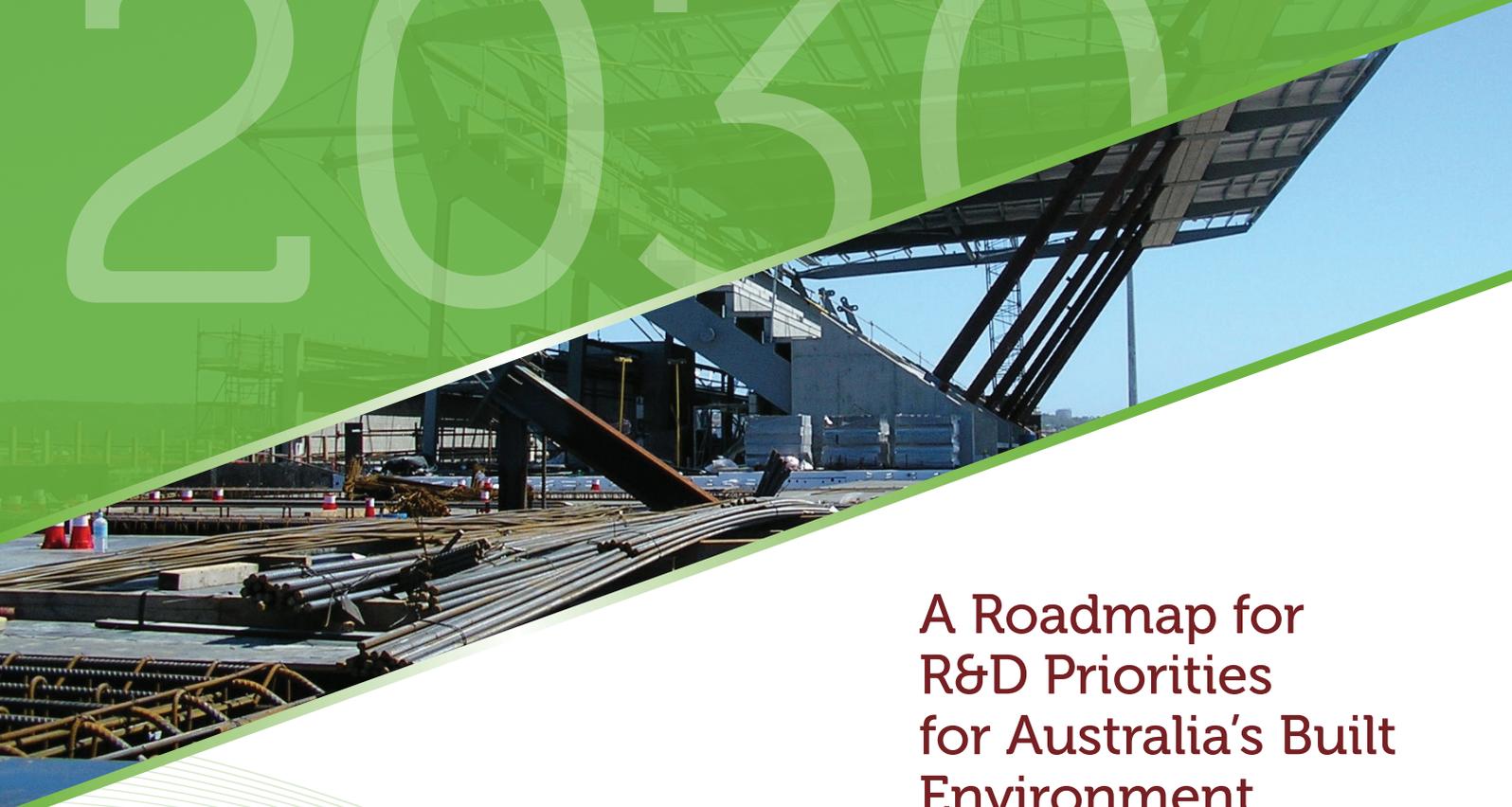


CONSTRUCTION

2030



A Roadmap for R&D Priorities for Australia's Built Environment

The property and construction industry is the foundation of the Australian economy and is responsible for the development, construction and maintenance of infrastructure that supports Australian society. Understanding the likely future landscape of this industry will be of strategic benefit to the industry future and our society.

Barbara Bok
Peter Hayward
Göran Roos
Joseph Voros



**Sustainable
Built Environment**
National Research Centre

CONSTRUCTION 2030

A Roadmap of R&D Priorities for Australia's Built Environment



Barbara Bok
Peter Hayward
Göran Roos
Joseph Voros

December 2012

This research would not be possible without the ongoing support of our industry, government and research partners:



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Foreword

The goal of Australia's Sustainable Built Environment National Research Centre (SBEnc) is to build an enduring value-adding national research and development centre in sustainable infrastructure and building.

In the 2004 report *Construction 2020*, the Cooperative Research Centre (CRC) for *Construction Innovation* captured aspirational visions of what the construction industry believed the shape of the industry should be in 2020, the barriers to achieving that future and the research needed to realise that future. Such statements are important as they help provide a focus for industry players when clarifying priorities and investment options. The *Construction 2020* report made an important contribution by providing nine visions within which the Australian construction industry could work towards, to achieve leadership in research and development, by setting its own collaborative agenda for innovation.

This report *Construction 2030 – A Roadmap for R&D Priorities for Australia's Built Environment* uses the *Construction 2020* report and process as a starting point to identify *where to from here?*

Research carried out through the Strategic Foresight team at Swinburne University of Technology and through the VTT Technical Research Centre of Finland generated a set of key macro-social drivers within which the Australian construction industry would need to achieve its visions. It is within this context that our industry will need to adapt if it is to retain leadership and remain viable.

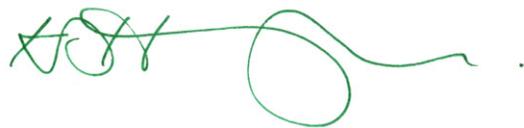
Construction 2030 identifies challenges and opportunities following extensive industry consultation and assessment of emergent technology capabilities. These technologies have been associated with research areas and classified for *Construction 2030*.

We sincerely thank the industry members who took the time to attend the national workshops as part of the consultation process for *Construction 2030*. We are committed to maximising the benefits of R&D to Australia's infrastructure and building industry through better matching funding strategies to industry needs.

We look forward to sharing the *Construction 2030* priorities as a basis for strategic conversations about the industry future. We trust this will allow our industry to take timely action to consider research priorities and to expand its repertoire of strategic options.



John V. McCarthy AO
Chair
Sustainable Built Environment
National Research Centre



Keith D. Hampson
Chief Executive Officer
Sustainable Built Environment
National Research Centre

CONSTRUCTION 2030

A Roadmap for R&D Priorities for Australia's Built Environment

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Barbara Bok is a researcher at the Faculty of Business and Enterprise, Swinburne University of Technology, where she is establishing a profile in transformative education and foresight. She teaches on the Master of Strategic Foresight and Micro-economics Program. Barbara holds degrees in operations research and statistics, business administration, and strategic foresight. Prior to her work at Swinburne, Barbara worked in her own management consulting business after a career in the manufacturing and mining-related industries in roles that facilitated management and engineering decision making.

Professor Peter Hayward is an accountant and economist with over 25 years of experience in taxation and public policy. He is also experienced in the use of systems thinking and modelling tools with regards to public policy initiatives. Peter has consulted to a range of organisations in the use of foresight methods. He is the Program Coordinator, Master of Management (Strategic Foresight), Deputy Head of Group (Resources) - Management and Entrepreneurship and a lecturer in strategic foresight at Swinburne University of Technology. In 2005 he completed his PhD, examining the development of foresight in individuals. Peter's interests include change management, organisational viability, sustainable futures and cultivating leadership.

Professor Göran Roos was named one of the world's 13 most influential thinkers for the 21st century by the Spanish business journal 'Dirección y Progreso'; and in 2011 was appointed 'Manufacturing for the Future Thinker in Residence' by the South Australian Premier. Göran chairs the Advanced Manufacturing Council in Adelaide; a Board member of VTT International (Finland); Honorary Professor at Warwick Business School (UK); Visiting Professor of Intangible Asset Management and Performance Measurement at the Centre for Business Performance at Cranfield University (UK); and Professor in Strategic Design in the Faculty of Design at Swinburne University of Technology. He has published numerous books, articles and case studies, has advised government bodies in UK, Sweden, Norway, Denmark, Finland, Spain, Austria and Australia on issues relating to strategy, R&D, national and regional innovation systems issues, knowledge management and intellectual capital.

Professor Joseph Voros began his career as a physicist working on mathematical extensions to the General Theory of Relativity and in Internet-related organisations (including Netscape Communications in Silicon Valley), before becoming a professional futurist. Prior to becoming an academic, he worked as a consultant and an organisationally-based foresight analyst and practitioner. He now teaches into the Master of Strategic Foresight at Swinburne University of Technology in Melbourne. For over a decade his research has focussed on developing a rigorous process–method view of foresight. Joseph is a member of the World Futures Studies Federation, the Shaping Tomorrow Foresight Network, a professional member of the World Future Society, and is a founding member and Board member of the International Big History Association. In February 2012, he was one of 42 world experts selected to present at the Global Future 2045 International Congress in Moscow.

About the Sustainable Built Environment National Research Centre

The Sustainable Built Environment National Research Centre (SBEnc) is the successor to Australia's CRC for Construction Innovation. The SBEnc is a key research broker between industry, government and research organisations servicing the built environment.

The SBEnc is continuing to build an enduring value-adding national research and development centre in sustainable infrastructure and building with significant support from public and private partners around Australia and internationally.

Benefits from SBEnc activities are realised through national, industry and firm-level competitive advantages; market premiums through engagement in the collaborative research and development process; and early adoption of Centre outputs. The Centre integrates research across the economic, social and environmental sustainability areas in programs respectively titled Driving Productivity through Innovation, People, Processes and Performance, and Greening the Built Environment.

The Construction 2030 roadmap was completed by the Strategic Foresight team at Swinburne University of Technology and VTT Technical Research Centre of Finland. It forms a component of the SBEnc Project 2.7 *Leveraging R&D Investment for the Australian Built Environment* which seeks to maximise the benefits of R&D investment to Australia's infrastructure and building industry through improved understanding of historic investment mechanisms and impacts, and future industry research needs.

Executive summary

The property and construction industry is the foundation of the Australian economy and is responsible for the development, construction and maintenance of infrastructure that supports Australian society. It contributes 6.8 per cent of the nation's wealth, employs 984,000 people and significantly impacts other industries. Understanding the likely future landscape of this industry and having a partnership plan between industry, government and research to collaborate in addressing challenges and promoting opportunities will be of strategic benefit to the industry future *and* our society.

Implementing visions of the future requires establishing robust priorities ...

In 2004, following extensive national consultation, the *Construction 2020* report was delivered by the Cooperative Research Centre (CRC) for Construction Innovation. It identified nine industry visions for future practice. The overall vision was that Australian industry would take more responsibility for leading and investing in R&D through tripartite industry, government and research collaboration. The need to build industry's capacity and ability to undertake robust and viable national research and innovation to deliver real value to property and construction businesses was also identified.

In 2012, the successor to the CRC for Construction Innovation – the Sustainable Built Environment National Research Centre (SBEnrc), has progressed this industry development initiative to create the basis of an industry R&D roadmap establishing priorities that respond to likely industry futures. Earlier analysis has revealed significant growth in engagement between industry, government and researchers and described case studies of R&D in advanced ICT and procurement, safety and green buildings. The roadmap can shape decisions as to how to more profitably engage in research to secure business advantages.

Construction 2030 identifies:

- areas that will need research for adaptation to local conditions or partnering with other industries to produce usable results for the Australian construction industry
- areas that the construction industry must direct specific research action. This is necessary because of the potential future benefits and because these areas are unlikely to progress without construction industry attention

This study refers to Australia's *built environment* – the physical infrastructure and buildings (e.g. roads, dams, health centres and commercial buildings) as well as how the built environment is conceived, designed, constructed and managed, including business and educational aspects.

Robust priorities need realistic assessments of future conditions ...

Visions for the future help provide a focus for industry when clarifying its investment priorities. However, aspirations must be cast within realistic assessments of the future conditions under which they will have to be achieved. The *Construction 2030* research team undertook this assessment to generate a map of key drivers of the large-scale social (macro-social) environment to which the industry may need to adjust.

The *what-if* map of key sectors of the Australian future landscape captures the greatest inherent uncertainties of the macro-social environment. The map includes a broad range of future applications of emergent trends relevant to the industry. The map was used to generate decision scenarios that covered combinations of likely future uncertainty settings including: climate change, skills, economy, attitudes, policies/governance, energy and technology. The scenarios were tested with industry representatives in a series of national workshops, who determined the challenges and opportunities presented by the scenarios. Participants then selected the possible technology capabilities that best

matched the scenario conditions.

Construction 2030 priorities

The list of technology capabilities was subjected to expert review regarding the timing and likelihood that the technologies were to emerge. Some technologies may be expected to emerge from existing research in construction or in other industries, others will not within a practical timeframe, if at all, unless the property and construction industry itself conducts the research.

Research that requires adaptation to local construction industry conditions or that requires partnering with other industries to produce usable results for construction has been identified - designated as amber below.

Areas that are likely to be critical to the industry and which are not currently receiving sufficient research effort – have been identified and designated as red. It will be necessary to strengthen existing research capacity and organisational relationships for industry-wide issues that do not respond to direct market forces.

All research areas must be continuously monitored for unplanned innovation and unexpected developments in the macro-social environment.

Introduction

This report, *Construction 2030 – A Roadmap for R&D Priorities for Australia's Property and Construction Industry (Construction 2030)*, is the output from Phase 3 of the SBEnc project *Leveraging R&D for the Australian Built Environment*. It presents a roadmap for industry Research and Development (R&D) priorities, responding to likely futures. It follows the first two phases of an audit and analysis of R&D investment in the Australian built environment since 1990; and an examination of diffusion mechanisms of research and innovation and its impact. This report will feed into the next phase to develop policy to maximise the value of R&D investments.

This project seeks to maximise the benefits of R&D investment to Australia's infrastructure and building sector through improved understanding of future industry research needs. It has received the support of the partners of the SBEnc, has the endorsement of the Australian Built Environment Industry Innovation Council (BEIC), with BEIC member Professor Catherin Bull serving on the project's steering committee.

Construction 2020 – A Vision for Australia's Property and Construction Industry (Hampson & Brandon 2004) was a significant initiative carried out by the CRC for *Construction Innovation* at a national level. It established direct interaction between industry and researchers to build the future direction and needs of the construction industry. *Construction 2030* expands on that initiative by engaging with industry thought leaders.

The SBEnc is the successor to the CRC for *Construction Innovation* and is a key research broker between industry, government and research organisations for the built environment industry. The SBEnc strongly supports Australian property and construction, government and research working together to advance the effectiveness and competitiveness of Australian industry through diffusion of applied research and innovation to industry.

According to the *Construction 2020* report, by 2020 the vision is for the industry to be taking more responsibility for leading and investing in research and innovation. The tripartite collaboration between industry, government and research is working towards the development of a robust and viable national research and innovation capability that delivers real value to Australian property and construction industry as well as the community.

The nine key visions for the future that emerged from the *Construction 2020* process are:

1. Environmentally sustainable construction
2. Meeting client needs
3. Improved business environment
4. Welfare and improvement of the labour force
5. Information and communication technologies for construction
6. Virtual prototyping for design, manufacture and operation
7. Off-site manufacture
8. Improved process of manufacture of constructed products
9. Australian leadership in research and innovation.

The ninth, and overarching, vision of *Construction 2020* highlighted that implicit benefits, such as mutual learning, are to be valued as much as formal research outcomes. Specifically, according to the vision, the long-term objectives, and therefore the values to be assessed from pursuing the R&D priorities, are:

1. Business and industry development - to improve the long-term effectiveness, competitiveness and dynamics of a viable property and construction industry in Australian and international contexts
2. Sustainable built assets - to drive healthy and sustainable constructed assets and optimise

the environmental impact of built facilities

3. Delivery and management of built assets - to deliver whole-of-life project value for stakeholders from business need, design and construction through to ownership, asset management and reuse (Hampson & Brandon 2004, p. 9).

The visions in *Construction 2020* also require that the R&D strategies impact the industry performance through design and performance evaluation tools, more appropriate skills requirements, national uniformity of codes and legislation, national and international comparisons, and improved practice.

Vision Two (Meeting client needs) sets out an aim for maximum value by adding value at every stage of the development cycle, while Vision Three (Improved business environment) is the highest priority vision delivering economic, social, environmental, and governance dividends. Assessment of the research priorities should include exploration of the link between value to stakeholders and economic, social, environmental and governance performance. The professional development and broad skills of industry leaders and managers form part of achieving this vision.

Continuing from the task begun with the *Construction 2020* report, and in particular its overarching R&D vision, *Construction 2030* undertook a process to identify areas where the industry needed to lead and invest in research and innovation. The study considered the in-built uncertainties of the large-scale (macro-social) environment impacting the industry between now and 2030.

In this report, Section 1 provides a brief overview of the research process carried out to produce the *Construction 2030* R&D priorities.

Section 2 presents an overarching view of issues related to the 'green', 'amber' and 'red' *Construction 2030* priorities. The 'red' and 'amber' research areas are described in more detail in Section 3.

The appendices provide a summary background to the research approach:

- major results delivered from the research, such as the macro-social sector and factor map and the complete list of workshop participants' responses to the scenarios and research areas
- acknowledgement of the contributions of workshop participants
- a bibliography and references.

Section 1

Conceiving the *Construction 2030* priorities

The research followed a combination of two methodologies: a morphological analysis method described by Voros (2009); and a technology roadmapping methodology described by VTT and ICS (2009). The first step of the research involved the production of a map of the key driving 'sectors' and a range of 'factors' for each sector. The sectors are expert assessments of the greatest in-built uncertainties of the large-sale (macro-social) environment that could conceivably and profoundly impact construction R&D decision making between now and 2030.

Each sector was described through a range of states (called 'factors') that define the plausible values that the sectors can have between now and 2030. This involved repeatedly refining and selecting the definitions of the sectors and factors for their greatest significance and uncertainty impacting the interactions between the industry and the macro-social Australian environment. The map also contained sets of technologies and potential building and construction applications from those technologies expected to emerge between now and 2030. For details of the sectors, factors and technologies see Appendix I, Voros and Hayward (2011), and Roos (2011a).

Using the sector-factor map, four scenario configurations were selected that together used all the factors and provided a good conceptual spread of future Australian macro-social conditions (see Appendix II and Voros and Hayward (2011) for more descriptions of the scenarios). For this research scenarios were used as decision scenarios and to provide a common reference language for use during and after this research. The scenarios form future worlds that can be used in realistic thought experiments within which construction projects are commissioned. In this way the conditions of the future worlds created by the scenarios direct the needs for, and uptake of, specific research.

These decision scenarios were tested for plausibility with key industry representatives at four workshops held in Perth, Brisbane, Sydney and Melbourne. The workshops provided the participants with an opportunity to use their industry experience to find operating solutions to the challenges and opportunities presented by the scenarios. Participants then selected the technological capabilities that best matched the scenario conditions and from their selections a list was compiled that formed the basis for identifying construction research areas. Following the workshops, participants responded to a questionnaire in order to gather statistics about the sectors, factors and emergent technologies.

The *Construction 2030* R&D priorities were developed after the workshops. The participants' list of the most important technology capabilities was reviewed by a technology and business innovation expert for commentary on the timing and likelihood that the technologies would emerge, and for contributing areas significant to the industry's visions but not specifically identified during the workshops. The research areas on the list were then classified as 'green', 'amber' or 'red' depending on the extent to which the areas were already receiving global research effort, whether the research needed adapting to the local Australian conditions or whether the research needed adapting for the construction industry. The study identified three 'red' and three 'amber' research areas and these are presented as the six *Construction 2030* priorities in this report. The eleven 'green' research areas are covered in Appendix II.

Section 2

Developing the *Construction 2030* priorities

The research context

It is important to recognise how the research of this project improves on existing research and studies in the construction industry where foresight or futures methodologies or tools have been used. In particular, the aims of the research are tied to a future context that is uncertain, which means it could be critiqued just as previous studies have been critiqued.

The aim of producing a list of R&D priority research areas in this study is so the industry has construction investment choices that allow it to achieve the visions of *Construction 2020*. At the same time, this process also takes into account the built-in uncertainties of future macro-social conditions to which the industry may need to adapt. The technology selections by industry thought leaders at the workshops represents the currently available industry thinking and experience with which to meet the challenges and opportunities of a range of future plausible conditions.

A critical view of this research might question firstly whether it is possible to identify a list of research areas from what is known *today* for what will be needed in an unknown *future*. Secondly, a critical view might question whether the number of scenarios presented in workshops could have posed to participants even a fraction of the challenges and opportunities created from complex interactions between macro-social factors.

In response to these questions, we note first that the construction industry is one of three principal industries (the other being automotive and environmental) where innovation is largely driven by regulation and less by the creative agency of industry participants. We also recognised that the 'sector-factor' map of macro-social conditions (see Appendix I) contains a policies and governance sector with a range of plausible factor settings. These settings introduced to the workshops the possibility of regulatory and governance changes, and thus also introduced regulatory and governance differences into the workshop scenarios.

In addition, we note that the existing built environment and the supporting practices and perceptions in Australia today impose constraints on the extent to which 'outside the box' innovations can be imagined. The common perception is that it is only regulation (aside from critical external events) that can introduce opportunities for 'outside the box' innovation against existing constraints. The vision expressed in *Construction 2020* includes the view that the construction industry need to adopt a more active self-improvement culture led by engagement with R&D. This would potentially change this perceived regulatory driven innovation characteristic of the industry in years to come. Such a change might be facilitated by what the 2020 visions expressed as a need for mutual learning and heightened understanding to be as important as formal research outcomes.

Harty et al. (2007) criticised construction futures studies for not fully exploring the interactions between macro-scale factors and their combined effects for the industry. The paper also questioned studies that do attempt to combine different factors into more complex scenarios on the basis that they tend to introduce simplifying assumptions and speculations into the scenario. Various other cautions, such as the effects of hindsight bias (see MacKay & McKiernan 2004) reinforce the critique of Harty et al. (2007). Therefore in response to a critical view, this research proposes that a robust foresight capacity must include strategic monitoring and horizon scanning activities, as pointed out in Voros (2009), that monitor and adapt the map of the macro-social landscape, the map of emergent technologies and the details of the map of research areas according to macro-social futures and R&D futures.

Enabling technologies

It is important to acknowledge the state of current R&D activity since this determines what may be delivered years from now and also what may *not* be delivered years from now. This will help prevent duplication of work and to pinpoint where work needs to be done. A Korean research group (Kim et al. 2009) has recently conducted a systematic analysis of academic research and patenting activities in order to identify the key R&D areas where new advanced technologies can be expected to emerge. One of the key findings is that the majority of research effort is focussed on construction robotics, automation and intelligent construction site management. The number of patents found for each area was: automation and modularisation (25%), maintenance and operation (22%), high performance material (18%), intelligent construction site (16%) and design optimisation (15%). The overall number of patents registered increased significantly during 1991–2006, from roughly 100 in 1991–1992 to almost 150 in 2005–2006, with the greatest increase being in design optimisation and intelligent construction site.

The key enabling technologies relevant for the construction industry are being developed in the four fields of new materials, nanotechnologies, information and communication technologies (ICT), and automation. Some of these are happening outside the construction industry and need to be monitored for transfer into the industry and some are happening within the global construction industry, but not necessarily in or for Australia, and again need to be monitored for transfer into the Australian industry. Research progress in industries outside construction will require further research to adapt and deploy the outcomes within the Australian construction industry.

Many of the key enabling technologies will not be effectively commercialised without a concurrent change in associated business models and the solutions they offer. Some of the technologies may enable profound transformations in the value chains in the design, construction and facility management value chain, such as information model-based design technologies. See Roos (2011b; 2011c; 2012) for a discussion about these issues. These areas should be looked upon as a priority for tracking both unplanned innovation in the marketplace and for undertaking active research.

According to Vision One of *Construction 2020*, the research agenda should develop tools for eco-efficient design and evaluation of the built environment which rely on technologies and clusters of technologies that would support the industry moving toward greater green advancements. This is complemented with international development of holistic models such as the Metabolic Impact Assessment (MIA) developed by Pinho et al. (2011) and tested on two cities by Lindblom et al. (2011).

The Australian construction industry is recognising the need for changes related to environmental sustainability. The economic downturn and global movements toward green buildings are driving the rethinking of the design and construction process. As green building certification schemes are adopted, more holistic definitions of sustainability are emerging, including also attention to occupant welfare issues. These two trends are increasingly supporting each other. The value of a technology may be different for different macro-social conditions; this has implications for the types of technologies that would make it onto a list of priorities.

Assessing value to stakeholders

According to *Construction 2020*, the client, the industry participants and society are major stakeholders that derive value from the R&D priorities. The value obtained for different stakeholders may not be equal or equivalent for the same research area, may not be associated with the same aspects or functionality of the research area, and there may be trade-offs of value between different research areas or trade-offs between aspects within a research area for the same stakeholders.

The value of specific research for the client could be assessed through the final product and service eventually produced. The value of specific results from R&D to an industry participant could be assessed by the final product or service contribution to the business and also by the extent to which

the research results give the firm ability to appropriate value (Roos 2005). The value of R&D research to society may be assessed through, for example, resilience frameworks (Maguire & Cartwright 2008) and could include dimensions such as social wellbeing, social capital, social learning and resources.

Potential risks and potential opportunities

A number of potential risks or potential areas of concern to the delivery of stakeholder value have been identified for the industry's consideration. These risks, if addressed early, may be turned into opportunities. They are:

- The macro-social map of sectors and factors and the *Construction 2020* report (in particular Vision Four) recognise that skills, leadership qualities, attitudes and the supporting systems for the expressions of those qualities that will achieve the R&D priorities and deliver the expected value to stakeholders are critical to success. Technology in isolation will not be sufficient to create the necessary culture and other characteristics of the industry for best use of a specific technology. The risk is that the macro-social conditions may not be supportive of having the required industry skills, leadership, attitudes or opportunities for the uptake of a specific technology or its applications; indeed it may be that the conditions may work against the use of advanced technologies. This risk is reinforced through the findings of Green et al. (2009) in the study 'Management Matters in Australia – just how productive are we?'
- Each vision in *Construction 2020* has an associated set of barriers to its achievement. Closer inspection of the barriers reveals that many are moral impediments and not purely physical or technological impediments that can be overcome with new materials, technologies, open systems or even training. These moral impediments limit the value derived from foresight research in the industry and the uptake of research outcomes that require transformation of the industry (see Hayward 2003). The overarching vision of *Construction 2020* identifies that up-skilling the Australian industry is critical to ensuring the awareness and uptake of advanced technologies. It is not only the question of skills, tools, standards, codes, or process analyses that is critical, but also the question of the development of industry managers and industry leaders to higher, broader and more expansive worldviews. Currently they may see issues as 'either/or' problems and not as 'both/and' aspects that are acknowledged in decision making (Hayward 2003, p.9).
- As recognised in *Construction 2020*, Australian research does not fully address all the issues identified in the visions, such as challenges of achieving collaboration, cohesion, communication and cooperation. This research project has contributed to that research in relation to the broader issues impacting the industry and regarding emergent technologies. However it does not resolve the challenges of dealing with the unresolvable uncertainty inherent in the future, how to create a healthy business environment, how to improve communications and knowledge transfer even when the ICT systems are available, or how to establish commitment for collaborative action.
- As stated previously, many of the R&D areas listed in this report will not be effectively commercialised without a concurrent change in associated business models and the solutions they offer. In fact, this may offer opportunities for profound transformations in the whole value chain. These research areas should be looked upon as priorities for tracking both unplanned innovation in the marketplace and to attract active research that will result in valuable outcomes for the businesses and other stakeholders. For a discussion of these aspects see Roos 2011b; 2011c; 2012.

Section 3

The Construction 2030 priorities in focus

This section discusses in more detail each of the ‘red’ and ‘amber’ research areas identified through this research. Table 1 provides a summary of these. The discussions are structured under the following headings:

- *The research area* – an overview of the priority research area
- *Why this research area?* – the significance for giving priority to this research area drawing on the challenges and opportunities identified in workshops, reasons provided by the visions of *Construction 2020*, and other rationale

Table 1: Summary of the R&D priorities for Australia’s Property and Construction Industry

Research area	Description	Industry need	Action focus
1. Model-based facility lifecycle business models	Model-based information technologies have the potential to facilitate profound changes in the way business is structured and value captured across the built environment life cycle. Enabling alternative business models will be crucial to commercialising critical technologies and solutions.	<ul style="list-style-type: none"> • Key link between the capital asset and more effective asset operations and management. • Collaborative processes supported by robust facility lifecycle management tools. 	Conduct active research
2. Intelligent infrastructure and buildings	Electronics, sensor and communication, analysis and network applications that improve the control, comfort, security, management and optimisation of infrastructure and buildings to improve occupant welfare and sustainability across the full lifecycle. Nano-scale sensors may be embedded in the structure itself.	<ul style="list-style-type: none"> • To enhance control, automation, integration and communication of facility durability, performance and sustainability along entire property and construction value chain using long-life sensor systems. • To enable a longer view of investment and planning with reduced life cycle costs. 	Conduct active research
3. Solutions for a more sustainable built environment	Different types of solutions can make the built environment more sustainable – through concept, design, construction and ownership. To create incentives for their development and use, many of these solutions are dependent on novel systems, standards, tools, and financial and business models.	<ul style="list-style-type: none"> • To adapt to changing business conditions including market and regulatory environment. • For greening the existing and future built environment and adapting to climate change. 	Conduct active research
4. Information and communications technology (ICT) for radical redesign	ICT is critical to facilitate improved conceptual and detailed design taking into account the need to disseminate information on and support new materials and trends, construction processes and asset management. Predictive tools and optimisation techniques for integrating product and process design at single asset level to	<ul style="list-style-type: none"> • To respond to climate change at multiple levels of design – facility, precinct, and regional design. • To find new energy balances in the design of built environment systems brought about by changes to energy generation. 	Conduct research for local conditions

Research area	Description	Industry need	Action focus
5. Biotechnology for tree-based materials	intermediate scales of urban or network level are required.		Conduct research for local conditions
	Considerable research is being conducted into materials, products and processes based on trees for structural and non-structural applications. These range from UV, moisture and decay resistance to increased insulating performance, through to new nano-cellulose–metal composite materials.	<ul style="list-style-type: none"> To respond to societal expectations, climate change and skills shortages. Possibilities for new materials with customised properties and more effective processes such as modular construction. 	
6. Educational curricula	The need for lifelong learning, shifts in business models, advanced ICT and sustainability presents challenges and opportunities to curricula. This includes initial and continuing education in the technical, operational and management aspects of the industry.	<ul style="list-style-type: none"> For integrated teaching in the use of new approaches and technologies. Stronger integration of research and teaching and customised career-long education. 	Conduct research for local conditions

Priority One Model-based facility lifecycle business models

The research area

Enabling alternative business models may be crucial to addressing specific challenges and opportunities for the industry given the forces from the macro-social environment and also for commercialising critical technologies and solutions. Model-based design technologies enable interoperability between applications. They therefore hold the potential to support profound changes in the way business is structured and value captured across the built environment life cycle. Such technology could enable transformation across the values chains of the design, construction and facility management processes. The American Institute of Architects has reviewed potential future business models powered by building information models (AIA 2006):

- building information models (BIM) through design only
- BIM through construction only
- BIM in design–build
- BIM in integrated delivery
- BIM in enterprise/project integration.

Because BIM enables sharing of information throughout the whole life cycle of buildings and infrastructure, it can support the management of information needed for sustainable design, construction and management of buildings and infrastructure. Data incorporated into a BIM can be used to analyse the performance of a building, including such green features as daylighting, energy efficiency and sustainable materials. For example, it could be used to track green building certification (e.g. Green Star) credits.

As BIM continues to develop, technology providers will need to improve its ability to address the sustainable design and construction demands of the industry. Building or structure simulation applications performing a variety of analyses with relevance to performance modelling are also envisioned. So far, building and infrastructure model data structures are not well suited to provide the

three-dimensional and connectivity information required by performance modelling.

Why this research area?

Workshop participants repeatedly identified the emergent information and communication technologies (ICT) technologies as key to changes in urban design, micro/meso (small- and medium-scale) design and environmental design and as a key link between building, infrastructure and information systems related to building/structure and operations (e.g. smart buildings and automated warehousing). Participants saw ICT as providing ways of dealing with challenges such as climate change or lack of skills, and as providing responses to opportunities such as with a green energy transition.

In *Construction 2020* Vision Four (ICT for construction) was dedicated to ICT technologies envisaging seamless transfer of information and the availability of information during the design, construction and operational phases of projects. Vision Four therefore forms a basis for the Priority One research area.

VTT scientists have recently reviewed relevant information and communication technologies for construction and built environment in a technology roadmap (Paiho et al. 2008). Current state-of-the-art solutions for information and communication technologies are provided mainly as separate services. The service providers offer niche services for specific purposes, such as planning, construction, operation and maintenance services, remote services, and security services. BIM is one of the most important applications identified that is developed from ICT technologies.

Model-based design is gaining wider acceptance in several countries, most notably in Scandinavia and the United States. A recent study reviewed the use of building information models in the Finnish real-estate and construction cluster (Kiviniemi et al. 2008). The exploitation rate was 22 per cent of the work volume. Eighty-four per cent of the respondents surveyed estimated that information modelling will increase and 85 per cent of designers see the increasing use of ICT as one of the main investments in their company. A market report on the use of model-based design in the United States finds that BIMs are becoming broadly accepted across the construction industry with over 50 per cent of each segment surveyed (architects, engineers, contractors and owners) (McGraw-Hill 2008).

In Australia, model-based design is also being more commonly used and the significance to the industry is being investigated (see for example buildingSMART 2012). National guidelines for BIMs have been recently issued. For instance, the design of the Eureka Tower in Melbourne, the tallest residential structure in the world, was accomplished using model-based design.

The move towards use of BIMs is driven by large building owners. In the United States, the General Services Administration has been accepting delivery of designs for major projects only as interoperable models since 2007. The Senate Properties of Finland, which manages a large stock of Finnish government buildings, requires designs to be delivered only in interoperable formats. Other public clients in Scandinavia are also taking up the advantage of BIM. Governments use it to support automated code checking, ensuring buildings meet environmental and energy performance requirements, and ensuring asset and management information is available at all tiers of government for operational, maintenance, fiscal and strategic planning.

In the future, model-based design is expected to serve three distinct but interrelated purposes:

- (1) BIM as a product or intelligent digital representation of data about a capital facility
- (2) BIM as a collaborative process which covers business drivers, automated process capabilities, and open information standards use for information sustainability and fidelity
- (3) BIM as a facility life cycle management tool of well understood information exchanges, workflows, and procedures which stakeholders use throughout the building lifecycle as a repeatable, verifiable, transparent, and sustainable information based environment (Motamedi & Hammad 2009).

Use of model-based design and construction may allow facility managers to enter in the process much earlier, where they can influence the design and construction.

BIM promises to deliver value to clients through items such as cost and delivery time reduction, less likelihood of disputes and improvements in facility operations and performance. Depending on how it is implemented, it is expected that industry participants will obtain benefits such as savings in costs and time and an ability to align risks and rewards with the performance of the entity. With BIM there is potential that the industry culture could change to be more open, collaborative and integrated and the industry could reduce waste, duplication of effort and improve quality.

Other considerations

The same issues and barriers identified in Vision Five in *Construction 2020* apply to BIM. The potential benefits of the technology in promoting multidisciplinary integration and cooperation in the industry to catalyse change are creating interest yet the issues such of interoperability, cost, education, personal preferences and getting to a critical mass where changes can be catalysed in the way the industry operates are to be addressed. Attitudes, habits and values of people in relation to the way the industry currently works are maintaining the status quo and will continue to do so unless sufficient will and motivation becomes available to make the required transitions.

It is conceivable that under certain macro-social conditions such as severe climate conditions creating communications or energy disruptions, under depressed economic conditions leading to a decline in security of communications, under fragmented governance systems, or when the required skills are not available that there will be a push to continue using current (2012) technologies and to more simple ways of doing things that may diminish the perceived value of BIM. It is perhaps of note that the workshop groups working with scenario B2 (with a 'skills leaving an isolated Australia' element) did not identify ICT technologies as important to the same extent as other groups who identified quite a number of reasons for choosing ICT.

Compared to Vision Five in *Construction 2020*, the suggested potential of the Priority One research area of model-based design – business models extends well beyond simply sharing of information: the potential is for allowing industry participants opportunity to innovate and transform the way they appropriate value. Sharing of technology is a type of innovation that companies are familiar with and involves technology based, design based and efficiency improvement. Model-based innovation as described here potentially allows firms to maximise the share of value they can obtain for themselves (Roos 2005). The R&D strategy identified in *Construction 2020* Vision Five would therefore need to include these additional elements of business and management as well as the technological aspects identified (see also Roos 2011a; 2011b; 2011c; 2012).

Research into Priority One research area 'model-based facility lifecycle business models' should be looked upon as a priority for undertaking active research and tracking unplanned innovation in the marketplace and monitoring for unexpected developments in the macro-social environment.

Priority Two

Intelligent infrastructure and buildings

The research area

Applications that help to improve control, comfort, security and cost optimisation of buildings and infrastructure hold the potential for driving greater value of occupant and green services targeted across the full life cycle. These trends are driving developments in electronics and automation of lighting, security, voice and data communication, health monitoring, energy management and HVAC (heating, ventilation and air conditioning). A similar drive in infrastructure has been identified with the changing needs for applications to monitor, control, optimise and provide security across the life cycle of infrastructure. This trend is driving developments in measurement, sensor and network technologies that enable more versatile applications. Potentially in the longer term, the formation of globally integrated operational models will start in planning and production. In this way, large networks will produce services across the built environment life cycle, offering different mechanisms for control, visualisation, modularisation and giving feedback (Paiho et al. 2008).

Products and services use tools and solutions that produce and display content that is specifically targeted to the needs of the user. The services of the built environment are produced with networked operation methods. In the short term, these will include the following four service entities:

- (1) information model services
- (2) data collection, maintenance and management services
- (3) information-based additional value services
- (4) the integration of services.

The application of ICT in the built environment emphasises the value of and services targeted across the life span of the product. (Paiho et al. 2008)

In the long term of 5 to 15 years, the formation of globally integrated operation models will start in planning and production, and large networks will produce services for the built environment (see Figure 1). The end-user will be served in the whole design, planning and construction process by offering different mechanisms for visualisation, modularisation and giving feedback.

The following service entities will especially increase: real-time building information systems, services based on integrated information models supporting decision making and operation, experience and health services, and automated property assessment services. Over time, a central factor supporting the change in operation methods will be the applications and tools designed for process management. In this respect, the key solution is found in the applications that use visualisation and information models and can officially be used as references for building inspections. New kinds of service providers may also be established for the services that exploit information models and integration (Paiho et al. 2008).

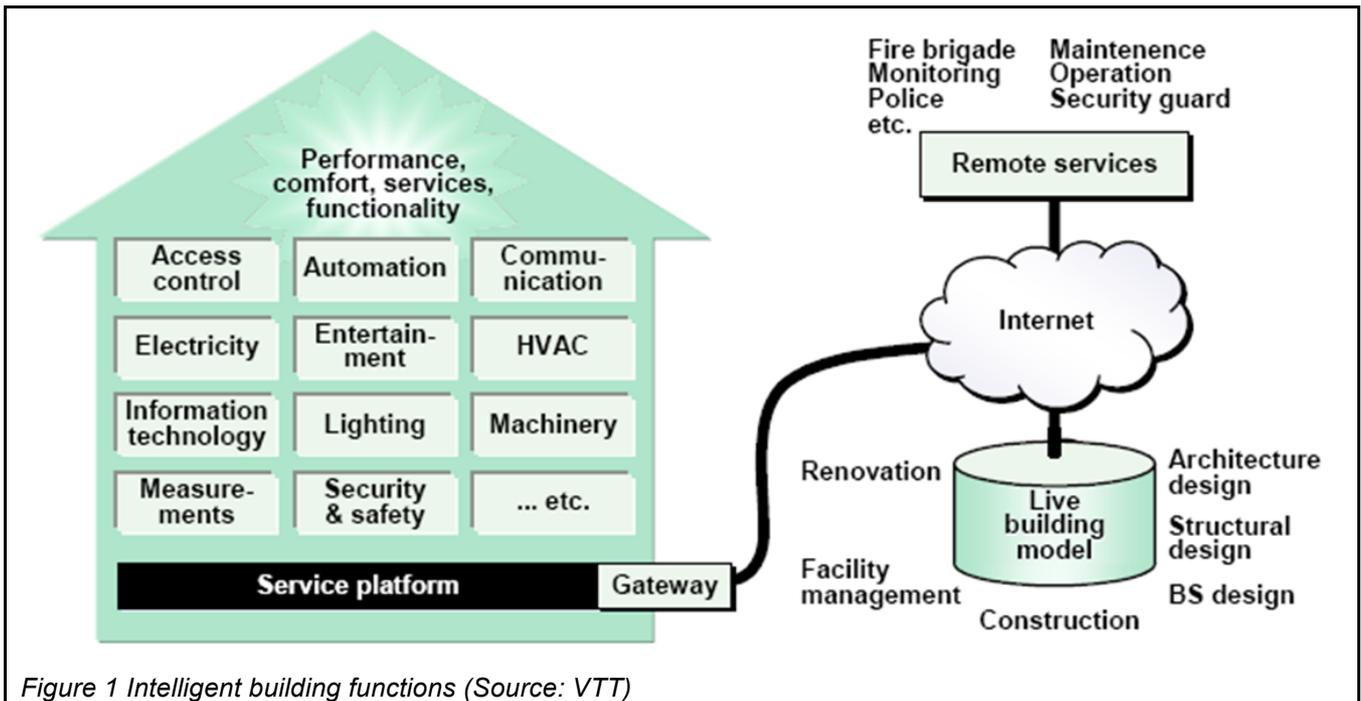


Figure 1 Intelligent building functions (Source: VTT)

Why this research area?

Workshop participants identified smart, high-end construction, distributed precincts and smart building and houses as opportunities, particularly under scenarios where the required skills and a supportive economy were available. Under other scenarios groups identified that new leasing and management structures will increase ownership and management of buildings particularly with the availability of information systems linking buildings and management.

The survey in *Construction 2020* showed that respondents felt that ICT would play a significant role in extending capacity to take longer term views leading to extended investment and planning horizons through the impact that technology will have for smart and intelligent buildings.

ICTs hold the key in enabling enhanced automation, integration and communication in the construction value chain. Customer-driven design, manufacturing and building, and sustainable construction are driven to a great extent by progress in ICT. Construction will be enormously affected by ICT through design, planning, construction projects, use, repairs, maintenance, and renovations. Construction business is carried out in networks. This requires compatible processes and operation methods that can use commonly available interoperable digital information, such as BIMs and real-time information.

The Priority Two research area ‘intelligent infrastructure and buildings’ identifies active research and tracking unplanned innovation in the marketplace and monitoring for unexpected developments in the macro-social environment.

Priority Three Solutions for a more sustainable built environment

The research area

As sustainability of the built environment is a function of a multitude of factors, together creating a complex system, there are numerous types of solutions available to green the built environment. Many of these solutions are dependent on novel systems, standards, tools, and financial and business models to create incentives for their development and use. The move towards green environments is driving a rethinking of the design and construction process, particularly towards new opportunities and business models.

Green infrastructure refers to the integration of nature with the built environment, including the emerging climate change adaptation technologies such as green roofs (see Figure 2). Examples of green infrastructure are: urban agriculture, green walls, remnant vegetation, rain gardens and city street trees (Hall et al. 2011, Melbourne School of Land and Environment 2011, Reeve et al. 2011). Green infrastructure can also be seen as an overarching spatial planning view of green infrastructure assets that have been interpreted based on their use and attributed value (Mell 2010).

Technologies characteristic of the green building industry include HVACs, building energy managements (BEMs), and the associated sensor technologies. Emerging technologies in the green building industry include smart windows, vacuum windows and door panes, online dashboard programs, self-powered wireless sensors, low volatile organic compounds (VOC) to no VOC-materials, photovoltaics (PVs) of thin film technologies, light emitting diodes (LED) and organic LED (OLED) lightings, and other building recycling of materials technology (Frost & Sullivan 2008).

Application of these technologies is in many cases dependent on creating incentives for their use through novel management systems and business models. Examples of such systems or models are: assessment and certification tools; energy management systems; simulations to study impacts of climate variations on the built environment; business models that share benefits from cost savings from sustainability performance; performance contracting that allows service providers to get monetary benefits from their efficiency-improving measures; smart commissioning; and performance-driven building insurances.



Figure 2 Victoria (British Columbia, Canada) Marriott green roof (Source: pnwra's flickr.com photostream)

A selection of these solutions for greener buildings is described in more detail below.

Assessment and certification tools – Green rating tools have developed rapidly in the Australian markets. Specified versions of the certification schemes have been developed for areas such as office design, office as built, office interiors, education, healthcare, retail centres, and convention centres. The development is likely to continue to become more encompassing and fine-grained, taking into account various building functionalities. It is expected that the performance criteria specified in certification schemes will develop into de facto standards in the industry, and will be streamlined with regulatory requirements.

Energy management systems – The functional capability of these systems is to control, monitor, and optimise building services, such as lighting, heating, ventilation, filtration and climate control security, closed-circuit television (CCTV), alarm systems, and access control. Research by sensor industries into these areas is intense, and advances can be expected from sensors that measure and detect factors such as carbon dioxide, temperature, motion, acoustics, smoke and occupancy.

Building simulation – In order to study the impacts of climate variations on the built environment, building simulation programs are often employed. These computer-based programs normally require the inputs of a series of hourly weather characteristics, including solar radiation, dry-bulb temperature, air humidity, atmospheric pressure and wind speed and direction, to simulate building thermal behaviour in order to assess and evaluate their thermal comfort and energy performance.

Green leases – A number of financial solutions are being developed in order to create the necessary financial incentives that will transfer the cost efficiency benefits to the building users. The Australian property industry has been a frontrunner in developing financial incentives to share benefits from cost-saving solutions among owners and tenants. By putting building sustainability issues in monetary terms, they provide the baseline for setting the sustainability performance, allocating responsibilities and enabling monitoring of progress. A green lease may contain a schedule outlining the mutual energy and environmental performance obligations of building owners, managers and tenants. Examples include:

- The Australian Conservation Foundation has demonstrated the green lease concept with their 60L building in Melbourne. The owner and tenants are bound to a lease document that obliges them to follow the highest level of environmental performance, specifying use of space, materials, and expectations for comfortable conditions.
- The New South Wales Police Service's new Parramatta headquarters has a tenant-driven green lease agreement. It puts the responsibility for building performance on the owner to bear. If the building's energy performance slips below the agreed level, the rent is reduced.
- The South Australian government has linked owners' fixed annual rent review to the achievement of a rating in environmental performance. This can be applied in cases where the building is marketing its environmental benefits.

Performance contracting – Facility managers may use performance contracting to ease first cost issues. This involves engaging the service providers to get monetary benefits from their efficiency improving measures, such as improved HVAC services, conceptual designing, or asset and capital planning.

Smart commissioning – Experts are envisioning that new 'smarter' commissioning will render obsolete the traditional commissioning practices as a one-time or periodic event. Real-time commissioning will be made possible by sophisticated, rules-based software. It may provide payback on a daily or even hourly basis.

Performance-driven building insurances – New insurance models are likely to become available, where insurance premiums are linked to the adoption of appropriate management procedures and adoption of sustainable management.

Why this research area?

Workshop participants consistently and repeatedly identified green technologies under all scenario conditions, whether for use to create green buildings specifically or for specific ways of greening buildings or infrastructure. All scenarios contained increasing severity of climate change from the current situation. The *Construction 2020* report also contains an overriding commitment to sustainability and solutions that make buildings greener and is therefore within the scope of the overarching vision.

The Priority Three research area 'solutions for a more sustainable built environment' prioritises active research and tracking unplanned innovation in the marketplace and monitoring for unexpected developments in the macro-social environment.

Priority Four

Information and communications technology for radical redesign

The research area

Design determines what is built and ICT is important to the future of design. Responding to climate change requires a radical redesign of housing, city-level and urban design (the small and intermediate scales) and changes in these practices will be enabled by ICT. Systems modelling and human interface design dominates design thinking and ICT has a large role to play in changing these practices.

Radical redesign will need predictive tools and techniques for integrated product and process design and enhanced optimisation (e.g. CASA 2012). Modelling technologies that link design, building and operation will improve the designs. The use of virtual spaces will make customisation across the life cycle possible and virtual prototyping will be one of the applications. It will need optimisation solutions of materials and energy balances, of the ways humans interact with the built environment and of the services during and after construction.

Urban design will become more integrated with the design of infrastructure such as ports and the infrastructure side of commerce. Changes such as modular buildings that have local low energy storage and new nano-materials will enable more efficient transport design solutions. The built facility side of urban design will be enabled as designs for fully automated warehousing appear. Fuzzy logic will enable new urban design solutions.

Distributed control systems and sensing networks allow ubiquitous sensing, inconspicuous and adjustable user interfaces that improve information presentation on devices such as head-up displays (HUD) or voice-activated subsystems. In this way buildings become 'self-managing' and 'intelligent'.

Why this research area?

Design activity affects what is built rather than the procedures and the materials with which it is built. Design is also a major contributor to finding solutions to problems at the right level (Snowden 2000). For example, by making tools and processes simple (but not simplistic) products and services can be improved (Norman 2010). Workshop participants identified that a response to climate change will require a radical redesign focus across a number of areas, from city design to modular design. Collaboration and integration of systems between the design and manufacturing teams is a strong theme in the *Construction 2020* report and ICT is seen as an enabler of this relationship.

While many ICT-based technologies have existed for years, recent market dynamics and maturity of solutions have created dynamics, where model-based technologies and related practices are gaining wider usage. The economic downturn and the move towards green buildings are driving towards a rethinking of the design and construction process. Energy balance is an important aspect in engineer systems design and with the changes to alternative forms of generating usable energy, design will play an important role.

Producing and harvesting energy is becoming a major area of interest both in research and commercial solution development and design is critical to the final solution. Tapping into renewable energy sources, such as solar energy by building-integrated photovoltaics (BIPV), rooftop photovoltaics, and solar thermal energy are among the most promising areas. Wind turbines are also integrated into buildings. Microgeneration of energy may contribute to zero-energy, or positive-sum energy buildings, able to feed into the power grid the excess energy, or saved into batteries as energy reserve.

An example of a commercial pilot can be found in United States, where a logistics centre in Aurora (Colorado) has been set up by Wal-Mart, integrating a 50 kilowatt wind turbine, natural gas micro-turbines, and photovoltaic systems attached to the rooftop. The long-term vision for energy solutions

is moving in the direction of zero-energy buildings, and net energy producing buildings. Buildings will become small power plants connected to the electricity grid.

Research into Priority Four 'information and communications technology for radical redesign' will require adaptation of research for local conditions.

Priority Five Biotechnology for tree-based materials

The research area

Biotechnology is a key underpinning technology for the construction industry and numerous possibilities for its uptake and implementation exist. In the short-term possibilities include increased UV-resistant wood, and increased moisture and decay resistance. In the longer term genetically modified trees for higher yield of wood, or wood with altered properties and even tailor-made wood with properties best suited to specific applications are envisaged. Beyond that, emerging research prospects foresee the possibility of greater insulating performance through new nanocellulose–metal materials. From research into the biology of trees, biomimetic materials research also holds enormous potential in structural adaptation, self-assembly, damage repair and self-healing (Fratzl 2007).

The concerns arising from biotechnology includes the release of genetically engineered material into the environment, ethical concerns about interfering with nature, and intellectual property and patent actions for genetically modified trees.

Tree-based materials refer to structural and non-structural materials based either on wood or on products derived from trees. These include boards and pulp-based materials, or mixtures of materials containing materials sourced from wood, such as wood-waste plastic composites. A considerable body of research is being conducted in materials engineering including in materials, products and processes based on trees. Examples of applications in this category include:

- wood-based fuels for domestic and industrial use
- technologies to boost energy content of wood fuels
- in-mill biorefinery technologies
- wood bio-fibres
- functional woods and boards
- wood laminates
- ubiquitous power/heat generation
- on-site bioethanol production
- high-value chemical products
- nanocellulose composite materials.

Why this research area?

Workshop participants repeatedly identified tree-based technologies as important solutions to the challenges presented by their scenarios, particularly in response to climate change and skills shortages. Tree-based technologies were also identified as most relevant to new housing construction models, renewables-based modular building, and when simple materials are required.

Research into Priority Five 'biotechnology for tree-based materials' will come out of the global construction industry and need to be monitored with the view to local research for specific local climate contexts.

Priority Six Educational curricula

The research area

Education is the foundation for a strong construction industry that has to combine practical and theoretical content that is positioned between architecture, engineering and complex project management. The Internet, social media, virtual classrooms, open educational resources, open source, cognitive technologies, collaborative research, collaborative learning and a variety of other new educational models of learning and integration of work and learning (e.g. the design factory in Figure 3), transformative learning, and ubiquitous systems are just some examples of forces that are driving the need for different expectations of and attitudes to learning and teaching. These are representative of a revolution that is taking place that will profoundly change the shape of education, research, and educational models.



Figure 3 A workshop at Aalto's University Design Factory

Why this research area?

Construction 2020 identified education as an important element of all visions. Workshop participants did not only identify technologies as a factor in delivery of education (whether for example technologies require advanced skills to be learned) but also that educational technologies are specifically needed for enabling a shift to sustainable practices.

Research into Priority Six 'Educational curricula' is emerging out of other industries and will need to adapt to the local context.

Appendices

Appendix I – Overview of methodology

The construction and building industry will be impacted by changes in the macro-social environment in the future. This section provides a brief overview of the process carried out to produce the *Construction 2030* roadmap of R&D priorities. Initially the research involved the production of a map of the key driving 'sectors' and associated 'factors' of the macro-social contextual environment within which the construction industry will plausibly need to operate until 2030. The map was then tested with key industry stakeholder groups.

Each sector was described through a range of states (called 'factors') that define the values that the sectors can plausibly come to have in the given time under consideration (Voros 2009). This involved repeatedly refining and selecting the definitions of the sectors and factors to determine those with the greatest significance and uncertainty impacting on the interactions between the industry and macro-social Australian environment (Voros & Hayward 2011).

The final map of the six most significant sectors and their associated ranges of factors had to also provide a range of alternative settings consistent with the range of world views and competing agendas of the different industry stakeholder groups so as to shift people's views toward those interactions (in Figure 4 the sectors are in green and the ranges of factors are in pink and blue). A seventh sector, the technology sector, was produced using a technology roadmapping methodology (VTT & ICS 2009). This produced sets of emergent technologies and potential building and construction applications from those technologies over three seven-year periods between now and 2030 (Roos 2011a).

Table 1 summarises the enabling technologies expected from current important R&D efforts in the construction industry.

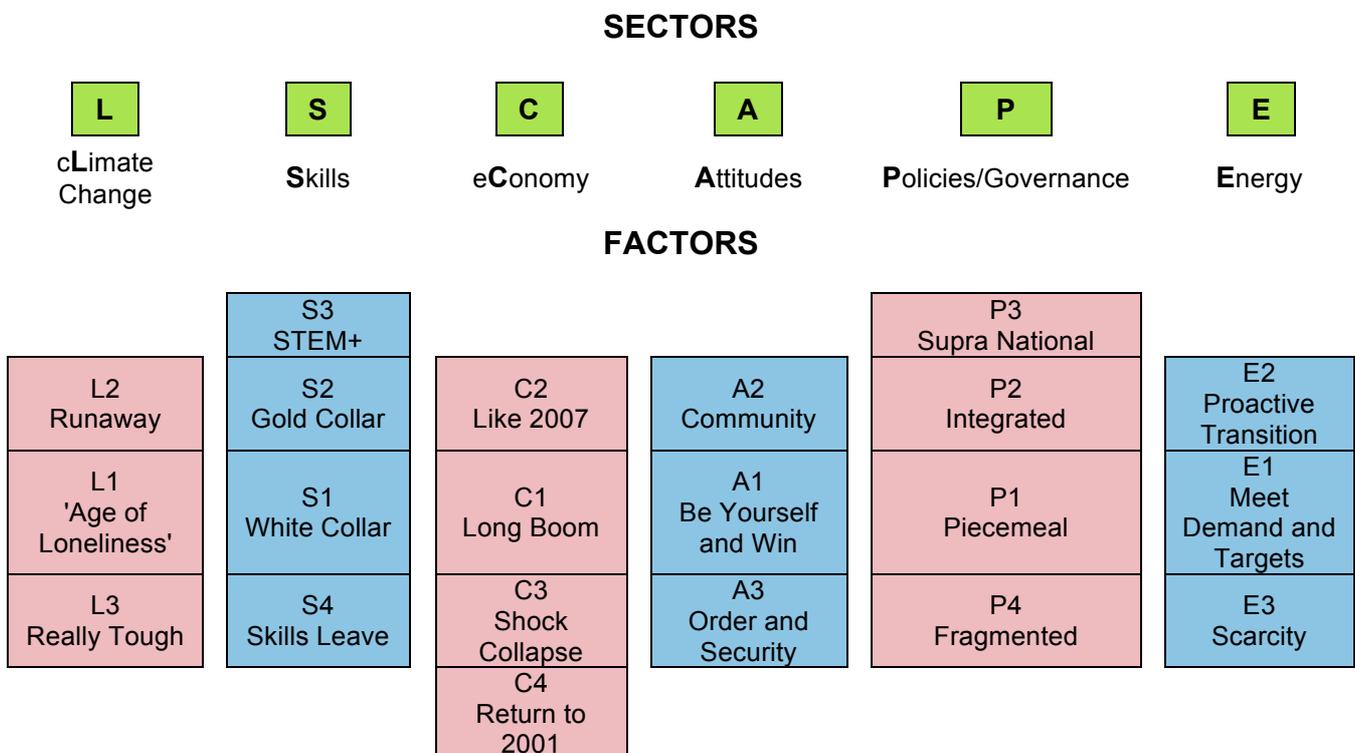


Figure 4 Significant forces on the construction industry in the future Australian macro-social environment

Table 1 Aggregated levels of technologies depicted with construction application areas

	Main application area	High-level enabling technology
Materials	<ul style="list-style-type: none"> • Polymers and composites • Tree-based • Metals • Concretes and ceramics • Smart/Other 	<ul style="list-style-type: none"> • Nanotechnology • Biotechnology • Materials engineering technologies
Design	<ul style="list-style-type: none"> • Design (micro/meso) • Environmental planning • Urban planning • Transport planning 	<ul style="list-style-type: none"> • Biotechnology • Materials engineering technologies • ICT • Cognitive technologies
Subsystems	<ul style="list-style-type: none"> • Control systems • Interface systems 	<ul style="list-style-type: none"> • Nanotechnology • Biotechnology • Materials engineering technologies • ICT • Cognitive technologies
Social innovation	<ul style="list-style-type: none"> • Social models • Social perspectives • Service applications 	<ul style="list-style-type: none"> • Service technologies

From this ‘what-if’ macro-social map of sectors and factors, four scenario configurations were selected that together covered all the factors and provided a good conceptual spread of scenarios (Voros & Hayward 2011). The ranges of factors are expert assessments of the greatest uncertainties for the construction industry characteristic of the future Australian landscape as it is experienced today. These irreducible uncertainties profoundly impact decision making about R&D investments and pathways that must be made if the results are to be available at the right time in the future.

When these scenarios are evolved forward in time over seven-year increments, they form plausible ‘pathways into the future’ acting as the social milieu ‘envelopes’ in which built environment projects are commissioned and which direct the uptake and need for specific technologies. In this way, the scenarios become decision scenarios that can be used in thought experiments of future worlds like those of the scenario conditions, to monitor the actual unfolding macro-social landscape over time and also to provide a common reference language during future-oriented strategic discussions.

Due to the duration of the research and the volume of documentation, the materials prepared for the workshops, such as Voros and Hayward (2011), are presented as separate documents and can be found at the website page as indicated in the references section.

This stage of the research also initiated consideration of the overall aspects of the final decision-making framework needed for generating the technology R&D priorities. The value of specific research outcomes for specific stakeholder groups may differ under the actual future conditions that eventuate compared to the value perceived today. Some foresight studies address this issue by establishing a desired vision that helps to narrow the range of the future context to be considered in the research today. However, as demonstrated by Harty et al. (2007), the same specified conditions

can lead to different actual future outcomes. When the impact of technology is studied in hindsight, then the technologies are often seen as having been instrumental in the developments that occurred. In contrast, when the impact of technologies are studied in foresight (that is looking to the future) then the plausible ranges of conditions that may eventuate impact the selection and application of a specific technology in those different conditions and this may or may not come about in actuality. Specific technological applications may also be developed in novel ways that could not have been anticipated earlier.

Appendix II – Workshops key results

There are benefits from adopting the approach taken in this research and it is critical that industry thought leaders are involved. One of the benefits from involving industry thought leaders is that the developed map of the macro-social landscape provides a range of alternative settings consistent with the range of world views and competing agendas of the different industry stakeholder groups. These help shift people's views to the interactions between the industry and the macro-social environment (Voros 2009).

Another benefit of the approach is that thought leaders can help to engage the mutual interests of people in the industry in alternative futures scenarios to move their focus beyond their preoccupations and concerns of present-day issues — this is particularly important for a sector that is traditionally short-term project focussed and reactive in its approach to the future (Harty et al. 2007). Furthermore, the built environment is a crucial element in several of our global challenges and the real estate and construction industry play an essential role in balancing natural cycles and societies' consumption of resources (Koukkari 2011).

From the sectors and factors map, a number of plausible decision scenario configurations were selected that together covered all the factors and provided a good conceptual spread of scenario conditions. Figure 5 shows one of the scenarios. These scenarios act as social milieu 'envelopes' in which industry stakeholder groups will commission projects which direct the uptake and need for technology. The sector and factor map and the decision scenarios were tested for plausibility with the industry in foresighting workshops held in Perth, Brisbane, Sydney and Melbourne (Voros & Hayward 2011).

Following the workshops, the participants were invited to complete a questionnaire about the sectors, factors and technologies.

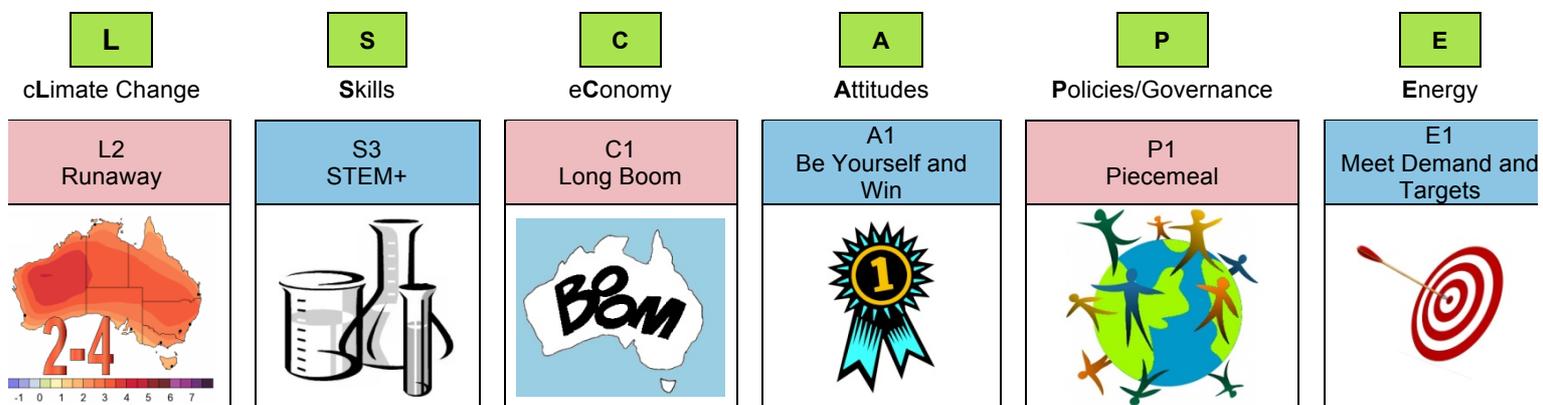


Figure 5 The B1 scenario

Industry thought leaders attending the foresighting workshops were asked to think deeply and creatively on how they would respond to a specific scenario, to identify the challenges and opportunities presented by the scenario and to identify what they would need to operate their businesses successfully. Workshop participants then had to select the top four or five most important emerging technology applications that best match the challenges and opportunities.

Table 2 captures the research areas that were identified from the workshop results through synthesising, collecting and collating requirements. The order of the research areas qualitatively represents the frequency with which the technology areas were identified and the clustering with other technology areas. Additional research areas were added to the list. Each research area was submitted to expert review and commentary on the timing and likelihood that the technologies would emerge. This allowed the research areas to be classified as follows.

1. Green (+ symbol). The technology is likely to emerge from either the global construction industry or other industries over the 2030 timeframe or is in the pipeline. The research area is already receiving the majority of global construction research effort.
2. Amber (= symbol). The technology has a likelihood of emerging, however it will require additional research, local research, adaptation to the construction industry, or partnering with other industries to produce usable results for construction.
3. RED (– symbol). The technology is unlikely to emerge or unlikely to emerge in the time frame unless the construction industry undertakes active research.

Table 2 Important technologies selected by workshop groups (with expert comment)

Research areas (with technology reference as used in workshops in brackets)	Description	Expert comment
Materials for micro/meso design (D1)	Modular buildings, modular materials, design and development, adaptable and simple structures and assembly for local adaptation.	+ This will evolve out of the construction industry and is to a great extent already emerging. Monitor only.
ICT for urban planning design (D5)	ICT for integrated smarter urban design, including automated warehousing for faster more efficient supplies and design for recovery. Also robotised. Design for recovery, for environmental and urban renewables design, for modular and renewable building for integration and energy storage, for community-driven urban development.	+ The ICT side can already be seen in applications on the micro level and in conceptual developments on the city level with smart city initiatives. In addition, there are systemic developments around for example smart grids that emerge out of the energy ecosystem and energy storage systems arising out of the electric vehicle industry. The robotic side has a somewhat slower development but will first be seen in predictable applications in definable environments. This will be driven by the producer industry.
ICT for micro/meso design (D2)	For radical redesign focus	= This will require local research.
ICT for interface systems (S5)	For smart buildings and smart building leasing management	+ This will be driven out of the ICT industry. Monitor only.
ICT for control systems (S2)	ICT micro management and smart device sensing - Intelligent systems for efficiency and effectiveness, that informs governance	+ This will be driven out of the producer industry and out of applications in other large systems such as precision agriculture and logistics, and production tracking and management. Monitor only.
Cognitive sciences applications (H6)	For integrated, integrative and collaborative planning and design, user-enabled human interface, design. To steer away from the	+ This will be driven out of defence applications and systems of systems approaches and the associated

	parking lot approach to design.	provider ecosystems. Monitor only.
Biotechnology for tree-based materials (M4)	Completely new ways of constructing with all the timber technologies, timber engineering for smart and extended timber products	+ This is driven by the cellulose fibre value chain and the building and construction procurers in both public and private sector with associated regulation changes from public sector. Monitor only.
Simple materials technology for tree-based materials (M5)	Simple materials for construction such as tree-based structural and non-structural materials	= This will come out of the construction industry. Monitor only but with local research for specific local climate context.
Nanotechnology for materials (M1, M6, M9, M12)	Nanotechnologies for design, for climate change/sustainability: energy, water and renewables	+ This is long-term development and will arise out of emerging or presently non-existent business ecosystems. Monitor only.
Polymers and composites materials (M1 to M3)	Polymers and composites, including clays and ceramics	+ This is emerging out of both construction and non-construction industries. Monitor only.
Management structures (H5)	Management system. Intra-industry relationships and integrated business models and management. How the industry works. 'Green Cloud building'	+ This is emerging out of both the construction industry as well as other project dependent industries. Monitor only.
Nanotechnology for interface systems (S3)	Interface systems for good information responding to climate change	= This will require research.
ICT for environmental planning design (D4)	Collaborative planning technologies	+ This is emerging out of other industries. Monitor only.
Community technologies	Everything from business models, planning, to design technologies.	+ This is emerging out of other industries. Monitor only.
Educational technologies	New teaching models, change perceptions	= This is emerging out of other industries but will require context adaptation.
Model-based design business models	Information modelling enables sharing of information throughout the whole life cycle of a building.	– Should be looked upon as a priority for both tracking spontaneous innovation in the marketplace and for active research.
Intelligent buildings	The services of the built environment are produced with networked operation methods.	– Should be looked upon as a priority for both tracking spontaneous innovation in the marketplace and for active research.
Solutions for green	As sustainability of a building is a function	– Should be looked upon as a priority

buildings	of a multitude of factors, together creating a complex system, many kinds of solutions make buildings greener.	for both tracking spontaneous innovation in the marketplace and for active research
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The workshop groups were able to participate in the scenario processes and imagined the future worlds and the conditions generated from the scenarios. Through their engagement, the participants demonstrated that the sectors and factors provided conceivable future landscapes within which industry participants and stakeholder groups could respond, and that the technologies could be used to facilitate those responses. The workshops helped to ensure that nothing has been missed (participants' comments and observations have been incorporated into the research), that systemic linkages have been identified and there was a chance to verify the research findings. Favourable comments were received from participants interested to see the results of this research.

Appendix III – Acknowledgements

In conducting this research we relied on the contributions from the workshop participants during the workshops, in responding to the questionnaire distributed after the workshop and providing feedback at other times. The list of organisations involved is below. Thank you all for demonstrating exactly those leadership and collaborative qualities that are needed for the industry to achieve the visions outlined in *Construction 2020*.

• Aalto University
• Australian Academy of Technological Sciences and Engineering
• Australian Industry Group (Ai Group)
• Australian Institute of Architects
• Brisbane City Council
• Built Environment Industry Innovation Council
• Collaborative Innovation Systems
• Consult Australia
• Copper Developments Centre
• CSIRO
• Curtin University
• CY O'Connor Institute
• Davis Langdon
• Facility Management Association of Australia
• Fulton Hogan
• Hames Sharley
• HASSELL
• Leighton Contractors
• Main Roads Western Australia
• NSW Department of Industry, Innovation, Science, Research & Tertiary Education
• Parsons Brinckerhoff
• Queensland Department of Housing and Public Works
• Queensland Department of Local Government and Planning, Queensland Government
• Queensland Department of Transport and Main Roads
• Queensland University of Technology
• Reliance Worldwide
• RMIT University
• Sinclair Knight Merz
• Swinburne University of Technology
• The Australian Green Infrastructure Council
• The University of Sydney
• University of Western Sydney
• Western Australia Department of Commerce - Building Commission
• Western Australia Department of Finance

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