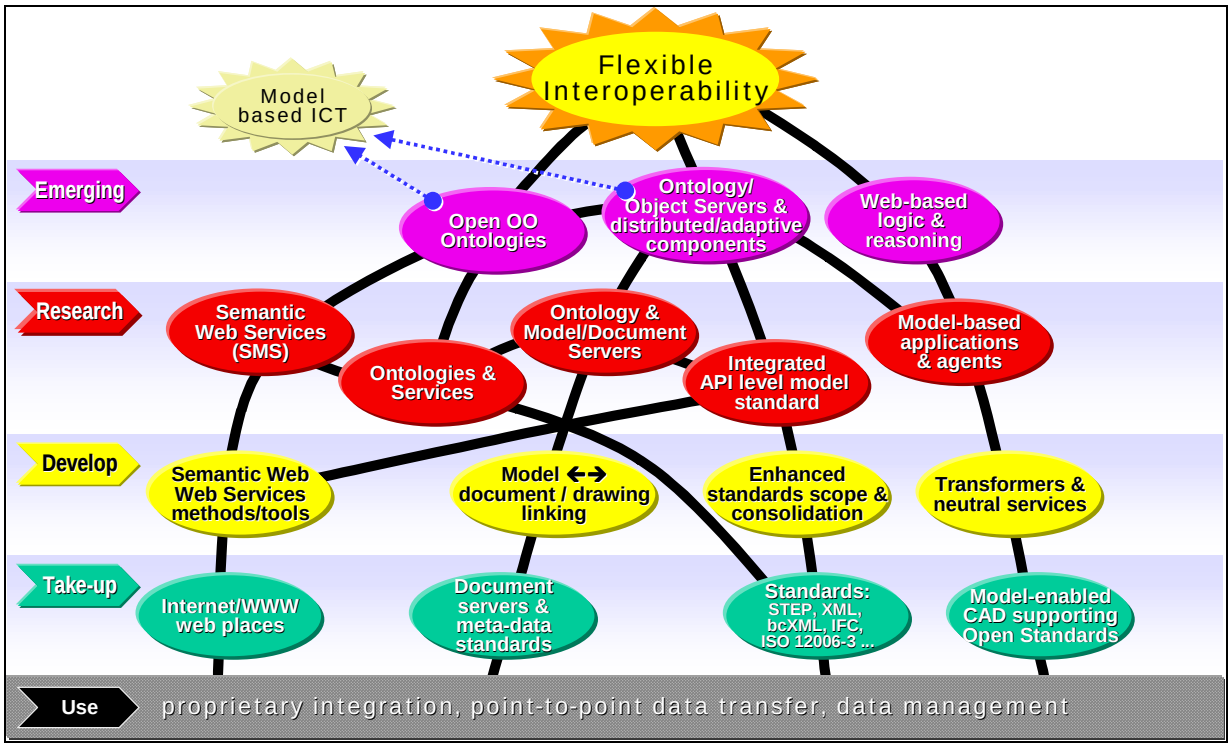

Figure 19. Roadmap for Flexible interoperability

Technologies in industrial use

- Proprietary (vendor suites and/or user dependent) integrated applications/modules
- Point-to-point interfaces between different applications
- Data management (black box approach)

Ready for take up

- The Internet/WWW as common communication platform (i.e. web places like eRoom)
- Document servers (EDM, PDM) & meta-data standards (Dublin Core)
- Common syntax specs (STEP SPFF, XML, RDF), Common language (grammar) specs (UML, STEP EXPRESS, RDFS, OWL) and Partial schemas for file exchange (bcXML, IAI IFC2x2, ISO 12006-3, ...).
- Model-enabled (not model-based ! and often just architectural) CAD systems supporting to some extent some open standards (like Autodesk Architectural Desktop, Nemtecsheck Allplan, Graphisoft ArchiCAD and Bentley Microstation TriForma)

Develop

- Semantic Web (SW) & Web Services (WS) methods/tools
- Model <==> Document/Drawing linking (association and/or derivation)
- Enhanced standards scope (whole life-cycle and supply-chain, all actors) & Standards consolidation & integration (like within CEN/ISSS eConstruction workshop)
- Transformers (Mappers, Translators, Convertors) for "beyond-CAD" support & Neutral utilities (viewers/browsers/editors like IFC browsers)

Research

- Semantic Web Services (SWS) methods & tools: fully integrated SW & WS technologies

- (Actual) Semantic Web -based Ontologies (global, detailed, generic, specific) & Web Services (WS) services
- Open model-level API standard & OO Model servers
- Model-based applications & Smart agents that can work with open grammar/syntax, ontologies and corresponding content.

Emerging

- Open OO Ontologies (not just data-driven)
- Ontology/Object Servers
- Distributed & Context aware (adaptive) ICT components
- Open Web-based Logic & Reasoning (on top of SWS)

4.4.6 ICT skills and awareness

Current state: There currently exists a shortage of ICT skills and awareness in the construction sector, particularly among SMEs. ICT training/education to construction profesionals and students focuses on skills to use basic ICT tools without providing a deeper understanding. E-learning initiatives are heterogenous and not yet widely spread, although gaining increasing acceptance in the field.

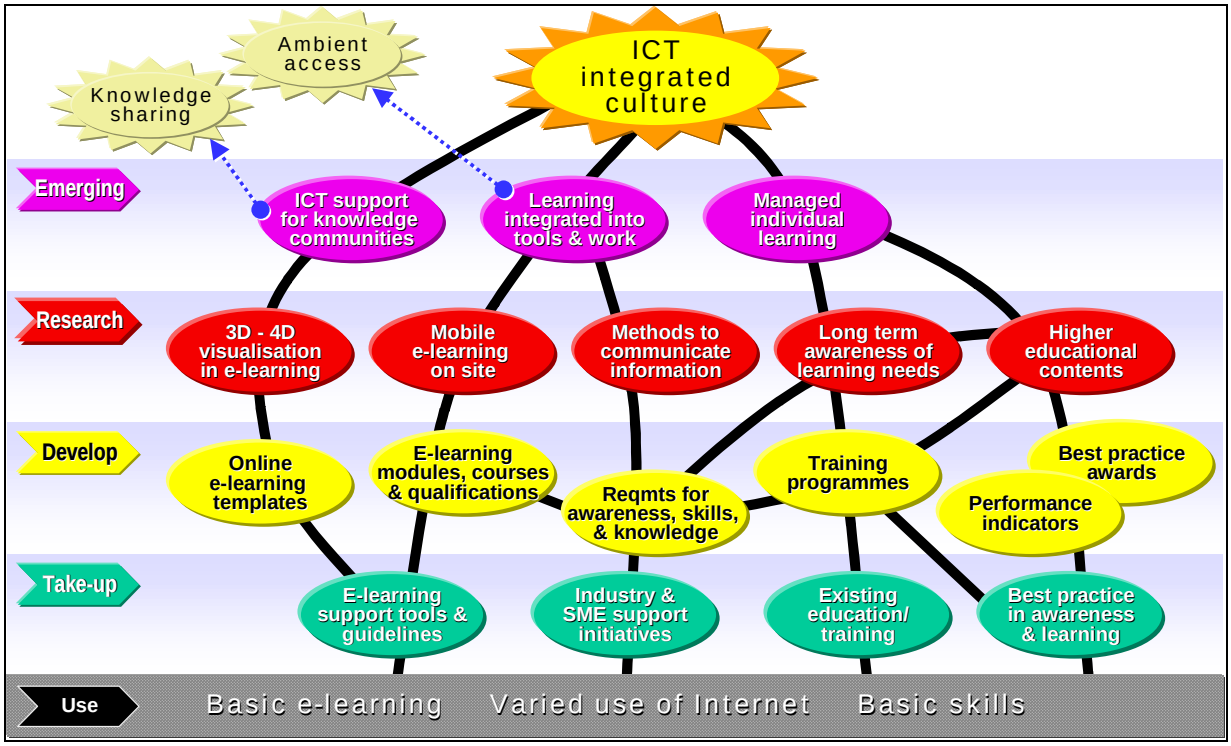

Figure 20. Roadmap for ICT skills and awareness

Vision: User-friendly clever tools (a) reduce the need for learning, and (b) provide built-in learning support when needed. E-Learning is used widely for transfering technology and lessons from good practice. SMEs are a special target group. Industry leaders and governments provide leadership by adopting and promoting proactively new ICT solutions. All students and professionals receive education / training that gives to them the skills to use state-of-the-art ICT. Higher education provides deep understanding of the underlying theories, models and methodologies of ICT applications for the construction sector. Special courses give the capability to specify and deploy new ICT in construction business context.

Scenario: e-Learning makes specialised education and professional and vocational training more accessible to SMEs in terms of affordability and availability. The learning process is enhanced by the provision of interactive learning material and tests that aid effective learning, and by helping individuals to keep abreast of cutting-edge industry developments. To fully realise its potential, an e-Learning programme is designed to the highest standards, both in terms of content and the technological platform. New technologies are made more widely accessible by providing appropriate training to all potential users, especially SMEs. E-learning comprising training on ICT use and vocational training assists in raising the skills level within the sector.

Technologies in industrial use

- Basic e-Learning, independent and heterogenous activities, yet no clear structured action.
- E-Learning is mostly done through the internet. No common ICT platform used.
- Basic skills to use common ICT tools.

Ready for take up

- E-Learning support tools and quality guidelines.
- Industry support initiatives such as the eEurope strategy or national SME support schemes.
- Existing education and training offereings.
- Current best practic. To be promoted by awareness measures: open forums, organised workshops, demonstrators, reference sites; through trade associations, research institutes and universities. Demonstration of the business benefits of implementing what is already available today and in the near future.

Develop

- E-learning templates, online available.
- Effective e-learning tools and concepts for the construction sector (learning fragments" related to specific problem solving queries, and integration of all these "fragments" into a complete and consistent e-Learning course eventually finishing with a recognised qualification. This qualification could become a new industry-wide training standard). Industry working together with universities and training professionals to develop.
- Requirements for awareness, skills and higher knowledge.
- Training programme to filling the skill gap and if necessary take advantage of the power of e-learning/e-training. Good quality training modules based on guidelines.
- A scheme of best practice awards to encourage and promote companies that lead the way in making e-Learning programmes available to their staff.
- Performance indicators to monitor the effectiveness and the impact of awareness / training / education activities.

Research

- Use of 3D-4D visualisations through e-learning programmes.
- e-Learning tools on site using mobile devices.
- Methods how to communicate and present what is available to potential users and in particular SMEs (representing more than 90% of industry), where the ICT skills generally do not exist.

- Awareness of what is available in the long term. This should be clearly defined in terms of what type of ICT to be addressed, i.e. e-commerce, e-work, e-business, general communication, best practice to assist in collaborative working, etc
- Higher education on ICT in construction context, its underlying theries, models and methodologies; undergraduate and postgraduate courses.

Emerging

- ICT support for knowledge communities, promoting sharing of knowledge and experience.
- E-Learning capabilities built into all ICT tools so that continuous learning is supported as an integral part of the work.
- Complete management of individual learning based on personal goals, objectives, roles and preferences (e.g. preferred learning styles). Individual ownership of learning and development, with support provided for planning of personal development. Clearly defined time is allocated to learning and development, with on-demand access for individuals to learning materials and experiences.

4.4.7 Knowledge sharing

Current state: Experience and previous solutions are available in personal and departmental archives but new solutions are regularly re-invented in every project.

Vision: Sharing previous experiences, best practice and knowledge within and, increasingly, between organisations. The aim is to have (transparently) immediate access to the right information, at the right time, in the right format, and from the right sources (both internal to an organisation and external).

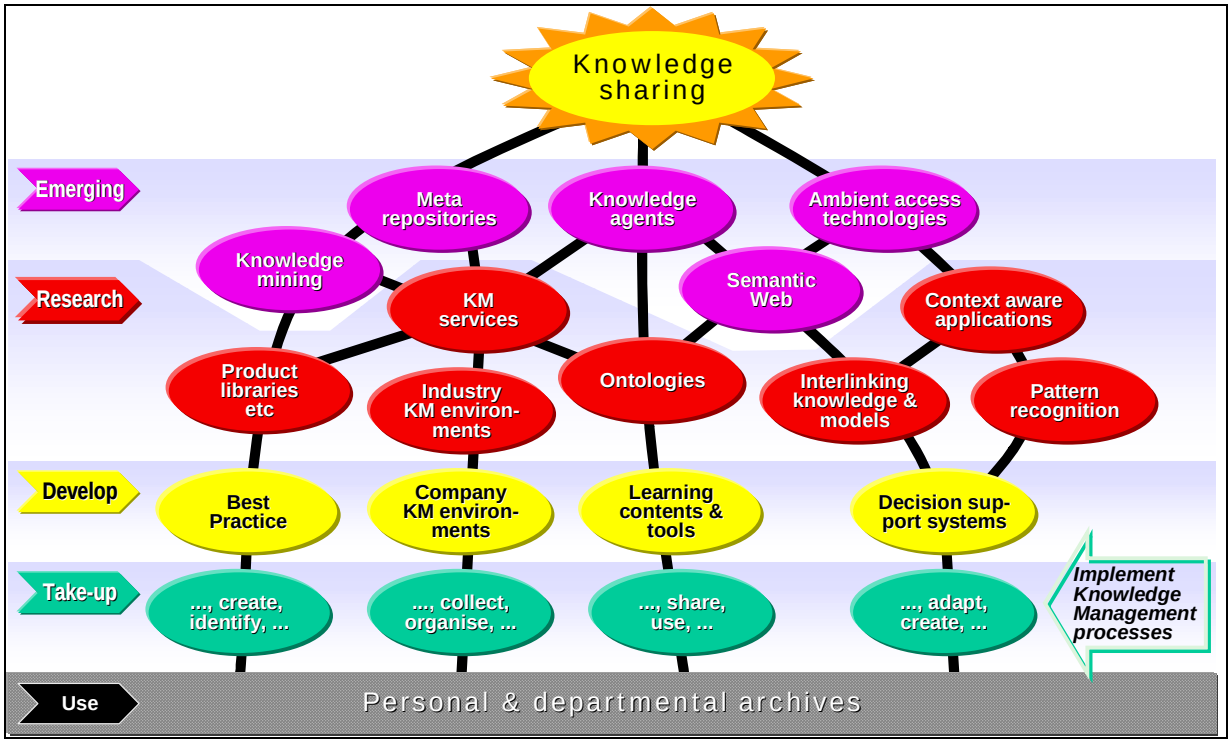

Figure 21. Roadmap for Knowledge sharing

Scenario: An individual faces a problem (e.g. leakage through the roof of a concrete basement due to excessive rainfall). His/her KM environment will be able to search across

multiple data repositories, mine the relevant information (e.g. from potential similar problems or occurrences) and return the potential solution(s) and relevant contact people. At the same time, it will have the capability through a combination of ontologies (or a meta-ontology) to exploit relevant content for identification through the semantic web and retrieval of the same into end-user applications using intelligent knowledge agents. The retrieved content may come from a different domain (e.g. aerospace) and relate to a different problem whose solution may yet be relevant and adaptable to the problem in context.

Technologies in industrial use

- Most information is stored in scattered archives, mainly paper-based, but in some cases digital. Content is not annotated, and is extremely difficult to find. Experiences from projects are not captured or retained efficiently and in most cases reside in the minds of those involved in the project. There is little, if any sharing or propagation of knowledge.

Ready for take up:

Standard KM processes: The following form a closed loop of basic processes for a knowledge management initiative. They are to be enabled through strategy and leadership; culture; measurement; and technology.

- Identify: Methods and tools for the identification of relevant experiences and practices that may form re-usable knowledge.
- Collect: Methods and tools for the collection of knowledge from various sources and archives (personal, organisational, inter-organistional)
- Organise: Methods and tools for knowledge systematisation and consolidation. Once knowledge has been collected, there is a need to structure it in a meaningful form for ease of extraction and use.
- Share: Methods and tools for knowledge dissemination/propagation, search and retrieval.
- Adapt: Knowledge is not necessarily always applicable in the form it is in. On most occurrences, it needs to be customised or adapted to organisational peculiarities. For this, it is necessary to have in place, o Organisational guidelines for business processes, task descriptions and the organisation of information
- Use: Methods and tools for knowledge re-use. These help in the retrieval, adaptation and re-use of past experiences and practices.
- Create: Methods and tools to re-create knowledge (new knowledge created on the basis of existing knowledge, or use of existing knowledge).

Develop

- Best Practice: Methods and tools for the identification, capture, consolidation, and dissemination of best practices. These should contain tools that enable the search and retrieval of past experiences, good (to-do) and bad (not-to-do).
- Company KM environments: Organisation specific KM environments that provide access to projects, experts, best practices, relevant documents (internal and external), support teamwork, etc.
- Learning contents & tools: Tools that support and enable continuous learning online. They could contain basic tutorials, or wizards to guide through execution of a certain task.
- Decision support systems: Tools that support decision making. The focus should be on support for real-time decision support as compared to decision support during planning phases only.

Research

- Product libraries etc.: Intelligent digital catalogues of building products. They should contain substantial product information (much more than simple geometry) in parametric form. As an example, they could contain built-in support for engineering analysisis and product configuration, and guidelines for the construction (how to build or how to use) of the product.
- Industry KM environments: KM environments at an industry level are needed to enable individuals to retrieve shared best practices and experiences. These should ideally be transparent to the users and be accessible by different applications and search services. Furthermore, they should provide relevant groupware functionality at an industry (e.g. network of experts) level.
- Ontologies: Identification of key concepts and their inter-relationships. Ontologies should not be too generic or too large. Rather, lifecycle phases, or topic specific (e.g. facilities management) should be developed in detail. A meta-ontology should be built on top of these to allow for interoperability and mapping between these ontologies when and where needed.
- KM services: These services should facilitate inter-enterprise knowledge management through provision of simple services such as searching, and sophisticated services such as eTendering. These services may be subscribed to on a per need basis.
- Interlinking knowledge & models: The ability to automatically link relevant knowledge entities (experts, documents, products) to a product model once it has been instantiated.
- Pattern recognition: Mechanisms and tools to identify for example usage patterns in the execution of a particular task using some application. These patterns may then be used by application wizards to help users in the execution of such tasks (e.g. provision of the first ten steps) without the user having to navigate through complex menus.
- Context aware applications: Applications that are context sensitive and can recognise what the user is aiming to do. They should thence be able to provide according guidance, menus, and make available the relevant information.

Emerging

- Knowledge mining: Tools for the retrieval of both knowledge, business logic, and rules from different information sources and applications. This should be automated, with the captured business logic and rules made reusable in the form of application components.
- Meta repositories: These will provide definitions of, and relationships, and mappings between different information repositories, knowledge sources and ontologies. As an example, through their support, when a search is made for a particular item (e.g. a standard), then only one instance of that standard will be retrieved with a note that the same is also available in XYZ locations. In simple terms, instead of hundreds of links/pointers to the same information, only one direct link to the source of information will be provided.
- Semantic Web: This will enable a paradigm shift in the way individuals and mainly applications solicit information from the Internet. As opposed to human interpretable and computer un-interpretable web content, annotations and intelligence will be added to content to all for ease of retrieval and interpretation by different applications.
- Knowledge agents: Intelligent knowledge agents will act as a transient entity between individuals and/or applications and knowledge sources. They will (if necessary through automation) be able to modify and adjust queries so as to retrieve the required information from the relevant sources. As an example, knowing that the calling user/application is from

the construction domain, when a search on “knowledge management” is done, the agent would search for “knowledge management + construction industry”. Furthermore, the results may be ranked and categorised (automatically) based on the typical preferences of the user/application. Many more such applications of knowledge agents can be envisaged.

- Ambient access technologies: Ubiquitous, personalized and context-dependent access to knowledge is necessary and will be provided through ambient access technologies. These technologies will be based on an integrated use of ontologies, semantic web, context aware applications, knowledge processes, personal usage patterns, mobility, etc.

4.4.8 Legal and contractual governance

In this chapter we highlight construction specific issues. There are several other IST roadmap projects that focus exclusively on user identification, privacy, security and safety: ACIP, AMSD, BVN, DDSI, PAMPAS, RAPID, RESET, STORK, WG-ALPINE. These roadmaps are expected to provide guidance about the specific technologies that industry sectors like construction can make use of.

Current state: The use of ICT speeds up the transmission process, but often has no legal validity. The legislation to support technology may exist, but has not been adopted by the construction industry within contractual practices, and hence, the use of ICT is currently not necessarily contractually valid. This renders ICT as an extra cost rather than an enabler.

Vision: Transaction management for electronic exchange of information and documentation to ensure that they meet a pre-defined level of legal validity (e.g. within an ICT contract) security (e.g. digitally signed) and trust.

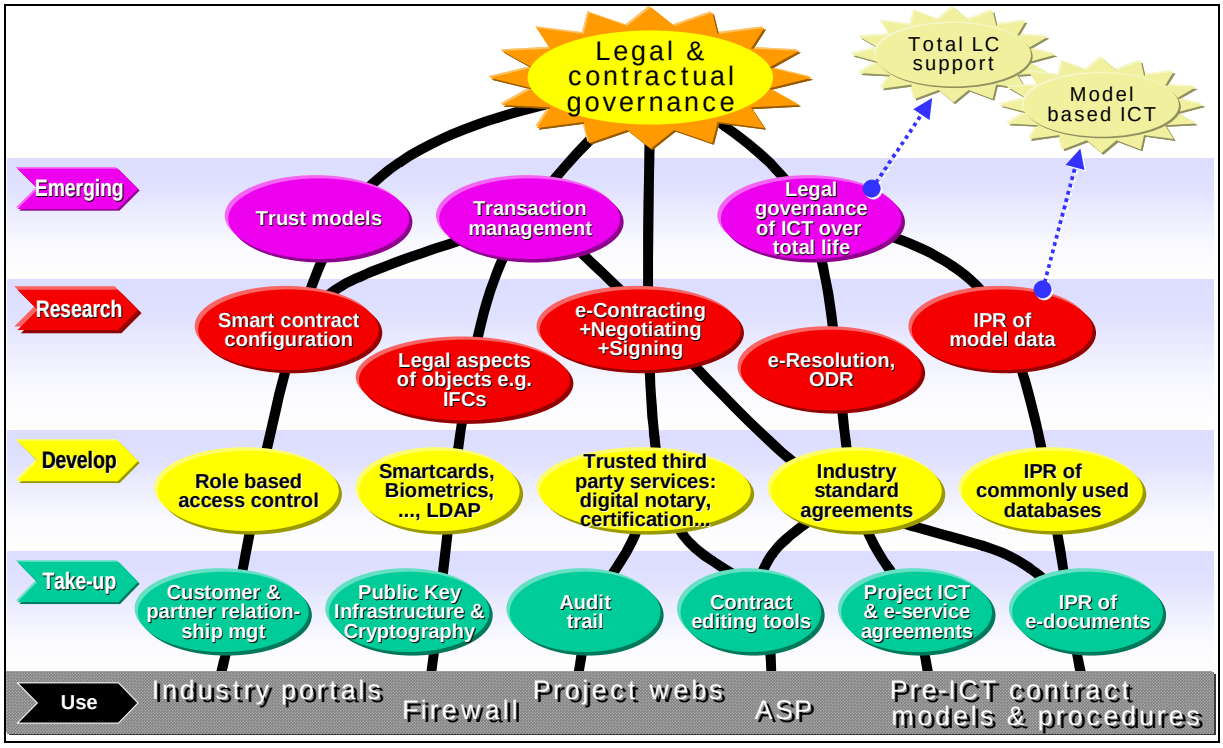

Figure 22. Roadmap for legal and contractual governance

In order to achieve exclusive use of ICT in electronic transactions, the three elements of legal, security and trust are coupled together. Legal barriers such as legal admissibility of emails, CAD drawings, use of ASPs, ownership of information, company vs. project information and legal issues of objects (such as IFCs) are overcome by specifying an ICT-related contract

governing these issues. E-contracting, contract configuration and on-line negotiation tools) are used to develop such ICT-related contracts. A virtual negotiation room on the internet is used to negotiate the contracts and exchange digitally signed versions. The ICT contracts specifies the ICT environment to be used. Different security levels are imposed on all transactions using digital signatures, third party certification authorities, biometric systems, smart cards and/or digital notaries. Different levels of trust are allocated to different transactions beyond which a transaction can not take place.

Scenario: The client of a large scale engineering construction project forms a partnership with the other stakeholders in the project and decides to use a collaborative platform hosted by an ASP. Based on the project circumstances and the nature of partners, the different project parties use a contract configurator through an ASP to edit and produce two types of ICT contracts (Figure 1): The first one will be between the client and the ASP itself, where the contract wizard will select the appropriate clauses related to the use of ASPs from the library of clauses and uses the pre-defined contract style sheets to produce an ASP contract. The ASP will grant access to the partners in order to use the collaborative platform initially to negotiate an ICT contract among the partners.

The client will use the contract editor to formulate an ICT contract which includes the relevant clauses specifying software versions, access rights, ownership of information etc., signs the contract digitally, and issues it to the negotiation room at the ASP. If partners are happy with the contract, they digitally sign it in return, alternatively, they suggest modifications and digitally sign the new version and re-issue it until all parties agree the ICT. All emails and documents exchanged within the ASP should be digitally signed, otherwise, a transaction monitor will not allow the processing of this transaction. Members from the supply chain could request access to the ASP for various purposes, however, based on previous track record, they will be allocated different levels of "trust". The transaction monitor will not allow such access if the trust level of any of such partners fails a pre-defined threshold based on the nature of transaction and its sensitivity. The ASP will issue end user licenses to all parties who use its service. The ASP contract, ICT contract and on-line end user licenses constitute the ICT-related contract as illustrated in Figure 23.

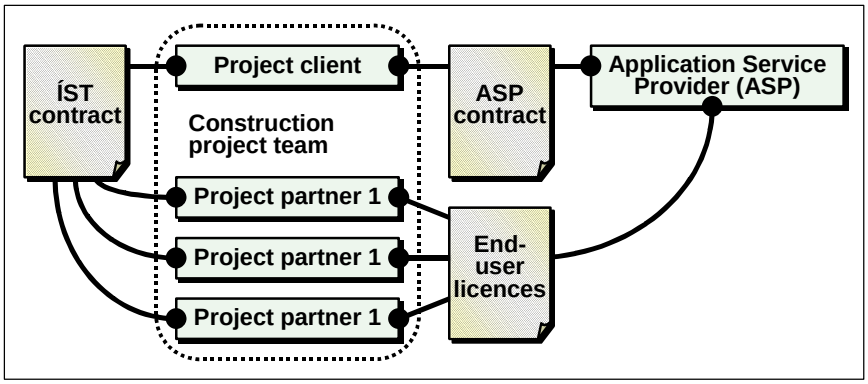

Figure 23. ICT-related contracts framework

Technologies in industrial use

- Security measures already in place, however they are not part of a comprehensive legal framework. These include firewalls, secure industry portals, restricted access project web sites and ASPs. This is in conjunction with standard model business contracts (e.g. JCT in the UK) which have very little reference to ICT.

Ready for take up

Recently developed technology mature enough for take up:

- *Customer and Partner relationship management*: techniques and mechanisms to implement a business strategy to select and manage the most valuable customer and partner relationships. It consists of a set of business processes that an organisation performs to identify, select, acquire, develop, better serve and, above all, retain its most profitable customers and maintain relationships with partners who add value. Techniques include skills-based routing & queue management, multi-channel contact tracking, workflow support & knowledge management, workforce management and reporting.
- *Public key Infrastructure and Cryptography*: technologies for digital signatures and encryption where the sender uses his/her unique private key for signing and encryption while the recipient uses the corresponding public key for decryption.
- *Audit trail*: techniques for tracing electronic transactions, logging, archiving, etc.
- *Contract editing tools:* Stand alone software for creating and editing business contracts and service level agreements based on standard templates without being part of a comprehensive legal framework.
- *Project ICT & e-service agreements*: simple isolated stand-alone ICT agreements specifying file formats, software versions and e-service agreements such as end user licenses.
- *IPR of e-documents:* Mechanisms to ensure and maintain Intellectual Property Rights for documents exchanged electronically. This should also be interrelated with role base access control.

Develop

Mechanisms and tools for enhanced levels of security on various levels:

- *Role based access control:* different levels of access to project databases, web sites, intranets and extranets, etc. depending on roles. These different levels should be read-only, update, create, delete, etc.
- *Smart cards, Biometrics, etc.:* Different technologies to ensure secure authorised access only. These technologies use magnetic cards (smart cards), human unique properties such as eye retina, iris, finger prints, etc (biometrics)
- *Digital Notaries*: the mechanism for electronic commerce that proves who has made an electronic interchange (what), with whom it was made, and when it was made. Digital Notaries provide a time stamping service, proving the existence of a document at a particular time.
- *Certification authorities*: an independent third party which examines the web-server's domain registration and other business documents to ensure that the server's managers are the valid owners of the domain, and that the organization is properly licensed and chartered in it's geographic area
- *Industry standard agreements*: standard industry related business contracts and agreements based on typical contract templates to be exchange electronically in a secure way
- *IPR of commonly used databases:* Mechanisms to ensure and maintain Intellectual Property Rights for information input to commonly used databases

Research

- *Smart contract configuration*: on-line comprehensive smart contract configuration from editing the contract till negotiating and digitally signing it. This should be a self learning

tool which is able to select the appropriate clauses based on various parameters. The vision is to have semantic / executable contracts that can be interpreted by ICT tools for monitoring and guidance for contract fulfillment by collaborating parties.

- *Legal aspects of objects e.g. IFCs*: attaching attributes to objects, who owns the object, who has the right to modify its attributes, etc
- *E*-contracting + Negotiating + Signing: extending the stand-alone econtracting tools to negotiate, digitally sign, exchange, archive and checking
- *E*-resolution and On-line dispute resolution (ODR): on-line techniques for mediation and resolving disputes
- *IPR of model data*: methods, techniques, and tools for assigning, maintaining and preserving IPRs for different components of the model data and cross checking for secure transactions.

Emerging

- *Trust models*: Trust models should be used to assign different levels of trust to different parties. These levels depend on the nature of transaction and the party using it. These models could be computational models or conceptual models.
- *Transaction Management*: Transaction monitors should be used to monitor the flow of electronic information and documentation to ensure that they meet a pre-defined level of legal validity (e.g. within an ICT contract) security (e.g. digitally signed) and trust. This could be achieved by imposing the necessary rules on all electronic transactions in collaborative platforms.
- *Legal governance of ICT over total life cycle*: mechanisms and tools to validate and cross check ICT transactions against ICT contracts and against the minimum levels of security and trust throughout the project life cycle. These mechanisms should also include “model checkers” to cross check product data models on model servers.

4.4.9 Model based ICT

Current state: Document based ICT augments the creation and sharing of human-interpretable information. The problem is that this kind of information can not be automatically processed and interpreted. This leads to manual interpretation and re-entry when data needs to be transferred between companies and systems. An example is 2D CAD. Another serious problem is that information is scattered into several documents containing different views of the subject. Updating this kind of information is difficult laborous. Keeping it consistent is close to impossible.

Vision: Model-based information is computer-interpretable enabling automation, systems integration and user/context specific presentations/view. Shared building information model covers all AEC/FM areas and enables all the needed views to the information and different computer simulations and analysis. The use of information covers the whole life cycle of the project and building, starting from early briefing and ending to the demolition of building and re-use of the materials.

Takeup scenario 1: Companies develop partnerships based on the capability to use model based applications. This is necessary because the lowest nominator will define the level of sophistication.

Takeup scenario 2: Advanced clients demand model based information, and will force the AEC companies to provide such services – in the same way that CAD changed from being an advanced tool to commodity very fast in the early 90's.

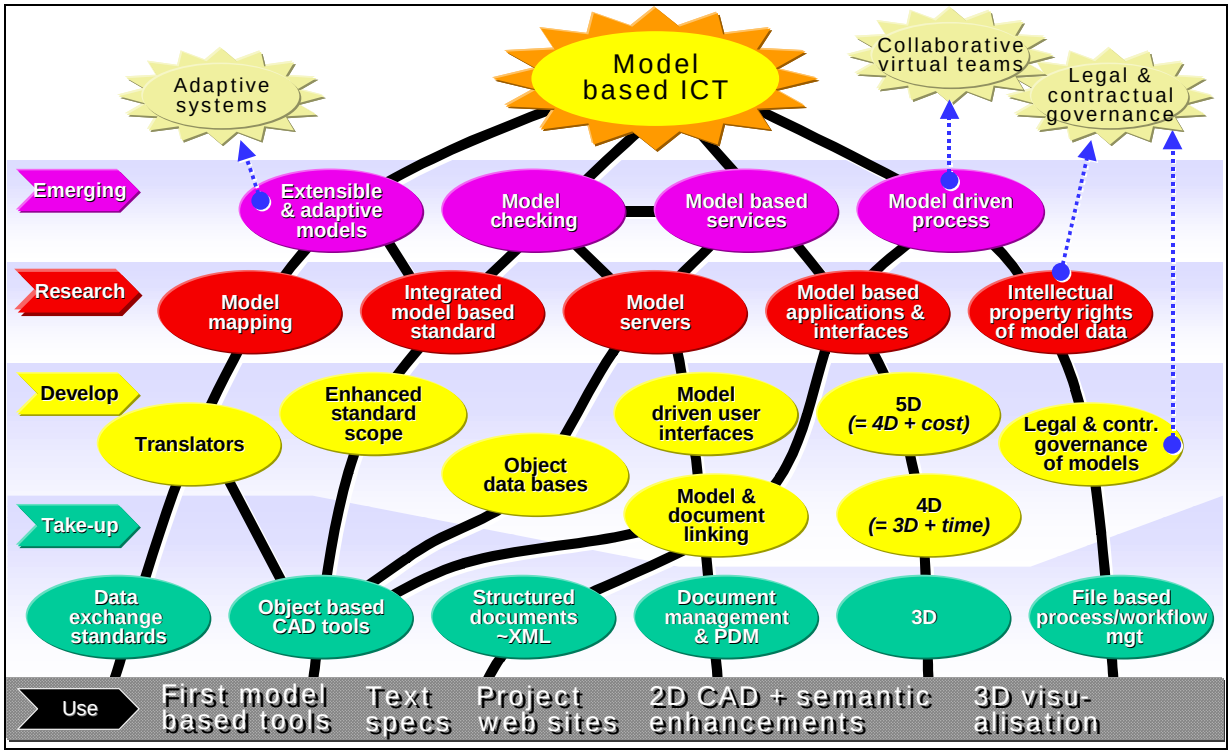

Figure 24. Roadmap for Model based ICT

Technologies in industrial use

- 2D CAD with semantic enhancements: e.g. grouping mechanisms (such as "blocks", standardised "layers" etc.), non-geometric attributes, links to external data sources etc. These primitive mechanisms require very strict discipline and are vulnerable to user mistakes. Thus their usability in collaborative engineering and data exchange is limited.
- Text based specifications.
- Project "web sites" for storing and exchanging files.
- Limited use of 3D for specific purposes like visualisation.
- Limited use by leading companies of model based CAD and file based data exchange using IFCs or proprietary data formats.

Ready for take up

- Data exchange standards (bcXML, IFC, STEP, ...)
- Several object based CAD tools (ArchiCAD, ADT, TriForma, Revit, even Visio) are available and ready to take up.
- Structured documents (XML). Mature XML editing and processing are available, including freeware.
- Document management and PDM. Numerous mature commercial systems are available. However, in most cases the licencing conditions are not feasible for multi-company temporary projects.
- 3D design and visualisation tools.

- File based process and workflow management. Mature workflow management tools are available but not suitable for poorly defined ad-hoc processes.

Develop

- Translators / interfaces between applications and standard data presentations (eg. IFC)..
- Enhanced standards scope to cover more broadly the information exchange requirements.
- Object databases e.g. product / component libraries.
- Model and document linking to cope with different levels of semantics.
- Model browsers and grahical user interfaces (GUI).
- 4D = 3D geometry added by time information enabling e.g. simulation of assembly process on site.
- 5D = as above with cost information added to geometry and time.
- Legal and contractual governance of model data e.g. access and change rights at object and attribute level.

Research

- Model mapping i.e.coverting data from one schema to another.
- Integrated model based standard bringing together several currently isolated standarsd.
- Model servers for sharing product model data.
- Model based applications & interfaces: increased intelligence of applications and intefaces for communication with other applications.
- Intellectual property rights of model data: protecting investment in value adding information which is shared with other stakeholders in construction projects.

Emerging

- Extensible models: metamodel enabling flexible extensions to standard models based on specific needs which are not covered by the standard.
- Model checking: tools for validating model data against standards, regulations, design rules, contracts etc. Notification of identified conflicts and, when possible, suggesting corrective measures.
- Model based services: new business opportunies enabled by model based data e.g. analysis, estimation, visualisation, simulation etc. Thanks to computer-interpretable information highly specilised services using sophisticated software become feasible.
- Model driven process / workflow management: intelligent workflow aid combining product model with scheduling, resource planning and progress monitoring.

4.4.10 Performance driven process

Current state: The current situation is closer to the prescriptive-based than to the performance-based (Table 4) (PeBBu Thematic Network, 1st International State-of-the-Art – report, August 2002). Customers, however, are increasingly aware of whole life costs, perceived value and intangible assets.

Vision: Performance driven process ensures conformity to customers' needs and emphasises on end user satisfaction and value. ICT solutions support for capturing and fulfilling predefined performance criteria. The topics described in the column, Performance driven, in the table above (Table 4) have been realised. Co-operation is the best way to generate future

well being. As the service component becomes an essential part of core business, the traditional value hierarchy in the sector will be transformed. Choices of material and the functionality of structures will be based on whole life considerations. Users choose service packages for housing, e.g. increasing the flexibility. It is essential to understand customer needs and integrate that to production processes

Table 4. Current prescriptive method vs. Performance driven process

Aspect	Prescriptive	Performance driven
Role of the principal advisor	Design the building and supervise construction	Assist client prepare performance brief and select most appropriate proposal.
Design process	Professionally driven. Designer appointed to prepare design.	Client driven. Designer selected on basis of proposal.
Tendering process	On the basis of fully detailed working drawings and a bill of quantities. No flexibility.	Scope for contractors and subcont-ractor to proposes best solutions and utilize specialist skills and plant.
Financial focus	Preference given to lowest construction cost	Preference given to value for money and lowest building life-cycle cost
Approval process	On the basis of compliance with prescriptive codes and standards	On the basis of performance criteria and using skill and judgment in the absence verification methods
Construction process	Controlled on basis of adherence to approved plans. Financial penalties for variations.	Controlled on basis of performance criteria. Incentives to do things more efficiently.
Commissioning, handover, operation and maintenance	Owners and users not properly informed on use and maintenance	Client fully briefed on use and maintenance of building.
Relationships	Litigious and adversary relationships between all parties. For life of project only.	Cooperation between all parties to ensure client's needs are met and building performs as required. Desire to build long term relationships.
The built environment and sustainable construction	Seen as outside the design and building process	Part of the design and building process. Including land care and waste management
Energy efficiency	Minimum regulatory compliance	Optimum investment in accordance with client's business plan
Post occupancy evaluation	Not part of contract. Same building shortcomings are destined to be repeated	Important performance evaluation tool. Information used on future projects.

Scenario: Shift of focus is needed; construction service providers have to see themselves as a short but regularly recurring chain of the client's business processes. The companies should be able to provide space for the customer in its entirety; helping client to define the needs, creating the performance brief based on those needs, designing the building, constructing, maintaining and operating it and finally, demolishing it. Performance approach forces the clients to think what is really needed to support their business processes. Performance based requirements give designers and suppliers possibilities to fully exploit their knowledge accomplishing creative and flexible solutions. When requirements are performance based, the variety of procurement methods is larger. The contractors can improve design and also benefit from this (Lahdenpera 1998). Feedback from other parts of the process enables learning and better buildings in the future.

Phases of performance based building process based on Becker (1999) are:
1. Translating human needs to user requirements.

2. Transforming the previous into technical performance requirements and quantitative criteria that do not dictate solution.
3. Responding to these requirements during various stages.

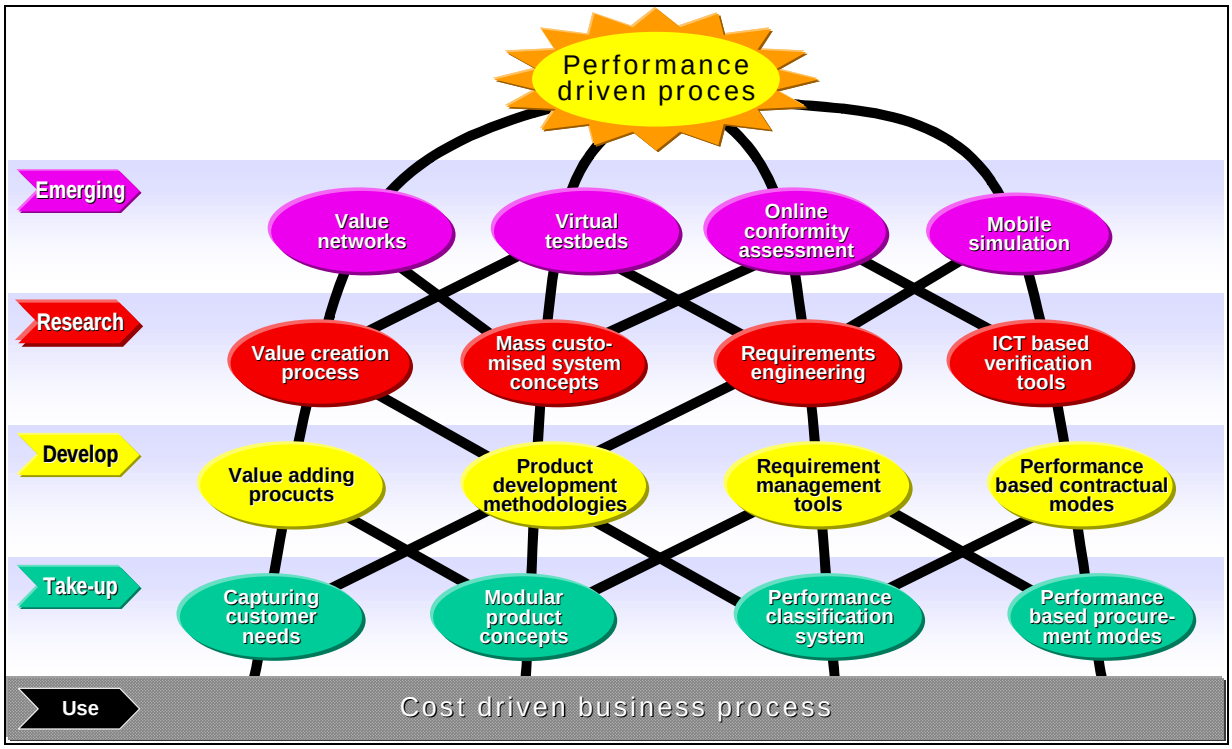

Figure 25. Roadmap for Performance driven process

State of the art / Technologies & practices already in industrial use

- Cost driven business process: Tendency to select the solutions that have the lowest investment costs drives the decision making in the building process at the moment.
- Quality management: The quality of the services, materials, and assemblies of the building process is checked regularly. Partly this is done by the providers themselves.
- Some examples of contractual models that enhance incentives for product life time performance e.g. Build-Operate-Transfer, Open Building etc. There are several examples where the end-user only vacates or uses the product (building, road, rail network) and the responsibility to maintain and operate stays with the original contractor.

Ready for take up

- Capturing customer needs: Capturing clients' needs and targets at the very beginning of the project is essential for a successful end result. It is also important to bridge the gap between client terminology (satisfactory lighting in the office rooms) and the domain terminology (750 lux in the working area, no glare, even distribution of light). Several tools for this purpose are available.
- Modular product concepts: Shorter delivery times are needed so that the structures of the built environment can adapt to the more rapidly changing business environment. Also more reliable and well-performing solutions are necessary. Modular product concept enables variety of end results from a limited number of modules that are effective to realise and easy to maintain.

- Performance classification system: As stated earlier, it is vital that the end users and the practioners of the domain have means to understand each other. Common classification is one key in enabling this.
- Performance based procurement modes: As presented above in the scenario section, performance based requirements give designers and suppliers possibilities to fully exploit their knowledge accomplishing creative and flexible solutions. When requirements are performance based, the variety of procurement methods is larger. The contractors can improve design and also benefit from this (Lahdenpera 1998).

Develop

- Value adding products: Typically the partners in the business networks (like supply chains) are required to participate in reducing waste from the process and provide services or goods that add the productivity of the network. It can be clearly seen that this same target will be set for building or other part of the built environment. The industry has to be able to provide products and services that improve the value of the business of the end users.
- Product development methodologies: As stated earlier the life cycles of the products are shortening dramatically. The development phase of the new materials, systems and services has to be shorter and provide better solutions. This requires new product development methodologies.
- Requirement management tools: Too often the original requirements are lost due to the deficient requirements management. It is important to capture the client requirements at the beginning of the project, but it is equally important to manage the changes, and maintain transparent decision making during the performance driven process.
- Performance based contractual modes: See above.

Research

- Value creation process: In addition to the value adding products, the whole delivery process of these products has to add value to the end user.
- Mass customised system concepts: The clients can order buildings like they now buy cars; selecting from a limited number of choices creating a widely different end results.
- Requirements engineering: The requirement engineering supports the mass customised product and system concepts. By clearly defining their targets with developed requirements engineering methods and tools, clients can transparently see how their requirements are transformed to the best-in-class –solutions.
- ICT based verification tools: The verification of the performance requirements has to be regular. In all phases of the performance driven process, the technical solutions are (automatically) verified against the set performance requirements ensuring the there are no defects in the final product.

Emerging

- Value networks: The current, unstable and changing supply chains turn into value networks, that provide excellent services and products for demanding clients effectively and value adding. The search for performance and productivity is a common goal for the partners of the value network. The win-win –situation finally exists.
- Virtual testbeds: It is difficult for a human being to create an understanding of the final product (building, built environment, road etc.) based on two dimensional drawings. In the future it will be possible to experience to environment much before it is realised.

Technologies like virtual reality, remote sensing, haptics and augmented reality work for people.

- Online conformity assessment: The ICT tools that are used to capture the clients' requirements and to transform them into the technical solutions have in-built verification and conformity systems operating in the background giving feedback when some requirement is threatened.
- Mobile simulation: All (ICT) solutions of the industry are available also in the mobile environment. For instance, the buildings can be seen with the augmented reality glasses in-situ before they are constructed.

Figure 26 below illustrates performance driven process. It relies on modular processes and products enabling each actor to invest in internal improvements of its products and services and accumulate re-usable knowledge through learning. In negotiations between parties in the supply chain the client can focus on functional and life time performance requirements. The supplying party can offer its proprietary value-adding technical solutions. The negotiation process needs to be supported by performance indicators, conformance evaluation methods (e.g. simulation) and decisions support (e.g. visualisation).

References: [Becker 1999], [Lahdenperä 1998], [PeBBu 2002].

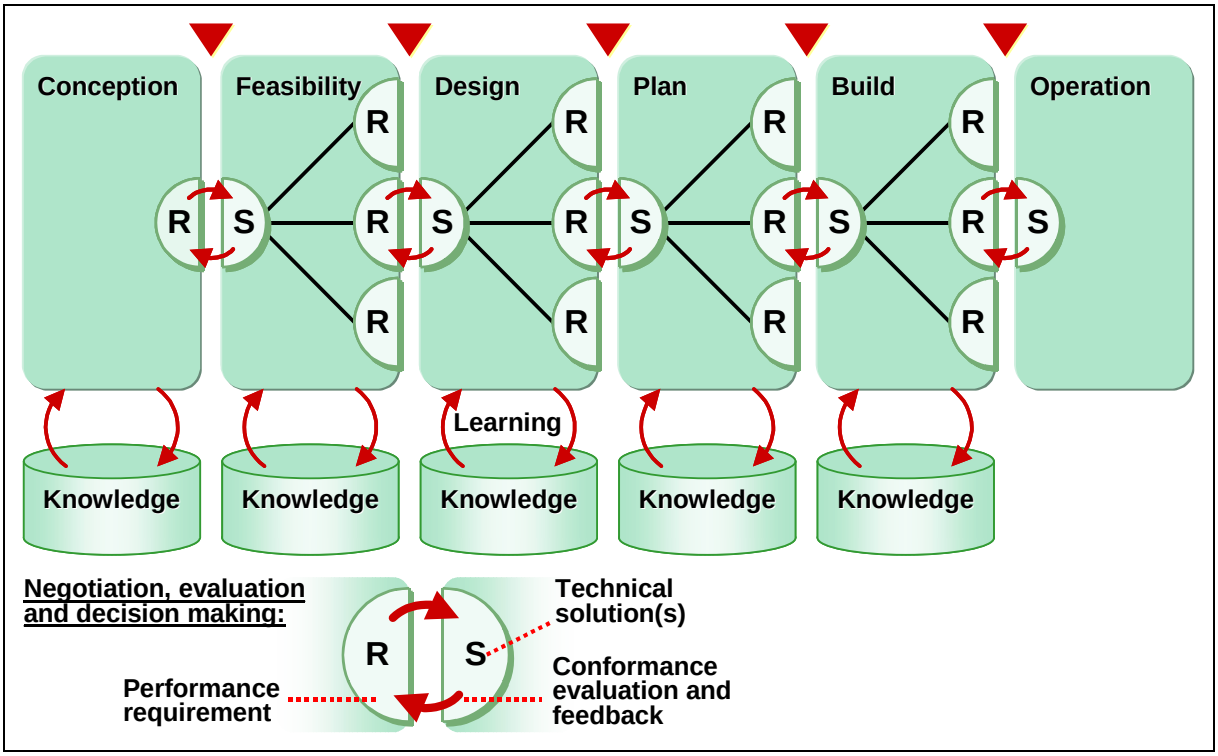

Figure 26. Illustration of performance based process

4.4.11 Smart buildings and embedded systems

Current state: Buildings contain various and increasingy versatile control and service systems. They are currently based on vendor-specific technologies using "dumb" devices, proprietary software platforms and wired connections and protocols. Monitoring, maintenace and services are done by specilised companies, each responsible of different systems.

Vision: All systems in buildings share common platform, network and protocols. Secure external connectivity via the internet enables remote and mobile monitoring, diagnostics, operation and self-reporting. Ambient access of all building information is available to all stakeholder anytime and anywhere. Wireless and powerless sensors support interactive spaces providing personalised, location and context aware services. Useful references: [CABA], [OSGi].

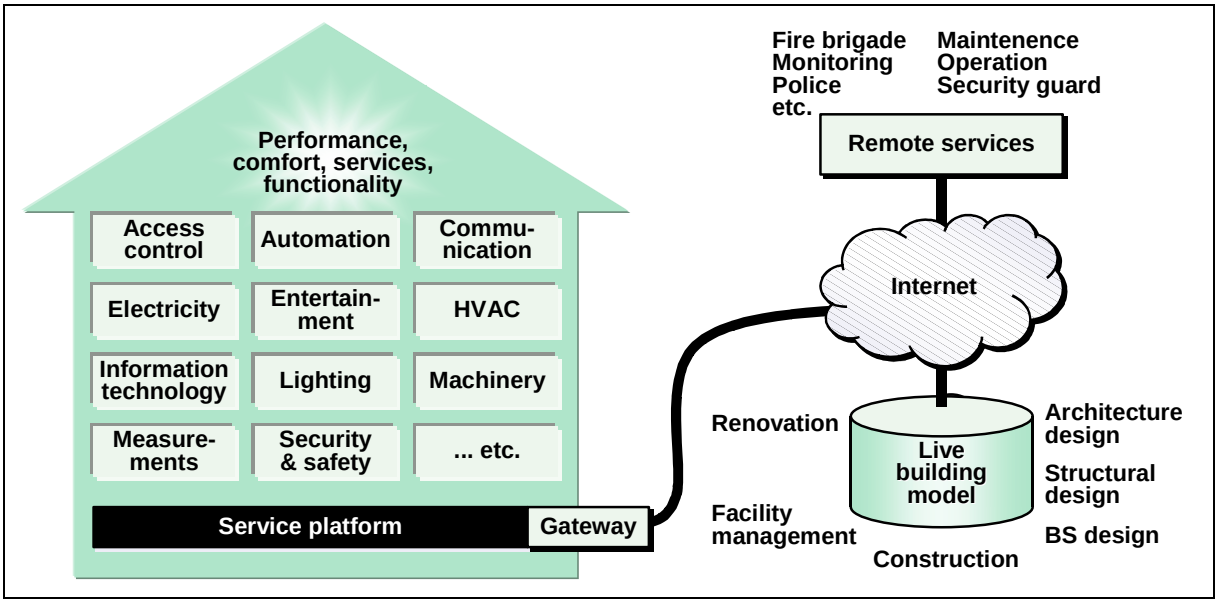

Figure 27. Smart building

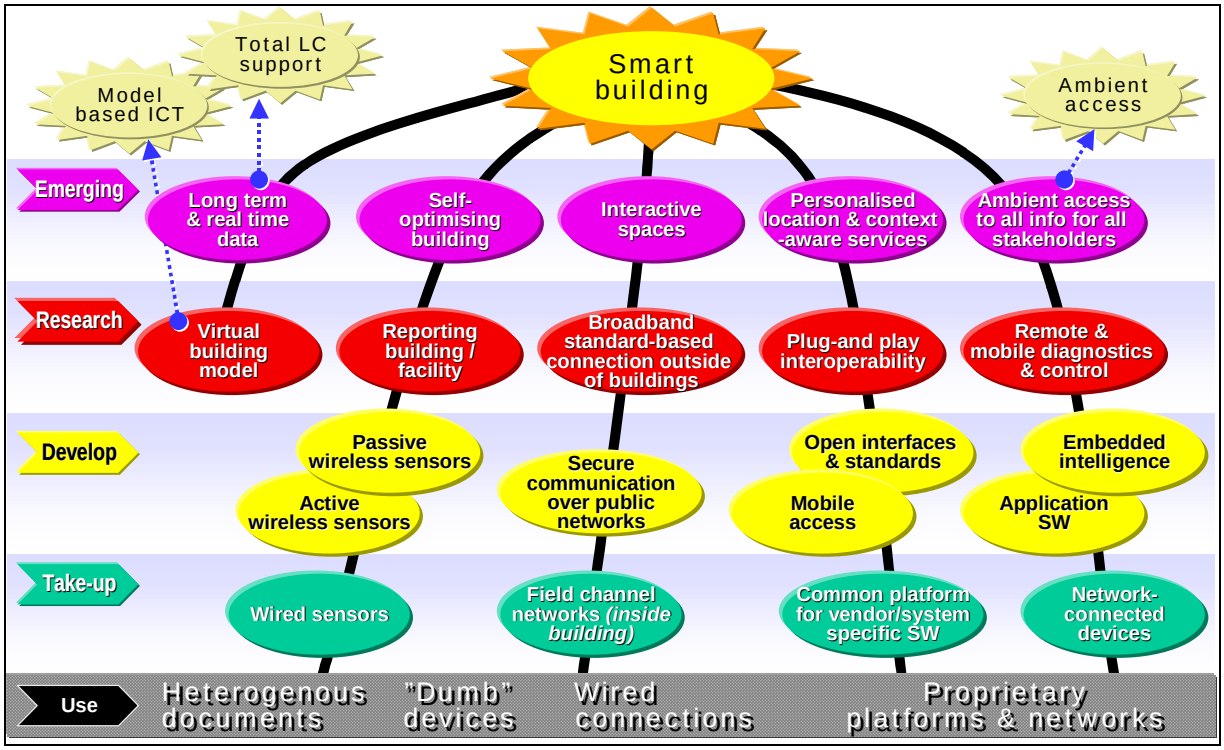

Figure 28. Roadmap for Smart buildings

Technologies in industrial use

- Heterpgenous documents describing various aspects of the building
- Dumb-devices with limited controllability
- Wired connections
- Proprietary software platforms, networks and protocols

Ready for take up

- Wired sensors
- Field channel networks inside buildings
- Platforms for vendor/system specific software
- Network-able devices

Develop

- Use of active wireless sensor and passive wireless sensors
- Secure connections over the internet
- Mobile access to critical building / facility information
- Open interfaces and standards
- New application software
- Embedded intelligence in products and components

Research

- Virtual building model containing comprehensive data of the building in one logical source.
- Self-reporting building / facility.
- Broadband standard-based connection outside of buildings.
- Plug-and-play interoperability.
- Remote mobile diagnostics and control.

Emerging

- Consistent long-term and real time data of the building / facility.
- Self-optimising building.
- Interactive spaces
- Personalised location and context aware services.
- Ambient access of all information for all systems and stakeholders.

4.4.12 Total Life Cycle support

Current state: Applications are dedicated to specific engineering functions and traditional sequential process phases. “Functional silos” prevent an efficient global project management i.e. across technical domains and through the overall life cycle.

Vision: Re-engineered process supported by innovate ICT allow to take into account different (and sometimes divergent) objectives and to address time of delivery, cost and quality issues from a global point a view. Special emphasis will be put on client satisfaction (the client

being who commissioned the work, but also users and society as a hole when it comes to public assets).

Scenario: Clients expectations and needs are captured and validated very early in the process. Visual information is used to inform the client about the project and also on previous similar developments. The expected TLC performances are defined at the beginning of the design phase and used, as inputs, to optimise different technical domains. Optimisation uses on-line information about building components. On-line geographical information is accessed to test implementation options and to require planning permission from authorities. During the design phase, simulation is used extensively to test "what-if" scenarios and to assess feasibility and buildability. Planning and cost estimations are conducted concurrently with the design. Long term partnering relations allow to simplify the procurement phase and to start the construction phase. The "design product model" is used on site through wearable and wireless computing and is updated regularly (along with planning and cost estimates) with "as built" information. Delivery information of components and materials is accessed on-line and in real-time to prepare site for deliveries. "How to build" information is checked on site through visual displays by subcontractors in order to avoid errors. At the end of the construction phase, an "as built" model is handed over and used for FM and for automatic generation of maintenance schedules. After demolition of the building, dangerous materials are tracked and oriented toward adapted facilities.

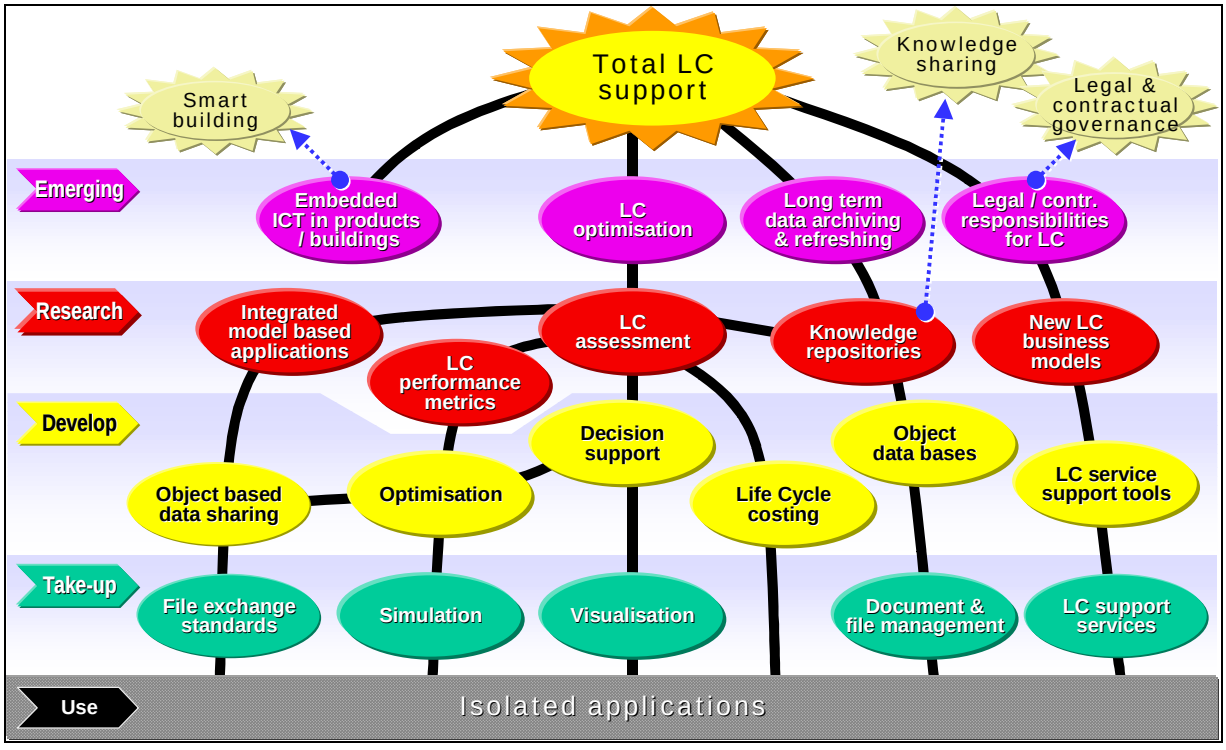

Figure 29. Roadmap for Total Life Cycle support

Technologies in industrial use

Technologies currently used are most of the time CAD tools and Office tools, with no real integration (even if some of those tools provide file exchange mechanisms and/or APIs for integration), and very few of them really object-oriented. The main technical barriers are the following:

- Use of standards is still not generalised, still not easy to understand, and still not fully adapted to business

- Lack of integration / interoperability between tools (e.g. business applications), databases (e.g. materials or products), information servers (e.g. regulations), etc.
- Lack of (smooth) automated integration in the production process, & link with design
- Still hard to find the relevant information on-line

Ready for take up

- File exchange standards: validate, demonstrate and deploy (potentially based on current best standards-compliant tools) the integration of Construction processes through exchange of files relying on well-defined communication standards – with a focus on IFC-based file exchange.
- Simulation: generalise and deploy the use of "single-simulation" tools (lighting, thermal, acoustics, etc.) for engineering processes, moreover integrating these simulation tools with other LC tools.
- Visualisation: 3D visualisation of the geometry of the building and real-time "walkthroughs" allowing to inspect the building from the inside and to visualize its integration in the neighbourhood
- LC support services: validate and deploy current or newly-merged software applications dedicated to Construction stages including work planning, (detailed) design, procurement and site operations, & Supply chain management, that should lead to the implementation of enhanced business processes.

Develop

- Object based data sharing: specify and develop tools that extend the concept of exchange towards "data access and sharing" of information and knowledge, improving search and filtering of information too. Also required here is connection with European and international bodies and initiatives for de jure and de facto standardization (e.g. IAI/IFC).
- Optimisation – Optimisation tools allowing to explore different options and solutions to meet the specified in each of the technical domains. Optimisation tools are coupled with product libraries and servers.
- Decision support: develop value-added services allowing e.g. improved querying on product detailed design, intelligent e-monitoring (HVAC, home / office automation) and "e-friendly buildings", automated systems for facility, property and asset management, and any tool specialising "Business Intelligence" to the Construction sector.
- Life Cycle costing: specify and develop new applications dealing with LC performance(s) of building & construction, including monitoring and performance measurements, as regards both total LC costs (investment, operation, maintenance), but also conformity with customer needs (that should lead to less customer un-satisfaction, and less required "re-work").
- Object data bases allowing to combine a product driven approach with a document driven approach
- LC service support tools: specify and develop potential support to TLC Construction processes by appropriate tools like 3D/4D/5D (object-oriented) CAD tools, Visualisation / publication on the Web, Global server dealing with project coherency (users' rights management, versioning, change notification, etc.), On-line forums, interactive conception / design reviews, etc.

Research

- Integrated model based applications: specify, and develop, infrastructures and applications based on open and public Standard specifications & frameworks (Today: SOAP, WSDL, UDDI, …, Tomorrow: XLANG, WSFL, BPML, WSCM, etc.), and to be to linked with the *Semantic Web*:
  - XML: structured information (with types: XML schemas)
  - Dublin Core & RDF(S): meta-information
  - Use of concepts in a specific domain (or context):
  - Semantic dictionaries (DAML, OIL, etc.)
  - Conceptualisation of domains: ontologies, with a focus on Business-oriented ontologies for the Construction industry, Web-enabled, IFC-connected
- Product property databases: specify and develop databases able to manage enhanced products that will be characterised not only by improved features (e.g. optimising the equation quality/duration/cost) and capabilities (e.g. smart buildings), but also by being the outcomes of projects based on new organisational models for global and distributed engineering supporting the total life cycle of the product. These databases must ship with standardised APIs for model-based collaboration, and should manage downloadable and re-usable objects
- Material property databases: these are to be similar to the previous ones, but specialised in order to tackle all information related to materials like material costs, influence of material choice on future exploitation, etc., and along with taxonomy / ontology of building materials, and standardised material description methodology
- LC performance metrics for different domains are provided and used to assess the project from a global point of view and allowing to aim for a global optimum that is acceptable by stakeholders rather than trying to optimise locally each of the domains. The confidence associated with information used is dealt with in a satisfying manner.
- LC assessment: specify and develop methodologies and seamlessly integrated tools (especially simulation and visualisation tools) for the AEC sector that support multidisciplinary performance assessment and overall project evaluation
- Knowledge repositories: long term data archiving & refreshing. Specialise (according to Construction need) and integrate current emerging technologies for digital archiving solutions, allowing to backup, retrieve and refresh large amounts of information (including historical ones) over the long term, and over the network and through infrastructures that are transparent, secure, virtually expandable, accessible everywhere and at any time (*ambient access*), etc.
- New LC business models – provide with methodologies that will support a “new procurement philosophy” and a “global design approach” associating all stakeholders and addressing issues such as distribution of benefits and ownership of data.

Emerging

- Embedded ICT in products / buildings (link with the Smart building roadmap): real-time traceability of materials and components on the construction site, real-time preparation of the site for delivery, electronic how-to build information delivered with products, as built product model delivered with building, FM done using the as built model, automatic maintenance schedules, regulating intelligent components.
- LC optimisation. Tools and methodologies are provided that allow, using the LC performance metrics, to optimise the project across domains and over time.

- Long term data archiving and refreshing. A project data ware house allows to inform client about similar developments and to take decisions. As built model provided with the building, updated on regular basis and used for FM and as feedback for future projects.
- Legal / contractual responsibilities for LC. Cultural changes and life cycle thinking supported through the overall process.

4.5 Implementation mechanisms and instruments

Different funding instruments for supporting the RTD actions suggested by ROADCON may be identified:

At a **European level** 6th Framework Programme (FP6) provides the following instruments:

Table 5. FP6 instruments

FP6 Instrument	Potentials in ROADCON context
Integrated Projects (IP): Large projects with ambitious scientific and technological objectives. The primary deliverable is new knowledge. Mobilisation of criticall mass to achieve a breakthrough.	RTD on the whole spectrum of the ROADCON roadmap, possibly in collaboration with other industry and research sectors.
Networks of Excellence (NOE): Integrating currently fragmented RTD under a common RTD agenda. The main deliverable is European leadership at global level and a durable change in carrying out research. Training is an essential component.	Network of key researchers, educators and developers in in Europe and around the world.
Specific targeted research projects (STREP): Research, technological development and demonstration activities of a more limited scope and ambition than required by the integrated projects. The main deliverable is new knowledge.	RTD on a targeted area, such as a subroadmap of ROADCON.
Coordination actions (CA): Networking and coordination of research and innovation activities.	Coordination of several independent, and otherwise funded European and national projects, and standardisation initiatives.
Specific support actions (SSA): *S*upport the implementation of the Framework Programme.	Assess previous or ongoing research projects in the area. Prepare suggestions for future RTD.

At the **national** level, the instruments and opportunities would vary significantly from country to country.

The European **Eureka** program, Europe-wide Network for Industrial R&D provides a platform for cooperative RTD supported by national funding organisations (http://www.eureka.be).

At **global level** collaborative RTD projects can be organised under the IMS programme, Intelligent Manufacturing System, (http://www.ims.org/). European partners may seek financial support from FP6.

5. References

Amor, R, Betts, M, Coetzee, G, Sexton, M. (2002). Information technology for construction: recent work and future directions. CIB W78 Aarhus, Denmark

Becker R. (1999). Research and development needs for better implementation of the performance concept in building. Automation in Construction Vol 8. 525-532 pp.

Böhms M. & al. (2003). Construction Sector Opportunities offered by ICT. ROADCON project deliverable report D4, IST-2001-37278, May 2003.

Ribak A. & Schaffers H (eds.) (2003). Context-Aware Collaborative Environments for Next-Generation Business Networks. RESEARCH AGENDA AND ROADMAP. COCONET CONSORTIUM, (COCONET IST-2001-37460). June 2003.
http://www.telin.nl/CSCW/coconet/ENindex.htm

Globemen (2003). Virtual Enterprise Reference Architecture and Methodology

Koivu T. (2002). Future of product modeling and knowledge sharing in the fm/aec industry. ITcon Vol.7, Electronic Journal of Information Technology in Construction, http://www.itcon.org/

Rezgui Y. & al. (2003). The ROADCON European Construction Vision. ROADCON project deliverable report D3, IST-2001-37278, November 2002.

ROADCON (2003). The web site of ROADCON project. http://www.roadcon.org.

AIAC: Aerospace & Defence Technology Roadmap. Office of Collaborative Technology Development.
http://technology.aiac.ca/roadmap.html

CABA: Technology Roadmap for Intelligent Building Technologies. Continental Automated Buildings Association. http://www.caba.org/trm/

DoE EERE: Building technology roadmaps.
http://www.eere.energy.gov/buildings/research/roadmaps.cfm

DoE OIT: Industries of the Future.
http://www.oit.doe.gov/industries.shtml

FIATECH: Capital Projects Technology Roadmap.
http://www.fiatech.org/projects/cptri.htm

Geomatics: Virtual Technology Roadmap.
http://www.geomatics.org/index-roadmap.html

IMTI: Roadmaps of the Integrated Manufacturing Technology Initiative.
http://www.imti21.org/

IST roadmaps towards FP6 launched in June 2002 (28 roadmap projects; the ones that are deemed as most relevant to ROADCON are marked with *: ACIP, AFORO, AMSD, AMSD, BPR LOGISTICS, BVN, COCONET*, COMPANION, DDSI, FUTURE_WORKSPACES*, G-NIKE, IDEAS*, INTELCITY*, MBNET, NESKEY*, PAMPAS, RAPID, RESET, ROADCON*, ROCKET, RURAL WINS, SASKIA, STORK, TEX-MAP, VIP-ROAM*, VISION, VOMAP*, WG-ALPINE).
http://www.cordis.lu/ist/ka2/roadmap.html ,
http://www.roadcon.org (Links / IST KA2 roadmaps)

ITEA: Technology Roadmap on Software Intensive Systems.
http://www.itea-office.org/projectcalls/itearoadmap.htm

Lahdenperä P (1998). The inevitable change, why and how to modify the operational modes of the construction industry for the common good. The Finnish Building Centre Ltd. Tampere, Finland.

LearningTrust: Vision Strategist - software tool for strategic roadmapping.
http://www.learningtrust.com/

LTRM: Lean Logistics Technology Roadmap.
http://www.infochain.org/roadmap/LRTM_en.html

NCSBCS: Streamlining the regulation of the siting, design, and construction.
http://www.ncsbcs.org/

OSGi: Open Service Gateway Initiative; Standards for integrating new generation devices in various environments (e.g. buildings, cars) with commercial Internet services.
http://www.osgi.org/

PATH: Several Technology Roadmaps for house building.
http://www.pathnet.org/sp.asp?mc=library_roadmaps

PeBBu (2002). IST Thematic Network. 1st International State-of-the-Art report, August 2002.

Purdue CTR: Purdue University Center for Technology Roadmapping.
http://roadmap.ecn.purdue.edu/CTR/default.htm

SABLE: Simple Access to the Building Lifecycle Exchange http://www.blis-project.org/~sable/about/description.html

Sandia: Fundamentals of Technology Roadmapping.
http://www.sandia.gov/Roadmap/home.htm

Stategis: Technology Roadmaps at Industry Canada.
http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwGeneratedInterE/Home

USPI-NL: Reaching the process industry vision. Roadmap to competitive advantage via sharing and storing plant lifecycle data. The Dutch Process and Power Industry Association.
http://www.uspi.nl/awareness/stappenplan2001.html
http://www.uspi.nl/download_folders/awareness/publications/USPI-NL_Roadmap_feb2002.pdf

6. Abbreviations

API .....Application Programming/Procedural Interface
AS .....Associated States (Incl. Associated candidate countries) [FP6]
ASP.....Application Service Provider
bcXML.....building and construction XML [eConstruct]
BPML4WS .....Business Process Modelling Language for Web Services
BTP .....Business Transaction Protocol [OASIS]
CA .....Coordination Action [FP6]
CEN/ISSS .....European Committee for Standardization; Comité Européen de Normalisation, Information Society Standardization System
CD .....Committee Draft [ISO]
CORBA IIOP.....Common Object Request Broker Architecture, Internet Inter-ORB Protocol [OMG]
CRM.....Customer Relationship Management
DAML.....DARPA Agent Markup Language
DGPS.....Differential Global Positioning System
DIS.....Draft International Standard [ISO]
DSML.....Directory Services Markup Language [OASIS]
EAI.....Enterprise Application Integration
EAN.....European Article Number
ebXML.....Electronic Business Extensible Markup Language
EDM.....Electronic Data Management
ENCORD VCP....European Network of COnstruction companies for Research and Development, Virtual Construction Platform (working group)
EPSRC.....Engineering and Physical Science Research Council, UK
Eureka.....A Europe-wide Network for Industrial R&D (www.eureka.be)
FP6 .....European 6th Framework Program for Research and development
GDL.....Geometric Description Language [Graphisoft/GDL Technology]
GSM.....Global System for Mobile Communications
HF.....High Frequency
HVAC .....Heating, Ventilation, & Air Conditioning
IAI.....International Alliance for Interoperability
ICT.....Information and Communication Technology
IFC.....Industry Foundation Classes [IAI]
IMS.....Intelligent Manufacturing Systems Initiative (http://www.ims.org/)
IP.....Integrated Project [FP6]
IP.....Intellectual Property
IP.....Internet Protocol
IPR.....Intellectual Property Rights
ISO.....International Standardization Organization
IST.....Information Society Technologoies [FP6]
KM.....Knowledge Management
LC.....Life Cycle
LDAP.....Lightweight Directory Access Protocol
MS.....Member States of the EU [FP6]
NoE.....Network of Excellence [FP6]
OIL.....Ontology Interchange Language
OO.....Object Oriented
OWL.....Ontology Web Language [W3C]

PAS.....Publicly Available Specification [ISO]
PDA.....Personal Digital Assistant
PDM.....Product Data Management
PDT.....Product Data Technology
PLIB.....Parts Library: International set of Standards for the computer-sensible representation and exchange of part library data (http://www.plib.ensma.fr) [ISO 13584]
PLM.....Product Life-cycle Management
RDF.....Resource Description Framework [W3C]
RFDS.....RDF Schema [W3C]
RFID.....Radio Frequency Identification
RMI.....Remote Method Invocation [Java]
RPC.....Remote Procedure Call
RTD.....Research and Technological Development [FP6]
SDAI.....Standard Data Access Interface [STEP, ISO 10303]
SG.....Support Group
SME.....Small and Medium Size Enterprise
SMTP.....Simple Mail Transfer Protocol [Internet email]
SOAP.....Simple Object Access Protocol [W3C]
STEP.....STandard for the Exchange of Product model data [ISO]
SPFF.....STEP Physical File Format [ISO STEP]
STREP.....Specific Targeted Research Project [FP6]
SW.....Semantic Web
SWS.....Semantic Web Services
TCL.....Total Life Cycle
TRM.....Technology Roadmap
UBL.....Universal Business Language
UDDI.....Universal Decsription, Discovery and Integration of Web Services (http://www.uddi.org/)
UML.....Unified Modeling Language [OMG]
URI.....Universal Resource Identifier
VHF.....Very High Frequency
VR.....Virtual Reality
WIFI.....Wireless Fidelity [IEEE]
WSDL.....Web Services Description Language [W3C]
WS.....Web Services
WSCM.....Web Services Component Model
WSFL.....Web Services Flow Language
X3D.....eXtensible 3D [Web3D] (http://www.web3d.org/)
XForms.....The Next Generation of Web Forms [W3C]
XLANG.....Web Services for Business Process Design
XLink.....XML Linking Laanguage [W3C]
XML.....eXtensible Mark-up Language [W3C]
XPath.....XML Path Language [W3C]
XQuery.....XML Query Language [W3C]
XSD.....eXtensible Schema Definition [W3C]
XSL.....eXtensible Stylesheet Language [W3C]
XSLT.....eXtensible Stylesheet Language Transformations [W3C]

Appendices

Appendix 1: Related IST roadmap projects
Short description of 8 other roadmap projects related to ROADCON.

Appendix 2: Suggested RTD topics
Summary of 79 RTD topic suggestions

Appendix 3: Expressions of interest
Summary of 56 EOIs out of 13000 that were submitted to the IST in 2002

Appendix 1: Related IST roadmap projects

This appendix describes shortly 8 other IST rodamap project that were deemed to be releated to ROADCON. Their main relations to ROADCON are illustrated in figure A1 below.

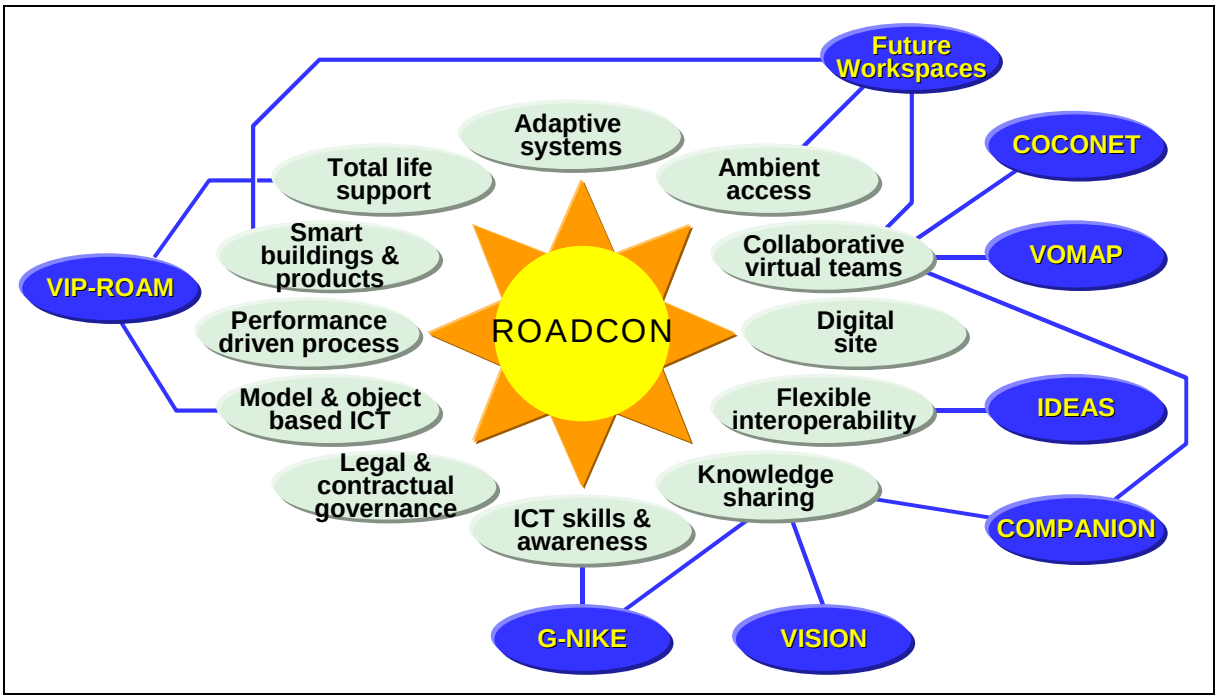

Figure A1. Other roarmap projects related to ROADCON

COCONET — Context-Aware Collaborative Environments for Next Generation Business Networks (http://coconet.telin.nl/)

COCONET aims to prepare a strategy and roadmap for RTD of high industrial impact in the area of next generation “context-aware collaborative environments”. Focus of COCONET is in identifying the key research tasks and the key players in Europe and beyond, in developing a RTD agenda for the next 5-10 years, and in discussing possible business implementation paths and innovative applications of next-generation 'context-aware collaborative environments' with potential industrial stakeholders. On the basis of a number of workshops and preparatory surveys consensus is built among key players resulting in advice to the Commission concerning an Integrated Project research plan for FP6. COCONET responds to the challenge to enhance European competitiveness and to mobilise human capital across boundaries, through creation of flexible, adaptive and context aware forms of collaboration and business.

- *COCONET is related to the collaboration support for distributed / virtual teams priority of ROADCON.*

COMPANION — Collaborative Commerce in expanding Value creating international networks (http://www.companion-roadmap.org/)

The COMPANION project developes a roadmap for collaborative business in expanding value creating international networks. The basic concept and (assumption) is that a Smart-

Collaborative Organisation is an organisation which is able to expose (i.e. make accessible under different use rights) its Knowledge Assets (resources, products, procedures, capabilities, capacity,…) to other companies for collaboration. The objective of the project is to explore future distributed business processes in the smart organisation of the future. The following research lines have been identified:

A. To identify industrial collaborative business models for smart organisations, including SME, which will be prevalent in 3, 5 and 10 years time

B. To identify the main elements (functional and non-functional) of business processes (BPs) to support industrial collaborative business networks and to define an evolutionary path to provide those elements.

C. To determine the inhibiting factors that exist and may arise from the adoption of collaborative business models identified above.

By focussing just on the objective B, we have identified 2 main research lines (different but complementary) which should be taken into account for roadmapping (S-O-t-A, vision, gap analysis, implementation plan): (1) BPM: Business Process Management, (2) BPR: Business Process Re-engineering.

- *COMPANION is related to the knowledge sharing and collaborative virtual teams priorities of ROADCON.*

FUTURE WORKSPACES (http://www.avprc.ac.uk/fws/)

The mission of this roadmap project is to define the 2010 European Vision of Collaborative Engineering Workspaces of the Future and to identify future research challenges in implementing this collective vision by bringing key players across Europe.

This project is focusing on the aerospace, automotive and building construction sectors, and the concept of Collaborative Engineering Workspaces of the Future is driven by end-user demands, user centred design and technological, economical and social needs. The concept of Collaborative Engineering Workspaces of the Future is being developed to increase the competitiveness of EU engineering companies in the global marketplace, whilst at the same time supporting sustainable development in the knowledge economy.

The key objectives of the Future Workspaces:

- To define the 2010 Vision of Collaborative Engineering Workspaces of the Future for the aerospace, automotive and the construction sectors through a series of scenarios.
- Identify end-user needs, human factor issues and technology challenges (gaps) in implementing the Collaborative Engineering Workspaces of the Future.
- To develop a roadmap for implementing the Collaborative Engineering Workspaces of the Future with prioritised key challenges over a 2, 5 and 10 year periods.
- To identify the key players who can contribute to the implementation of the roadmap.
- To prepare for a possible industry-supported Integrated Project in the 6th Framework Programme.

- *FUTURES WORKSPACES is related to the collaborative virtual teams, smart buildings and ambient access priorities of ROADCON.*

G-NIKE — Growth-Nodes in a knowledge-based Europe (http://www.uoc.edu/in3/gnike/)

The research focuses on the dynamics of ICT-enabled 'growth nodes' in Europe, i.e. regional high growth rate clusters which identified Information and Communication Technologies (ICTs) as strategic enabling factor.

Regional growth has been the subject of research going back to François Perroux' work on growth poles in the 1950s. In the US such research currently goes on under the label of 'clusters'. Michael Porter of the Harvard Business School has researched how clusters enhance productivity and spur innovation by bringing together technology, information, talent, companies, academic institutions, and other organizations. He concludes that the drivers of innovations are becoming increasingly local; i.e. the ability to produce high-value products and services depends on the creation and strengthening of regional clusters that become hubs of innovation.

The early literature on growth poles was concerned with the transport of physical goods and, for this reason, stressed the importance of physical proximity to the eventual success of a given growth pole. Work on clusters also stresses the importance of physical proximity, but with a much greater stress on face-to-face knowledge flows than on the flow of physical goods. This closer proximity leads to tighter linkages, which in turn yield better market insights, more refined research agendas, larger pools of specialized talent, and faster deployment of new knowledge.

- *G-NIKE addresses regional clusters and take-up measures and thus relates to the awereness and learning priority of ROADCON.*

IDEAS — Interoperability Developments for Enterprise Application and Software – Roadmaps (http://www.ideas-roadmap.net/)

The objectives of IDEAS project is to create and to manage a Working Group to elaborate a strategic roadmap in the domain of enterprise application and software interoperability for the next ten years. It is aimed at proposing to the EC a structure and an organisation to support the implementation of this roadmap in the sixth FP.

For each of the technology areas of the interoperability study: architecture, modelling and ontology, the Working Group will provide a State of the Art and User requirements.

IDEAS WG will provide a «vision» and scenarios on how the European Industry will face the challenges of interoperability. The Technology Roadmaps for the interoperability will be extracted form the gap analysis between the state of the art and the vision. Then, management tools to pilot roadmaps implementation will be defined, based on the tools proposed by EC for FP6.

- *IDEAS is related to the flexible interoperability priority of ROADCON. It focuses mainly on iteroperability of management information systems, such as Enterprise Resource Planning (ERP), while the focus of ROADCON is more on product related information.*

VISION — Towards Next Generation Knowledge Management (http://www.km-vision.org/)

The VISION project will provide a strategic roadmap towards next-generation organisational knowledge management.

VISION pursues a cyclic and incremental approach for reviewing existing show cases (research projects, products, etc.) and state-of-the-art technology.

The results of the VISION roadmap project will provide guidelines for enabling ambient access to knowledge within next-generation applications.

VISION will prepare the ground for future research and development activities and provide recommendations for integrated projects in the context of organisational knowledge management.

- *VISION is related to the knowledge sharing priority of ROADCON.*

VIP-ROAM The Future of Virtual Product Creation - Strategic Roadmap (http://www.vip-roam.de/)

To succeed in the global competition European industry has to improve its product creation processes by applying information society technologies. Focussing on this aim ViP-RoaM develops a vision on Virtual Product Creation technologies and methodologies and defines a strategic roadmap for RTD activities for the next 5-10 years. This ensures a precise and synergetic use of RTD resources. The development of the roadmap is based on a comprehensive collection and integration of information gathered from industrial key players and research organisations. Business implementation paths and integrating scenarios will be derived to enable European industry to set up and follow a strategy for future product creation procedures based on innovative technologies and to be competitive in international markets.

The project is driven by the goals of the Automotive & Aerospace Industry: Reduce time to market; Reduce costs (development & manufacturing & maintenance); Increase safety ("Zero Accident Strategy"); Allow maximum customisation/ individualization of products; Increase "ecological friendliness" (low pollution, low noise,...).

The vision on Virtual Product Creation is: Complete virtual car/plane; Near-physical product simulation; Realistic simulation in any situation with complete environment; Customer "designs" the product; Intelligent product model; Automatic process optimisation.

- *VIP-ROAM has a focus on collaborative product engineering and is related to the model based ICTand total life cycle support priorities of ROADCON.*

VOMAP Roadmap Design For Collaborative Virtual Organisations in Dynamic Business Ecosystems (http://www.vomap.org/)

VOmap aims to define a roadmap towards a strategic European initiative, supporting the emerging Virtual Organisations (VO) and VO Communities of Practice. It will identify and characterise the key research challenges, required multi-disciplinary constituency, and an implementation plan for a comprehensive initiative to affirm the EU leadership on VO in the coming Digital Age. VOmap aims to empower European enterprises for both regional sustainability and competitiveness in global market, towards a society of collaborative relationships. Further scientific and technical goals include: Consolidate multi-disciplinary paradigms, Design a common reference model, Identify future needs and scenarios, Understand and characterise the VO nesting environments, Plan the necessary IT and non-IT developments, Design a strategy and implementation mechanisms for a major initiative to support emerging VOs. The work will be done in tight collaboration with a large VO industry network.

- *VOMAP addresses generic Virtual Organisation issues related to the collaborative virtual teams priority of ROACON.*

Appendix 2: Suggested RTD topics

Members of the ROADCON consortium and the Support Group were invited to submit short research idea proposals as inputs to the roadmap. During November 2002 - February 2003 we received 79 proposals from 40 persons representing 24 organisations in 12 countries. Half of the proposals were from others than ROADCON partners. Most proposals were from RTD organisations. These proposals focused on collaboration infrastructures, knowledge sharing, interoperability and model based systems while the Expressions of Interest to IST (Appendix 3) focused more on stand-alone applications.

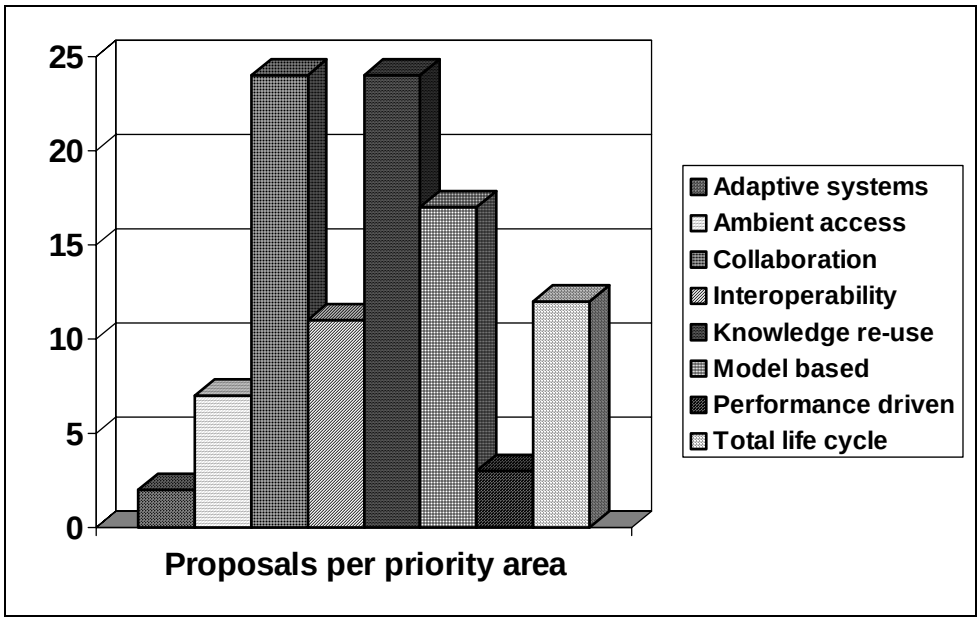

Figure A2.1. Priority areas of RTD proposals to ROADCON.
(The most popular ones were: 1. Collaboration support, 2. Knowledge sharinge, 3. Model based systems.)

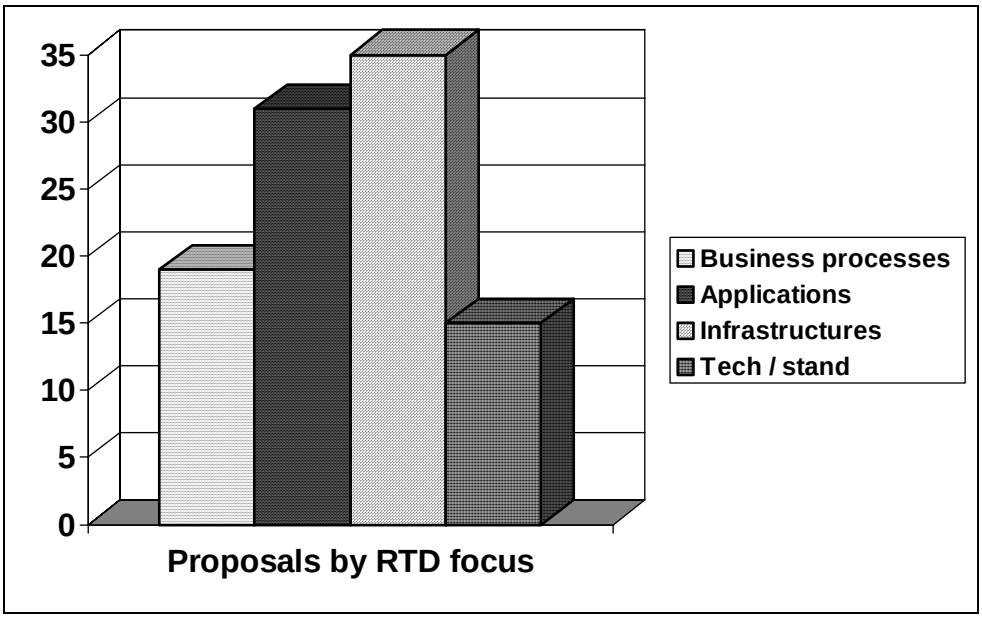

Figure A2.2. Focus of RTD proposals.
(The most popular ones were: 1. ICT infrastructures / platforms, 2. ICT applications.)

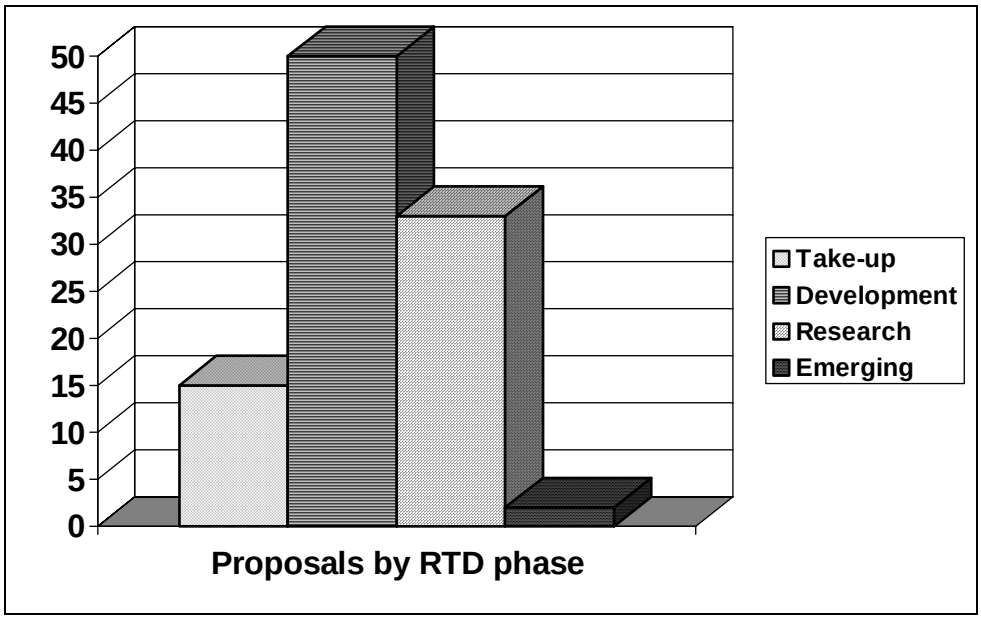

Figure A2.3. Innovation phase of RTD proposals.
(The most popular ones were: 1. Development, 2. Research.)

The 79 proposals are listed below:

- **5-Star** - Creation and implementation of a 5-Star scheme for enterprise accreditation in AEC sector (Yuhua Luo, University of Balearic Islands, Es)
- **ActInfo** - Activity information for interoperability (Anders Ekholm, Lund Institute of Technology, Se)
- **ActMo** - Activity Modelling for a Sustainable Built Environment (Anders Ekholm, Lund Institute of Technology, Se)
- **ADS-I** - Decision-chains as a focus for knowledge integration (Grahame Cooper, University of Salford, UK)
- **AgeSID** - Agent-based Software Interoperation and Decision Support for Design (Bimal Kumar, Glasgow Caledonian University, UK)
- **ArtControl** - Smart Management System for Construction Projects Through Automated Real Time Control of Resources and On-line Image Processing (Juan Manuel Mieres Royo NECSO, Es)
- **AS-Interop** - Advanced ICT solutions for AEC system interoperability (Vitaly Semenov ISP RAS, Ru)
- **BEIR** - Building Envelope Integration Research (Alastair Watson, University of Leeds, UK)
- **CLE-Hub** - Collaborative Learning Engineering e-Hub in Virtual Enterprises (Tarek Hassan, Loughborough University, UK)
- **CoDesK** - Distributed object model for Collaborative Design Knowledge (J.P. van Leeuwen, TU Eindhoven, Nl)
- **Coll Flow** - Collaborative Workflow Solutions for eWork in Construction (Yacine Rezgui, University of Salford, UK)
- **Collaboration** - Supply chain collaboration amongst project participants through Internet (ENCORD: M. F. de Jonge, Ballast-Nedam, Nl)
- **Complement** - Ambient Collaboration in A/E/C & FM Through Mobile ICT (Danijel Rebolj, University of Maribor, Si & Karsten Menzel, TU Dresden, De)

- **CONFORM** - Innovative Approach to Sustainable Construction for the Knowledge Economy: The CONstruction InFORMation Platform (Tarek Hassan, Loughborough University, UK)
- **Construct-TLCC** - Supporting systems for Total Life-Cycle Costs for construction projects and products (Alain Zarli & Régis Bonetto, CSTB, Fr)
- **CSM** - Construction Site Memory (Marc Bourdeau & Alain Zarli, CSTB, Fr)
- **DeLTA** - Distributed e-Learning and Training Approach for Construction (Mustafa Alshawi, University of Salford, UK)
- **Divercity** - Piloting of Divercity (Marjan Sarshar, University of Salford, UK)
- **DSS-nD** - Development of a decision support system for nD modelling (Ghassan Aouad, University of Salford, UK)
- **eC-BPI** - Business Process Integration for e-Construction (Alain Zarli & Régis Bonetto, CSTB, Fr)
- **e-CHAIN** - Integrated e-business Process Model for the Whole Value Chain of AEC (Yuhua Luo, University of Balearic Islands, Es)
- **EDEE** - Electronic dialogue to enhance B2A exchanges (Eric Gaduel & Bruno Fies, CSTB, Fr)
- **eDev4BC** - Concurrent eDevelopment for Building Construction (Alain Zarli & Rémi Vankeisbelck, CSTB, Fr)
- **ELCI** - Electronic Life Cycle of Information in the Building Process (Juan Pérez, LABEIN, Es)
- **eLib** - Electronic Product Libraries (Foroutan Parand, BRE, UK)
- **eMarket4BC** - eBusiness and open on-line markets for Building Construction (Alain Zarli & Celson Lima, CSTB, Fr)
- **gridAEC** - AEC computing grid architecture (Ziga Turk, University of Ljubljana, Si)
- **HumanICT** - Human Oriented Support for ICT Development and Deployment in Construction (Ian Wilson & Yacine Rezgui, University of Salford, UK)
- **I2C-KM** - Intra- and Inter-company Knowledge Management (Marc Bourdeau, CSTB, Fr)
- **IBEX** - Interactive Building Exploration (Souheil Soubra, CSTB, Fr & Kalle Kähkönen, VTT, Fi)
- **i-CAT** - Intelligent product catalogs for construction (Matti Hannus, VTT, Fi & Gudni Gudnason, IBRI, Is)
- **ICon** - Imaging in Construction (Juan Manuel Mieres Royo, NECSO, Es)
- **IFC/GIS** - Enhance interoperability between GIS and CAD/CAFM (Bernard Ferries LAURENTI, Fr)
- **IFCISO** - Co-ordination of IFC and ISO 12006-2 classification framework (Anders Ekholm, Lund Institute of Technology, Se)
- **i-Know** - Integral Knowledge Network for the transfer of Information & Know-how (Marcelo Blasco, BBRI, Be)
- **ILCA** - Integrated Life Cycle Analysis (Juan Pérez, LABEIN, Es)
- **Include** - Regulatory Information Infrastructure with Application to Accessibility Codes for Sustainable Inclusive Design (Bimal Kumar, Glasgow Caledonian University, UK)
- **iSketcher** - Intelligent 3D sketcher for architect (Benachir Medjdoub, University of Nottingham, UK)

- **ISWork** - Research into an integrated surveillance system for heavy construction workers (Adele Seniori Costantini, CSPO, It)
- **ITbrief** - ICT Support for Performance Oriented Construction Briefing (Yacine Rezgui, University of Salford, UK)
- **KM-Proc** - Knowledge Management Practices - a Socio-Technical Perspective (Elaine Ferneley, University of Salford, UK)
- **KnowBank** - Construction Project Knowledge Bank (Foroutan Parand, BRE, UK)
- **Know-CAD** - Exploitation of Knowledge from CAD (Elaine Ferneley, University of Salford, UK)
- **MacBuild** - Mobile agent-enabled collaboration environment for the building site (Peter Katranuschkov & Raimar Scherer, TU Dresden, De)
- **Metis** - Building information model-based environment and platform for collaboration within the integrated supply chain (Foroutan Parand, BRE, UK)
- **MobileWare** - Mobile Facilities to support Networked Businesses in A/E/C (Karsten Menzel & Raimar Scherer, TU Dresden, De)
- **MoWLC** - Model based WLC and LCA (Foroutan Parand, BRE, UK)
- **Multi-Coll** - Multi-modal collaborative environment for multi-disciplinary projects in AEC (Vitaly Semenov, ISP RAS, Ru)
- **MyRoad** - Model-Based Life Cycle Management of Road Facilities (Peter Katranuschkov & Raimar Scherer, TU Dresden, De)
- **Next** - Engineering Knowledge Exchange Platform (Ziga Turk, University of Ljubljana, Si)
- **NTT** - Network of Technology Transfer, (Antti Lakka, VTT, Fi)
- **On4e-BC** - Ontology for the e-Business in Construction (Alain Zarli & Bruno Fies, CSTB, Fr)
- **OnTime** - Construction and supply chain collaboration through integrated Field Force Automation and product model planning & simulation tools (Thomas Olofsson, Luleå University of Technology, Se)
- **Onto2build** - Construction of a large ontology for a new European standard in Construction (Laura Campoy-Gomez, University of Salford, UK)
- **PMS-Know** - A Semantic Web to Support IFC2x Knowledge Extraction (Elaine Ferneley, University of Salford, UK)
- **Primary** - LCC driven project resource management process (ENCORD: Adina Jägbec, SKANSKA, Se)
- **ProductModel** - Model based integrated solutions (ENCORD: Jeff Stephens, Taylor Woodrow, UK & Wilfred van Woudenberg, HBG, Nl)
- **ProNLP** - Natural Language Processing for Project Management (Bimal Kumar, Glasgow Caledonian University, UK)
- **Rapid3D** - Design Management via 3D CAD Model (ENCORD: Jeff Stephens, Taylor Woodrow, UK & Wilfred van Woudenberg, HBG, UK)
- **RBACC** - Role Based Access Controls for Construction (David Chadwick, University of Salford, UK)
- **ResponceGrid** - Emergency Response Management in the Built Environment Using GRID Technology (Dino Bouchlaghem, Loughborough University, UK)
- **Reuse** - Knowledge based collaboration and process tools (ENCORD: Riitta Takanen, NCC, Fi)

- **sHVPD** - Building Services Standard Solutions: Heating and Ventilation Plant Design (Benachir Medjdoub, University of Nottingham, UK)
- **SiteKnow** - Structuring and managing site knowledge and information (ENCORD: Vincent Cousin, Processus & Innovation, Fr)
- **SmartDoc** - Smart Building Design and Construction Documents (M. R. Beheshti TU Delft, Nl)
- **SmartStart** - Principles, methodologies and tools for electronic decision support at building brief stage (François Giraud-Carrier, DERBI, Fr)
- **Smile** - SMart BuILding ManagEment Systems (Alain Anfosso & Rémi Vankeisbelck, CSTB, Fr)
- **SnowBall** - Framework for Rapid implementation of 6th framework investments and future R&D planning (ENCORD: Wilfred van Woudenberg, HBG, NL & Wolfgang Katzer, Hochtief, De)
- **SO-LEGAL** - Smart Organisations solutions for LEGAL validity of ICT (Tarek Hassan, Loughborough University, UK)
- **SOLICiTER** - Smart Organisations use of Legal and contractual Information & Communication Technologies in the European Region (Tarek Hassan, Loughborough University, UK)
- **Standardisation** - Building Services Standard Solutions implemented in CAD: Heating and Ventilation Plant Design (Benachir Medjdoub, University of Nottingham, UK)
- **Sus-Life** - Sustainability driven Total Life-Cycle Costing for construction projects (Elaine Ferneley, University of Salford)
- **Sustainor** - Methodology, tools and architectures for sustainable buildings through collaboration and performance monitoring (François Giraud-Carrier, DERBI, Fr)
- **Trainer** - A Global approach for distance teaching of practical knowledge in vocational Training (Benoit Vinot, CSTB, Fr)
- **TrusteD-BPS** - Trusted e-development of building products and services (Alain Zarli & Bruno Fies, CSTB, Fr)
- **Vir-C** - Virtual Construction (Souheil Soubra, CSTB, Fr & Kalle Kähkönen, VTT, Fi)
- **Vis-Know** - Visual representations of large bodies of data to support knowledge management activities (Elaine Ferneley, University of Salford)
- **Visualisation** - Constraint-Based 3D Variational modeller for architect (Benachir Medjdoub, University of Nottingham, UK)
- **VWM** - Virtual workplaces for mobile workers (Alain Anfosso & Alain Zarli, CSTB, Fr)

Appendix 3: Expressions of Interest

In June 2002 about 13.000 Expressions of Interest were submitted to the European Commission suggesting RTD topics to the 6th Framework Programme. We identified 56 EoI:s within the scope of ROADCON. Most of them suggest miscellaneous applications of ICT. The next most popular area (see figure) was Collaboration support.

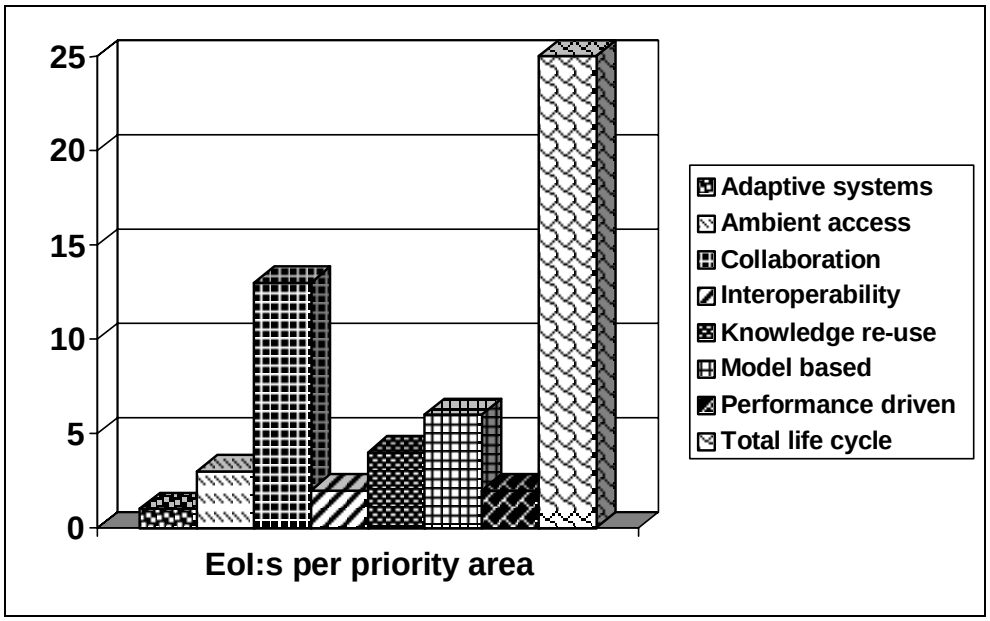

Figure A3. Priority areas of EOI:s.

The following 56 EOIs were analysed for ROADCON:

- **ACCOLADE** - Architecture - Collaboration - Design
- **AIMCE** - Ambient Interfaces for Immersive Collaborative Virtual Environments
- **AMSBET** - Activity modelling for a sustainable built environment
- **BE-HARMONY** - Harmonisation of Assessment Tools for Sustainability of the Built Environment
- **BEVER** - Best Value - Exploring the Requirement
- **BIOCHAIN** - Pre-engineered and sustainable buildings
- **CASBE** - The Application of Complex Adaptive Systems in Solving Built Environment Problems
- **CONFORM** - CONstruction InFORMation Platform
- **CONSIMOPT** - Simulation and optimisation of construction : facilities and site activities
- **CONSTRSECTORICT** - Construction sector cost-efficiency improvements through integrated use of ICT
- **CONSTRUCTION IT** - Bridging the Gap
- **ConTraSim** - Simulation for development of, **and** training in new construction processes
- **DDSS-EC** - Design and Decision Support Systems for the European Citizen
- **DRAGOn** - Methodology for resolving of disharmony for product models in construction
- **EASMAC** - Efficient and Sustainable Manufacturing and Construction

- **E-CONSTRUCT** - Integrated Project for Knowledge-driven and Sustainable Construction in Europe
- **e-Construction** - e-Learning tools supporting civil engineering courses in High-Schools
- **E-COPIN** - European Construction Process Improvement Network
- **EMAGIN** - e-management for sustainable infrastructures
- **e-MCP** - E-Management of Construction Projects
- **Engineering PACT** - e-Engineering partnerships across global communities
- **eSYSCOM** - Networked System for Sustainable Conservation and Management of Built Cultural Heritage
- **EuroFISH** - European Forum on Information Standards in Heritage
- **FACIMEM** - Live digital memory for existing and new infrastructures
- **Future_Workspaces** - Collaborative Engineering Workspaces of the Future
- **HI** - Home Intelligent
- **i-CAT** - Intelligent product catalogs for construction
- **i-CODE** - Model-based methods of work and ICT components for Construction in the digital economy
- **ICON** - Imaging in Construction
- **InBuild** - Performance of Intelligent Buildings
- **INDECORE** - Intelligent decision tools - enabling accurate predictions of a building's impact
- **INFRA&SOCIETY** - An Inclusive Society in The Built Environment: A Global Approach
- **INTELCITY** - Towards Intelligent Sustainable Cities
- **INTMOD** - Integrated modelling within building design practice: towards sustainable buildings
- **ISWork** - Research into an integrated surveillance system for heavy construction workers
- **KMIC** - Knowledge Management for Intelligent Construction
- **LeXICON** - Laboratory for ebXML-based business process interconnection
- **LIFEOPTIMUMBUILDINGS** - Whole Life Optimised Building Concept Models
- **MobileITC** - Mobile Computing in Construction
- **MoLiB** - Models as the Language in Building Projects
- **MUVE** - Multi-User Virtual Environments
- **NECAL** - Network of Excellence for Construction Ambient Learning
- **NetIS-H&B** - Network Intelligent Systems for Homes and Buildings
- **NETVIB** - Distributed Virtual Technologies for the Built Environment
- **PCS-SUITE** - intelligent e-business suite for small and medium construction enterprises
- **PROActivity** - Point-of-activity digital tools for the construction and maintenance industries
- **REDBE** - Real Time Data Handling in the Built Environment
- **RE-THICOP** - Rethinking the Construction Process
- **SAFECON** - Development and validation of a holistic methodology to improve the safety in construction
- **SITEKNOW** - Flow of production knowledge in construction sites

- **SmartDoc** - Smart Building Design and Construction Documents
- **SME-Focus** - Inter-sectorial systems interoperability for SMEs competitive performance
- **SOLICiTER** - Structured Organisational use of Legal and contractual Information & Communication Technologies in the European Region
- **SUPA** - Sustainability, public participation and aesthetics
- **SWN** - Sustainable Workplace Network
- **Worknow** - European Workplace Knowledge Network