European Commission

ENERGY-EFFICIENT BUILDINGS

Multi-annual roadmap for the contractual PPP under Horizon 2020

Prepared by

Energy Efficient Buildings E2B

ECTP European Construction Technology Platform

Policy Research

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EUROPEAN COMMISSION

ENERGY-EFFICIENT BUILDINGS

MULTI-ANNUAL ROADMAP

FOR THE CONTRACTUAL PPP UNDER HORIZON 2020

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Executive Summary

This multiannual roadmap sets our vision and outlines our routes **towards a high-tech building industry, which turns energy efficiency into a sustainable business**. This roadmap is the backbone of a long term Research and Innovation programme with shared priorities openly agreed amongst the vast community of stakeholders across enlarged Europe. In line with Horizon 2020, this PPP aims at developing breakthrough affordable solutions at building and district scale, connecting them at a larger scale to future smart cities and in a broader framework with all suitable instruments and initiatives along the innovation chain to create impact. This challenge based approach would ultimately benefit all EU citizens and users as well as local public authorities. In this Executive Summary the key objectives, the priorities and the mechanisms for effective monitoring of progress are provided, including the intended level of resources and industry commitment as well as the mechanisms for engagement of all stakeholders through an open, transparent and participatory governance model. This is **fully in line with article 19 of the Horizon 2020 regulations**.

A key European employer and contributor to quality of life

Worth at least EUR 1.2 trillion of yearly turnover (2011), the **European construction sector,** including its extended value chain (e.g. material and equipment manufacturers, construction and service companies), is the **largest European single activity** (9.6 % GDP) and biggest industrial employer (14.6 million direct operatives, 30.7 % of industrial employment, 43.8 million indirect workers). The built environment affects the quality of life and work of all EU-citizens.

A major energy consumer and CO_2 producer

Buildings use **40 % of total EU energy consumption** and generate **36 % of greenhouse gases** in Europe. The construction sector is **on its critical path to decarbonise the European economy by 2050**, reducing its CO_2 emissions by at least 80 % and its energy consumption by as much as 50 %. As the **replacement rate** of the existing stock is very small (1-2 % per year), acceleration is urgently needed. Simultaneously, this offers a unique opportunity for **sustainable business growth**, provided that products and related services for both new and refurbished buildings are affordable, non intrusive and of durable quality, in line with European Directives.

An SME driven sector not yet recovered from the financial and economic crisis

Together with the 2050 targets, Directives are putting more constraints on **a sector which is directly impacted by the ongoing financial and economic crisis,** taking into account that, although Europe has major industrial players, it is highly fragmented with **over 95 % of SMEs.** The turnover decreased significantly during the crisis and has not yet recovered.

The need for (public-private) partnerships

The industry vision of becoming a high-tech building industry, turning energy efficiency into sustainable business, cannot be achieved by the industry alone as it requires:

- **Breakthrough multidisciplinary and cross-sectoral research** efforts across different domains;
- The **mobilisation of a critical mass that is larger than industry can provide and the creation of innovative chains** to speed up the development, demonstration and deployment of new technologies;
- A **proactive approach** between research and demonstration activities and innovative demand side measures in full synergy with EU wide policy initiatives, including among others the need to address EU business models, innovation friendly procurement, interoperability and standardisation to create a unified market.

General objective and scale of impact: research to accelerate, to recover and to become globally competitive

Within this framework, the Energy Efficient Buildings Association (E2BA) acknowledges the proposal of the European Commission to include research and innovation activities in the Horizon 2020 proposal, in continuation with the current PPP EeB[1]. Based on the successful achievements so far, its extension over 2014-2020 would allow to:

1 http://ec.europa.eu/research/industrial_technologies/energy-efficient-buildings_en.html

- **Develop technologies and solutions enabling to speed up the reduction in energy use and GHG emission** in line with the 2020 goals, e.g. through a higher renovation rate of the building stock at lower cost and to meet regulatory needs;
- **Develop energy efficiency solutions** in order to **turn the building industry into a knowledge-driven sustainable business**, with higher productivity and higher-skilled employees;
- **Develop innovative and smart systemic approaches** for green buildings and districts, helping to **improve the competitiveness** of EU building industry by providing cost-effective, user-friendly, healthy and safe products for smart cities.

This would ultimately create a solid foundation for **continuous innovation** in the building sector through sustainable partnerships, fostering **an innovation eco-system** across value chains, which is not project based with episodic innovation activities as current practices.

Specific objectives and key deliverables

Our specific Research and Innovation objectives are based on a clearly identified set of priorities to develop, integrate and demonstrate at least **40 new technologies** in:

- **Innovative construction** e.g. building envelope, multi-target design, materials and pre-fabrication methods, approaches adapted to public buildings or commercial/private-housing ones;
- Systemic, cost-effective, mass-customised, high-performing, and minimally invasive **building-retrofitting solutions integrating innovative energy equipment and storage**, to multiply at least by 2.5 by 2020 the yearly energy efficient and high quality renovation rate with tangible benefits for users;
- **Interactive sustainable buildings** for energy neutrality/positivity in a block of buildings, for a further 15 % reduction at district and city scale in energy and emissions by 2020;
- **Performance monitoring tools** to ensure energy efficiency during the service life, by providing the full performance predicted at the design phase and long-lasting quality to the end-user, in combination with durable components.

We envisage that new technologies would cover the whole segments of the value chain from design to end-of-life in line with the proposed budget breakdown and resources prioritisation.

Transforming energy efficiency into a sustainable business, by 2020 the PPP would contribute to:

- Increase private **investment in research & innovation up to 3 % of turnover**;
- **10 new types of high-skilled jobs** implemented through knowledge transfer and training;

- **Reduce energy and CO_2** respectively by 50 % and by 80 % compared to 2010 levels;
- At least **100 demonstration buildings and districts** would be retrofitted with ICT-based solutions and monitored to reduce up to 75 % in energy use and help **standardisation** and **interoperability**, and at least **10 000 dwellings** would be engaged by 2020 through the project activities.

This would ultimately contribute on health and safety, both at work site as well as for occupants, due to enhanced indoor environmental conditions.

The added value of action at Union level through a PPP

Energy efficiency in the built environment has a European dimension and **cannot be solved on a Member State scale.** Novel technologies and systemic solutions at EU scale are needed which leverage on research capabilities across different Member States while being deployed and customised at local scale, and this contractual PPP is indeed gathering all stakeholders. Harmonised standards and regulations are needed, enabled by pre-normative research and effective metrics which would be difficult to develop at the level of single Member States or with a market push approach by industry alone. To ensure such deployment, collaboration of the relevant industrial players is needed at an early stage of the innovation chain. A sizeable and stable long term multi-annual research and innovation strategy implemented through a **PPP** between industry and the EU Commission, with **defined priorities** and **a critical mass** of resources is required to reduce risks, to stimulate solid and lasting partnerships as well as to accelerate innovation.

A long-term industry commitment, leveraging additional investments to bring innovations to the market

In order to pave the way to create impact and make the step towards business creation, industry would mobilise additional investments for industrial deployment of at least a **factor of 4** on top of EC financial contribution to bring results to market. In this framework, the following targets and measures are set for exploitation of project results and their market take-up:

- At least **doubling the private resources allocated to demonstration** targeting early adopters and to pilot implementation targeting fast followers;
- **Tripling the current level of investments in training** by the supply chain and development of building skills (with at least 20 % of companies engaged in training against current 7 %);
- Bringing innovative results to the market via **systematic use of the whole set of funding tools,** fostered through a large yearly conference (at least 300 participants) to promote and monitor the use of **cohesion funds** within the broader **smart specialisation strategy**;
- Implementing a **cross-fertilisation platform** which gathers all main public deliverables from projects, supporting clustering along main horizontal issues, as well as Yearly Project Review and four Yearly Technical Editions on cross-cutting issues;
- Implementing **programme monitoring** through a yearly Impact and Project Review Workshop and appointment of a Third Party to assess the industry and sector investments;
- Contribution to potential **standards in building retrofitting**, e.g. for large action in social/public buildings. Manage a **Research and Innovation Forum** for awareness and dissemination with at least 5 000 members to exchange research needs and best practices in innovation-friendly demand side measures (i.e. pre-normative research, Regulations, Certification and Standards, Procurement, Socio-Economic Modelling and Planning, SME engagement).

Keeping track of progress and impact through focused KPIs

Two levels of Key Performance Indicators are proposed:

- '**Level 1' KPIs** address the implementation of the PPP and include:
  - New systems and technologies developed in the relevant sectors
  - Participation and benefits for SMEs
  - Contribution to the reduction of energy use and CO_2 emissions
  - Contribution to the reduction of waste
  - Contribution to the reduction in the use of material resources
  - New high-skilled profiles and new curricula developed
  - Private investment mobilised in relation to the PPP activities
  - Contributions to new standards

- ‘**Level 2’ KPIs** address the impact of projects funded under the PPP and include:
    - Scale of reduction in energy, material resources and waste
    - Project results taken-up for further investments (into higher TRLs)
    - Trainings for a higher quality workforce
    - Patents and activities leading to standardisation

Concerning the intermediate targets, we aim at a dissemination platform available at the end of 2014 while by 2015 training courses would be mapped across consortia and compared to training investments before entering PPP projects. Not later than 2016, a methodology for project clustering would be defined and clustering initiatives would be launched, involving all running projects. Furthermore, by 2017 at least half of the intended demonstrators would have started implementation and at least one third would be undergoing validation activities through a shared methodology across projects. Impact on health and safety at work site and for occupants would be proven with full scale buildings. By 2018 at least 10 % of projects funded within the first two calls would be undergoing an IPR protection process to secure patents on most innovative technologies and solutions.

The PPP as part of the whole EU strategy

Within the broader EU strategy towards a more energy efficient built environment and sustainable construction, industry-led research and innovation activities should be complemented with effective public mechanisms, such as lean and innovation friendly **public procurement mechanisms**, adoption of **EU wide standards** and promotion of **regulations**, as more flexible regulations would improve the market adoption of innovative technologies. Although they are inherently complementary to the PPP, actions to convince and stimulate users to invest in energy efficiency are critical to make innovation happen and fulfil the ambition of a European building stock consisting of Zero-CO_2 and energy positive neighbourhoods by 2050. In this way, a new dimension to the PPP is introduced, implementing **People** (job creation), **Planet** (energy, CO_2 and climate) and **Profit** (competitiveness) as the leading principle.

Open, transparent and participatory governance model

The Private side through E2BA is ready to get engaged with EC in the overall governance of the PPP, nominating experts for a Partnership Board as main instrument to ensure effective cooperation and dialogue, following up the successful experience with the Ad Hoc Industrial Advisory Group in FP7. In order to ensure high openness and transparency and to ensure an adequate participation of all relevant stakeholders in the preparation of the inputs to the Commission, in addition to the democratic governance of the Association and the way to nominate representatives in the Partnership Board, the Association would implement other means, already used for the preparation of this Roadmap, such as:

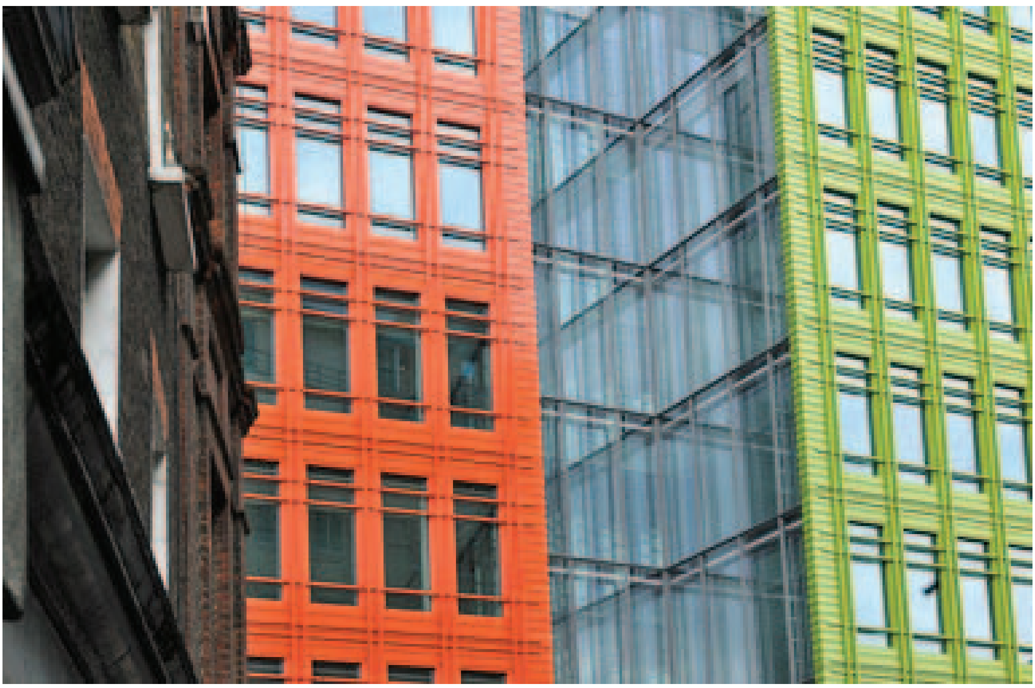
- The setting up of a network of National Liaison Points in Member States, in order to facilitate exchange of information between the European level and the National and Regional levels,

- The development of large consultation processes on major document such as Roadmaps, through press releases and website announcements, e-mailings, information meetings…;

- The organisation of dedicated workshops or webinars (possibly open to stakeholders from other sectors when appropriate), for example on specific technical topics, to prepare inputs on specific issues requested by the European Commission or on the initiative of the Association;

- The support to the European Commission in the organisation of large Info Days open to the whole community of stakeholders.

This approach has proven very effective and allowed a broad participation of organisations not members of E2BA in projects awarded within the period 2010-2013, where roughly 70 % of EC funding was awarded to non-E2BA members.



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List of acronyms and abbreviations

BIM: Building Information Modelling
BEMS: Building Energy Management System
BREAAM: BRE Environmental Assessment Method
E2BA: Energy Efficient Buildings Association, an initiative of the European Construction Technology Platform
EeB: Energy-efficient Building
ErP/EuP: Energy related Products / Energy using Products
GHG: Green House Gases
H2020: Horizon 2020
HQE: Haute Qualité Environnementale (High Environmental Quality)
HVAC: Heating, Ventilation and Air Conditioning
ICT: Information and Communication Technologies
IDM: Information Delivery Manual
IFC: Industry Foundation Classes
IFD: International Framework for Dictionaries
IPMVP: International Performance Measurement and Verification Protocol
KPI: Key Performance Indicators
LCA: Life Cycle Assessment
LCC: Life Cycle Cost
MVD: Model View Definitions
PPP: Public-Private Partnerships
RD&D: Research, Development and Demonstration
RFID: Radio Frequency Identification
TRL: Technology Readiness Level

Definitions

Active envelope

A package of technical solutions and associated control-command systems dedicated to the control and management of solar inputs or its thermal inertia.

Adaptable [2]

The meaning of 'adaptable' is twofold:

1. For a building/envelope/component, it means that it is designed in such a way that, over time, it can be readily transformed to accommodate uses for which it was not originally conceived and facilitate the conversion of rooms or buildings to new usage, the adaptation to the users' evolution (people ageing), and the integration of new solutions (upcoming technologies).

2 See '*Intelligent Building Envelopes — Architectural Concept & Applications for Day lighting Quality*', Annemie Wyckman, 2005.

2. An adaptable envelope is also able to adapt to a dynamic and intricate environment by measuring and processing multi-sources information (e.g. outdoor and indoor environment conditions, occupancy, behaviour of users and envelope performances) in order to respond to the building occupant's instructions and to evolving environmental conditions in an appropriate timing and extent.

Barriers

The term 'Barrier' refers to any obstacle that prevents or slows down R & D investments by industry to meet the 2020 targets.

Building sector

In the context of this document, 'building sector' encompasses activities along the whole building value chain from design to end-of-life, which includes architects and engineering services, manufacturers of construction materials and technologies, onsite construction companies, property developers and facilities managers, energy companies as well as building users (households, offices, ...).

Challenges

The term 'Challenge' refers to any major breakthrough impacting the building sector and its enlarged value chain with regards to energy efficiency, and that must be faced by industry to meet the 2020 intermediate targets (required to support the 2050 vision): they reveal several urgent changes to be implemented by industry within the next ten years.

Construction sector

According to the statistical classification of economic activities in the EU (NACE Rev 1.1), this sector covers five different NACE groups which correspond to different chronological stages of the construction process:

- Demolition and site preparation (NACE Group 45.1);
- General construction activities (NACE Group 45.2);
- Installation work (NACE Group 45.3);
- Completion work (NACE Group 45.4);
- Renting of construction equipment (NACE Group 45.5).

District[3]

A set of connected buildings, public spaces, transport infrastructure, and networks (e.g. electricity, heating, cooling, water and wastewater, etc.), including inhabitants, building users and managers.

3 Source: CSTB.

Drivers

The term ‘Driver’ refers to any endogenous or exogenous factor capable of triggering R & D investments by industry in view of achieving agreed 2020 targets.

Embodied energy

Total of all energy consumed in the processes associated with the production (and transport) of the materials and components that go into a building or structure.

Integration [4]

Whole-building integration is in principle similar to the process used in the automotive industry: ideally, every part would be designed and manufactured to work together to create high-performance buildings. The process begins with computer simulated design to analyse building components and systems, and then integrates them so that the overall building performance is optimised. A systems integration approach enables advanced technologies to function more efficiently while still meeting the challenging reliability and cost requirements for buildings.

Neighbourhood [5]

In this document, the term Neighbourhood refers to a group of adjacent buildings.

Reuse

In this document, the term ‘reuse’ has a broad sense which covers:

- the reuse of products and components as defined in the Waste Framework Directive (2008/98/EC): any operation by which products or components are used again for the same purpose for which they were conceived;
- The reuse of materials in producing the same or other materials: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes:
    - Recycling: in the strictest sense, to produce a fresh supply of the same material;
    - Down-cycling: to produce new materials /products of lesser quality and reduced functionality;
    - Up-cycling: to produce new materials /products of better quality or higher environmental value.

Smart City

A city is a network of connected districts. Six dimensions of ‘smartness’ can be identified [6]: economy, people, governance, mobility, environment, and living. A city can therefore be defined

4 Source: NREL.

5 Source: CSTB.

6 From EU project ‘*European Smart Cities*’.

as 'smart' when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory governance.

Targets
'Target' refers to intermediate performances typical of each of the value chain steps requiring industry's R & D investments before 2020.

Targeted Areas
Specific research and innovation areas which are of relevance for this roadmap within a given Target

Use value or value for the user
The use value is the value that people derive from the direct use of a commodity (good or service). It depends on the utility delivered to the user as well as the user's needs and knowledge in a specified context.

User-centric
For a system, product or service, it refers to users having more control, more choices or more flexibility than they might have had previously. Users include end-users (e.g. inhabitants, occupants, tenants) as well as professional users (e.g. maintenance personnel, facility managers).

Vision
In this roadmap, the term 'Vision' refers to E2BA's convictions of what the building industry and its enlarged value chain would be able to reach by 2050, thanks to the energy efficiency aspects of its activities from 2014 up to 2050.

Part I: Vision 2030

1 Introduction

The preparation of this Roadmap was driven by industry in the framework of the **Ad-hoc Industrial Advisory Group**[7] **set-up within the running PPP EeB**. The **private sector is represented by E2BA**, as industrial interlocutor of the European Commission in the PPP EeB, represented by DG RTD (Themes NMP and ENV), DG Energy and DG CONNECT. E2BA has started the review of the achievements of projects and updating of the PPP EeB Roadmap since mid 2011 in order to set the research and innovation priorities beyond 2013 with a specific focus to the period 2014-2020.

The scope of this document is indeed to **update the research and innovation priorities to align the industry long-term plans with the content of the Horizon 2020 proposal**, where a clear research line on 'Technologies for Energy efficient Buildings' was proposed by EC[8]. In this framework an extensive review of running research and demonstration projects and major initiatives at EU scale such as the **SET Plan** (including the recent Materials Roadmap enabling low carbon energy technologies[9,10], see Appendix 6), the **Smart Cities** European Innovation Partnership, the **Intelligent Energy** and **Eco-innovation** programmes under the CIP framework,

7 http://ec.europa.eu/research/industrial_technologies/ad-hoc-eeb_en.html

8 http://ec.europa.eu/research/horizon2020/pdf/proposals/communication_from_the_commission_-_horizon_2020_-_the_framework_programme_for_research_and_innovation.pdf#view=fit&pagemode=none

9 http://setis.ec.europa.eu/activities/materials-roadmap

10 http://ec.europa.eu/research/industrial_technologies/pdf/materials-roadmap-elcet-13122011_en.pdf

the **InnoEnergy** Knowledge and Innovation Community (KIC) running under the European Institute for Innovation and Technology (EIT), the **Lead Market** initiative and recent **Communication on 'Sustainable Construction'** by DG Enterprise as well as the **Energy efficient Roadmap** and consultation on 'Financial support for energy efficiency in buildings' by DG Energy, to name a few. Inputs and contributions from key stakeholders were mobilised within the framework of the ICT4E2B Forum (www.ict4e2b.eu) and Building-Up (www.buildingup-e2b.eu) projects gathering **experts from construction, energy as well as ICT domains**, and relevant **European Technology Platforms** (i.e. European Steel Technology Platform (ESTEP), Forest-Based Sector Technology Platform (FTP), European Technology Platform for Sustainable Chemistry (SusChem), European Technology Platform for Advanced Engineering Materials and Technologies (EUMAT), European Technology Platform for the future of Textiles and Clothing, Renewable Heat and Cooling Technology Platform, European Photovoltaic Technology Platform). They have been complemented by inputs and feedbacks received within an open consultation launched in early July 2012 and closed on October 1st 2012 as well as within a final validation public process launched at the end of 2012.

In Part 1 the main drivers, pillars and **strategic objectives** at the basis of the roadmap are presented, highlighting the industry vision, the need to address the existing buildings stock and overcome a potential market failure through research and innovation on technologies and integrated solutions for buildings and districts.

In Part 2, specific **challenges, barriers, targets and innovation drivers are presented for each area of the value chain** concurring to the identification of the research and innovation targets and priorities, focused on demand side reduction and building renovation. An overview of the investments associated with the broader implementation of the roadmap is provided. In line with the H2020 strategy, the identified **priorities include all those horizontal non technological aspects that hinder innovation and which are instrumental to generate the expected impact in enlarged Europe**.

In Part 3 the **expected impact both from the economic, social and policy point of view** is presented, highlighting for instance contributions to job creation and the implementation of the Innovation Union [11] strategy. **KPIs and the expected logic to monitor progress** are provided jointly with a preliminary analysis of the **expected leverage effect** both on mobilised investments by industry to bring results to market as well as on those indirect aspects as training and effective use of resources at local scale in line with the 'smart specialisation' strategy.

Appendix 1 provides an overview of the intended governance at the level of the PPP and E2BA to ultimately guarantee openness and transparency. Appendixes 2 and 3 provide a detailed description of the drivers and challenges per each element of the value chain. Appendices 4 and 5 provide an overview of key priorities identified within the framework of the Building-Up and ICT4E2B Forum projects, respectively. Appendix 6 provides an overview of the Materials Roadmap Enabling Low Carbon Energy Technologies (within the Set Plan).

11 http://ec.europa.eu/research/innovation-union/index_en.cfm

2 Overall Vision till 2030 and PPP objectives

2.1 Strategic and general objectives

In line with H2020 strategic targets, our vision is to drive the **creation of a high-tech building industry which turns energy efficiency into a sustainable business**, extending the scope of the running and successful PPP EeB beyond 2013. Connecting construction industry to other built environment system suppliers and stakeholders would be the decisive step for Europe to reach its economic, social and environmental goals, contributing to the objectives of the Innovation Union. By creating and fostering this research driven paradigm shift, **EU companies would become competitive on a global level in the design, construction and operation of the built environment while sustaining local economies across EU-27 through job creation and skills enhancement**, driven by the vast majority of SMEs active in the value chain.

In this framework, our **strategic objectives** are to:

- **Develop technologies and solutions enabling to speed up the reduction in energy use and GHG emission** in line with the 2020 goals, e.g. through a higher renovation rate of the building stock at lower cost and to meet regulatory needs;
- **Develop energy efficiency solutions** in order to **turn the building industry into a knowledge-driven sustainable business**, with higher productivity and higher-skilled employees;
- **Develop innovative and smart systemic approaches** for green buildings and districts, helping to **improve the competitiveness** of EU building industry by providing cost-effective, user-friendly, healthy and safe products for smart cities.

This would ultimately create a solid foundation for **continuous innovation** in the building sector through sustainable partnerships, fostering **an innovation eco-system** across value chains, which is not project based with episodic innovation activities as current practices.

By 2030, increased and faster collective research and innovation would allow the **European building sector to mutate into a mature, innovative and energy efficient enabling industry**:

- **Delivering new or refurbished, user centric and affordable buildings/districts** in line with EU2020 and national strategic objectives and commitments towards 2050;
- Working safely according to **quality standards** that encompass the whole life cycle of any building, thus guaranteeing durable building performances;
- **Valuing not only energy performances** but also environmental, aesthetics, historic value, acoustics, safety, accessibility or comfort as purchase criteria for end users;
- **Committing to long term performance guaranteed contracts** on the energy bills.

2.2 Specific objectives

Our specific Research and Innovation objectives are to develop, integrate and demonstrate at least **40 new technologies** by 2020 in:

- **Innovative construction** e.g. building envelope, multi-target design, pre-fabrication methods, approaches adapted to public buildings or commercial/private-housing ones;
- Systemic, cost-effective, mass-customised, high-performing, and minimally invasive **building-retrofitting solutions integrating innovative energy equipment and storage**, to multiply at least by **2.5 the yearly energy efficient and high quality renovation rate** with tangible benefits for users;
- **Interactive sustainable buildings** for energy neutrality/positivity in a block of buildings, for a further 15 % reduction at district and city scale in energy and emissions by 2020;
- **Performance monitoring tools** to ensure energy efficiency during the service life, by providing the full performance predicted at the design phase and long-lasting quality to the end-user, in combination with durable components.

Transforming energy efficiency into a sustainable business, by 2020 the PPP would contribute to:

- Increase **private investment in research & innovation up to 3 % of turnover** associated with high quality and energy efficient building retrofitting;
- **10 new types of high-skilled jobs** through knowledge transfer and training;
- **Reduce energy and CO_2 respectively by 50 % and by 80 %** compared to 2010 levels;
- At least **100 demonstration buildings and districts** would be retrofitted with ICT-based solutions and monitored to reduce up to 75 % in energy use and help **standardisation** and **interoperability**, and at least **10 000 dwellings** would be engaged by 2020 through the project activities.

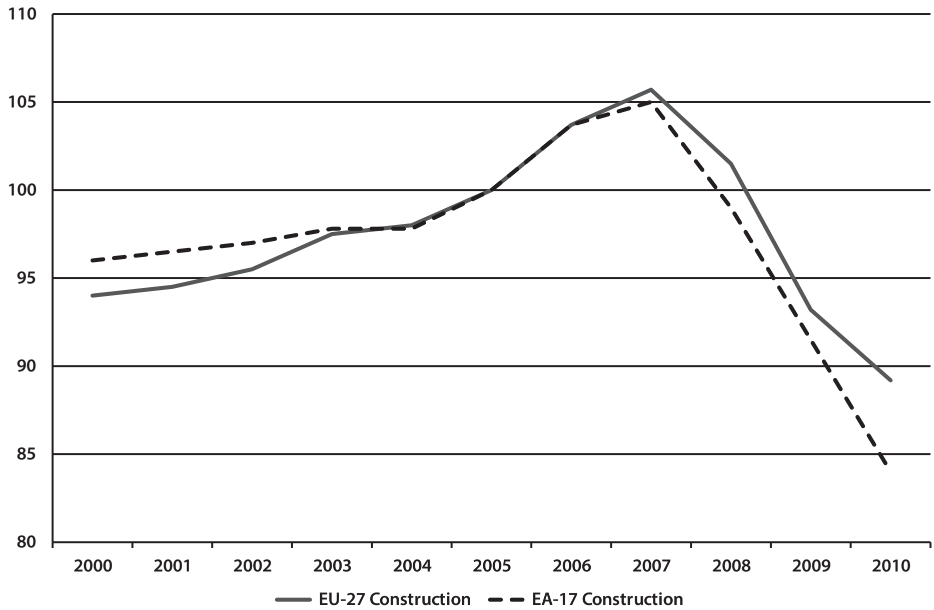
This would ultimately contribute on health and safety, both at work site as well as for occupants, due to enhanced indoor environmental conditions.

3 Importance of the building sector for the European economy

Construction is a lucrative sector for the European economy. The 2011 statistics from the European Construction Industry Federation (FIEC)[12] report that construction is the **largest European single activity** accounting for 9.6 % of the EU-27 GDP worth just above EUR 1.2 trillion, when considering the extended value chain (e.g. the manufacture of construction products, architecture and engineering). It is the **biggest European industrial employer** accounting for 30.7 % of industrial employment, directly involving nearly 15 million people within more than 3 million enterprises, 95 % of which being SMEs with less than 20 people. FIEC estimates that 43.8 million workers in the EU depend, directly or indirectly, on the construction sector. Yet, this sector remains **fragmented, involving a large number of highly specialised skills, but with significant regional market differences**. Since 2007, the recent financial and economic crisis has significantly impacted on the activities in the construction sector.

The sector continues to experience a significant reduction in the construction outputs. Eurostat reports that, when compared with February 2011, the output of February 2012 dropped by 12.9 % in the Euro area and by 9.4 % in the EU-27[13].

Figure 1. EU-27 & EA-17 Construction output (production index[14], 2000-2010, annual data, 2005=100, Source: Eurostat



12 FIEC latest available statistics, http://www.fiec.eu/Content/Default.asp?PageID=5

13 Source: Eurostat News Release 58/2012 – 18 April 2012.

14 The production index for construction is a business cycle indicator which measures monthly changes in the price adjusted output of construction. Despite its name the production index is not intended to measure production but should – in theory – reflect the development of value added.

4 New economic, environmental and societal challenges for the EU building industry

The construction sector is fully aware of a huge responsibility, being the **highest energy consumer in EU** (about 40 %) and **main contributor to GHG emissions** (about 36 % of the EU's total CO_2 emissions and for about half of the CO_2 emissions which are not covered by the Emission Trading System). In this framework, **the building industry would be one of the key enablers of the 2050 decarbonisation goal for the European economy**. This goal links two European policies:

- The energy policy: scenarios by 2050 show that a 40 % to 50 % reduction of the building 'sector'[15] energy consumption is mandatory by 2050, where fossil fuel heating represents a major share (60 %);

- The climate policy: scenarios by 2050 show that the building 'sector' must target a reduction of at least 80 % of its CO_2 emissions, accounting for about 1.4 Gtons of CO_2 per year.

The implementation of the 2050 decarbonisation goals raises new grand European challenges for the building industry and the entire value chain (e.g. technology manufacturers, construction companies, energy service companies, etc.):

- How to make the routes to reach the 2050 goals realistic when complying with intermediate targets by 2020[16]?

- How to reduce the risk of potential market failures ahead?

4.1 The critical role of refurbishment

Tackling refurbishment of existing buildings (historic buildings included) is a top priority; it is expected that, by 2050, about half of the existing building stock in 2012 would be still operational. In 2011, the Buildings Performance Institute Europe's (BPIE)[17] study emphasised the critical role of refurbishment, when considering various pathways to achieve the 2050 building sector decarbonisation goals. The proposed pathways[18] differ from one another by:

- The speed at which buildings are refurbished (the refurbishment rate);

- The level of energy or greenhouse gas emission savings that are achieved when refurbishing a building (the refurbishment depth).

15 Meaning the technology manufacturers, the construction companies, the energy companies and the building users.

16 1. A reduction in EU greenhouse gas emissions of at least 20 % below 1990 levels; 2. 20 % of EU energy consumption to come from renewable resources; 3.a 20 % reduction in primary energy use compared with projected levels, achieved by improving energy efficiency.

17 The institute was founded in 2010, by the ClimateWorks, the European Climate Foundation and the European Council for an Energy Efficient Economy (ECEEE), providing analyses targeted at the Energy Performance of Buildings Directive (EPBD).

18 There is at least one other vision, i.e. 'Refurbishing Europe' (Tofield and Ingham, 2012), that presents a vision for the building sector, but it does not include alternative pathways.

The BPIE study developed five scenarios that may or may not achieve the 2050 target for the building sector: only two work well – the Deep Scenario and the Two-Stage Scenario. When comparing these two scenarios with the current situation, it can be seen that:

- Both rate and depth of refurbishment must **at least double and even triple**, compared to the currently observed situation;
- The depth of refurbishment must **start increasing before 2020** to avoid the need for a two-stage refurbishment process, which in turn would yield a higher share of zero energy buildings by 2050.

Table 1. Scenarios (Source: BPIE 2011)

	Current	Deep Scenario	Two-Stage Scenario
Building sector GHG emissions reduction by 2050 (compared to 2010 level)	72 %	90 %	91 %
Average depth of refurbishment	9 %	68 %	71 %
Average rate of refurbishment	1 %	2.5 %	3.3 %

Nevertheless, the BPIE study did not address the impact of a third critical parameter discussed earlier: the **district dimension** which could possibly relax either one of the above trajectory parameters and **innovation**, allowing for cross building energy cooperation and/or smart energy generation and use within districts.

At any rate, deep refurbishment would be required, meaning:

- **Breakthrough technological and economic performance improvements** for the building envelope (reduce the demand);
- Proper **downscaling/management of energy equipment** (adjust to a lower demand without losing energy use efficiency);
- **Durable performance improvements** (avoiding user's misuses and/or building disorders).

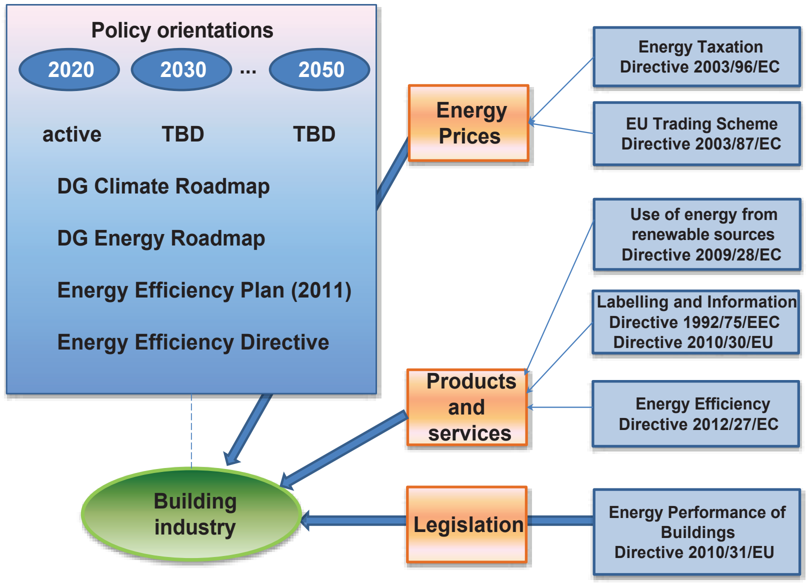
A relevant aspect not considered in the BPIE report is the associated investment to these scenarios. **Research and innovation are clearly needed** to reduce the huge additional investment required to reach the renovation targets in terms of energy efficiency, which are measured over EUR 60 billion additional investment per year.

Finally, another aspect which the paper does not include but may hinder innovative and energy efficient refurbishment is represented by the **large number of micro and small enterprises involved in the refurbishment operations**: it is well known that the uptake of innovative technologies by SMEs is rather slow due to limited economical and knowledge resources.

4.2 Avoiding the risk of a market failure

The building sector is a **highly regulated market**. Figure 2 below summarises the European Directives which to-day shape the building industry.

Figure 2. European regulations and policy strategies impacting the building industry



Additionally manifold national regulations have to be fulfilled, often differing between the EU Member States. The measured rate of refurbishment today is still much lower than the one which should be observed to remain in line with the above future 2050 ambitions. Today buildings are renovated every 30 to 40 years on average [19], and every 60 to 80 years in the Mediterranean regions [20]. Energy or greenhouse gas emission savings are rarely the main drivers. Typical drivers include the end of the lifetime of building components and/or subsystems, the improvement of the living quality and comfort of the building, or even the improvement of the building appearance and economic value [21].

The probability of a market failure is therefore rising above all during this period of economic crisis at global level: Reducing the probability of a major market failure requires that all the stakeholders of the building sector accelerate and deepen refurbishment, while keeping construction costs under control. Increased **technological, social and business innovation is therefore needed** now and in parallel to address several issues:

- **Most technology solutions are too expensive**: volume effects to reduce unit manufacturing costs cannot be obtained in a highly segmented building

19 EC, 2012, European Commission, Directorate-General for Energy, Consultation Paper — *Financial support for energy efficiency in buildings.* Brussels, February 2012.

20 IREC 2012.*Integrated Regional Benchmark Analysis. Work in progress within the MARIE project.* Final report to be released by July 2012 (http://www.marie-medstrategic.eu/).

21 See for instance: 1) Jakob, M., 2007. *The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners.* CEPE Working Paper No 56 and 2) Caird, S., Roy, R., Herring, H., 2008. *Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low- and zero-carbon technologies.* Energy Efficiency (2008) 1:149–166.

stock; technological innovation is still needed to find solutions complying with constraints, such as aesthetics, acoustics, health at affordable prices;

- **Construction processes lack productivity and quality**: the most promising technologies would deliver savings if and only if their building integration is carried out properly and controlled step by step. Innovation on construction processes is needed to find reliable and worker-centric approaches where existing gaps between performance by design and performance at commissioning are narrowed down;

- **Renewable energy sources have not yet reached mature integration** into existing or new buildings to provide users with heat and/or electricity that are independent from fossil fuel uses. Innovation is still needed to optimise renewable energy impacts and uses at building and district level;

- The refurbishment market (supply and demand) must be better understood:

    - **What is basically traded in refurbishment?** Energy savings are difficult to quantify since they depend on the users' behaviour. Moreover, several other building use values can hardly be monetised (acoustic comfort, indoor air quality, preservation of the historic value, improved accessibility ….);
    - **How much is traded in refurbishment?** Energy consumption is still poorly measured in buildings. The other use values (acoustic comfort, indoor air quality, preservation of historic value, etc.) can hardly, if ever, be measured;
    - **How is refurbishment trade organised?** A myriad of market players (fragmented in many micro and small industries) is involved, showing that refurbishment is not yet built around an industrial supply of services, purchased through a value appraisal which may go beyond mere energy savings.

- Users must be engaged and their **behaviour** properly considered along the different steps in the value chain.

5 Research and Innovation to meet the EU decarbonisation goals

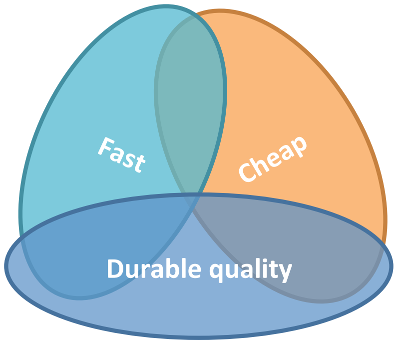
Managing the above innovation pathways requires meeting three constraints, like in any technology development:

- The **time required to deliver** innovative technologies and/or construction processes (fast);

- The **quality** of the technologies and/or construction processes (durable energy efficiency and sustainable quality);

- The **total costs, including the external ones,** required for developing and implementing the product or construction process (affordable).

Figure 3. The speed/cost/quality trilemma



The classical 'trilemma' of technology development (see Figure 3) tells us that only two of the above constraints can be simultaneously considered.

In this framework, **public intervention at European level is needed to foster the research, development and deployment of innovative technologies and solutions** in a partnership between industry and the public stakeholders. It allows supporting very early more innovation investments in parallel, transforming regulatory constraints into business opportunities with new SME driven value chain creation. It helps concentrating public support at developing a large portfolio of innovative services and products, which in turn must position this whole value chain into a virtuous circle much earlier and with a broader scope:

- **The technology supply chain benefits** very early from appropriate business models to accelerate the refurbishment of the existing building stocks;
- **Increased manufacturing volumes** to meet both new and refurbished building demands help the supply chain keeping the costs and prices down;
- **The demand for refurbishment services** may then rise, since becoming more and more financially attractive (and triggered by affordable prices and value creation for the users that can go beyond mere energy savings). An increasing concern for the preservation of cultural heritage may also have a role to play in this context;
- **SMEs which represent 95 % of the players in the value chain are engaged** since the early stages, developing skills and know-how that would be instrumental to achieve the expected energy efficient performance at building and operation stage.

6 The need to extend the ambition of the PPP EeB in Horizon 2020

6.1 The need for a European approach through a PPP

Energy efficiency in the built environment has a European dimension and **cannot be solved on a Member State scale.** Novel technologies and systemic solutions at EU scale are needed which leverage on research capabilities across different Member States while being deployed and customised at local scale, and this contractual PPP is indeed gathering all stakeholders. Harmonised standards and regulations are needed, enabled by pre-normative research and effective metrics which would be difficult to develop at the level of single Member States or with a market push approach by industry alone. To ensure such deployment, collaboration of the relevant industrial players is needed at an early stage of the innovation chain. A sizeable and stable long term multi-annual research and innovation strategy Implemented through a **PPP** between industry and the EU Commission, with **defined priorities** and **a critical mass** of resources is required to reduce risks, to stimulate solid and lasting partnerships as well as to accelerate innovation.

6.2 The added value of continuing EeB PPP beyond 2013

The PPP EeB was launched as part of the economic recovery plan in 2008. The PPP EeB used existing FP7 mechanisms whilst providing a mid-term approach to R & D activities. It brought together various Directorates Generals (DGs): DG Research and Innovation (RTD) (Nano, Materials and Processes — NMP- and Environment — ENV-), DG Energy and DG CONNECT in close dialogue with industry. In this framework, a roadmap was built on the following **pillars**, namely: 1) **systemic approach**; 2) **exploitation of the potential at district level**; 3) **geo-clusters,** conceived as virtual trans-national areas/markets where strong similarities are found, for instance, in terms of climate, culture and behaviour, construction typologies, economy and energy/resources price policies, Gross Domestic Product, but also types of technological solutions (because of local demand-supply aspects) or building materials applied etc.

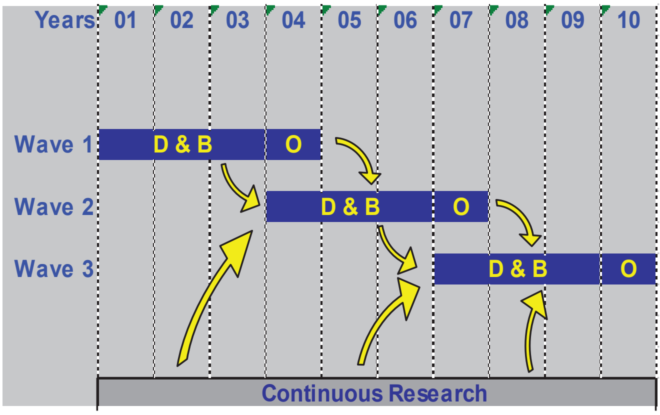
These pillars are definitely brought forward in this Research and Innovation Roadmap which indeed is strongly based on the long term programme defined in 2009[22] around a '**wave action**'. In this 'wave action' plan, continuous, on-going research feeds successive waves of projects as stated here below. The knowledge gained in the first 'wave' feeds in the second at the design stage, realising a continuous implementation process.

The roadmap is based therefore on the following logic:

- Continuous, on-going research feeding successive 'waves' of projects (Design and Building followed by Operation) as stated here below;

22 PPP EeB '*Research priorities for the definition of a multi-annual roadmap and longer term strategy*', July 2009.

Figure 4. Wave action along the roadmap (D&B: Design and Building; O: Operation)



- Knowledge gained in the first 'wave' feeding also the second one at the design stage, realising a continuous implementation process (see Figure 4 below).

As a result of this 'wave action' industry expects to reach impact following a stepped approach, namely:

- **Step 1: Reducing the energy use of buildings and its negative impacts on environment** through integration of existing technologies (main focus of the current PPP EeB);

- **Step 2: Buildings cover their own energy needs**;

- **Step 3: Transformation of buildings into energy providers**, preferably at district level.

The long term programme set by the industry tackles also the development of those **enabling knowledge and technologies** which are instrumental to achieve these targets, launching the required more fundamental and applied research actions. In this framework, the extension of the PPP EeB beyond 2013 would **accelerate the innovation pace of the on-going projects** while at the same time addressing those priorities which industry has identified as key for impact following up the first 'wave' and have not yet been extensively covered so far.

The results and knowledge gained in the first 'wave' of R & D project financed within the PPP EeB till 2013 have created a solid foundation and would feed the next project waves, leading ultimately to full scale demonstration of integrated and standardised/interoperable solutions, a prerequisite to prepare scaling-up and replication. This analysis clearly shows an **added value for the industry in teaming up with EC to bring forward the current PPP beyond 2013**, keeping the overall ambition to share a long term programme which would lead to growth and job creation while enabling the solution of relevant societal challenges.

6.3 Compliance with article 19 of Horizon 2020 regulation

This roadmap is the backbone of a long term Research and Innovation programme with shared priorities openly agreed amongst the vast community of stakeholders across enlarged Europe. In line with Horizon 2020, this PPP aims at developing breakthrough affordable solutions at building and district scale, connecting them at a larger scale to future smart cities and in a broader framework with all suitable instruments and initiatives along the innovation chain to create impact. This challenge based approach would ultimately benefit all EU citizens and users as well as local public authorities.

This is **fully in line with the main criteria set in article 19 under Horizon 2020 regulation**, as summarised in table 2.

Table 2. Compliance of the PPP with criteria under article 19 of H2020 regulation

CRITERIA	RELEVANCE
Added value of action at Union level	Energy efficiency in the built environment cannot be solved on a Member State scale: novel technologies and systemic solutions are needed, which are optimised leveraging on research at EU scale, but customised at local scale, and this contractual PPP is gathering all stakeholders
Scale of impact on industrial competitiveness, sustainable growth and socioeconomic issues	40 new technologies along the value chain, increase in private investment in research & innovation up to 3 % of turnover, 10 new types of high-skilled jobs through knowledge transfer and training, a reduction in energy and CO_2 respectively by 50 % and by 80 % compared to 2010 levels, at least 100 demonstration buildings and districts retrofitted with ICT-based solutions and monitored to reduce up to 75 % in energy use and help standardisation, with at least 10 000 dwellings engaged
Long-term commitment from all partners based on a shared vision and clearly defined objectives	Clear set of strategic and general objectives as well as specific objectives and deliverables
Scale of the resources involved and the ability to leverage additional investments in research and innovation	2.1 billion Europe financial envelope, investments of at least a factor of 4 by industry on top of EC contribution to bring results to market
Clear definition of roles for each of the partners and agreed key performance indicators	Setting up of a Partnership Board to get engage with EC in a continuous dialogue along implementation, open and transparent mechanisms for engagement of stakeholders beyond E2BA, clear set of KPIs to monitor PPP implementation and impact at project level

Part II: Research and innovation strategy

1 Research and innovation issues: a value chain perspective

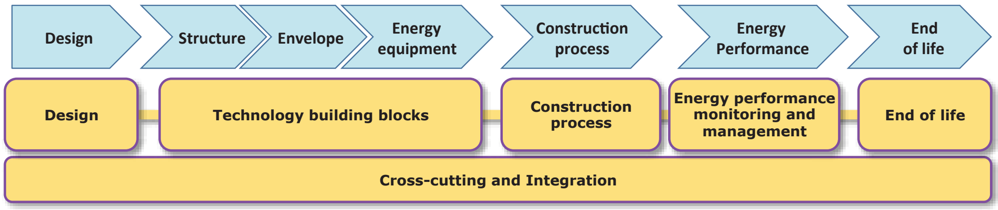
The innovation rationale proposed by industry is to extend the ambition of the running PPP EeB beyond 2013 in line with the 2030 vision to develop and to validate a set of innovative tools, technology and process components **covering the whole value chain, having districts as a proper dimension to address**. They would be integrated to meet future market conditions and opportunities at the larger city scale, thus:

- **Transforming barriers and regulatory constraints** into innovation opportunities;
- **Fostering the creation of innovative supply chains**, that become more user centric to cope with the difficulty of implementing refurbishment strategies[23];
- **Reorganising and stimulating innovative procurement** of buildings and ordering of technology/services with the integration of new smart grids technologies for single buildings as well as for whole districts (new buildings and existing stock).

Today's fragmented nature of the construction chain still gives little freedom for innovations that are indispensable to shape a more sustainable built environment. Yet, collaborative project

23 The subsectors by decreasing order of refurbishment difficulty are: condominiums, private houses, private commercial building, public office social housing building.

Figure 5. Representation of the segmentation of the value chain



management in the construction sector has become a prerequisite to develop a building stock that is technically and economically optimised: this goes against centuries of working habits.

Moreover, the focus must be on creating value (not only in terms of economics, but also in terms of comfort, health, environment, etc.) for all the users involved. This requires new skills together with a major behavioural shift within the entire construction sector. Coalitions [24] must be created, which are dedicated to the collaboration among players from different disciplines to contribute to the realisation of buildings and districts with energy-ambitious goals.

The whole value chain would be involved in this continuous optimisation process to cope with Europe's strategic goals. The biggest efforts must lie upon the refurbishment of the existing stock due to its quantity of CO_2 emissions, taking into account the cultural heritage of Europe's cities and the need to find adequate solutions.

The **energy transition and decarbonisation, sustainability and innovative solutions within smart districts and cities** are integral parts of the following three major steps for the built environment:

Step 1: From design to commissioning of new or refurbished buildings, the optimisation consists in picking from a portfolio of material and energy equipment solutions, the ones which meet both a cost of ownership target and minimal potential GHG emissions over the foreseen life cycle.

Step 2: During this life cycle, robust user-centric energy management systems ensure that the initial GHG emissions targets are continuously met thanks to continuous optimisation able to cope with changing climate conditions and to correct for or modify behaviours of users.

Step 3: The next refurbishment involves another optimisation approach where the investment for refurbishment can be recovered through further savings on the cost of ownership. A number of different new technologies would create new markets for affordable solutions.

This optimisation approach requires that all the **stakeholders perform according to quality rules** where interfaces and responsibilities between any of them are transparently exchanged. The innovation process would be open to various technologies, materials or processes focussing on valuable improvements. Interaction with other research areas especially the integration of supply systems for renewable energy including storage systems would be mandatory.

24 *'Energy Leap long term program'* TNO (2011).

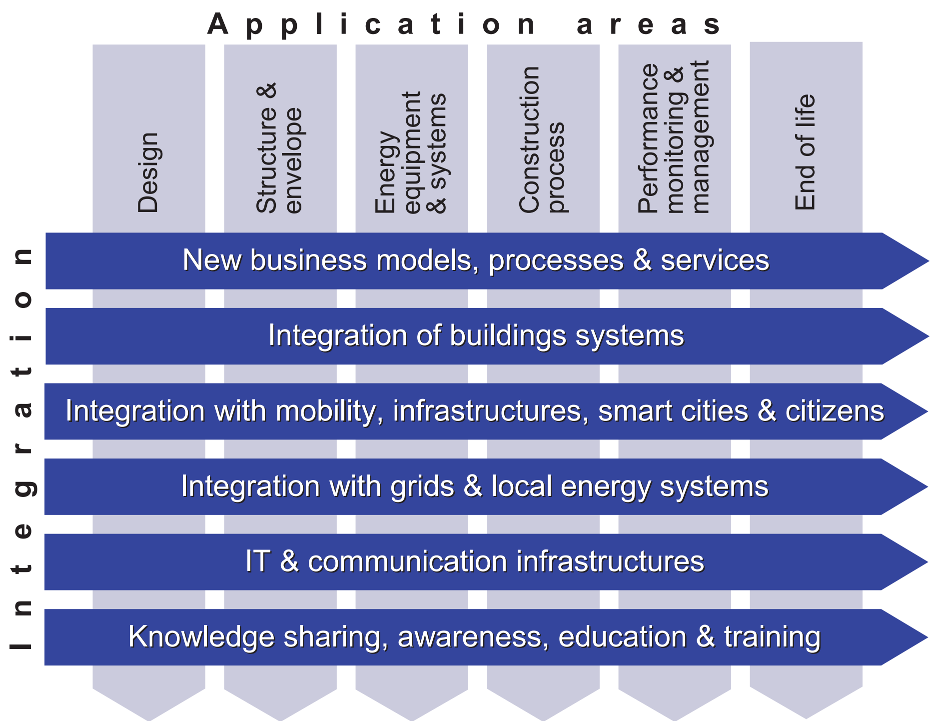
Indeed novel **Information and Communication Technologies (ICT)** as well as **materials technologies would be key enablers throughout the whole value chain**, from the design phase to the end of life.

An overview of the **enabling role of ICT** is provided in the figure below.

It is at the **design stage** that more than 80 % of the building performance is set both in terms of energy savings (generation when embedded in a zero energy district) and cost of ownership over the life cycle before refurbishment. Yet, the relative gap between the design value for energy performance and the commissioning measured result is still too large (and would probably widen when the more stringent building code standards for 2020 are in place). A new **regional and urban (master) planning of smart grids and cities promotes decisions at the design phase for better solutions**. Thus, planning with a holistic approach for energy-efficient and sustainable buildings and districts (new and refurbished) would be mandatory. Hereby, ICT technologies from true interoperability to decision support systems can be exploited.

Load bearing structural parts of a building can be mechanically and thermally optimised with sophisticated tools: the focus must be put on the embedded CO_2 which is associated with the materials (e.g. concrete, various brickwork, steel, wood, etc.). This CO_2 would become the most

Figure 6. The pervasive role of ICT along the value chain



prominent part of GHG emissions as the share of energy neutral building grows. Alternative construction processes (e.g. with significantly lower embodied energy) would help to bind CO_2. Hereby, renewable energies and sustainable cultivation plays a key role[25].

The envelope becomes the most critical part when it comes to energy efficient buildings:

- For new buildings, materials and energy equipment integration already allows reaching very low energy demand (e.g. based on a high heat resistance, high air tightness or integrated ventilation systems with connection to heat recovery systems). Yet, the investment costs have to be further reduced while taking care of several other design constraints (e.g. acoustics, fire, seismic, air quality, adaptation requirements for ageing population...). In the long run, active envelopes could make buildings energy positive by, for instance, smartly managing solar fluxes onto the building;

- For refurbishment, the diversity of architectures, building types, categories, structures as well as climates in Europe requires a whole value chain innovation process where design, technology choice and construction are even more intertwined than for new buildings — special efforts are likely to be necessary for cultural heritage buildings. The integration of the district dimension can allocate refurbishment performance settings to reach very ambitious zero energy districts. Overall, refurbishment depths must go beyond 70 % while valuing non- energy related benefits to make the business models more attractive;

25 http://ec.europa.eu/agriculture/fore/action_plan/index_en.htm

- Prefabrication of envelope parts, multi-functionality and compact solutions presumably would significantly reduce costs and produce new markets.

The energy equipment must adapt to the new smart grids and to lower unit energy demands from more energy efficient buildings, which requires sizing down the current portfolio while keeping energy efficiency at the highest level possible as well as unit investment cost down. Beyond existing technologies, breakthrough solutions can be expected from heating/cooling systems combined with renewable energy sources, storage (heat and electricity) and building or district integrated solutions in combination with smart grid technologies. Interoperable systems which integrate all different energy fluxes like electric energy sources and sinks, heat sources (including waste heat) and sinks (including storage) and innovative control systems are required. The costs for different energy sources would vary depending on supply and demand. Smart solutions would offer best prices for investors and end-users.

Construction processes are now part of the critical path to reach the final energy performance: any defect can lead to disorders and even pathologies which hamper the durability of the building performance. Several complementary routes can be envisaged, with the envelope and the technical equipment at the heart of the integration process:

- Prefabrication of standard units which facilitate field integration;

- New field integration process with more detailed internal performance control following elementary construction steps. New sensors can help check intermediate performance steps before commissioning (ex: blower-door test in combination with thermal imaging for air tightness) which, in turn, require collective work in the field;

- Continuous improvement processes become part of a quality process which increases energy and comfort performances for new and refurbished buildings. RFID technology would improve productivity at the building site as well as the training of workers, e.g. on the impacts of a wrong installation on the buildings' performance;

- Starting at the design phase new standardised BIM exchange formats allow a continuous information flow towards a computer aided construction process.

Performance monitoring and Continuous Optimisation (either before a refurbishment intervention, either at commissioning and during the building life) is mandatory: it enables smart grid integration, allows users to oversee and control their own consumption and allows detecting inappropriate operating conditions. Moreover, conditional maintenance approaches can bring added value in guaranteed performance contracts. New IT solutions such as Model Based Control and embedded sensors would come from other fields of use (transportation for instance) as pervasive technologies that would be user-centric. **Performance management** allows merging the best available technologies and processes to optimise both costs and performances of new or refurbished buildings. The ability to interact with smart grids would be mandatory. This implies not only connection capacities for energy supply including smart storage functionality, but also adaptable solutions for the buildings or districts themselves. The prediction of peak loads (e.g. by weather forecast) or support for low prices to load batteries for e-mobility would be implemented. Any changes of the boundary conditions in terms of changing energy production, energy demands, load cases, etc. would be handled. New learning control systems or control systems based on human behaviour may be introduced. Mitigation strategies for climate change can be part of this strategy. All these technologies are based on ICT.

End of life: building demolition is an environmental issue which would grow under the pressure of deeper refurbishment. It can be addressed, both at design (reusable components) and demolition levels (reusable materials). Selective deconstruction to reuse single components and LCA approaches should be pursued further. The building industry is already involved in significant waste recovery (with a focus on concrete, metal and plastics). Innovation is expected in view of contributing both to the lowering of embodied energy/CO_2 and resource efficiency.

Some of the **ICT technologies have an even broader context** for future new or refurbished buildings and districts:

- **Sensor networks** are key components not only as standalone devices, but also embedded in smart Energy Consuming and Producing Products [EupP]. The vision of these devices includes growing embedded intelligence for instance product and repair information;

- **User awareness, occupancy modelling and decision support** now become more complex in a scenario with variable prices for energy and changing supply and demand. Highly integrated solutions are planned at the design phase and influence even the buildings' end of life;

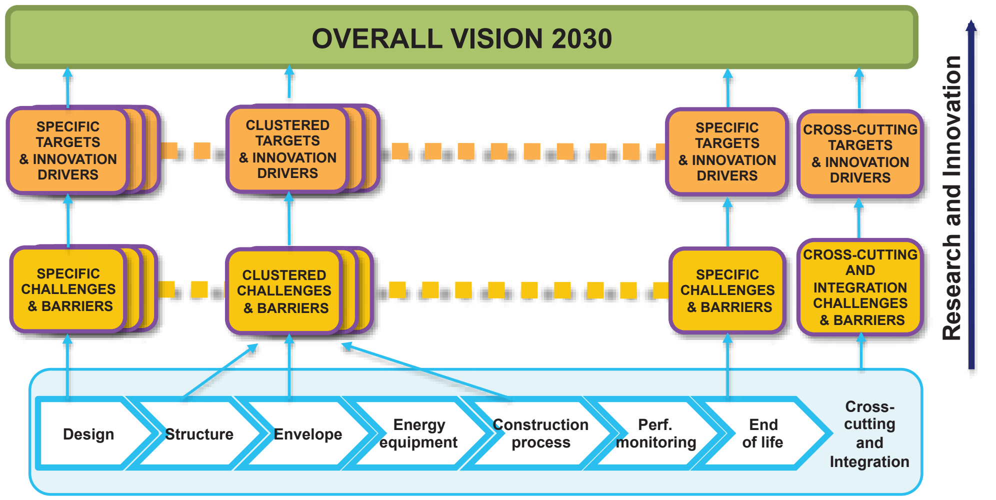
- **True interoperability** would reduce redundant information and information affected with errors. Beginning at the design phase all components of the value chain can be enhanced by secure and long-term working data models and interfaces;

- **New data support systems** provide reporting; data aggregation and statistical elaboration guidance and facilities (see www.concerto.eu). Regulation and standardisation e.g. for EPDs (Environmental Product Declarations) can benefit from it.

The present roadmap provides dedicated innovation trajectories for each element of the value chain (see Figure 7): progressive market availability of technologies and processes would come from large scale demonstrations. They would show irrefutably that the minimum technical and maximum cost performances can be reached on time for the market demand, thanks to integration processes taking care of the global optimisation at building or even district level, and data sharing to help minimising the interface risks inherent to any such complex system optimisation process. Many challenges, barriers, targets and innovation drivers can be clustered (e.g. design, envelope and the construction process) depending on a particular (market) situation. To simplify the structure of this document examples are given at the specific parts of the value chain.

Cross cutting and integration aspects create links along the value chain areas and address the vision of the buildings and districts as part of a smart community and innovation eco-system.

Figure 7. Road mapping process



2 Main drivers to meet the 2050 long term goals

The following drivers were identified as highly relevant for the whole value chain, namely:

- **GHG reduction:** this implies the lowering of the energy demand during the use-phase of the buildings (mainly envelope and HVAC-systems), the lowering of the amount of embodied energy in materials used during the construction process as well as lowering the energy demand for recycling;

- **Material availability and resource efficiency:** due to the decreasing availability of some raw materials, accompanied by the growing public awareness to protect remaining resources, alternative solutions have to be identified and developed. Some renewable material sources would become more cost-efficient and available for a growing number of buildings (e.g. multi story buildings), with direct impact in lowering embodied energy;

- **Increasing prices for energy:** the pay-back time of investments in energy-efficient technologies depend on energy prices. Due to the fact that energy prices increased more than average, the market for such investments would rise not only in Europe. This offers great opportunities for the building industry if it is prepared to deal with the requirements in different regions. Yet, these technologies are not cost-efficient enough for a refurbishment rate above 1 %. Today the costs for energy rise for both owners and tenants disproportionately fast. This affects the spending capacity of more and more EU citizens. Especially households with low income need affordable living spaces in the nearer future. Energy-efficient buildings and districts built with new cost-efficient technologies would offer this;

- **Improving the long-term values of buildings:** energy-efficient new buildings and refurbished buildings offer monetary safety for long-term investments.

A low energy demand makes them more independent from rising energy prices. Furthermore, comfort, health, and the fulfilling of social needs can be improved by investing in energy-efficiency. Other aspects like safety, cultural heritage or new possibilities for an ageing society can be part of it;

- **Mitigation strategies for climate change:** buildings must be ready for climate change. Depending on regional aspects this includes changing energy demands for heating and cooling, changing material requirements or construction, durability for all kind of weather extremes;

- **Growing interaction between buildings or districts and grids/networks:** building design would more and more benefit from evolving electricity, heating and cooling distribution networks which integrate more decentralised and renewable energy sources, as well as emerging flexibility in the consumers' demand (demand response schemes). Electrical and thermal loads of building would less and less be a burden for the local grid (e.g. adding to the peak load). Rather, energy management systems in buildings would support energy management; thanks to the increased flexibility in energy consumption behaviours – this includes e-mobility;

- **Integration with ICT technologies:** various ICT-technologies offer major improvements for planners, owners and end-users. Adaptable long-term data models need to be developed and should be available from the design phase to the end-of-life and inform about all necessary aspects in the different phases of the building. Smart ICT would interact with the buildings' supply systems, the monitoring systems and the occupants not only for heating cooling shading and lighting but also to interact with smart grid technologies e.g. for energy storage. End-users would benefit from information about cost-efficient energy supply but also from improvements concerning various social aspects;

- **Taking into account the whole life cycle:** based on new ICT-models LCA and LCC would become standard procedures for energy-efficient new buildings and refurbishment. European directives for material usage and safety would be part of optimisation within the planning process from the beginning design phase;

- **End of life improvements:** today approximately five times more building material mass is used for new and refurbished buildings than disposed or recycled in the EU. Many valuable components or materials can be reused or recycled instead, but only in a few EU countries corresponding markets develop especially for valuable goods like metals.

Energy independence and renewable energy as well as safety, comfort and indoor air quality could be considered as additional drivers. Specific drivers were identified for each area of the value chain and they are reported in Appendix 2.

3 Main research and innovation areas: specific challenges, barriers and targets

3.1 Design

Design Challenges and Barriers

The Design phase affects all other parts of the value chain. The development of new innovative products may be connected to only some of these parts of the value chain. In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

	Challenge	Barriers	
Design	The design of energy/ resource efficient buildings (new or to be refurbished) must involve all stake-holders within a collaborative approach, allowing cost-efficient solutions Improving the planning process implies shared data, practices and tools with proper training and education	**Technical/ Technological**	No proper tools for easy holistic planning of energy-efficient buildings exist for a number of building types, especially for refurbishment. Several software products and lack of tool interoperability: exchange of error-free data from one 3D building-CAD to another is not possible at present; Reliable material and equipment data base for holistic planning
		Industrial	Software vendors still hesitate to invest in BIM interoperability due to the lack of demand in having compatible BIM, IFC, IFD, IDM/MVD limitations
		Economic	Little realisation at district or city level for large scale improvements of the existing stock or new urban development at reasonable costs. Time constraints impact iterative design in terms of energy efficiency
		Societal	Resistance to change Considerations for cultural heritage buildings
		Organisational	Building Information Modelling makes responsibility sharing fuzzy Lack of Experts on combined BIM and IFC knowledge
		Regulatory	Simplification in approval procedures for building permissions of energy-efficient districts. IFC certification suffers low quality Regulating qualitative issues is difficult

Design Targets

Target 1: A multi-scale cross-disciplinary holistic approach fostering interactions among players (including software suite and training) is set up for the design of energy efficient buildings and districts in Europe

By 2020, the design process would be able to integrate different spatial dimensions from the building (micro scale) to the district, and to urban planning (macro scale), in order to optimise the design phase at a micro-scale and coordinate the integrated operational performance of the macro-components.

This multi-scale approach includes:

- The interactions among players (contractors/architects/engineers with local governing bodies and institutions, utilities, and all stakeholders from cities and neighbourhoods);
- The interactions among different infrastructures of the environment (building, set of buildings, networks, (including grids), transport...);
- Methodologies and tools that go beyond the building scale, for example new models of costs/benefits analysis.

The change of mindsets supports integrated design and collaboration among architects, engineers, contractors and material engineers. A robust design approach allows dealing with possible deviations in the whole design process. The attention to the acceptability of the

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innovative building products by end-user is of outmost importance. Education and training is a key pillar. Innovative learning-by-doing techniques must be developed to trigger the behavioural changes, since best practices and successful examples are already identified and available. Such innovative training techniques should lean on the learning possibilities related to simulation and gaming.

The following research and innovation '**Targeted Areas (TA)**' can be identified:

- *TA1.1: Eco-design tools for new buildings involving model-based CAD approaches and interoperable interface;*
- *TA1.2: Innovative training approaches to promote design tools for refurbishment;*
- *TA1.3: Eco design and resource efficient approaches are implemented for all new technology development projects using LCA and European data bases allowing responsible sourcing.*

Target 2: A validated European cross-disciplinary 'design for affordable sustainability' framework supports new and refurbished construction projects which minimise building GHG emissions AND their cost of ownership

A holistic approach must be developed to optimise both the GHG emissions and building costs[26], within a quality system, such as ISO 9000, supporting a continuous process improvement mindset. A European collaborative framework, therefore, aims at promoting collaborative work and at setting up principles for design, engineering (envelope, HVAC-systems, fittings, structure) and construction processes in order to:

- For refurbishment:
  - Facilitate the interactions between players;
  - Provide guidelines to assess and evaluate the historic value of buildings;
  - Provide methodologies, tools and guidelines supporting refurbishment design for the different buildings types and categories (including buildings of historical and cultural value), including structural upgrading and retrofit for safety issues (e.g. fire, seismic, structural stability);
  - Intensify the certification processes,;
  - Share information on the technological performances;
  - Develop business models.
- For new buildings:
  - Reduce the overall CO_2emissions and environmental impact of materials used in the whole building;
  - Reduce the buildings' cost by using components, materials, or other equipment more efficiently (design and construction principles);
  - Simplify the assembly of all parts of the building during the construction process and provide smart grid / cities interaction;

26 A template for such a system born from industry initiatives is the Six Sigma framework introduced by General Electric in the late 90's in the USA.

  - Provide adaptability to changing demands on the utilisation;
  - Comply with building codes and standards (energy-efficiency, resistance to fire, earthquakes, etc.).

- For buildings end-of-life:

  - Select reuse, demolition or deconstruction options in a transparent way;
  - Take into account the dismantling issues at the building design stage, including LCA approaches[27];
  - Identify and disseminate good practices for recycling and deconstruction.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA2.1: Shared engineering and economic databases (materials, products, reference design solutions, building energy profiles, user group profiles) to support the minimisation of building GHG emissions and their cost of ownership (new and refurbished buildings,* including buildings of historical and cultural value*);*

- *TA2.2: Innovative design tools for refurbishment (from building to district,* including those having an historical and cultural value*) with improved design accuracy validated on large scale district refurbishment demonstration (to narrow the gap between design value and performance after building and district commissioning) and involving all stakeholders (including construction companies);*

- *TA2.3: Libraries of reference design solutions (including EE product catalogue, good practices, compliance with building codes) with semantic research tools.*

Target 3: Improved collaborative building management tools integrating the whole lifecycle information from sourcing to building construction, refurbishing and end-of-life

Management tools are needed to support the integrated design and the collaborative work between architects, engineers and contractors, including the sharing of technical information on the building over its whole lifecycle. Such management tools include techniques and tools related to Life Cycle Assessment (LCA) and Building Information Modelling (BIM). Life Cycle Assessment and Life Cycle Costing (LCC) methods and tools must allow transparent and reliable evaluations of building design and end-of-life options. The most critical issues to be addressed by such tools encompass:

- The development of an appropriate database;

- The development of LCA and LCC synergies with BIM;

- The comparative assessment of partial/total refurbishment options against demolition;

- The comparative assessment of dismantling versus demolition, at the whole-building level, also linking to broader dimensions such as the district scale;

27 The same idea applies at the building component level: designing for reuse/recycling.

- The acknowledgment of social parameters (such as preservation of cultural heritage);
- The acknowledgment of reuse and recycling issues of the building material and components;
- The affordability of implementation.

In parallel, the use of BIM must be encouraged and expanded, as a support to information sharing and more intensive collaboration along the whole building value chain. BIM tools must show clear positive Return on Investment, and full interoperability, from design to construction and monitoring processes:

- BIM cost and staff investment must be balanced by clear benefits, not only for contractors and constructors, but also for architects and engineers of the design stage, often bearing the BIM investment;
- BIM tools must guarantee transparent and neutral simulations and assessments, i.e. certified evaluation of building options;
- Synergies with other ICT tools and LCA tools would be made possible thanks to a full interoperability of BIM systems, not only for the design stage, but also for the construction and monitoring process.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA3.1: Enhanced BIM models based on standardised energy efficient attributes and modelling of building energy profiles;*
- *TA3.2: Ontologies (data models) to describe materials, equipment and technology interfaces typical of building and district projects;*
- *TA3.3: Cost effective BIM tools able to merge building models and building construction process management;*
- *TA3.4: BIM control and certification methodologies;*
- *TA3.5: Approaches to enforce the long term legal and contractual validity of building information models.*

3.2 Structure

Structure Challenges and Barriers

In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

	Challenge	Barriers	
STRUCTURE	• The embodied CO_2 of building structure materials must be significantly lowered • The structure can be used as a thermal storage for smart heating or cooling	**Technical/ Technological**	Reuse of existing structures to be equipped with innovative envelopes, fittings and HVAC-systems instead of demolition Innovative structural materials with low embodied CO_2 for new structures possessing same performance parameters that state-of-the-art technology and to be produced on a multi-million tons or m^3 scale are not available
		Industrial	Characterisation methods and standards for eco construction materials are missing
		Economic	The costs for demolition and new construction are easier to calculate than reuse and retrofitting Costs of future low CO_2 solutions need to be competitive with state-of-the art technology to enable market penetration Costs of renovation may be very high in case of historic buildings
		Societal	The trust of the construction sector towards new materials is poor; Cultural heritage value may be underestimated The contribution of structural engineers to energy efficiency is underestimated
		Organisational	Structural eco products and solutions are lacking visibility
		Regulatory	Codes and regulations need to evolve and become supportive regarding the reuse of existing structures and use of eco materials for new structures Need to further raise awareness of regulations concerning the preservation of historic buildings

Structure Targets

Target 4: Reuse of existing structures with their embodied energy

Innovative solutions for the reuse of existing structures can prevent the demolition and the need to dispose or to down-cycle materials. In order to increase the retrofitting rate significantly it would be necessary to find new solutions for economic reuse. If neither the envelope nor fittings or HVAC-systems fulfil the requirements for an economical retrofitting nor complete or partial dismantling is carried out, new construction procedures for the reuse of the structural parts would be introduced.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA4.1: Development of strategies to identify economic construction procedures for reuse of structures;*
- *TA4.2: Development of procedures to determine the structural load capacity of existing structures accurately, which are easy to use and cost-efficient.*

Target 5: Affordable, adaptable and durable structural systems have a low embodied CO_2 content

Future materials must demonstrate a significantly reduced level of embodied carbon via a systematic carbon footprint assessment based on life cycle approaches. The materials would also:


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- Demonstrate a good workability for an easy placement, installation and integration during the construction process: each component shall meet building integration requirements that make it easy to implement and interface in the structure subsystem and with the other subsystems (envelope in particular) during the construction process;

- Be responsibly sourced[28];

- Be non-toxic (low VOC and hazardous substances emissions level);

- Be reusable or recyclable, including those derived from renewable resource-based materials;

- Have a high durability and stability over very long periods of time.

The following research and innovation '**Targeted Area**' can be identified:

- *TA5.1: Development of novel cost competitive high volume and high performance eco-construction materials (including cement, concrete, gypsum, glass, steel, FRP materials, wood, to name a few) to cost efficiently cut down CO_2 emissions of the construction sector and associated with low embodied carbon and improved resource efficiency.*

3.3 Envelope

Envelope Challenges and Barriers

Envelope is a critical element to reach the 2050 decarbonisation goals, indeed according to US DoE[29] estimation, the building envelope impacts 57 % of the building thermal loads. In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

28 See BES 6001 certification in the UK for example.

29 *Building Technologies Program, Roadmap overview*, Marc LaFrance, Buildings XI Conference DOE Roadmap Meeting, December 2010.

<table>
<tr><th></th><th>Challenge</th><th colspan="2">Barriers</th></tr>
<tr><td rowspan="6">ENVELOPE</td><td rowspan="6">• A reliable multi-objective envelope optimisation methodology allows integrating all envelope constraints for new and refurbished buildings
• Performances keep improving in terms of insulation, costs, energy harvesting, building integration and building adaptability
• Innovative materials and prefabricated components help improving energy & resource efficiency durably
• Users are accounted for the delivery of the full energy performance potential of envelopes
• full exploitation of different climate potential</td><td>Technical/ Technological</td><td>Meeting the design performances of integrated envelopes is still difficult;
Assessing the contribution of each envelope component to the system performance over time is still difficult;
The detection of users' misbehaviour is very limited;
Data on material characteristics and energy needs are lacking</td></tr>
<tr><td>Industrial</td><td>Industrialisation of building envelope solutions still very costly and prefabrication is under represented;
Characterisation methods and standards lack high volume / high performance eco construction materials;</td></tr>
<tr><td>Economic</td><td>The selection of envelope solutions is still driven by investment costs and building codes;
Integrating the envelope components is still costly to meet the final performance targets;
Return on investment for refurbishment projects is not attractive;
High intrusiveness in refurbishment intervention;</td></tr>
<tr><td>Societal</td><td>Building owners are not open enough to make sustainable choices;
High intrusiveness in refurbishment intervention;
New multifunctional components require continuous education of craftsmen which is often not the case.
Limited awareness of cultural heritage value.</td></tr>
<tr><td>Organisational</td><td>Lack of performance commitments on refurbishment contracts;
Skills on envelope design and selection to be raised;
Dispersed ownership in large housing/buildings prevents from refurbishment;
Fragmented value chain often leads to non-optimal overall performance;
Building planners often have problems with innovative materials and components.</td></tr>
<tr><td>Regulatory</td><td>Differences in national standards slow components standardisation and prefabrication;
Guarantee and insurance schemes for refurbishment;
Regulations for public decision promote lowest prices, not best performances
Regulations for historic buildings preservation may be complex and it may vary considerably from country to country</td></tr>
</table>

Envelope Targets

Energy efficient buildings would use envelopes that are well-performing in terms of heat transfer and air tightness, durable, adaptable, user-centric and cost effective. Envelopes become more resistant to external (i.e. climate, fire, and natural hazards) and internal aggressions (moisture): they require less maintenance and allow for easier and better-quality maintenance work. Thermal bridges are addresses and the ageing of components is better understood which allows appraising their loss of performance over time.

Target 6: Energy efficient envelopes combine easy to integrate materials and components to lower building energy demand

Materials and components are critical to envelope both for insulating properties but also for anchoring the resulting envelope on existing or new structural elements. Current technologies are not efficient enough in terms of performance and costs, especially for refurbishment and cultural heritage where details and original aesthetics need to be kept (e.g. windows). Further research is needed to improve understanding of material and component behaviour in the whole life cycle and, as a consequence, to be able to produce corresponding products. Know-how is thus needed to help designers and construction companies to define more exactly the materials and components really needed to fulfil the needs of the works through service life modelling and design. Durability has to be evaluated in real installation conditions, as these may influence final product performances. Mass manufacturing including pre-fabrication must be investigated to lower manufacturing costs and ease building integration processes, including aesthetics. Advanced and high-performance materials/products (i.e. concrete and composite products, steel-based products, ceramic products, tiles, bricks, nanotechnology-based insulation materials and coatings…) are needed mainly to reduce the building energy demand in the use-phase. Further actions are necessary to lower the content of embodied energy. New materials combining structural properties and/or thermal resistance/ inertia and/or light weight need to be developed. Solutions should address the well known problem of thermal bridges while taking into account overall resource efficiency issues along life cycle.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA6.1: Development of innovative super insulating materials and components, and associated manufacturing processes, for refurbishing existing buildings (including those of historical and cultural value) and new buildings:*
    - *new cost-effective energy efficient insulating materials from renewable sources or waste materials*
    - *materials with λ<0.03 W/mK based on nano-foams, silica aerogels or mineral foams, capable to both retain and reflect heat from inside or outside or integrate other functions with solutions for both new buildings and for energetic improvement of existing ones*
    - *bio-based materials like natural fibres or foams for insulation with high durability*
    - *innovative materials for barriers, pipes etc. for easy integration and reduction of thermal bridges*
- *TA6.2: New value chains for bio-based construction materials and bio-based treatments considering the complete life cycle;*
- *TA6.3: Improve technical properties (e.g. fire resistance) for organic materials;*
- *TA6.4:Development of chemical coupling agents and binders;*

- *TA6.5: New masonry based building components with integrated high-efficient insulation materials;*
- *TA6.6: Low-CO_2 advanced concrete available for durable building envelopes;*
- *TA6.7: Basement insulation, moisture protecting systems and new building materials for draining;*
- *TA6.8: Mass manufactured prefabricated modules for optimum cost, performance, product handling and personal safety during construction, both for new buildings and for refurbishing;*
- *TA6.9: Demonstration of photo-catalyst or other de-polluting materials to extend the life of construction materials (with e.g. automatic cleaning process) and at the same time* substantially decrease the concentration of some air pollutants in urban air (COV, SOx, NOx), especially in confined spaces such as canyon streets, tunnels and parking;
- *TA6.10: Modular, 'plug and play', mass customised envelope solutions to ease construction processes and replacement of components (i.e. windows).*

Target 7: User centric envelopes maximise the envelope value, including improved aesthetics, acoustic and lighting comfort, quality of indoor environment

Envelopes demonstrate usability and flexibility to contribute to improved health and comfort, while taking into account use values which reinforces users' acceptance:

- The adaptation to the users' evolution (people ageing) and users' behaviour;
- The reduction of the intrusiveness of façade retrofitting activities in order to maintain the general building functionalities and reducing the impact for the user.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA7.1: Technologies and methods to understand and maximise user acceptance of adaptable envelopes in new and existing buildings (including buildings of historical and cultural value), addressing for instance air quality, moisture control, ventilation control or automated blinds, with interrelated issues of summer overheating, air-tightness and indoor air quality;*
- *TA7.2: Techniques to minimise the Volatile and Semi-volatile Organic Compound (VOC, SVOC) content of building materials (in the production phase and the use-phase).*

Target 8: Envelopes are adaptable to a dynamic and complex environment

The envelope functional characteristics enable the building envelope to adapt to a dynamic and complex environment during its lifetime[30] ('Perception, Reasoning, Action'). Envelopes also

30 See *Intelligent Building Envelopes — Architectural Concept & Applications for Day lighting Quality*, Annemie Wyckman, 2005.

facilitate the future renovation or conversion of the whole or part of the building fostering creativity and an active role of architects and engineers at design stage:

- The capability of adapting to different shapes, façade conditions, building orientations and general conditions of the building along its lifetime;
- The conversion of rooms, or buildings, to new usage;
- The possibility to integrate new solutions (upcoming technologies) and systems;
- The capability of dynamic adaptation or self-adaptation, which becomes also crucial due to:
  - Current weather and building load situation, taking into account the actual user's preferences.
  - Changing use patterns, including new users, or family instead of single users.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA8.1: Development and manufacturing of envelope improving and optimising natural light and ventilation inside building;*
- *TA8.2: Development and manufacturing of energy storing converting materials (e.g., Phase Change Materials and switchable glazing (e.g. thermochromic, photochromic or electrochromic) combined with PV in glazing panes);*
- *TA8.3: Development of semi permeable insulation membranes and pigments with adaptable absorption reflection spectrum, Façade component with changing IR absorption and reflection on demand in combination with insulation and switchable U-values;*
- *TA8.4: New testing procedures to measure material performances (e.g. with reference also to adaptive performances), including a wide range of expected exposure conditions;*
- *TA8.5: Seamless system integration of ICT components used to optimise the real time performance of envelopes;*
- *TA8.6: Improved flexible and durable façade systems with movable sun barriers;*
- *TA8.7: Full scale demonstrations of adaptable envelope integration in building refurbishment projects, including smart insulation materials (e.g. aerogels, vacuum insulation panels or other innovative materials);*
- *TA8.8: Full scale demonstrations of adaptable envelope integration in district refurbishment project.*

Target 9: Envelopes are able to integrate generation and conversion of incoming solar radiation

Both PV and thermal conversion can be smartly integrated to recover further solar incoming radiation, together with storage solutions. Façades can then be made active or reactive to signals from energy management systems. System integration must then be based on interoperable IT systems and interfaced with building energy management systems, smart grids or smart cities.

The following research and innovation '**Targeted Areas**' can be identified:

- TA9.1: Smart building envelopes capable of adapting their energy generation and storage to external condition;
- TA9.2: Integration of existing and innovative PV components (e.g. OPV, DSSC) into building envelopes;
- TA9.3: System integration of 'thermally activated' material to reduce energy consumption;
- TA9.4: Interaction with smart grid/city systems.

3.4 Energy equipment

Energy Equipment Challenges and Barriers

Envelope and energy equipment are synergically integrated into building design. Building envelope and energy equipment would progressively merge to ensure optimised energy management. The envelope, controlled by innovative BEMS, can store and release energy to minimise energy peak demand. In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.


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	Challenge	Barriers	
STRUCTURE	• Interconnected energy equipment is deployed in existing and new buildings to contribute to global energy performance • The socioeconomic aspects of energy management are taken into account to make sure that high performance buildings are used properly	**Technical/ Technological**	Efficient storage systems for electrical and thermal power are missing Energy equipment is insufficiently interoperable Energy efficient heating, cooling and generating systems are difficult to integrate in smart cities environments The actual performance and robustness of advanced BEMS with interconnected energy equipment is unclear Standard technological components are missing to ensure data security and confidentiality Operation of thermal storage systems against networks is not properly optimised
		Industrial	Industrialisation costs to reach mass market
		Economic	Trustworthy energy saving potential not yet operational. Flexible pricing systems for changing demand and supply of both thermal and electrical grids are missing.
		Societal	End-users must understand and exploit new pricing models for changing thermal and electric energy supply and demand. Public acceptance of smart metering Public acceptance of mechanical equipment (e.g. ventilation system, automatic lighting, ...) End-users behaviour is poorly understood Limited awareness of cultural heritage buildings and districts specific issues
		Organisational	The variety of equipment suppliers with no interoperable solutions Installers lacking dedicated knowledge
		Regulatory	European legislation at district level probably needed The future legislation on data protection is uncertain

Energy Equipment Targets

Target 10: Energy efficient, interoperable, self-diagnostic and scalable storage, HVAC, lighting and energy solutions in line with energy consumption standards are available for integration into new and refurbished buildings

Effective and affordable storage systems are most crucial for all future energy supply systems based on an increasing amount of fluctuating supply from renewable energies. These systems are interconnected with heat or electricity generators of different size for single buildings to districts or cities. Furthermore, their storage capacity varies according to specific needs. Energy consuming equipment as heating systems and HVAC in general, for example, become more and more energy efficient either for new or refurbished buildings (commercial or residential, including buildings of historical or cultural value) but they have to be sized down and re-optimised since less operational energy is needed in energy efficient buildings. Energy equipment needs to be designed to an optimal energy efficient level depending on supply and demand of energy with integrated storage systems. When considering residential buildings, specific attention must be paid first to **heating, domestic hot water** and then to **cooling,** for instance using a scaled-down heating system based on heat pumps at full load is more efficient than under-using an oversised fossil boiler partly loaded. However, depending on the equipment and application, the optimal size would vary: in some cases maximising the operating time at peak load is best, in other cases maximising the operating time at part load provides efficiency (turbo compressors in modern chillers). The development of district heating and cooling networks is another pathway which deserves more attention, when addressing district issues (e.g. district heating optimised for space heating (40°C) or for domestic hot water (60°C). In this framework, the potential of renewable energy sources or integrated solutions (i.e. heat pumps, geothermal, solar or biomass, possibly combined with Organic Rankine Cycles or other low temperature heat recovery technologies) should be better exploited at district scale. This may include the possible integration with existing networks (i.e. electric, heating or cooling) and waste heat recovery from industrial facilities.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA10.1: Building integrated electrical storage (building and district level);*
- *TA10.2: Building integrated thermal storage (at building and district level);*
- *TA10.3: Space and domestic hot water heating systems integrated at building and district level (including for instance Hybrid heat pumps or Thermo-electrical heat pumps) combined with storage;*
- *TA10.4:Cooling systems integrated at building level and district level (including Heat pumps and storage);*
- *TA10.5: Combined Heat and Power systems integrated at building and district levels, fully exploiting the renewable energy potential;*
- *TA10.6: Flexible and active demand to optimise local production/consumption strategies;*
- *TA10.7: Renewable energy production (heating, cooling, electricity) integrated at building level;*
- *TA10.8: Renewable energy production (heating, cooling, electricity) integrated at district level (incl. heat networks);*
- *TA10.9: Building integrated Ventilation systems with heat recovery (air quality, air tightness);*
- *TA10.10: Heat management and optimisation (high/low temperature systems) at district level (e.g. exploiting ICT or waste heat recovery technologies — e.g. Organic Rankine Cycles — from industrial facilities);*
- *TA10.11: Low GHG refrigerants;*
- *TA10.12: Building integrated flexible lighting system using LEDs or OLEDs.*

Target 11: Minimum European energy performance standards, certification and labelling schemes are applied to building-integrated, interoperable energy using and energy generating equipment

The deployment of energy efficient Energy using Products in buildings implies that independent information perceived as trustworthy, comparable and unbiased supports their uptake. The provision of objective information on the performance (and guarantee of performance) of available technologies can boost customers' acceptance and accelerate deployment. Reliable, tailor-made, 'easy to understand' information for end-users is therefore important. Standardised national and international testing and evaluation procedures for specific technologies would also increase understanding among developers, architects and installers and accelerate the maturity of the industry more broadly. In line with European directives (such as the EPBD Directive 2010/31/EC which provides minimum energy performance requirements and a set of standards) and programmes (e.g. the Environmental Verification programme), **European certification schemes** are harmonised and adaptable for different regions /climate conditions. They include:

- HVAC components, in particular systems for space heating and, to some extent, for air cooling systems, whose demand is increasing, and which currently typically use refrigerants with very high global warming potential;
- Hot domestic water systems;
- Lighting;
- Direct current networks inside buildings and with connection to new grids to reduce losses by eliminating AC/DC conversion and increase level of control;
- Energy storage equipment (electricity, heat and cool).

Objective and transparent labelling[31] of energy related products needs to be accelerated, in order to build on the impacts of the EU Appliance Labelling[32]. **More stringent European standards** might also be envisaged in order to maximise the energy efficiency of energy consuming equipment. Standards should be revised from time to time to provide European manufacturers with the needed stimulus to take the lead in the development of more efficient appliances (i.e. appliances fitting the highest efficiency class), thereby increasing their worldwide competitiveness[33].

31 This labelling should be in line in the ErP Directive 2009/125/EC and Energy Labelling directive 2010/30/EU. The consistency and harmonisation of the rules set up by the EPBD, Energy Labelling and ErP Directives is however a prerequisite to ensure the effectiveness of such labelling.

32 An evaluation of the impact of the EU appliance-labelling scheme showed a dramatic shift in the efficiency of refrigerators sold in the EU in the first decade of its standards and labelling programme (Bertoldi, P., 2000: *The European strategy for reducing standby losses in consumer electronics: status and results*. In *Proceeding of the ACEEE 2000 Summer Study on Energy Efficiency in Buildings*, Washington D.C.).

33 For example, Japan imposes stringent energy efficiency standards on equipment through its 'Top Runner Programme' by distinctly setting the target values based on the most energy-efficient model on the market at the time of the value-setting process.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA11.1: Development of novel methodologies to set up more stringent and ambitious standards with a continuous improvement approach for different regions/climate conditions across Europe;*
- *TA11.2: Benchmarking and calculation tools to deliver information to decision-makers (architects, engineers, professional builders) on energy performance of different technologies;*
- *TA11.3: Harmonise test procedures and efficiency labelling schemes to facilitate trade and transparency about the performances of energy using products.*

Target 12: User-centric multi-scale BEMS allow improving the level of users' awareness and optimising energy demand at buildings and district levels

BEMS implement holistic approaches in managing energy related systems (intelligent HVAC, lighting, smart plugs, local generation, energy storage, etc.), accounting for the different reaction times, and in synergy with the envelope. These novel and interoperable BEMS ensure that building systems are coupled for maximum energy efficiency (energy optimal coordination algorithms) without forgetting to limit peak demand on the grid, which either reduces the bill or maximises the revenues in case of positive energy buildings. The BEMS interact with users to depict how energy has been spent or produced, providing continuous improvement directions to the stakeholders. Ambient intelligence and intuitive users' interfaces take into account users' behaviours and tolerate users' behaviour changes. They are applicable to new and existing buildings, including those of historical and cultural value.

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The following research and innovation '**Targeted Areas**' can be identified:

- *TA12.1:Multi-parameter (light, temperature, air quality, moisture, instrumentation of HVAC, ...) low cost sensors for BEMS integration;*
- *TA12.2: Standardised functionalities for sensors and actuators to allow 'plug & play' of new devices (e.g. motorised shutters) and self-reconfiguration of sensor networks;*
- *TA12.3: Robust, resilient and reconfigurable sensor networks;*
- *TA12.4: Building embedded sensors;*
- *TA12.5: Interoperable and adaptable BEMS able to optimise energy use spatially (at a building and district level) and temporally with predicting capability (energy loads forecast);*

- *TA12.6: Interoperable smart meters able to measure, record and visualise all kinds of energy consumption (incl. building generated energy supply, water and heat-transfer fluids);*

- *TA12.7: Standard transmission protocols to ensure reliability, security and privacy of data streams;*

- *TA12.8: User-centric interfaces measuring the use value, with associated acceptance studies;*

- *TA12.9: Smart consumption display to motivate users at reducing their energy needs through behavioural changes and/or good practices implementation.*

Target 13: Dynamic Energy management systems and management protocols are available to optimise energy generation, storage and distribution at district level

Individual homes and buildings optimisation should be considered within their district dimension in order to address the building-grid interactions and reduce the urban heat island effects. Whereas urban heat island effects could be tackled through district and building design (land use, surfaces and shading effects), protocols, interoperable systems and interfaces to local energy networks (heating and cooling, electricity) need to be developed to manage the energy demand (using the potential flexibility of the usages), to dynamically optimise the distribution of locally generated and stored energy and to minimise imports from the grid, in particular during peak hours. Energy pooling and sharing has to be effective at a district level as well as at a subsystem level (i.e. between groups of buildings).

The following research and innovation '**Targeted Areas**' can be identified:

- *TA13.1: Development and demonstration of multi-scale real time optimisation tools (flat, building, district, city-wide level) including peak load management, demand-side management, building- and grid-integrated thermal and electrical energy storage, having the potential for energy storage pooling and local energy generation (based on reliable data model for neighbourhood/district level energy systems);*

- *TA13.2: Holistic control strategies based on building simulation tools;*

- *TA13.3: Development and demonstration of Direct Current building electricity networks;*

- *TA13.4: Modelling district energy consumption and building interactions for instance with Cloud computing;*

- *TA13.5: Demonstration of systems and protocols to optimise energy storage and production at district level, involving possibly district energy market places and participation of large prosumers to local markets.*

3.5 Construction process

Construction Challenges and Barriers

In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

<table>
<tr><th></th><th>Challenge</th><th colspan="2">Barriers</th></tr>
<tr><td rowspan="7">Construction Processes</td><td rowspan="7">• Worker-centric construction processes are durable, adaptable, with better productivity and are able to cope with the increasing complexity of buildings
• Quality driven construction processes involving skilled workers are developed to improve the predictability of energy performance
• The construction process becomes a more collective process
• Lean Management of the construction process in particular in retrofitting case</td><td>Technical/ Technological</td><td>Methods for energy related self-inspection are still lacking</td></tr>
<tr><td>Industrial</td><td>The construction industry is not yet fully ready for prefabrication away from the construction site</td></tr>
<tr><td>Economic</td><td>Upfront investment costs are high for new construction technologies
Refurbishing costs are high</td></tr>
<tr><td>Societal</td><td>Concerns about health and safety of the workers may slow down the pace of the refurbishing process
Compatibility of processes with buildings of historical value</td></tr>
<tr><td>Organisational</td><td>The building sector is slow to adopt new technologies and lacks the skilled workforce to meet the refurbishment rate</td></tr>
<tr><td>Regulatory</td><td>Harmonised building codes and regulations</td></tr>
</table>

Construction Processes Targets

Construction processes of energy efficient buildings ought to be durable, adaptable, and worker-centric. The increasing productivity of construction companies shall counterbalance the increasing complexity of the construction of energy efficient buildings.

Target 14: Self-inspection techniques support the commitment of each worker to meet intermediate performance targets for the built environment

Each player of the construction value chain must ensure that its share of work fits into a quality framework defined collectively at the design level. Self-inspection and quality checks are implemented to guarantee the final thermal, acoustic and energy performance of the building which would be quantified during commissioning. Undamaged thermal insulation layers and the air tightness of buildings must be reported as well as fully functional building services equipment.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA14.1: Techniques to measure the contribution of each critical component to thermal insulation, air-tightness and building services equipment in energy efficient construction;*
- *TA14.2: Development of standardised self-testing sensors/meters and performance verification procedures (air-tightness testing, thermal survey with IR cameras and spectral imaging approaches, etc.)*

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Target 15: Interoperable, safe and cost-effective solutions and quality driven management approaches help workers meet more stringent quality criteria

ICT-assisted construction processes expand since their adoption is facilitated by workers that are used to play familiar with electronic game-devices having intrinsic user-friendliness. These worker-centric solutions make use of smart interfaces implemented in robust smart-phones or tablets, involving cloud computing and ubiquitous wireless web access. A broader adoption of robust RFID (Radio Frequency Identification) technologies could significantly improve quality control mechanisms. Such solutions should allow increased productivity, increased reliability (reduced errors) and improved safety for the workers: they indeed include interoperable information systems and shared databases to describe the building's main features, and collect quality control information at intermediate milestones of the construction process.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA15.1: Cost effective innovative ICT-based technologies (e.g. based on robust smartphones and tablets, cameras for 3D scanning, RFID, spectral imaging etc.) to deliver building data in real time to the workers involved in the construction process (model-based design and production planning integrating information flows across the value network, flexible project team management, contract configuration and management);*

- *TA15.2: Innovative construction processes to provide workers with safer and healthier environments (for instance asbestos handling during refurbishment processes).*

- *TA15.3:* Lean Construction Management of refurbishment works, to improve communication among involved stakeholders, reduce costs and improve quality.

Target 16: Advanced and automated processes that favour the use of prefabricated modular solutions are available to ease new building and refurbishing high performance works

Building components could, when relevant, be prefabricated in factories to gain on construction time, to improve health and safety at work and to reduce the embodied energy of the building. This is particularly adapted to refurbishment, where parts of the new envelope can be pre-assembled off-site: it can borrow from mass customisation techniques already available for windows. Prefabricated parts can be monitored in combination with a Building Information Model so that their location and guidelines for integration and installation are made readily available to all the parties involved. New processes would need to be developed, tested and implemented considering the use of dedicated handling tools, enhanced scanning technology to collect spectral and geometric information as well as automated machines which are deployed in parallel to assist workers in reducing time to deploy and increasing quality standards. These new processes would require additional training and definition of new emerging risks.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA16.1: Cost effective innovative automated/robotised construction tools for refurbishing applications and new constructions;*

- *TA16.2: Mobile factories (portable manufacturing facilities, placed near the construction site);*

- *TA16.3: Tracking systems (e.g. RFID, WSN, or with barcode/QR code etc.) for material and product implementation in new or existing buildings, including those of historical or cultural value.*

Target 17: Setting up of appropriate training schemes to continuously improve worker skills

All parties of the construction process are continuously provided with certified education and training schemes: the qualified worker base is expanded in order to meet the demand for a workforce specialised in energy-efficient buildings. A special attention is paid to SMEs to ensure that, as companies, they meet the appropriate qualification expected by contractors. Training techniques are developed to:

- Promote collaborative work within the construction sector;

- Make people responsible for the quality level of their work (understanding the importance of air tightness, minimisation of thermal bridges, etc.);

- Train on the appropriate use of self-inspection techniques;

- Train on component integration and finishes to help with future building reuse or deconstruction.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA17.1: Training and education platforms (using ICT-enabled tools) to provide certified construction training sanctioned by new skills evaluation processes;*

- *TA17.2: Development and implementation of builder certification schemes, targeting construction SMEs.*

3.6 Performance monitoring

Performance monitoring Challenges and Barriers

Measurements would be integrated as part of the buildings and districts monitoring and as management technologies. The performance monitoring and management are fundamental requirements for future smart grid/cities technologies. In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

<table>
<tr><th></th><th>Challenge</th><th colspan="2">Barriers</th></tr>
<tr><td rowspan="4">Performance monitoring</td><td rowspan="4">• Energy performance would be monitored steadily at the building and wider district levels over long period of times, combined with safety, security, comfort and any other monitoring system
• The building and district energy performance is continuously optimised to meet performance criteria and evolving user's requirement and behaviour (including load forecast)
• Reduce the excess of unused, difficult to understand and not accessible information and data on real energy performance of buildings
• Energy performance based contracts grow steadily
• The actual performances of energy efficient buildings and districts are used as benchmarks by the construction sector for future constructions and refurbishments
• Monitoring system commissioning and building continuous commissioning through the monitoring system</td><td>Technical/ Technological</td><td>Low cost and low maintenance sensors and systems are still lacking
The connection to greater units at district or city level does not exist yet
Energy performance monitoring systems with advanced functionalities are not yet available
Energy equipment is insufficiently interoperable</td></tr>
<tr><td>Economic</td><td>Innovative energy performance monitoring equipment is too expensive</td></tr>
<tr><td>Societal</td><td>Public acceptability of performance monitoring is lacking
The use value and behaviour of end-users is poorly understood
Energy performance need to cope with other monitoring and management aspects, including those related to buildings of cultural value</td></tr>
<tr><td>Regulatory</td><td>Legislation to frame appropriate energy metering in buildings is needed
European legislation on energy management and trading at district level is needed</td></tr>
</table>

Performance Monitoring Targets

Target 18: A European framework on energy performance metering and analysis, going beyond the IPMVP standard (International Performance Measurement and Verification Protocol) favours guaranteed performance contracts:

Common indicators, metering technologies and data analysis methods need to be developed to measure and investigate building performance at commissioning and beyond. Such guidelines are required at European level to promote guaranteed performance contracts in view of securing pathways towards sustainable building decarbonisation and enhanced well-being by

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2050. This European wide approach must go beyond the IPMVP methodology which is very US centric and proved to be ineffective in certain applications.

The energy performance metering and analysis system shall be integrated within the existing systems (safety, security, comfort, etc.) in order to optimise the whole system and would monitor the user's behaviour to enable performance-based contracts. The integration of all existing monitoring systems reduces the cost and increases the synergies among all systems, allowing a more reliable and robust system. By considering the user in the monitoring of the building, a major key factor influencing the overall energy performance of the building, performance-based contracts reduce risks and facilitate implementation.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA18.1: Monitoring of envelope and energy equipment performances in new or existing buildings (including those of historical or cultural value);*

- *TA18.2: Efficient and practical means of measuring and monitoring the IEQ (Indoor Environment Quality, including CO_2 — as an indicator for air quality and triggering the air exchange rate — as well as global temperature, humidity, glare effects, VOC, SVOC, bacteria, fungi, etc.);*

- *TA18.3: Performance indicators at European level allowing comparisons among regulations, user/client requirements, design models and real-life data, including end user behaviour and end-user perception (indoor environment including air quality, ventilation, lighting, etc.);*

- *TA18.4: Performance indicators at European level allowing comparisons among regulations, design models and real life data for district energy efficiency performance.*

- *TA18.5:* Post Occupancy Evaluation to standardise final user surveys and collected data elaboration/presentation.

Target 19: Conditional maintenance techniques are deployed to maximise building energy use efficiency

Condition-based maintenance requires extensive instrumentation of energy equipment[34], and data processing tools at BEMS level to produce real-time diagnosis of building working conditions and energy performances. It would become part of performance guarantee contracts, which may be also envisaged at district level for cooperative buildings. Strategies and business models for efficient and cost effective maintenance, such as performance-driven condition-based maintenance, need to be developed and implemented, taking into consideration the scaling-up and replication issues brought by national regulatory schemes.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA19.1: Development of self-diagnosis subsystems (sensors and algorithms) leading to conditional maintenance improvement, based on LCC optimisation of subsystems (energy equipment, envelope) or systems;*

- *TA19.2: Development of virtual reality approaches to make diagnosis, maintenance and repair more efficient.*

Target 20: A European approach is implemented to measure, monitor and compare the energy performances and use values of energy efficient buildings in Europe: it uses a European observatory on energy performance involving a European wide database

A European observatory on the building stock is established with the goal to measure and monitor energy performance, the use value of energy efficient buildings and of building-integrated technologies or services.

This use value can be appraised through *'in vitro'* or *'in vivo'* approaches and depends, inter alia, on utility (i.e. the perceived benefit), usability and acceptability:

- **Testing labs and facilities need to be networked all over Europe** to undertake *'in vitro'* studies on the use value of energy efficient solutions and assess how it is related to cultural and climatic specificities. Experimental methodologies for *'in vitro'* validation have to be developed, and should be based on modular testing facilities, able to reproduce a wide variety of living habitats and boundary conditions;

- *'In vivo'* experiments (or **pilot sites**) with **adequate panels of real life end-users** need to be developed in parallel. These pilot sites would measure the actual impact of the energy efficient solutions on users' behaviour and would integrate the users' feedback with respect to these various solutions. Using methodologies similar to clinical studies (e.g. placebo groups), the pilots would directly involve end-users sorted by profiles (age, activity, type of building, etc.).

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34 Conditional maintenance also calls for improved defect forecasting/diagnosis using fault detection sensors.

The investigation should help determine the optimal strategies to obtain long-lasting eco-behaviours.

Based on best practices and repositories available, the observatory[35] would monitor energy performance and would create a European wide database of real life results on new and refurbished buildings, tracking progress towards the achievement of 2020 and 2050 targets. This observatory keeps an updated track record database, including accurate and useful building specifications in order to establish a knowledge base that would record and centralise energy performance data and global cost data of exemplary buildings that are representative of larger segments of the stock. Each record would include comprehensive information about the building specifications and usage. Knowledge on the building stock and its dynamics (i.e. medium-long trends in new construction, renovation and demolition activities) would constitute the scientific background for effective policy-making and allowing monitoring the progress of such policies and addressing adjustments where necessary.

Roadmaps for building stock renovation can be set up with optimised level of incentives to attain macroeconomic optimality. Market strategies can be developed based on the observatory's database by addressing the most relevant solution sets and type-age groups of buildings that would undergo renovation in a given area in a given period, hence facilitating customised mass production and industrialisation. This knowledge base would also serve as reference data to crosscheck results from building simulation tools, but also as calibration/performance objective for future real constructions. This observatory would also foster an online community to share and rank energy information to compare performance data[36].

The following research and innovation '**Targeted Areas**' can be identified:

- *TA20.1: 'Wiki-like' database to report on R & D, demonstrations and real life results, dealing with energy efficient buildings;*
- *TA20.2: Development and demonstration of energy performance monitoring systems at district level;*
- *TA20.3: Development of monitoring tools able to discriminate the contribution of design, technologies, construction process and user behaviour from the overall building energy performance;*
- *TA20.4: Development of standard protocols for 'in vitro' and 'in vivo' use-value measurements of energy efficient building;*
- *TA20.5: European network of use-value measurement laboratories.*

35 A similar approach is used by the DoE in the USA, which yearly publishes an annual building book, next to best practices which implies that the proposed approach makes use of modern communication technologies.

36 *ICT supported Energy Efficiency in Construction – Strategic Research Roadmap and Implementation Recommendations*, 2010, REEB consortium.

3.7 End of life

End of life Challenges and Barriers

In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

	Challenge	Barriers	
BUILDING'S END OF LIFE	• Building deconstruction practices must evolve from demolition to selective demolition and deconstruction/ dismantling, introducing novel solutions • The choice between demolition/deconstruction or rehabilitation must be based on informed decision-making processes • Sustainable and profitable exit markets must be created and enabled the reuse or recycled materials	**Technical/ Technological**	Technical solutions for producing construction materials and prefabricated elements based on recycled material (like-to-like applications) are uncommon Cost-efficient technologies are lacking 'Contaminating' finishes limit dismantling and reuse Changes in material characteristics prevent from recycling and reuse
		Economic	Deconstruction/dismantling is costly
		Organisational	Lack of a certification scheme for reusing Aesthetics of ageing components A coherent supply chain is missing for reclaimed materials Average lack of skills in Europe to implement deconstruction

End of life Target

Target 21: Innovative paths allow increasing the further utilisation of construction components and materials

End-of-life innovation must be in line with the target of the Waste Framework Directive 2008/98/EC to be achieved by 2020: 70 % by weight of construction and demolition waste preparing for reuse, recycling and other type of recovery[37]. This requires:

- Technical solutions and markets for large scale reuse and recycling of construction materials and components/elements in 'like to like' (equal value) applications (including for example refurbishing energy equipment or reusing in another building or another country where there is a need for energy equipment);
- Cost effective separation technologies for composite construction materials;
- New certification and insurance systems;
- Demonstrations as examples of good practices in recycling and reuse;
- Innovative financial support schemes.

37 EC Waste Directive related abstract: '*the preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.*'

Achieving that target and promoting viable business models requires:

- A clear procedure for the characterisation of waste materials and components in order to acknowledge their ability to be reused or recycled in new components or for applications in sectors outside the building industry;
- The development of procedures for the assessment of the durability and long-term performance of recycled materials;
- The development of specific design rules and construction procedures based on recycled and/or reused components from within or beyond the building sector.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA21.1: Waste collection, separation and reaction techniques in order to increase the reuse of the building waste into recycled composites;*
- *TA21.2: Optimal re-usability or recyclability of different types of products, including deconstruction;*
- *TA21.3: Development of construction materials and elements (incl. prefabricate) containing a high level of recycled materials and recycled components leading to CO_2 savings, energy savings and higher resource efficiency, which ultimately contribute to a resource-efficient and climate change resilient economy;*
- *TA21.4: Development of new materials and processes based on LCA/LCC to account for environmental and sanitary impacts of disassembling: a) Environmental & health impacts of dismantling to be in LCC/CCA; b) materials and processes with no environmental/health impact and easy to disassemble.*

3.8 Cross-cutting and Integration

Cross-cutting and Integration Challenges and Barriers

Beyond the challenges identified at each step of the value chain, some critical issues are related to the integration of these steps of the value chain altogether. Indeed, cross disciplinary approaches must be further developed, allowing the transfer and sharing of good practices and efficient tools along the value chain, either addressing market, technology, quality or any other aspect. Also, system integration of innovative technology components would become the critical process to meet ambitious energy efficiency in the building sector, addressing both new and existing buildings/districts (including those of historical and cultural value). Current integration processes can take care of validated prototypes coming from the on-going PPP EeB. Yet, new integration processes are needed to implement large scale demonstrations up to 2025, but also to minimise industrialisation costs of the validated solutions up to 2025. In the following table we provide an overview of the main challenges and barriers. Details are provided in Appendix 3.

	Challenge	Barriers
CROSS CUTTING	• Research and innovation must be better linked to speed up the market uptake of promising solutions (= pre-normative research) • Standardisation • Comparable labelling (with respect to different regions) • Major social, demographic and climate evolutions by 2050 must be anticipated • The use value of buildings based on an in-depth understanding of users' behaviour must be scientifically assessed and taken into account over the whole building life cycle • A holistic optimisation framework is required to minimise CO_2 emission, energy consumption and cost of ownership, where Life Cycle Assessment supports decision-making stage of the building value chain • The deployment of Building Information Models and Building Automation (BASCS) makes planning and realisation and utilisation of energy efficient solutions more cost-efficient and enables the engagement of constructors and manufacturers • Resource efficiency in buildings must integrate a district dimension with smart grids • The shift in mind set required for collaborative optimisation should be supported by innovative education and training techniques • Innovation processes dealing with the whole building value chain are able to facilitate the integration of novel technologies and construction processes • Networked cooperation involving laboratories to accelerate innovation • Increase citizen awareness on Energy Efficiency	Coordination among architects, engineering means and construction companies can be improved Performance-based construction contracts are difficult to settle down within national legal frameworks Technology costs are high and productivity is decreasing Current LCA methods and tools suffer limitations (data bases on markets and technologies) A conservative attitude and 'silo-based' thinking is still prevailing in the building sector Eco-responsibility is perceived as a burden Lack of knowledge about building lifecycle energy management and difficulty to adapt new technological solutions to existing buildings. Too much property protocols and communications standards coexisting in the market. Access to the knowledge generated in all the fields related to energy efficiency in buildings.

Cross Cutting and Integration Targets

Target 22: A supply chain of adaptable refurbishment solutions is structured taking into account the use value of building users in districts

Pre-fabricated solutions used as configurable 'templates' are available for adaptation into dedicated refurbishment applications. These solutions, based on 'reusable' designs, can be customised to account for local specificities (climate conditions, geographical constraints, cultural habits, architectural and aesthetical coherence at district level including historic value) or regulations. A trade-off must be found between the possibilities of standardising to reduce manufacturing and construction costs, and the level of adaptability that such solutions must have to comply with local specificities. The use value of buildings for inhabitants and users has to be taken into account at building and district level: users' feedback on different criteria, such as wellbeing, comfort, accessibility and aesthetics in refurbished buildings, is required to make refurbishments specifications and adaptable solutions more robust ('user-proof') and more flexible (e.g. better adaptability to the constraints, comfort tolerance adapted to the local culture, etc.).

The following research and innovation '**Targeted Areas**' can be identified:

- *TA22.1: Full scale demonstration of deep building refurbishment based on mass customised envelopes for the different building/construction types;*
- *TA22.2: Decision tools to choose refurbishment versus demolition processes based on LCA/LCC optimisation, addressing where relevant historical and cultural values;*
- *TA22.3: Generic building stock dynamic modelling to optimise refurbishment roadmaps.*

Target 23: The systemic integration of components and sub-systems (e.g. structure, envelope, energy equipment in a smart grid/city environment) covers the whole building value chain

All links at the building value chain (such as, design at district level, servicing the district, design at building level, building, management of buildings and built-up areas, refurbishment) contribute to the energy performance of buildings, including those of historical and cultural value. Between these components, different companies, professions and authorities play a role. Specific points of interest are the connections between undertakings and economic operators, working within the context of the Single European Market, and the authorities, working primarily within a context of national law. Different innovations are necessary to bridge these contexts in a way that promotes energy efficiency of buildings and districts. Transferring these innovations between contexts may contribute to the integration of components and sub-systems.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA23.1: Collaborative platform for concurrent building engineering (design, construction, commissioning, service life, refurbishment, end of life);*
- *TA23.2: Optimal integration processes of components and subsystems to reduce construction costs and risks;*
- *TA23.3: Envelope design tools involving a dynamic multi criteria (incl. use value e.g. thermal, visual and acoustic comfort) optimisation of building integrated envelope, coupled with HVAC, to minimise the cost of ownership while enhancing indoor health and wellness;*
- *TA23.4: Probabilistic tools to model/predict the ageing performance of complex refurbishment projects under European climatic conditions;*
- *TA23.5: Probabilistic tools to model/predict the ageing performance of zero energy buildings;*
- *TA23.6: Models and experimental tests capable of assessing the ageing properties of construction materials and components (including envelopes).*

Target 24: Cross-cutting innovation topics are addressed to speed up innovation take-up at Member State level (pre-normative research, procurement management, standardisation, energy labelling)

Integration covers more than technology and business model issues. National programmes show that pre-normative activities, public procurement management and standardisation issues would be raised and would require dedicated collective approaches. Energy Labelling in all aspects of the built environment would also form a major focal area for the research and innovation activities in order to be brought to the EU citizen as an effective awareness raising tool to gain public acceptance and engagement.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA24.1: Demonstrations of concurrent building engineering which are sustainable and affordable (new building and refurbishment);*
- *TA24.2: Develop and disseminate innovations for the better integration of the value chain in bridging the Single European Market with contexts of national laws;*
- *TA24.3 Review the mechanisms used in the various Member States in relation to energy labelling and its effect, develop an intelligent and well balanced portfolio of mechanisms to raise public awareness, set regulations, codes and practices, fiscal and financial tooling.*

Target 25: Integration Technologies allows the full interoperability among stakeholders and systems

The dynamic nature of design projects requires parallel processes, smooth workflow and tight control. There are applications to give support to all these needs and allowing different profiles of experts work together in a project with no difficulty related to coordination of processes and the shared control of the entire project. These kinds of applications offer smart workflows that are synchronised automatically depending on the status of the project without any help. Data models and real-time communication protocols are standardised in order to allow all the stakeholders to develop their devices without problems at the moment to plug them and make them work together.

Devices from different producers are in use at the moment when plugging them, because all the devices inside and outside the buildings share the same protocols. Other domains protocols and standards are integrated as needs and applications of buildings would increase. The information from different stakeholders is shared between them using inter-organisational knowledge platforms, where the information is organised by term and which offers an easy way to be consulted.

The following research and innovation '**Targeted Areas**' can be identified:

- *TA25.1: Systems integration from building to neighbourhood level;*
- *TA25.2: Centralised application able to control parallel processes done by different kinds of experts works in a project;*
- *TA25.3: Development of protocols and communications standards that fit better with the needs of the vendors and the existing devices;*
- *TA25.4: Development of a knowledge sharing platform among construction, energy and ICT stakeholders.*

4 Implementation Plan: priorities, timeline, scale of resources and proposed investment distribution

The proposed roadmap is intended as a **guideline from industry for the implementation of an ambitious research and innovation programme in the period 2014-2020**. It has been structured as a natural continuation of the successful PPP EeB within the Recovery Plan in line with its original long term strategy and 'wave action' strategy: demonstrations followed by industrialisation by industry would allow integration in our built environment and future smart cities in line with industry 2030 vision highlighted in Part 1.

Based on the detailed analysis of the challenges along the value chain, the targets identified in Chapter 3 have been clustered and articulated along three main lines:

- **Breakthrough acceleration of building stock renovation** (including cultural heritage buildings) through research on innovative construction and **systemic**, cost attractive, mass-customised, prefabricated, high-performing, **geo-clustered** and minimally invasive solutions, integrating energy equipment and storage, to multiply by at least 2.5 the yearly energy efficient and high quality renovation rate by 2020;

- **Interactive and sustainable buildings** for energy neutrality/positivity in a block of buildings, delivering pan-European innovative approaches for a further 15 **%** reduction at district and city scale in energy and emissions by 2020;

- **Ensuring energy performance** as predicted at design phase and long-lasting quality to the end-user with long term Energy Performance Contracts including guaranteed savings, **end-user satisfaction** and cost-optimality, through cross disciplinary, collaborative, holistic design approaches, ICT enabled solutions and durable and reliable materials, components, structures and equipment; adaptable and worker-centric construction processes; performance monitoring for feedback information.

Adopting these leading principles as the starting point, we have identified a focused and limited set of R & D priorities needed to create the desired breakthrough acceleration and implementation in the market. **Sixteen priorities in different positions in the value chain have been identified**, wherein ICT plays a key enabling role, namely:

- **Design**, with focus on: 1) **Integrated — holistic — multi-target design**; 2) **Tools to disclose existing knowledge and technologies** (e.g. ICT BIM);

- **Structure**, with focus on: 3) **Safety, Sustainability, adaptability and affordability** of structures;

- **The building envelope**, with focus on: 4) **energy and environmental** (including embodied energy/CO_2) **performance of the full envelope**, requiring specifically technological breakthroughs with respect to compact (robust, ultrathin, high performing) thermal insulation, considering minimised air infiltration losses, for cost effective application in existing building (including cultural heritage

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buildings); 5) **prefabrication**, as a crucial step to guaranteed energy performance; 6) **multifunctional and adaptive components**, surfaces and finishes to create added energy functionality and durability;

- **Energy equipment and systems**, with focus on: 7) **Advanced heating/cooling and domestic hot water solutions**, including renewable energy sources, focusing on sustainable generation as well as on heat recovery, primarily dedicated to the most promising solutions requiring large scale application; 8) **Thermal storage** (including both heat and cold) as a major breakthrough on building and district level, referring both to compactness as a main requirement for the existing stock, and the balance between different kinds of storage; 9) **Distributed/decentralised energy generation at district level**, addressing the key requirement of finding smart solutions for grid-system interactions on a large scale. ICT smart networks would form a key component in such solutions;

- **Construction Processes**, with focus on: 10) **ICT aided construction**; 11) Improving delivered **energy performance**; 12) **automated construction tools**;

- **Performance monitoring and management**, wherein ICT plays a dominant role, with particular focus on: 13) **ICT interoperability**, actually being a cross-cutting issue for all priority areas; 14) **Smart Energy Management system** (i.e. the portfolio of flexible actions aiming to reduce the gap between predicted and actual energy performance), including occupancy modelling, fast and reproducible assessment of designed or actual performance, and continuous monitoring and control during service life; 15) **Knowledge sharing** (i.e. Open data standards allowing collaboration among stakeholders and interoperability among systems);

- **End of life**, with focus on: 16) **Decision-support on renovation or new buildings and associated solutions** (taking into account the specific issues related to historic buildings).

The centre of gravity is in the building envelope, energy equipment and performance monitoring and management. The recommended priority areas were elaborated considering time, budget (assimilating technology maturity) and activity type (Research and Development or Demonstration) as indicators for prioritisation.

In this roadmap, demonstration has different forms and sizes. Small scale demonstration (at lab scale for instance, delivering the proof of concept) should inherently be connected to applied research and development actions. Large scale demonstration targeting early adopters, and initial implementation targeting fast followers, however, addresses the systems performance on a large scale level by definition, often involving population (end-user) behaviour.

They involve far bigger efforts and are accompanied by substantial investments, with high financial risk in the former and somewhat lesser risk in the latter case. Such actions that would pave the way to large scale market uptake are not considered within the R & D context, but require synergy with other instruments effectively stimulating investments in innovative technology, while mitigating the financial risks, as cohesion funds for instance (see Part 3).

The specification and validation parts in these actions are nevertheless clear innovation tasks in the H2020 context and as such have been duly considered while structuring the document. **Cross cutting and Integration aspects** are mainly associated to each element of the value chain, in particular under demonstration and innovation activities.

Table 3 provides an overview of the **budget associated to the key priorities, associated targets and activity type** per each element of the value chain.

Table 3. Proposed distribution of budget per Priority are as well as activity type

Core area	Priority	Corresponding Target	Activity Type: Research & Development	Activity Type: Demo and innovation (i.e. suppport actions)	Budget (%)
Design	Design (average)		45%	55%	10%
	Integrated (holistic) design	1; 2; 23	40%	60%	5%
	Tools to disclose existing knowledge and technologies (e.g. ICT BIM)	2	50%	50%	5%
Structure	Structure (average)		70%	30%	2.5%
	Sustainability, adaptability and affordability of structures	4; 5	70%	30%	2.5%
Envelope (incl. finishes)	Envelope (average)		65%	35%	30%
	Energy and environmental performance of the full envelope	6; 7; 8; 23	60%	40%	15%
	Prefabrication	6	50%	50%	5%
	Multifunctional and adaptive components, surfaces and finishes	6; 7; 8; 9; 22	80%	20%	10%
Energy equipment	Energy equipment (average)		60%	40%	25%
	Thermal storage	10	80%	20%	10%
	Distributed/decentralised generation on a district level	10;13; 25	40%	60%	5%
	Advanced heating and cooling, domestic hot water including heat recovery	10	50%	50%	10%
Construction process	Construction process (average)		39%	61%	10%
	ICT aided construction	16; 25	40%	60%	3%
	Improving delivered energy performance	14; 15; 17	30%	70%	5%
	Automated Construction Tools	16	60%	40%	2%
Performance monitoring	Performance & Monitoring (average)		50%	50%	20%
	ICT systems interoperability	12; 25	40%	60%	7.5%
	Open data standards	20	50%	50%	5%
	Prediction = reality (incl. occupancy modelling)	12; 18; 19; 20	60%	40%	7.5%
End of Life	End of Life (average)		50%	50%	2.5%
	Innovative solutions and decision-support on renovation or new building	21; 22	50%	50%	2.5%
Average weighting across all areas			55.9%	44.1%	100%

Targets (and associated Targeted Areas as better specified in Chapter 3) behind each priority are highly **interrelated and interdependent**, in particular in a single priority, highlighting the importance of integration. In addition, for some Targets it would be needed to have **repeated/recurring calls**, taking account of the expected lead time to bring innovations to maturity and the results emerging from funded projects in the current and possibly future PPP. Table 4 summarise an industry point of view and suggestions for any future possible launch of calls, providing an **overview of the priorities and the proposed timeline** to address them in the period 2014-20.

An overall budget of EUR 2.1 billion over 2014-2020 is proposed to support this programme which is equally shared between industry and the European Commission. This budget proposal is based on the available elements of the EC proposal concerning Horizon 2020, the financial envelope and ambition of the running PPP EeB and associated industry mobilisation and investments to address the priorities jointly identified in the dialogue with the public side. This ambition in terms of resources is in line with the additional industrial investments that would be progressively needed to bring the prototypes and demonstrators resulting from such new innovation activities to the market. **An average leverage factor of 4 is expected**, a figure based on a dedicated analysis of each value chain segment and of past experiences by E2BA members, as better detailed in Part 3.

The research and innovation intensity of both the seven value chain steps was sized for the period 2014-2020 as a function of the expected impacts and of the projects launched or to be launched during FP7 (see Figure 8).

It must be emphasised that a large industry funding is expected in the Envelope, Energy equipment and performance monitoring and management, with design and construction processes being a relevant slice: the innovations would be tested on real life buildings (both new and refurbished, with probably districts concerned by a combination of both) for which EC funds would cover only the innovative part of the real life project. **Cross cutting and integration activities would be tackled in each step of the value chain and by each large demonstration project that would be later on launched**.

Figure 8. Proposal for a breakdown of the PPP budget beyond 2013 along the value chain

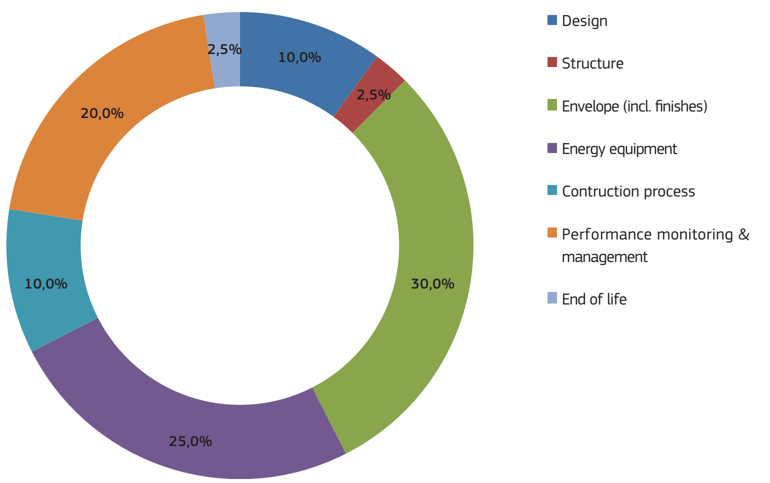

Table 4. Overview of priorities distributed along time

Core area	Priority	Short Term (2014-16)	Medium term (2017-18)	Long term (2019-20)
Design	Integrated (holistic) design	✖	✖	✖
	Tools to disclose existing knowledge and technologies (e.g. ICT BIM)		✖	✖
Structure	Sustainability, adaptability and affordability of structures		✖	✖
Envelope (incl. finishes)	Energy and environmental performance of the full envelope	✖	✖	✖
	Prefabrication		✖	✖
	Multifunctional and adaptive components, surfaces and finishes	✖	✖	✖
Energy equipment	Thermal storage	✖	✖	✖
	Distributed/decentralised energy generation on a district level		✖	✖
	Advanced heating and cooling, domestic hot water including renewable energy sources and heat recovery	✖	✖	✖
Construction process	ICT aided construction		✖	✖
	Improving delivered energy performance	✖	✖	
	Automated Construction Tools	✖	✖	✖
Performance monitoring	ICT systems interoperability	✖		
	Open data standards		✖	✖
	Prediction = reality (incl. occupancy modelling)	✖	✖	✖
End of Life	Innovative solutions and decision-support on renovation or new building		✖	✖

The **relevant funding allocated to R & D projects** demonstrates the need to address significant barriers where a close collaboration between large industrial players, SMEs and Research Organisations is instrumental for successful deployment. These include proof of concept demonstrations for specific applications to attract additional industrial engagement and extend the range of products and applications in the market. This would help to further develop technology, reduce investment risks and thus lay the foundations needed for sustainable commercialisation.

Over 44 % of the total budget proposed would be concerned with demonstrations, addressing every step of the value chain. This is in line with the industry leadership and ambitions of the PPP as well as Horizon 2020 overall objectives to bring innovations close to the market, tackling also non technological barriers. The main goal of a demonstration action is indeed to validate technology. This validation gives industry insights on the unique selling points of their technology and basically addresses the question under what conditions the users are willing to invest in energy efficient technology, offering economic and ecological savings. Without such an assessment individual industrial players would need to invest in technology without knowing whether they can build a profitable business around it. In view of the fact that the construction sector is highly disperse, such actions do not serve solely the needs of the partners involved in the demonstration action, but they would also be highly relevant for all players in the built environment. The individual early adopters and the fast followers participating in these actions would profit immediately of the economic and ecological benefits offered by the innovative technology. European, national and regional authorities would get more reliable information on where to focus on in their policies, tax measures and funding instruments in order to realise the energy and climate targets set for 2020 and 2050.

In E2BA view, the demonstration action is not a goal in itself but should be followed by **dissemination actions and training of the work force** active in the built environment. Industry should clearly take the lead to address these priority actions. As anticipated, **a substantial part of the budget is indeed dedicated to Cross Cutting and Integration issues** addressing technological and non technological horizontal aspects addressing the need for programme level actions on Regulations, Labelling and Standards (e.g. Target 11 in Chapter 3), Pre-normative Research, Socio-Economic Modelling and Planning, Technology Monitoring and Assessment, Lifecycle Analysis, support to SME engagement, setting up a monitoring platform at programme level, addressing interoperability, to name a few. These cross-cutting and integration aspects would be in most cases addressed at the level of each single project to be mobilised while in very specific cases they would be addressed with dedicated CSA projects. In particular **the following CSAs are identified as highly relevant**:

- **A KPI top down cross cutting action**, providing reporting, data aggregation and statistical elaboration guidance and facilities. It should take advantage of the KPI existing from the CONCERTO action (www.concerto.eu) that has already been running since FP6. A single Technical Monitoring Database (TMD) would provide the synergy between all EeB projects, including the FP7 projects finishing when H2020 starts. Similar outcomes from the CIP programme like 'eemeasure' (http://eemeasure.clicksandlinks.com/eemeasure/generalUser/) could be mainstreamed. It would provide inputs for LCA standardisation and regulation;

- A cross-cutting action on **interoperability of ICT systems**.

Part III: Expected impacts

1 Expected impact on industry and society

1.1 Industrial competitiveness and growth

Some of the large actors in the different sub-sectors of the industry (e.g., architects and engineering companies), currently operate across European borders and even in international markets, while other actors in the value chain mainly operate in national or local markets. As a result, **the different actors face very different challenges with regard to competitiveness**, as highlighted by Ecorys[38]. While the overall construction sector in the EU27 grew considerably prior to the beginning of the financial crisis both in terms of persons employed (just below 3 % per year during the period from 2000 to 2007 with lower rates in Manufacturing of construction materials and higher rates in Professional construction services), **productivity levels were relatively stagnant**. According to the Ecorys report, a number of factors are likely to influence the future competitiveness of the building sector (in a 10-year perspective) and to improve quality and productivity:

- Access to a more **qualified labour force**, thanks to training efforts;
- Access to **finance and new financial models**;

38 Ecorys (2011), FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – *Sustainable Competitiveness of the Construction Sector.* Final report.

- Closer customer and **end user relations** and process innovation;
- **Professionalisation** of the clients;
- Access to **applied research and technology transfer** such as new technologies, materials, smart and eco-efficient solutions and buildings;
- New **service models** to complement actual construction, retrofitting and renovation activities, which allow taking into account the upfront investment more efficiently;
- **Modularisation and pre-assembling** of critical components (envelopes, energy equipment);
- **Coordination** across players to achieve lean construction;
- Future **growth markets outside the EU** that can be addressed by European industry.

European industries are still in a leading position for space and water heating, but not for cooling applications. The PPP would prepare them to address future market needs where equipment must be sized down to address lower demand profiles. European industries are leading in the field of ICT for energy management, but are threatened by the Japanese and US competition. The PPP would prepare them to address multi scale BEMS markets covering single houses/apartments, buildings and districts. The European cement and construction materials industry must face competition from growing countries like China. Setting new standards on the CO_2 footprint of such materials should give a new leading edge at world level for the

European industry. As highlighted by the Ecorys report, **investments in new technology and innovation are potentially a major driver for increasing the competitiveness of European construction companies**: productivity increases by using ICT, innovative building products and new construction methods, together with parallel trainings to improve the worker skills. Beyond current economic growth, which would generate a demand for new energy efficient buildings, a mature refurbishment market required to meet the 2050 decarbonisation goals leads approximately to an **additional EUR 60 billion/year** ambitions[39] at least over the next 35 years.

Meeting such ambitious challenges has three direct consequences on trade issues:

- Energy efficiency in Europe becomes a **profitable business**;
- European manufacturers and constructors locate added value in Europe based on sound business models which foreign industry has hard times to comply with due to stringent **European quality and performance standards**;
- Energy service and/or construction companies are able to take **long term energy guarantee contracts** that shape new behaviours from building end-users.

This means that affordable innovative solutions are commercially available for refurbishment before 2025 in order to both increase the rate of refurbishment and the deeper refurbishment objectives as anticipated in Part 1.

Europe is not on track to achieve its energy efficiency goals by 2020. Two recent studies[40] indicate that the cost-effective energy savings potential in the building sector (i.e. covering both residential and non-residential buildings and estimated to be 65 Mtoe) corresponds to a cumulated investment need of approximately EUR 587 billion for the period 2011-2020. This translates into an investment need of around EUR 60 billion per year to realise this savings potential[41] which represents an **extra 5 % of the annual turnover** which means an enormous challenge for the building sector. Clearly the present PPP aims at structuring a building refurbishment market in Europe as from 2030. It also initiates certification procedures to promote a market for the recycling/reuse of scrapped pieces of buildings. Last but not least, it makes the implementation of energy performance guaranteed contracts a unique approach to commit the value chain players into durable performances for new or refurbished buildings By selling new performance standards for structural materials and energy equipment, **Europe is able to take the lead at world level**[42]. Moreover it stresses the needs for increased productivity of the construction players which is a major challenge when observing the past trends over 2000-2010 when productivity decreased.

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39 Eichhammer, W. et al.: *Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries*. 2009.

40 Wesselink, B. et al.: *Energy Savings 2020 – How to triple the impact of energy saving policies in Europe. Report to the European Climate Foundation,* 2010.

41 Consultation Paper: *'Financial Support for Energy Efficiency in Buildings'*.

42 See for example the ALCIMED study (2012, in French) highlighting the importance of standards and certifications in China and the recent developments on Green Building certification; and the analyses by *Global Construction Perspectives* and *Oxford Economics.*

1.2 Jobs and skills creation

The construction industry accounts for more than 10 % of the EU's GDP and according to FIEC data employs 20 million people in large, medium and small enterprises. Construction is indeed a key sector for job creation: **every job created in the construction sector generates two further jobs in related sectors**[43]. According to the BPIE study[44], a slow but constant increase in the renovation rates would generate on average 400 000 jobs annually by 2020, and a fast ramping up would lead to an average 600 000 jobs each year. The deep scenario would create up to 1 million jobs. This is in line with the recent consultation by DG Energy on '*Financial support for energy efficiency in buildings*' highlighting the fact that, although often difficult to quantify exactly, increasing the level of investment in building energy efficiency would also have a strong effect on job creation. For example, the United Nations Environment Programme (UNEP) in its 2011 Green Economy Report[45]states that 'investments in improved energy efficiency in buildings could generate an additional 2 to 3.5 million jobs in Europe and the United States alone'.

The French Ministry for Ecology, Energy, Sustainable Development and Spatial Planning estimates that for every EUR 1 million of investment in property-related thermal renovation, 14.2 jobs are created or maintained in the field of energy performance-related work[46]. **Applying these numbers to the above-identified investment need of EUR 60 billion per year would result in the creation or retention of around 850 000 jobs per year in the EU**. Similar figures can be found in the Impact Assessment of the Energy Directive where a more realistic assessment in the Energy Efficiency Plan estimated the employment potential to up to 2 million jobs based on data from the building sector. **As the construction sector is in general highly locally oriented**[47]**, this means that job creation in this sector would have a high impact on local employment.** The availability of a long term roadmap and the possible extension of the PPP EeB beyond 2013 would have a positive effect on increasing nationally funded programmes and private research investment, even to the extent of **encouraging multi-national enterprises to maintain research and innovation efforts in the EU** rather than move them elsewhere and promote inward investment from outside of the EU. A key feature of the construction sector is indeed that employment generated is indeed rather local and this would provide a clear boost to local economies which are struggling in the crisis time, thus **fostering smart specialisation**.

1.3 Overall PPP impact at EU scale

As a result of PPP implementation, the following table summarises the expected benefits brought by an energy-efficient building value chain to building users and EU society as a whole,

43 Communication from the Commission '*The Competitiveness of the Construction Industry*', COM(97) 539 of 4/11/1997.

44 BPIE (2011) Europe's buildings under the microscope.

45 Green Economy Report 2011, United Nations Environment Programme.

46 *Plan européen pour la relance économique COM(2008) 800 final Mesure No 6: Améliorer l'efficacité énergétique dans les bâtiments. Reprogrammation des programmes opérationnels régionaux des Fonds structurels en faveur des logements sociaux. Evaluation a Mi-Parcours 2009–2011* — France, L'Union Social pour l'Habitat, May 2011.

47 Ecorys (2011)FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – Sustainable Competitiveness of the Construction Sector

with respect to Sustainability, Security of Supply and Competitive markets parameters for the EU Climate and Energy policies.

Table 5. Overall PPP EeB impact mapped against EU policies

	EU Climate &Energy policy		
Overall PPP EeB impact	Sustainability	Security of Supply	Competitive markets
Higher building renovation rate	X	X	
Lower costs, higher quality and higher productivity throughout the value chain	X	X	X
Transformation of the building sector to a knowledge and technology driven sector			X
Reduced embodied CO_2 per M_2 of new floor space	X		
Cost-effective, user-friendly, healthy and safe products and solutions at district and city scale	X	X	X

2 Monitoring impact: Key Performance Indicators

Fast implementation and performance feedback are keys issues of the PPP, and represent a major pillar in building up the long term strategy expected as a natural continuation of the running PPP EeB. Monitoring and proper reactive actions are then major components. Both are included in what industry has called a 'wave action', as better introduced in Part 1. In this 'wave action' plan, continuous, on-going research feeds successive waves of projects. The knowledge gained in the first 'wave' feeds in the second at the design stage, realising a continuous implementation process.

It is proposed to implement all the validated technology or process prototypes within real life demonstrations allowing the assessment of the programme progress with the help of an appropriate set of KPIs. **Two levels of Key Performance Indicators** are proposed as described in the following.

2.1 Level 1 KPIs

In line with the strategic objectives and directions described within the Overall Vision (see Chapter 2 in Part 1), it is possible to identify a set of KPIs level 1, that enables the evaluation of the implementation of the overall PPP goals. They would enable the monitoring of the PPP progress and measuring how the specific research and innovation objectives defined by 2020 are met. From this point of view the KPIs are related to three main aspects:

1. **Realised physical examples and their potential (energy) impact**: This focuses on the number of concrete example projects (at building and district level) and the impact thereof on the total primary energy usage and the number of market-accepted concepts that are available:

- Direct: the number of realised energy efficient buildings/districts, subsidised through the programme, multiplied by the reduction of primary energy usage with respect to the reference buildings/districts;
- Indirect: potential reduction in primary energy usage when the developed concepts are applied on all similar building types to which the concepts can be applied.

The latter is more important than the former, because of the current phase in the transition curve and because it illustrates the potential impact.

- Market demand (% market share): The level of demand from building (complex) owners (including housing organisations) for the building concepts developed through the programme;
- Market supply (% market share): The number of innovative coalitions that is actively offering/promoting the available building concepts.

2. **Improved market conditions:** in line with the removed barriers and developed stimuli through the PPP. Underneath this there are aspects such as:

   - Knowledge disclosure: the level to which the knowledge platforms (set up under the PPP, such as clustered communities of projects to share best practices, forums, ...), and knowledge carriers (performance-driven building methodology, toolkits, example 'booklets', etc.) are actively used;
   - Number of successful examples: where (new) forms of value-driven approach resulted in the creation/(re)valuation of building and district concepts with high performance levels (ranging from 45 %, 60 % to 80 % reduction of primary energy usage);
   - Performance driven building process: successful approaches/measures through which the difference between the energy performance level as designed and the energy performance as realised is minimised. This may consider also the amount of projects using the performance drive building methodology, as developed in our programme;
   - Regulations: (number of) successful examples of projects, where adaptation of local (and/or national) rules and regulations contributed to building owners adopting and realising innovative building concepts;
   - Finance opportunity: available and applied financing constructions with which higher (energy) performance levels can be funded (without subsidies) and the number of times they were applied, as a result of the innovations funded within the PPP.

3. **Created market dynamic**: In the end the success should be visible by the fact that a substantial part of the market actors are making business through the outcome of the PPP, either directly as partner in the programme (the frontrunners) or indirectly using the outcome provided by the frontrunners (the early adaptors):

   - Number of coalitions actively working with the Energy leap ambition levels and (building and district) concepts;
   - The building (surface area) portfolio of those coalitions.

KPI level 1 comprise:

- New systems and technologies developed in the relevant sectors
- Participation and benefits for SMEs
- Contribution to the reduction of energy use and CO_2 emissions
- Contribution to the reduction of waste
- Contribution to the reduction in the use of material resources
- New high-skilled profiles and new curricula developed
- Private investment mobilised in relation to the PPP activities
- Contributions to new standards

2.2 Level 2 KPIs

Level 2 KPIs are associated to the expected impact of each project to be mobilised in the framework of the PPP. We have identified the following general indicators:

- Scale of reduction in energy, material resources and waste
- Project results taken-up for further investments (into higher TRLs)
- Trainings for a higher quality workforce
- Patents and activities leading to standardisation

More specific KPIs level 2 for the different segments of the value chain are detailed in the table below, associating the **expected benefits for the players in the value chain.**

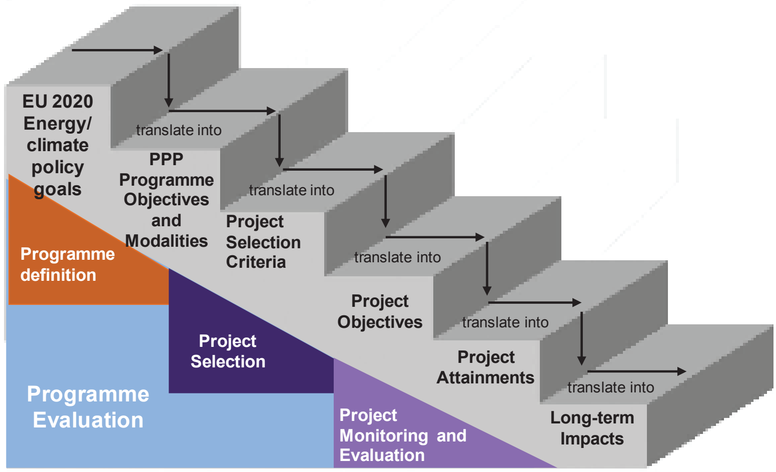
Table 6. Specific KPIs level 2 for the different segments of the value chain

Segment of the value chain	Key Performance Indicators (KPIs)	Expected benefits for the players in the value chain
DESIGN	• The gap between building performance by design and built performance at commissioning is narrowed down to a value consistent with energy performance contracts	• More reliable design tools • Higher quality in the construction process • Good the first time: commissioning is made faster and cheaper • ICT platforms and interoperable tools for integrated design
STRUCTURE	• The embodied CO_2 content per m² of useful floor area due to construction materials in building structures reduced by at least a factor of 2	• New standards for suitable construction materials that put European manufacturers as world leaders
ENVELOPE	• New envelope solutions that maintain architectural flexibility respond to integration constraints (seismic, acoustic, air quality, …) while improving annual energy performance of buildings by at least 50 % when compared against building of same type and function (measured in kWh/m² floor area/year)	• Prefabricated solutions to reduce investments at constant quality • Durable high performance solutions for new buildings that minimises cost of ownership • Active envelope available at affordable costs • Refurbishment processes involving standard envelope configurations built on purpose

Segment of the value chain	Key Performance Indicators (KPIs)	Expected benefits for the players in the value chain
ENERGY EQUIPMENT	• Financially attractive zero energy districts possible • CO_2 neutral energy districts financially attractive in Europe when combining 2020 building standards and renewable energy use • Widespread uses of energy performance certificates for all major energy equipment (50 % of all equipment purchased A+ or equivalent) • Supply of energy after refurbishment ensured at least by 50 % from renewable or waste energy sources • Reduction of difference between peak power demand and minimum night time demand by 50 % • Real time optimisation of energy demand and supply using intelligent energy management systems	• Zero energy building as a standard for new buildings (office, housing) • Refurbishment strategies for existing districts that are attractive financially: ICT is a cheap investment to maximise energy efficiency at district level at affordable investments • European standards for interoperability of equipment that facilitate their seamless integration within BEMS • Innovative high efficient systems dedicated to space and water heating
CONSTRUCTION PROCESS	• Reduction by 80 % of the number of failing commissioning for new and renovated buildings • Reduction of the average deep refurbishment works duration by at least 20 %	• Higher construction productivity for both refurbishment and new buildings
PERFORMANCE MONITORING	• By 2020, 15 % of all refurbishment contracts are performance guaranteed contracts	• Durable energy performance for new and refurbished buildings, leading to improved control of building ownership costs and CO_2 footprints
END OF LIFE	• Full scale, real life demonstrations show that reusable/recycled building components can be part of future viable business models for the building sector	• Recyclability/reusability criteria defined to launch business models on reliable sound grounds
INTEGRATION	• Energy efficient building technologies ready for mass-market: 1) Sound business models with end-users ready to purchase innovations based on criteria which may go beyond energy savings (comfort, accessibility, aesthet-ics, ...); 2) Scalability/replication of innovations proven via full-scale demonstrations; 3) Harmonisation of performance standards at EU level • Large scale demonstrations integrates at least 50 % of the R & D project outputs performed at EU level • The construction sector ready to increase productivity over the next thirty years (0.5 % average year)	• Higher productivity of players along the value chain • Validated business models to ensure replication before 2025 • Industrialisation costs of validated technologies under control • Industrial making before 2025

The overall logic of the KPIs is presented in the Figure below.

Figure 9. Overview of the KPIs logic



3 Additionality to existing activities and European added value

3.1 Additionality to existing activities

This roadmap aims at providing research and innovation priorities for the period 2014-2020 with the ultimate goal of **accelerating the pace of innovation towards affordable energy efficient building, at a time where the economic and financial crisis addressed within the Recovery Plan is still there and limits the investment capabilities of the whole sector and extended value chain**, whereas ambitions set forth by 2050 require breakthrough changes coming from each of the players in the value chain.

Public funding, even though very low when compared to the overall turnover of the construction sector, aims at **circumventing a possible market failure** when imposing long term energy efficiency ambitions to the sector:

- It sends signals on the role of innovation to develop technologies and processes able to make the whole building sector an enabler of low energy buildings;
- It supports collaborative approaches instead of single isolated developer project to make purchasers and providers understand that a systemic approach to reducing building energy demand is a prerequisite to meet the deadlines set by the 2050 decarbonisation goals;

- It allows for more innovative technology and business models to be tested in parallel thus giving manufacturers and constructors access to more viable options in view of facing both new construction and refurbishment scenarios beyond 2020.

In this framework, there are three components of additionality:

- **Input Additionality**: the PPP EeB clearly showed that collaborative Research and Innovation activities around an industry led programme in close dialogue with different EC services would not have been launched without public support, at first due to the on-going economic and financial crisis, but also because of the peculiar nature of the sector and its extended value chain. These conditions apply also today and despite the successful achievements so far it can be observed that a critical mass has not yet been reached;

- **Process Additionality**: the innovation process is managed and implemented in a more efficient way due to the value chain approach, this is a clear improvement in this current roadmap that is well aligned to the Horizon 2020 objectives while addressing additional research areas not fully covered in the running PPP EeB;

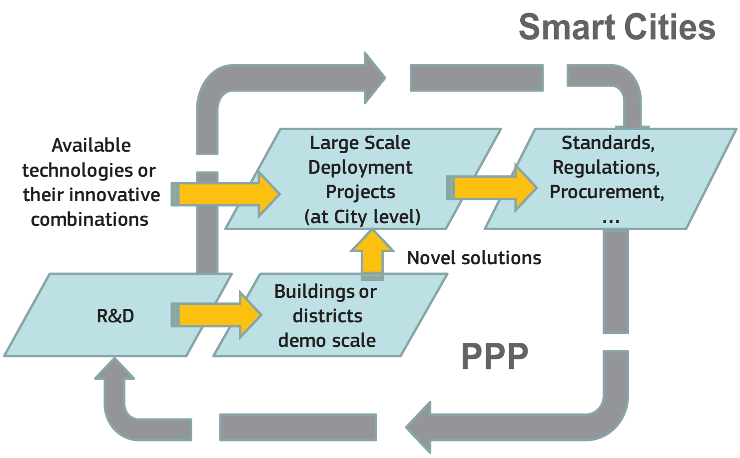
- **Output Additionality**: the partners have drawn pathways to meet the 2050 decarbonisation goals, whatever economic scenarios may be faced by investors over 2020-2050. This means a European refurbishment technology roadmap and the tests of various business models which all address the guarantee that energy performance at commissioning would be kept durable over the life cycle of the new building or the refurbishment. It brings direct benefits to the participants and to the building sector as a whole, showing that the barriers against affordable energy efficient buildings are not insurmountable.

The intended extension of the running PPP EeB in line with the present Research and Innovation Roadmap represents an additional and fully complementary **pillar of the broader Smart Cities and Communities strategy** aimed at demonstrating available technologies or their innovative combinations in large projects up to city scale meeting available non technological barriers. **The ambition of this Research & Innovation Roadmap is indeed to fully complement this vision by developing innovative technologies and solutions which are validated at buildings and districts scale** to be tested in the larger Cities framework when available. It is important to notice that the intended extension of the current non technological barriers is tackled from the early stages of the innovation chain to speed up implementation in line with the overall Horizon 2020 ambition, as shown in Figure 10 below.

3.2 Added value of action at EU level and of public intervention using EU research funds

Significant **EU public funds have already been directed to research activities for energy efficiency in buildings within the running PPP EeB**, contributing to build a large community of stakeholders which is growing call by call. The participation of industry exceeds 50 % with SMEs involvement at the level of 30 %. **Yet a critical mass is not reached to self-propagate**. The innovative technologies needed to boost energy efficient buildings are unlikely to be commercially available as quickly as is desirable especially for buildings renovation. Still there

Figure 10. Additionality and complementary of PPP EeB beyond 2013 within the frame-work of the broader Smart Cities strategy



is a danger that energy efficient buildings development does not meet with the energy and environmental mandates due to the lack of standardised cost effective technologies and solutions and business models. **Further EU wide public intervention is needed to avoid a market failure**: very high constraints on building performance while the players are not able to meet affordability before 2025, which means that the 2050 deadline is unrealistic. Public intervention allows investigating innovative solutions in a more parallel way, thus **giving industry more options to address economic scenarios over a very long period of time (2020-2050)**.

Tackling these challenges within the framework of a coordinated effort at EU level between industry and the European Commission is justified by:

- The **research needed which is often so complex** that no single company or public research institution can perform it alone;
- The **absence of an agreed long-term budget plan and strategic technical and market objectives** to encourage industry and the research community to commit more of their own resources would slow down the pace of innovation;
- The **sub-optimal application of funds** leaving gaps and overlaps in a fragmented research coverage;
- An **insufficient volume of funds for an integrated and continuous programme** covering fundamental research, applied research and large-scale EU-level demonstrations;
- The fact that the **European energy efficient buildings value chain is dispersed** across different countries and activity areas (public and private promoters, designers and architects, construction companies, technology developers and providers, SMEs, Research Organisations) which restricts the exchange and pooling of knowledge and experience;

- The fact that **technical breakthroughs are needed** to improve the cost effectiveness, the performance, the reliability and durability of materials, components and systems for Energy Efficient Buildings and Districts to meet the expectations of potential customers.

The conclusion that might reasonably be drawn from the foregoing discussion is that there is a clear **European added value in extending the current PPP EeB beyond 2013** as a EU wide continuous research and demonstration programme to allow large industrial companies and SMEs, including those in the new Member States, to collaborate between themselves and with other stakeholders, working towards shared short, medium and long-term objectives in the different areas of the value chain. Without public and private research and innovation investments at European level in a focused and coherent industrial programme accompanied by longer-term research taking account of industrial development priorities, efforts addressing the research bottlenecks and the search for technological breakthroughs would continue in a scattered and unstructured manner.

These objectives cannot be sufficiently achieved by the Member States because the scale of the challenge exceeds the capacity of any Member State to act alone. The pooling and coordination of research and development efforts at EU level stand for a better chance of success, given the trans-national nature of the technologies and systemic solutions to be developed, and also given the need to achieve finally the critical mass of players and resources. The intervention of the European Commission would help to rationalise research programmes and ensure inter-operability of the developed systems not only through common pre-normative research to support the preparation of standards but also through the de-facto standardisation which would arise from the close research cooperation and the trans-national demonstration projects. This standardisation would open a wider market and promote competition. This Research & Innovation Roadmap is conceived to encourage the Member States to pursue complementary initiatives at national level, in the spirit of reinforcing the European Research Area — indeed the intention of the extension of the PPP EeB initiative beyond 2013 is to leverage these national and regional programmes to make best use of the combined efforts for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local deployment and replication. A clear added value at European scale is also associated with the intended innovation model mobilised along the value chain as well as the innovation chain, as illustrated in the Figure below where the contribution of the research and innovation activities within the framework of the extended PPP EeB beyond 2013 are integrated with larger demonstration projects expected as part of the overall Horizon 2020 strategy and Innovation Union objectives and tools, including European Innovation Partnerships.

Indeed our roadmap to extend the PPP EeB beyond 2013 foresees an integrated approach along the innovation chain in line with the Horizon 2020 ambition, where **non technological activities** are properly addressed, such as:

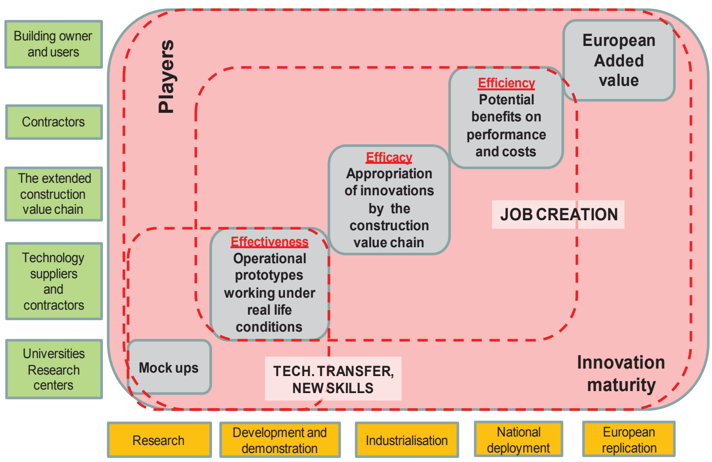
Social and behavioural aspects:

- More accurate and better understanding of the potential for change and the most appropriate ways to communicate it;
- Involvement of civil society organisations of all kinds in the process of spreading awareness and acceptance on the necessary changes, particularly those that affect lifestyles and behaviour;
- Guidelines for improvement of individual behaviours, to raise awareness and concern;
- Promoting change in collective behaviours, tackling large groups.

Standardisation aspects:

- Pre-normative research towards standardisation of components and systems that shall complain with building codes, electrical normative and grid integration (when applicable);
- Possible barriers in existing standards and legislation would be analyzed;

Figure 11. The intended innovation model and the associated European Added Value



- Activities would be developed within national and international certification bodies;

- The standardisation of components and systems developed would contribute to a wider uptake of the technologies by SMEs as well as a wider deployment in the market;

- R & D effort in standardisation would allow moving from small to mass production, therefore reducing costs, while integrating the whole value chain and user and customer requirements.

Business model aspects, which concern the fact that the building market is characterised by its diversity, complexity and high fragmentation of the value chain with very different views concerning energy:

- Local Authorities influence the value chain through policies but high levels of energy performance are often compromised by cost considerations,

- Capital Providers are more focused on the short term and reduction of energy consumption is not part of their concerns;

- Developers (Designers, Engineers, Contractors, Materials and Equipment Suppliers) as primary actors of the construction are focussed in the short term, and would care about energy efficiency only when implemented in the programme or when it is a key factor in the buying decision,;

- Investors who rent buildings have recently started to consider energy-saving measures as a long term valuable investment;

- End Users are often the most sensitive to energy savings but very often are not in the position to commit the necessary investment;

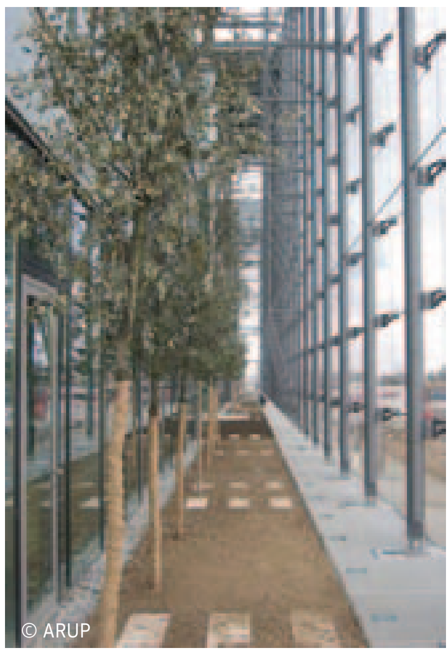
- Therefore, new business models must be developed to take into account clients and users requirements, the entire supply chain, legal and financial framework, technical aspects, geographical and local features and the whole life cycle;

- The use of the financing instruments like the Risk Sharing Financing Facility, the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) would be reinforced as well as private industrial banks at European, national and regional level.

Pre-commercial Procurement, Procurement of Innovation and Sustainable Procurement in the Energy Efficient Buildings market, is a major driver for increasing the innovation level in the Energy Efficient Buildings market, where advanced procurement models have to established, implemented and used, mainly by Public Administrations. This is indeed complicated by the peculiar value chain of the construction sector, where many innovations come from the industry of products and components and are then applied at the construction level. The involvement in this roadmapping exercise of organisations active in the **EIT KIC Innoenergy initiative** has also contributed to properly consider **links with the innovation triangle to enable synergy and possible future closer collaborations which leverage on new skills and entrepreneurship** to take advantage of the huge market opportunities which could be generated by a joint long term strategy between industry and the public side. Ultimately the PPP would address the FP6 and FP7 barrier to bring the results to market and the European paradox where most of our promising results are exploited elsewhere where innovation friendly environments are in place, including support to large scale pre-commercial demo-projects. In our view the intended mix of R & D and small to large scale demo projects would allow reaching the critical mass needed in terms of research and innovation to self-sustain the transition to an energy efficient built environment, **radically shifting the innovation trajectory**. This would fully exploit synergy with the current portfolio of project results, future projects in key enabling technology areas as well as major initiatives as Smart Cities EIP. In this framework, there is a **clear win-win opportunity in joining efforts between the public and private sides within the PPP**. Responses to identified socioeconomic challenges require a very significant degree of innovation which is first and foremost based on solutions enabled by solutions for the energy efficiency of buildings. EU and Member States public authorities can trigger and support such developments by proactively establishing regulatory frameworks that set standardised targets for the industry that focus on achieving appropriate solutions in specific critical areas, supported by stimulus packages to accelerate the development and diffusion of required innovative technologies and processes within a defined time horizon.

3.3 Benefit of a Contractual PPP in comparison to other options

The Framework Programme for research and demonstration plus national and regional efforts, supported by Technology Platforms (to provide strategic directions and priorities), has to be considered very seriously as it has served the community well for more than 20 years. Nevertheless, efforts in this domain would result fragmented across a number of different FP7 themes, which are overseen by different programme committees, each with different priorities, giving rise to operational difficulties in coordinating calls and difficulties in feeding back results from demonstration actions to re-focus research priorities. The Framework Programme is scale limited to provide a satisfactory answer to all challenges and opportunities presented in this document, not being conceived to maintain continuous calls on energy efficiency in buildings and districts, although we acknowledge the simplifications proposed by EC in the Horizon 2020 proposal and the foreseen integration of other successful instruments such as the Competitiveness and Innovation Programme's (CIP), the Intelligent Energy for Europe and ICT Policy Support Programme as well as EIT and other funding tools from EIB and private sources. A lack of continuity and strategic technical and policy focus can give rise to knowledge gaps and overlapping effort, an inconsistent approach, and an over-emphasis on new, untested technologies. Even with support from Technology Platforms, the research portfolio might leave critical technologies under-funded or unaddressed. A major issue for industry is the unpredictability of funding levels, which is critical for long-term investment planning. They need well-defined strategic goals and a sustained, stable funding regime to raise confidence in private sector investors.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Establishing a Public Private Partnership on Energy Efficient Buildings in the form of a Contractual Partnership is the option preferred by industry and the stakeholders collectively. Industry prefers an action with a strategically-managed route from research through development and demonstration to market deployment and it also favours a **pre-defined budget as this allows industry to make long-term investment plans**. This would also encourage confidence in industry to engage in the necessary longer-term projects in cooperation with basic research organisations. Under the present concept for a Contractual PPP, the energy efficient buildings supply and value chains (industry, SMEs, research organisations, public and private promoters, standardisation bodies, users…) in consultation with the European Commission, would take the leading role in defining the programme priorities and timelines, set against commercialisation targets for cost and performance, with **milestones and KPIs to take strategic decisions and mobilise additional investments**. Although the PPP initiative would apply the general principles of the Framework Programme regarding **equal treatment, openness and transparency**, there is scope for a more dynamic and efficient implementation.

The following benefits are expected from the extension of the running PPP EeB beyond 2013, based on lessons learnt and experiences gained so far:

- **A critical mass of players** is created faster to face the critical issues raised by the 2050 goals;
- The **whole value chain of players** is involved in the management of the programme with the concerned EC Directorates;
- **New players (both large groups and SMEs) join** the collective Research and Innovation projects to contribute to the new innovation waves;
- **Increased visibility for new business models and integration activities** in support of both new and refurbished buildings having low energy demand profiles;
- A **refurbishment roadmap** managed by both the EC and industry, in accordance with the most recent findings[48] at EU level.

4 Ability to leverage additional industrial investments and monitoring of commitment

According to the 2011 Industrial R & D Scoreboard[49], the private R & D investment made by the industry of the building sector has been so far limited in comparison to other industries where a closer collaboration along the value chain is in place and is driving investments in product/process and service innovation, such as the automobile industry (EUR 30 billion , 4,7 % of net sales for the automobile industry). In buildings and construction in general, **the scattered nature of the industry does not allow a precise tracking of all investments along the value chain**

48 ‘*How to refurbish all buildings by 2050?*’ THINK Topic 7, Final report, June 2012.

49 http://iri.jrc.ec.europa.eu/research/scoreboard_2011.htm

and during the different steps of the innovation chain. If we consider official figures from the Industrial R & D Scoreboard, we may have the following very conservative estimates:

- The R & D investment in 2010 of the '**Construction and materials**' industry amounted to EUR 1 405 million (0.6 % of net sales, figures calculated for 34 companies);

- With regards to the '**Household goods and home construction**', R & D investment amounted to EUR 1 377 milliomn (2.1 % of net sales, figures calculated for 19 companies);

- R & D investment was higher for '**Electrical components and equipment**' (EUR 5 903, 4.6 % of net sales, figures calculated for 30 companies), however only part of this amount is allocated to the building sector.

The extension of the PPP EeB beyond 2013 with its expected ambition in terms of public and private resources is expected to **trigger industrial research and innovation investments in line with the innovation model** presented earlier, which is expected ultimately to generate leverage for additional private investments:

- During real life demonstrations in support of the validation of integration processes;

- During the industrialisation phases which remain indispensable on the industry side to reach the first sales of commercial products or services.

In line with the commitment already shown within the Recovery Plan PPP EeB, **industry would indeed commit substantial resources** in the period 2014-20. The following targets and measures are set for exploitation of project results and their market take-up:

- At least **doubling the private resources allocated to demonstration** targeting early adopters and to pilot implementation targeting fast followers;

- **Tripling the current level of investments in training** by the supply chain and development of building skills (with at least 20 % of companies engaged in training against current 7 %);

- Bringing innovative results to the market via **systematic use of the whole set of funding tools,** fostered through a large conference (at least 300 participants) yearly to promote and monitor the use of **cohesion funds** within the broader **smart specialisation strategy**;

- Implementing a **cross-fertilisation platform** which gathers all main public deliverables from projects, supporting clustering along main horizontal issues, as well as Yearly Project Review and four Yearly Technical Editions on cross-cutting issues;

- Implementing **programme monitoring** through a yearly Impact and Project Review Workshop and appointment of a Third Party to assess the industry and sector investments;

- Contribution to potential **standards in building retrofitting**, e.g. for large action in social/public buildings. Manage a **Research and Innovation Forum** for awareness and dissemination with at least 5000 members to exchange research needs and best practices in innovation-friendly demand side measures (i.e. pre-normative research, Regulations, Certification and Standards, Procurement, Socio-Economic Modelling and Planning, SME engagement).

Concerning the **intermediate targets**, we aim at a dissemination platform available at the end of 2014 while by 2015 training courses would be mapped across consortia and compared to training investments before entering PPP projects. Not later than 2016, a methodology for project clustering would be defined and clustering initiatives would be launched, involving all running projects. Furthermore, by 2017 at least half of the intended demonstrators would have started implementation and at least one third would be undergoing validation activities through a shared methodology across projects. Impact on health and safety at work site and for occupants would be proven with full scale buildings. By 2018 at least 10 % of projects funded within the first two calls would be undergoing an IPR protection process to secure patents on most innovative technologies and solutions.

Quantifying the leverage factor is a highly complex task considering the scattered nature of the value chain today and the different business models and value propositions of the players, with different levels of involvement along the innovation chain. A case study on gas absorption heat pumps for commercial buildings (Robur SpA, see Figure 12) suggests that the leverage factor of public funding for such private investment can be as high as 8, leading to a significant burden for the industry before reaching significant revenues out of innovative products.

In line with the proposed budget breakdown provided in Part 2, the following table reports an estimate made by E2BA on the investments required to bring the results to market associated with each element of the value chain. This estimate is based on the proposed budget of EUR 2 100 for the extension of the PPP EeB beyond 2013.

Figure 12. Leverage factor: an example

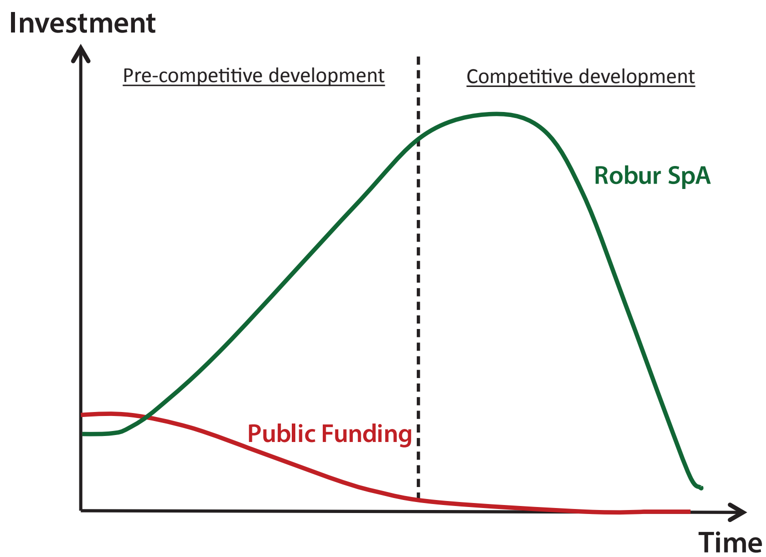


Table 7. Expected leverage factor for each element of the value chain

	% of total Research and Innovation	Total Research and Innovation investments (pre-competitive) — *(million EUR)*	Industrialisation (competitive) investments — *(million EUR)*
Design	10.0 %	210.0	680
Structure	2.5 %	52.5	260
Envelope	30.0 %	630.0	2480
Energy equipment	25.0 %	525.0	3020
Construction processes	10.0 %	210.0	650
Performance monitoring	20.0 %	420.0	1020
End of life	2.5 %	52.5	140
TOTAL		2100.0	8250

The expected **leverage factor** (excluding the direct leverage coming from real life demonstrations which would support the real life validation of innovative technologies and processes) **is therefore evaluated to be conservatively a factor 4**. This is confirmed if we analyse the funding evolution as projects evolve, tracing both private and public investments. Funding sources indeed evolve from public to private moving along the TRL scale with large efforts deployed by industry in integration (see Figure below).

Structural Funds are indeed needed to complement financial needs in terms of deployment and replication of the developed technologies. Once a solution fit for use can be specified, based on the demonstration and validation actions within the PPP, there is still a need for a European wide implementation of the results. The present Structural and Cohesion Funds are highly suited to alleviate the financial risk taken by the early adapters of new technology. The fast followers, taking less risk, could be stimulated to invest in innovative technology by implementing **European Investment Bank instruments** mitigating the financial risks with favourable loan conditions.

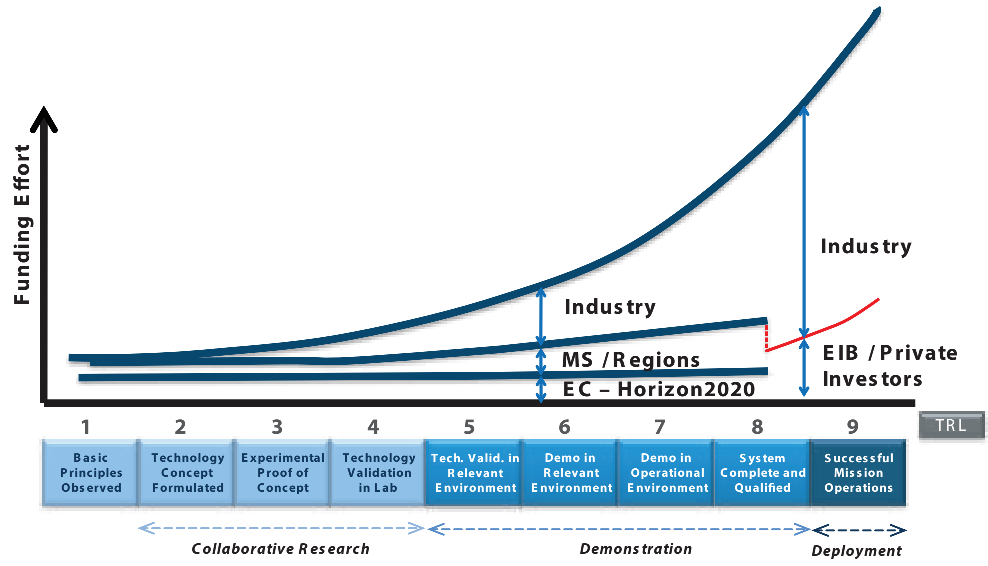
Ultimately **it would be the industry that would make the major part of the total project investment for scaling up and going to market (TRL 7 to 9)**, exploiting additional mechanisms beyond the PPP and Horizon 2020, as cohesion funds or eventually EIB instruments. There are also several other elements which should be considered when considering industry commitment and leverage factors. For instance **industry is committed to increase the current investments in training** as this is a critical aspect when it comes to deploy the intended innovative solutions to be developed in the years to come.

Because industry commits a significant share of resources with an expected leverage factor of at least 4, the set of leading indicators would include **industry investments along the innovation chain** at two different levels:

- At the sector level: based on macroeconomic and balance sheet data, an independent Third Party would assess '**the ratio between innovation investments by the representative sample of industrial stakeholders engaged in PPP projects and the EC investments in the PPP**' which should be above 4;

50 Source EMIRI.

Figure 13. Overall synergy between private and public investments, highlighting industry leverage factor[50]



- At the project level: in contracts to be signed with EC by each project, the leading principle, as far as exploitation is concerned, should be that '**the ratio between industrial consortium partners investments and the EC funding**' should be above 4.

5 International cooperation

International cooperation is an important element of the overall strategy as the challenges highlighted in the document are shared by each government and economic block. Taking into account IPR issues and priorities which may impact on European competitiveness, there are several horizontal areas which would benefit from synergies with similar programmes and initiatives at worldwide level. This would require for instance benchmarking with other programmes implemented in US, Australia, Russia, etc.

APPENDIX 1 — Information on the legal entity and suggested roles

PPP GOVERNANCE AND DIALOGUE WITH THE EUROPEAN COMMISSION

The Partnership Board

Within a contractual Public-Private Partnership, E2BA is committed to continue a close dialogue with the European Commission services by getting engaged in a Partnership Board to facilitate the advisory role of the Private Side. In this framework, E2BA would nominate their representatives for the Partnership Board, to be then appointed by the Commission subject to its own procedures.

In line with the *modus operandi* set up and successfully implemented in the framework of the ad hoc Industrial Advisory Group within the PPP under the Recovery Plan, the Association would propose to the European Commission to appoint the members of the Steering Committee and Scientific Council of the Association (see details below) as representatives of the Private Side. This proposal would ensure:

- A perfect coherence between the governance of the Association and the representation of the private side in the Partnership Board;
- A proper representation of the wider community of stakeholders, with representatives of key industries, including SMEs, research centres and universities;
- A high degree of continuity and collective memory, even if according to availabilities of Members a variable composition may be observed and if an adapting of attendees along their profiles may be needed to match specific needs of meetings;

- A perfect handover of the advisory role of the Scientific Council to the Steering Committee at the level of the Partnership Board in order to guarantee a continuity between the decisions taken within the Association and the advisory role of the private side within the Partnership Board;
- A coherent responsiveness of the private side representatives in line with the views of the private side conveyed through the Association:
- The possibility to engage ad-hoc (non E2BA members) experts, including representatives of municipalities or municipal associations, as foreseen in the statute for the Scientific Council membership

Openness and transparency

In order to ensure high openness and transparency and to ensure the adequate involvement of all relevant stakeholders in the preparation of the inputs to the Commission, in addition to the democratic governance of the Association and the way to nominate representatives in the Partnership Board, the Association would implement other means, already used for the preparation of this Roadmap.

These would include, for instance:

- The setting up of a network of National Liaison Points in Member States, in order to facilitate exchange of information between the European level and the National and Regional levels;
- The development of large consultation processes on major document such as Roadmaps, through press releases and website announcements, e-mailings, information meetings;
- The organisation of dedicated workshops or webinars (possibly open to stakeholders from other sectors when appropriate), for example on specific technical topics, to prepare inputs on specific issues requested by the European Commission or on the initiative of the Association;
- The support to the European Commission in the organisation of large Info Days open to the whole community of stakeholders.

This approach has proven very effective and allowed a broad participation of organisations not members of E2BA in projects awarded within the period 2010-2013, where roughly 70 % of EC funding was awarded to non E2BA members.

E2BA INTERNAL GOVERNANCE

E2BA Foundation

In the framework of the Recovery Plan launched by President Barroso in November 2008, a non profit association was created in 2009 by the Construction Industry, under the umbrella of the European Construction Technology Platform (ECTP) in order to enter into a Public Private Partnership with the European Commission. The Energy Efficient Buildings Association (E2BA) is ruled by the Belgian law as an A.i.s.b.l. (Association internationale sans but lucratif) registered on April 24, 2009 and its office is located in Brussels.

The Association has an aim, without search for any profit, to contribute to foster cooperation in the field of research, development and innovation in the domain of energy efficiency in buildings.

As a grouping of stakeholders of the sector, especially industry, research institutes and universities, the objectives of E2BA A.i.s.b.l. include:

a. Seeking to ensure the coherence of the position of these actors in order to contribute to reaching the objectives of the European Union;

b. Seeking to generate a favourable environment in Europe for education, research, development and innovation in the field of energy efficiency in buildings;

c. Definition of a roadmap to contribute to the definition of the R & D Programme of the European Union in this field;

d. Advising on a regular basis to the content of the calls for R & D Project proposals;

e. Contributing to the coordination of the projects and dissemination of their outputs.

The Association was set up by nine Founding Members, representative of the main categories of industrial stakeholders (not only from the construction sector) from all around Europe (France, Spain, Poland, the Netherlands, Germany, Sweden and Italy): 3 contractors, 1 electric utility, 3 suppliers and 2 engineering and design companies.

The Association quickly engaged more than 150 members across the whole value chain from contractors to equipment suppliers, from material producers to energy suppliers, including engineering and architect consultants as well as ESCOs and facility managers, and of course representatives from the public research side, to name a few. Regional clusters and representatives of end-users and public owners also engaged within the activities of the Association.

Membership of the Association

The Association is open to any organisation active in the field of energy efficiency in buildings, districts and cities. Four categories of Members are defined:

A. Members: large industrial and commercial enterprises or related associations;

B. Members: universities and public or private non-profit research institutes or related associations;

C. Members: micro, small or medium sized enterprises or related associations

D. Members: public or private organisations active in the promotion of construction or renovation of buildings, including associations, public or private constituencies and municipalities.

New Members are admitted by the General Assembly by simple majority.

Financial Resources of the Association

Financial resources of the Association may consist of any income, including mainly up to now the annual contributions of the Members. The amount of the annual contribution is determined by the General Assembly and may be differentiated between categories of Members and their sizes. So far, the annual contribution has ranged from EUR 1 000 (SMEs, Universities…) up to EUR 10 000 (large companies).

Organisation of the Association and Management Bodies

The governance of the Association is ensured by:

- The General Assembly
- The Steering Committee
- The Executive Board of the Steering Committee that included a Presidium.
- A Scientific Committee that guarantees the pertinence of the orientations and decisions of the association on the scientific side.
- A General Secretariat that ensures the operational implementation of the decisions.

General Assembly
All Members have voting rights (proportional to the paid contributions) at the General Assembly (at least annual meeting) which has all powers in the Association.

Steering Committee
The Steering Committee is the body entrusted with the management of the Association, in accordance with the guidance given by the General Assembly and with resolutions adopted by it. It is comprised of two Colleges: the College of the nine Founding Members, who are members by right, and the College of the 21 'Elected Members'. The Founding Members could make available their seat, which would be then occupied through an open election. The College of the 21 'Elected Members' is composed as follows:

- Nine Members A,
- Five Members B,
- Four Members C,
- Three Members D.

These Members are elected every two years by the General Assembly on the basis of binding nominations decided by each of the four categories of Members.

Every Member of the Steering Committee has one vote. Decisions shall be passed by a majority of at least three quarters, with a needed quorum of two thirds.

Executive Board
The Executive Board is in charge of the execution of the decisions taken by the Steering Committee and it assures the day-to-day management of the association.

The Executive Board has nine Members elected by the Steering Committee for a period of two years. The Executive Board meets every 1 to 2 months. It is chaired by a President and 2 Vice-Presidents elected from among its Members for a period of two years.

All decisions are taken by an absolute majority with a quorum of two thirds.

Scientific Council
The Scientific Council is an advisory body to the Steering Committee. It guarantees the quality and pertinence of the decisions of the bodies in charge of the governance of the Association on the scientific level.

The Scientific Council is composed of at least 10 Members of the Association appointed by the Steering Committee. B Members should have the majority of seats. The current composition of the Scientific Council is kept at this minimum level of Members in order to ensure an efficient work.

APPENDIX 2 — Drivers per value chain's element

DESIGN

Emerging standards for BIM (Building Information Modelling) deployment[51]

The IFC format is becoming an official ISO/IS 16739 International Standard. In complement, the IFD (International Framework for Dictionaries) Library and the IDM/MVD (Information Delivery Manual/ Model View Definitions) approach are also on their way towards ISO standardisation. This provides further grounds for in-depth cross-disciplinary collaboration and information sharing. Public clients are supporting IFC[52], helping leading software vendors to increase their investment on the matter. Though, the deployment of IFC in BIM is a long-term trend that would really succeed only far beyond 2020, and conditioned by large investment from the BIM vendors.

Recognised market value of LCA-based green building certification[53]

The most widely recognised environmental assessment methodologies in the construction industry (e.g. BREEAM, HQE) use LCA approaches. So far, LCA databases applicable for the

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51 In general, to be able to share information, three specifications must be in place:
- An exchange format, defining HOW to share the information (IFC is such a specification).
- A reference library, to define WHAT information we are sharing (the IFD Library).
- Information requirements, defining WHICH information to share WHEN (the IDM/MVD).

52 However a new exchange format based on the new semantic web data language might prove more adapted than IFC.

53 OPEN HOUSE — Benchmarking and mainstreaming building sustainability in the EU based on transparency and openness (open source and availability) from model to implementation. The overall objective of OPEN HOUSE is to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings by means of an open approach and technical platform. This project receives funding from the European Community's Seventh Framework Programme under Grant Agreement No 244130 (OPEN HOUSE). http://www.openhouse-fp7.eu

whole Europe are still of limited quality, and at least a decade is needed to build adequate databases at European level.

Integrated design and improved modelling tools, which may help reduce the gap between calculated and measured performances

Integrated design and improved modelling tools make building performance more predictable and easier to optimise at the design stage. The increasing IT culture among project managers paves the way to more extensive use of modelling and simulation tools as decision support processes.

Societal benefits, safety, comfort and health improvement

Energy efficient design leads to thermally improved building envelope with excellent thermal resistance and optimal thermal inertia, resulting in healthier indoor environment and higher thermal comfort for occupants. Buildings which favour day-lighting and natural ventilation are shown to increase staff productivity and retention [54]. CABA [55] indicated a few years ago that while, on average, the cost of an office infrastructure amounts to USD 10/square foot, the yearly cost of the work force amounts to USD 100/square foot. In their recent report on the Solid-State Lighting market, Goldman Sachs pointed out that 90 % of the office cost is related to productivity, while energy savings make only a small fraction of the remaining 10 %. Hence, the quality of the working environment in offices, schools, factories by far outnumbers the savings in energy [56] and should become one of the major drivers next to energy efficiency.

STRUCTURE

Coherent GHG emissions abatement

In line with Europe's 20-20-20 target [57], EU greenhouse gas emissions have to be cut by at least 20 % below 1990 levels by 2020. Yet, CO_2 emissions are still steadily increasing: the increasing demand for cement (already more than 3 billion tons/y worldwide) as well as concrete contributes to the on-going increase of worldwide CO_2 emissions, although the first R & D efforts have been successful. The development and successful market introduction of cement and concrete with significantly reduced embodied CO_2 is a major lever to cut down CO_2 emissions of the construction industry on a European and worldwide level and to move towards a low carbon economy in general. Further on, other construction materials or mix material solutions (wood, steel, concrete, ...) can provides a way to reduce the construction industry CO_2 emissions while providing energy efficient and comfortable surroundings in urban areas.

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54 '*Rethinking the Design Process',* Energy Studies in Buildings Laboratory, University of Oregon, and Konstrukt 2006.

55 *Bright Green Buildings: Convergence of Green and Intelligent Buildings*; CABA; 2008Most remarks pointing in the same direction seem to be triggered by this publication.

56 See also Kosonen, R. and Tan, F.: *Assessment of productivity loss in air-conditioned buildings using PMV index. In: Energy and Buildings* — An international journal devoted to investigations of energy use and efficiency in buildings, Vol. 36 (2004), Issue 10, Elsevier, p. 987–993.

57 The '20-20-20' targets are a series of demanding climate and energy targets to be met by 2020. These are: A reduction in EU greenhouse gas emissions of at least 20 % below 1990 levels; 20 % of EU energy consumption to come from renewable resources; a 20 % reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

Raw material availability, which pushes for improved resource efficiency, increased recycling, and increased use of alternative raw materials

Due to the decreasing availability of some raw materials, accompanied by the growing public awareness to protect remaining resources, alternative solutions have to be identified and developed, such renewable resource-based materials and biotechnology based materials and treatments.

Competition with China for world material standards

The competition from the Chinese cement industry is growing: it is important for Europe that innovative construction materials for large volume applications and related manufacturing processes leading to drastically reduced embodied CO_2 are developed in order to maintain and improve the European competitiveness and to preserve and create jobs in this industrial sector. Driving the implementation of new world standards would contribute realising this.

ENVELOPE

The development of mass customisation and standardisation

Recent market trends show a shift towards mass customisation and standardisation[58] (modular homes, prefabricated building components). Factory-made modules, produced in a controlled industrial environment, facilitate the proper integration of modules during the construction phase, allowing a better achievement of the building performance targets at commissioning and during its life time and a reduction of the final cost.

The use value of envelopes, which goes beyond energy performance

Envelope technologies provide the user with additional value (higher thermal comfort due to more friendly wall surface temperatures, high efficient insulation, aesthetics, acoustics, cultural heritage preservation, safety, climate robustness, lighting, visual comfort, air quality, user friendliness): they increase the overall value of the building in operations and lead to more attractive refurbishment.

The new functionalities brought by innovative materials

Innovative structural materials bring additional functionalities: composites, composites and ultra-thin or elastic multifunctional ceramics or other insulation materials; nanotechnologies for new materials and surface properties which improve durability and reduce maintenance needs.

The new functionalities brought by ICT

ICT, beyond the spread of Building Information Modelling and simulation platforms, allows for a better structuring and sharing of the building's technical information, and an improved simulation and consequent analysis of the envelope performances (embedded sensors for life-long monitoring and control of envelope subsystems).

58 See *Building Envelope Technology Roadmap, a 20-year industry plan for building envelopes*, DoE, 2001.

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ENERGY EQUIPMENT

World Competition for heating and cooling equipment

The global market for heating and cooling is very large, the yearly market for cooling is worth as much as USD 70 billion in 2008[59]. The value of the residential boiler market in 22 EU countries was estimated to be EUR 5.6 billion in 2004 (at manufacturers' prices, not installed costs). OECD countries dominate the market for space and water heating, but not for cooling, or for individual technologies. China leads the world for the annual installed capacity of solar thermal systems and residential (room/unitary) air conditioners.

Increasing needs for energy management at district level

The growing importance of locally generated electricity (e.g. PV systems), of corresponding storage devices and e-mobility requiring local charging stations would increase the need for a holistic energy management approach at building and district level. There is economic evidence that energy consumption optimisation at constant or improved level of comfort must be performed at district level, where a combination of old and new buildings (interconnected through electricity and/or heat networks) can be managed more efficiently in terms of costs and resources. ICT and smart metering can therefore be used to automate the control of larger energy use systems, such as street and building lighting, heat pumps, chillers, and many types of industrial machines.

CONSTRUCTION PROCESS

Growing IT and sustainable culture amongst the construction workers

The new generation of professionals has been playing and learning with computers and video games (and now smart phones and tablets) and is more aware of the sustainable principles.

59 EIA (2011).*Technology Roadmap. Energy-efficient Buildings: Heating and Cooling Equipment.*

This increasing IT and sustainable culture among workers paves the way to an extensive use of modelling and simulation tools which facilitate the construction process and ensure quality, using low-cost high-impact technologies (low power sensors networks allowing data gathering in real time and communication among workers, new materials, resource efficient technologies, etc).

Managing productivity growth despite the increasing complexity of the construction processes of energy efficient buildings

The increasing complexity of building construction processes may have a negative impact on the players' productivity, which in turn drives construction costs up. A holistic approach of productivity must be encouraged leaning on training, real time information exchanges, dedicated tooling to assist workers and quality frameworks which support self-inspection of work done at critical milestones of unit work processes.

PERFORMANCE MONITORING

The 'Smart Cities' EIP[60]

This initiative is dedicated to demonstrating commercial-scale solutions in a small number of locations, thus supporting European cities and communities to meet their commitments in, for example, the fields of energy, transport, air quality or climate change mitigation. Measures on buildings and local energy networks are the major components of the initiative.

The mindset change from professionals: from 'best effort' to 'commitment contracts'

National refurbishment targets in line with Europe's 2020 energy savings targets are initialised with the support of professional organisations[61]. They know that a change of mindset is needed at contract level: usual 'best effort' approaches would be progressively replaced by 'commitment contracts', including energy refurbishment contracts. Insurance systems have started implementing the appropriate legal framework on which construction companies can lean to sign future contracts.

Overcoming poor building operations on a daily basis

The use of data recording and analysis would show a hierarchy of areas of improvement for building operations and maintenance.

END OF LIFE

Public sector procurement

Government procurement procedures would increasingly 'kick-start' the reclaimed materials market by specifying that some percentage of the materials within its new buildings must be made from reclaimed sources. This evolution can be observed in the Netherlands and may

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60 http://ec.europa.eu/research/horizon2020/pdf/proposals/communication_from_the_commission_-_horizon_2020_-_the_framework_programme_for_research_and_innovation.pdf#view=fit&pagemode=none

61 See for instance RAGE 2012 in France where a collective approach of new standard implementation is producing the new sections of the building code which will deal with high performance buildings.

be expected to be followed in other countries in the future. This would provide a large buyer arena for reused materials, encouraging the growth of a large-scale market.

Costs and charges

Increasing charges on mining virgin raw materials, such as the aggregate levy tax in the UK, contribute to generate markets for construction materials based on recycled materials. Price increases for virgin raw materials arising from their increasing scarcity have started contributing — in some cases — to a similar trend. For sand and coarse aggregates, this trend is frequently accelerated by increasing challenges in opening new quarries.

Creating new value-added markets from waste materials

The success of the existing quality assurance/control systems on recycling of building materials (for instance European Quality Association for Recycling[62] shows that there is a potential for the building recycling market provided that the quality of recycled parts is guaranteed.

Resource management

By 2020 the renovation and construction of buildings would have to reach high resource efficiency levels according to the European Commission Roadmap to a Resource Efficient Europe (COM (2011) 571). The management of waste building materials and their reuse or recycling is indeed of primary importance to alleviate the decreasing availability of certain raw materials and avoid their further depletion, as well as to diminish the quantity of ultimate waste sent to landfills.

CROSS-CUTTING AND INTEGRATION

EC regulations

According to the **European Commission Roadmap to a Resource Efficient Europe** (COM (2011) 571), the renovation and construction of buildings and infrastructure would be made to high resource efficiency levels by 2020. The life-cycle approach would be widely applied; all new buildings would be nearly zero-energy and highly material efficient and policies for renovating the existing building stock would be in place so that it is cost-efficiently refurbished at a rate of 2 % per year. 70 % of non-hazardous construction and demolition waste would be recycled (Waste Framework Directive). The **Directive on energy performance of buildings** (2010/31/EC) leads to national obligations in terms of building energy performances and monitoring, which clearly push for improved building envelope taking into account energy efficiency strategies and related economic evaluations. The **Energy Efficiency Directive**, repealing Directives 2004/8/EC and 2006/32/EC (COM (2011) 370) proposes a new set of measures for increased Energy Efficiency to fill the gap and put back the EU on track. The proposal for this new directive brings forward measures to step up Member States efforts to use energy more efficiently at all stages of the energy chain — from the transformation of energy and its distribution to its final consumption, therefore including the building sector. The **Construction Products Regulation** (305/2011/EU) aims at ensuring reliable information on construction products in relation to their performances. This is achieved by providing a 'common technical language', offering uniform assessment methods of the performance of construction products. The revision of the **Waste Framework Directive** 2008/98/EC has consolidated the primary role

62 The European Quality Association for Recycling e.V. (EQAR) is the European roof organization of national quality protection organizations and producers of quality-controlled recycled building materials from the EU Member States.

of waste prevention. The revised Directive laid down a five-step hierarchy of waste management options: Waste prevention; Preparing for reuse; Recycling; Recovery (including energy recovery); and Safe disposal, as a last resort. With regards to building, the directive states that '*the preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.*'

The strive for cost reduction

The building's energy performances depend for a large part on the **choices made on the envelope**: return on investment optimisation requires innovative approaches and public acceptance/support to ease the upfront cost issue. New business models with performance guarantee contracts can provide more favourable funding schemes for refurbishment. Another significant source for cost reduction is the **optimisation of energy flows during building operation**, from the building level up to the **district dimension** (through electricity and/or heat and/or cooling networks, and load peak management), relying on Building Energy Management Systems that can optimise consumption, CO_2 emissions, operating costs, and user comfort. Last, the resort to **reclaimed materials** should allow cost savings, as they should be cheaper than the new ones, provided that there is sufficient information to guarantee quality as well as ease-of-location. Networks such as SalvoWeb [63] are starting to link buyers and sellers; however a more detailed database with quality-assurance would allow reclaimed products to compete with new ones.

The potential market associated with refurbishment over 2015-2050

There is a massive market potential for refurbishment in the next decades: however all the active market forces do not see this market with similar eyes, since refurbishment is still very shallow. Let us recall such antagonist forces as the need for skill improvement in the construction sector to tackle deep refurbishment at affordable prices, the lack of upfront investment capabilities form flat owners without public support or the supply push approach of energy equipment which favour replacement of old units with the promise of fats energy savings at lower upfront costs, which in turn inhibit deep refurbishment for another 15 years.

The changing behaviour of end-users and consumers with regards to environmental impact, comfort and energy price

The behaviour of end-users and consumers is rapidly evolving, as shown by the increasing awareness of environmental issues (e.g. climate change), the growing concern regarding hazardous substances (e.g. VOC emissions and indoor air quality), the importance given to comfort at work and at home, and the raising awareness that energy efficiency is a way to save money. Demographic trends also need to be taken into account (e.g. ageing of the European population). Among the end-users' drivers, one may mention:

- Ageing 'traditional' clients with increased needs in terms of accessibility and practicability, and new needs for refurbishment which could encompass energy optimisation;

- More and more demanding customers and end-users, able to compare construction services and products prices on Internet;

63 http://www.salvoweb.com/

- ‘Flexible customers’ who are ready to modify their energy consumption behaviour (to support peak load management) in exchange of economic incentives based on clear price signals

- A growing interest in eco-construction materials (for good acoustic performance, to reduce the emission of hazardous substances, reduce allergies and improve air quality, etc.) and local sourcing;

- DIY[64] ‘experts’ who prefer to do part of the construction works by themselves and like to ‘customise’ and adapt their home to their changing needs;

- Organisations in commercial and offices buildings that require an increasing level of comfort, ergonomics and safety.

Another dimension is to be taken into account: the concept of **‘sustainable sourcing’,** addressing the environmental and societal impact of the extraction and transformation of construction materials (i.e. resource depletion, energy consumption and CO_2 emissions). Sustainable sourcing is increasingly requested in public procurements together with corporate responsibility, which has to be demonstrated by the construction industry. It is a very clear driver in some countries (e.g. The Netherlands) and is also becoming in important asset in other European countries.

The needs to better link building codes, real life practices and worker skills

The new building standards require new building codes but also new worker skills. It requires training, quality control via self-inspection which is not yet a standard practice.

The changing behaviour of research centres willing to better network in order to address innovation challenges

Pre-normative research, benchmarking of construction processes, standardisation and interoperability of IT tools are topics which could be covered at a faster pace once such Research Centres are networked to address them.

64 Do It Yourself.

APPENDIX 3 — Challenges per value chain's element

DESIGN

The design of energy/resource efficient buildings (new or to be refurbished) must involve all stakeholders within a collaborative approach, allowing cost-efficient solutions

Design approaches integrate all aspects of energy-efficiency and sustainability from the beginning to the end-of-life to cope with the various new challenges. Energy/resource efficient building design must account for climate and country-dependence of building codes. Building design is impacted by climate, national regulations, the interactions between stakeholders, and the way they share responsibilities. An optimal design would progressively include the district/smart cities dimension. District morphology, local micro climates in urban areas, electrical/heating network configurations, connections with neighbour buildings for energy management, phasing with other local works influences the optimal design. The assessment of design options requires taking account of three physical levels:

- The building's operation (in particular its energy performances on the long term), maintenance and end of life (including options from knock down to selective or full deconstruction, refurbishment and conversion);
- The building components' reuse, and recycling potential, (including options from knock down to selective or full deconstruction, refurbishment, preservation and conversion);
- The building material durability and recycling potential.

The complex multi-criteria optimisation process covers:

- The environmental impact (minimisation of CO_2 emissions and embodied CO_2/energy);
- The **value for the user** (internalising aesthetics, accessibility, increased comfort and productivity, preservation of cultural heritage, public health).

Improving the planning process implies shared data, practices and tools with proper training and education

Design approaches move from a conventional, linear process (going from architect to engineering bureaus and construction contractors), to a more collective, yet iterative, approach which appears indispensable to complete the optimal design, commonly called *integrated design*. Commonly collaborative design tools with easy to use interfaces and long-time data formats are required. A **knowledge-based approach to collaborative design** allows designers accessing the right information and provides performances of real cases, thanks to:

- Interoperable databases to manage economic assessment;
- Building Information Modelling and Building Automation tools that are cost effective and interoperable thanks to a new exchange format based on the new semantic web data language (eventually replacing the IFC[65] open standards);
- Harmonised Life Cycle Assessment methods at the whole-building level and up to district scale.

The necessary shift in mindsets requires innovation in education and training practices in order to foster:

- Collaboration between architect, engineers and contractors for resource efficient designs and the planning of the preparation/interaction with smart grid technologies;
- Collaboration between contractors and structural engineers to favour innovation at material level.

STRUCTURE

The embodied CO_2 of building structure materials must be significantly lowered

85-95 % of the overall embodied CO_2 of construction materials used in the building structural parts build up prior to leaving the factory gates. Sources of significant CO_2 emissions include mining and processing of the raw materials and the related logistics. In the case of cement clinker production more than 60 % of the released CO_2 is due to the decarbonisation of the raw materials and responsible for more than 500 kg CO_2/t of cement clinker produced. The remaining 5-15 % of the embodied CO_2 of the materials used in the building structure relates

65 IFC: Industry Foundation Classes.

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to the construction, maintenance and demolition of the building[66]. For some office buildings, it is reported[67] that the embodied CO_2 of the structure's building materials (concrete and reinforcement steel) represents the largest part of the building's total embodied CO_2, varying from 68 % to 70 % (typically concrete accounts for two thirds of this amount and steel reinforcement for a third). Future technical solutions must have a low level of embodied carbon while meeting performance requirements such as workability, strength development and long term durability to ensure that structural engineers specify the use of such materials. Various approaches exist to lower the embodied carbon of construction materials:

- **Cement and concrete with low embodied CO_2**: cement production accounts for an estimated 5 % (or more) of the world's CO_2 emissions[68]. Although concrete has relatively low embodied carbon content, it is massively used worldwide and therefore has the highest total GHG emissions: cement is manufactured at the

66 Berge, B. (2009) *The ecology of building materials*, 2nd edn. Architectural Press, Oxford.

67 Dimoudi, A., Tompa, C. (2008) *Energy and environmental indicators related to construction of office buildings Resources Conservation and Recycling* 53:86–95.

68 WBSCD and EIA (2009). *Cement Technology Roadmap 2009: Carbon emissions reductions up to 2050.*

annual rate of over 3 billion tons per year[69], enough to produce over 10 billion cubic meters — around 25 billion tons — of concrete[70];

- **Use of timber** (or other renewable-based materials including biotechnology-based materials and treatments for paints and adhesives) for the construction of individual homes, but also multi-storey buildings, in areas where it is adequate, for example areas with large wood resources located in reasonable proximity to the construction site, or timber harvested in forests where sustainable forestry is practised;

- Building materials, which are entirely or partly based on raw materials extracted close to the building site (**local sourcing**), may contribute to minimising transportation related CO_2 emissions;

- **Use of reclaimed materials**, especially steel sections and concrete, from demolition sites.

The structure can be used as a thermal storage for smart heating or cooling

Depending on the integration with smart grid technologies the mass of the structure can be utilised especially for short term thermal storage. Buffering of peaks prevent grid overloads and minimises the thermal energy supply systems (cost reduction).

ENVELOPE

A reliable multi-objective envelope optimisation methodology allows integrating all envelope constraints for new and refurbished buildings

Envelope design constraints include energy performance, acoustics, fire resistance, indoor air quality, thermal comfort, legislation, aesthetics, cultural heritage, preservation, seismic, availability of products, regional differences, etc. and, of course, costs and energy harvesting. Envelope optimisation implies searching for complex trade–offs between conflictive objectives (insulation and acoustics, air tightness and humidity, daylight and thermal insulation, or more generally energy consumption, comfort and energy harvesting). A wide range of methodologies and tools[71] are under development. They are yet difficult to benchmark (different coverage — for instance only HVAC optimisation- or different objectives -energy efficiency, CO_2 reduction, environmental impact reduction...) with no data on robustness and cost efficiency. A systemic approach should therefore be encouraged to optimise the integration of new materials and components in the envelope.

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69 World statistical review 1999 – 2009, CEMBUREAU. Cement production, trade and consumption data.

70 http://minerals.usgs.gov/minerals/pubs/commodity/cement/mcs-2012-cemen.pdf and van Oss & Padovani (2003) Cement Manufacture and the Environment Part II: Environmental Challenges and Opportunities. Journal of Industrial Ecology 7(1):93–126.

71 See for instance *Generic multi-objective optimization method of indoor and envelope systems' control*, Boithias et all, 2012; or *Optimization method for building envelope design to minimize carbon emissions of building operational energy consumption using orthogonal experimental design*, Zhu et all, 2012.

Performances keep improving in terms of insulation, costs, energy harvesting, building integration and building adaptability.

The technical and unit cost performances of each envelope are a compromise between embodied CO_2, the insulation performance targets for the building over its life time and the potential energy harvesting. Each envelope component must meet specific building integration requirements to ensure air tightness and minimise thermal bridges, whatever the building's age, all of it is optimised in terms of final costs and energy harvesting. Energy harvesting optimisation takes into consideration other functionalities of building envelope components, such as natural light control which also impacts the general energy efficiency of the building, which is indeed the final aim. The performance of each component is controllable, which allows guaranteeing its contribution to the overall building performance improvement by having implemented a holistic and integrative approach in the design of the building components (energy harvesting systems are also integrated in the general energy systems of the building). Envelope components must favour easy dismantling, replacement and repair, reuse, and recycling. Building envelopes contribute significantly to the energy performance but also to indoor quality and comfort, in connection with the Building Energy Management Systems (BEMS). The 'smart building envelope' would 'adapt to its environment by means of perception, reasoning and action'[72], namely:

- Handling variations (i.e. provide an acceptable response to regular variations[73], unanticipated events, changes in priorities and performance criteria, variations in its own envelope performances over time);

- Handling conflict (anticipating the effect of an action on all other tasks to be performed, and implementing multi criteria optimisation);

- Handling occupant behaviour (adapt to user needs and behaviour, and to the effects of their presence).

This also implies a substantial improvement in building management systems to operate in a more efficient and integrated way with the whole building.

Innovative materials and prefabricated components help improving energy & resource efficiency durably

Innovative materials and components contribute to the reduction of embodied energy and manufacturing cost reduction. They include:

- Better insulation materials: novel insulation solutions are thinner, cheaper and easier to integrate. They rely on innovative technologies such as intelligent materials, nanofoams, aerogels vacuum insulation panels, multi-material composites, or include biomass, new insulation products based on cellulose and nanocellulose fibres, functionalised heavy clay, that can be developed to improve the building hygrothermal performance;

- Radiation control (cool roofs,) for example by using smart pigments;

72 See *Intelligent Building Envelopes — Architectural Concept & Applications for Day lighting Quality*, Annemie Wyckman, 2005.

73 *Integration* of day lighting and daylight/solar control is of particular importance as artificial lighting is responsible for approximately a third of the primary energy demand of an office building.

- Improved glazing materials and components e.g. for switchable glazing (smart windows);
- Improved solid construction materials and components, e.g. concrete based on composite cement used in connection with innovative insulation solutions is another possible approach to improve energy and resource efficiency;
- Improved light weight construction materials, e.g. prefabricated timber construction elements (Reference: TES-ENERGY-FAÇADE an EU-funded research project see www.tesenergyfacade.com.);
- Multi-functional components, e.g. with integrated ventilation ducts for ventilation with heat recovery systems;
- Timber elements for urban energy efficient multi-storey buildings: wood and timber elements are both lightweight and fast to assembly thus reducing building times and providing comfortable and cost-effective way to produce multi-storey buildings at affordably.

Users are accounted for the delivery of the full energy performance potential of envelopes

An optimum must be found between comfort (thermal, visual, acoustics …) and primary energy demand. Envelope can indeed bring more than energy savings to building end-users[74]. Similarly, the façade components of the building can be affected by the user behaviour having at the end impact in the energy performance. The user therefore must be taken into account not only as a passive element being affected by the general performance of the envelope, but also as an active part through behavioural patterns. In case of façade solutions for retrofitting activities, solutions are deployed in buildings with low impact in the user behaviour[75] causing low intrusiveness in the general functionalities of the building. Learning platforms or other ways of information for end-users are required for high acceptance of these new technologies.

ENERGY EQUIPMENT

Interconnected energy equipment are deployed in existing and new buildings to contribute to global energy performance

The energy system is facing a paradigm change: while previously energy was produced when needed, in the future energy would be used, as much as possible, when it is available from renewable sources. Energy storage would also play an increasingly important role, saving cheaply produced energy to be used at high demand times of the day. This kind of system change needs adaptations in energy networks, management systems and also in appliances, energy equipment and their control systems. Within each building, energy consuming

74 For instance, following to refurbishing, the degradation in only one aspect of a user's environment is likely to outweigh all achieved improvements, in terms of users' perception of benefits. (*A Climatic Envelope Extension of an Office Building – Perception and Reality of the Change in Environmental Conditions*, Jentsch et all, 2006).

75 For example, in a district composed of buildings with mainly active envelopes, moving façade components of other buildings and the resulting glints can cause discomfort and push occupants to shade their own rooms, then impacting the energy performance of their own building envelope.

equipment (ventilation, space heating and cooling, domestic hot water and lighting) would be appliances with individual high energy performances: they are integrated, interconnected and controlled in order to optimise their efficiency in real time. Ventilation systems would be efficient and air quality monitored in real time with heat recovery systems, independent humidity control, and linked to heating and cooling generators. The whole building would be supervised by networked intelligence able to collect data from all connected devices and to combine them to efficiently control HVAC, lighting, hot water systems, local energy generation and storage — a smart grid interaction.

Future buildings would be able to communicate with each other and their environment. They would manage the energy use taking into consideration the availability of local renewable resources and the more profitable periods for network connections. BEMS (Building Energy Management System) control would be able to manage the gap between demand and availability periods, by taking advantage of inertia in heating and cooling systems and by using energy storage equipment. Low temperature thermal networks at district level would contribute to manage the mismatch between local centralised generation and instant demand, allowing bidirectional exchange with generation, storage, and demand. Systems capable of operating with low temperature networks would be used. Thermal storage systems, both passive, such as wall mass, and active, such as hot water storage, or thermo-chemical heat which stores heat with very low losses in chemical bonds (using for example phase change materials), would become one of the most crucial technologies to manage the gap between renewable energy systems supply and energy demand. Short term, (days), mid-term (weeks) and long term (seasonal) storage systems are required. The interaction with smart grids would also help to offer lower costs when enough energy for heating, cooling and electricity is available. Future buildings could also use direct current networks and benefit from removing unnecessary transformation losses between AC networks and DC equipment and electricity storage batteries.

Addressing this challenge implies a prompt market take-up of such technologies by all the players of the building value chain (from architects to installers and building owners).

The socioeconomic aspects of energy management are taken into account to make sure that high performance buildings are used properly

Intelligent control systems take into account end-users' needs and wishes, being designed to ensure:

- User acceptance (individual or collective), driven by the added value to the user;
- Coherence between investment costs and the purchasing power of customers;
- Demographic trends (ageing of the population);
- Changes in consumer behaviour (increasing environmental awareness, growing IT culture);
- Possible rebound effects.

Energy labelling of energy equipment would be effective at European level, and would have the trust of the market and of the users as it improves the transparency of the equipment performance and maximise comfort, energy performance and reliability. The labels are key communication media to raise user awareness of energy efficiency.

CONSTRUCTION PROCESSES

Worker-centric construction processes are durable, adaptable, with better productivity and are able to cope with the increasing complexity of buildings

It is to drive construction costs down (while improving the energy efficiency and durability of buildings) that construction processes have to be durable, adaptable, while ready for increased complexity. 'Worker-centricity' is of paramount importance to ensure higher productivity and to expand on a pool of qualified workers.

Quality driven construction processes involving skilled workers are developed to improve the predictability of energy performance

Construction of energy efficient buildings must be quality driven. Poor and unreliable construction processes would compromise the final performance of the building, despite all efforts done during the design and the structure and envelope engineering steps, and would impact the operational phase as well. The increasing complexity of the construction process involves a variety of skills and expertise located in various company sizes (from SMEs to multinationals) that have different roles and responsibilities in each of the construction processes. This segmented approach makes quality level difficult to be met. Appropriate education and training are needed to create a virtuous circle: a qualified worker base ready to meet the potential deployment growth of energy-efficient buildings, and skilled intermediate management to improve construction quality are of paramount importance.

Although construction is naturally based on a sequence of works (foundations first, then the structure, walls, roof, etc.), complementary skills may work in parallel for some elements (in particular for the envelope). More transversal skills (e.g. thermal, acoustics and/or cultural heritage expertise) must be promoted within the construction sector, in particular for the middle management. Procedures of control and inspection, and innovative construction processes have to be developed in order to achieve the expected energy parameters at commissioning stage.

The construction process becomes a more collective process

Ensuring high energy efficiency in buildings would require moving from a conventional, usually not interconnected, construction value chain to a seamless one where players work collectively. This value chain encourages innovation and **self-inspection of workers at intermediate milestones** using irrefutable techniques to validate the quality of past work and results. User

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involvement in renovation processes would require special attention, in particular when a deep retrofitting is required. Social aspects are becoming very relevant and are a critical factor for project success. In parallel, new low intrusive techniques and the utilisation of tools and technologies that speed up construction processes with high quality standards are required.

Best effort contracts are replaced by performance guarantee contracts
On top of the quality challenge, the construction sector has to meet a guarantee of performance:

- Guarantee measured **energy performance** to meet pre-set contractual values;
- Guarantee measured performances related to comfort and health (thermal comfort, acoustics, indoor air quality and accessibility in particular).

Shared building construction tools and practices are deployed
Increased collaboration between players during the construction phase would rely on shared tools, data and practices in order

- To meet the guarantee of performance;
- To increase the reliability and productivity of the construction process.

Common tools have to be developed for technical information storage and exchange and contractual obligations. Building Information Modelling (BIM) tools must prove to be cost effective and interoperable enough in order to overcome contractors' resistance to change. User-centric interfaces must be developed accordingly. There is a trend to go for prefabricated components in the construction sector (e.g. precast or prefabricated structural components, preassembled parts of the envelope). This technology transition, compared to traditional construction processes, aims at further reducing costs and at increasing quality standards: it requires the development of new processes and possibly automated tools, which have to demonstrate their cost-effectiveness. Finally, shared tools and practices have to demonstrate that they lead to a high level of occupational safety. For example, multi-users scaffoldings that stay on the site during the whole construction duration are cost-effective and ensure an improved safety for workers as well as reduced nuisance to the neighbourhood, in particular for refurbishing works. Prefabricated components can also lead to health and safety benefits.

PERFORMANCE MONITORING

Energy performance is monitored steadily at the building and wider district levels over long period of times, combined with safety, security, comfort and any other monitoring system
Standardised methods and indicators are available to assess and benchmark the energy performance of buildings, systems and components. Performance audits and continuous commissioning are supported by recorded data of real time performance. A key challenge would be to better understand the dynamic changes in energy use. Sensing techniques, possibly coupled with dynamic building and district simulation models, should allow for the allocation of performance contributions between the critical components, as well as the impacts of the user habits:

- The envelope performance should be measured according to key energy criteria: air infiltration, heat conduction including bridging and solar heat gains;
- Energy equipment should be monitored using an appropriate level of sub metering;
- It is necessary to measure the weather conditions or to have access to these data to understand the buildings / districts performance.

The uncertainty of measurements and monitoring data should be carefully evaluated to quantify the impacts both on energy management decision-making processes and on energy refurbishing design. Low-cost sensor networks and measurement technologies should be used to accurately represent energy and comfort parameters. Energy performance monitoring systems are integrated in any other existing system and sensor in order to exploit potential synergies between the systems leading to a more cost-effective solution in a smart city environment.

The building and district energy performance is continuously optimised to meet performance criteria and evolving user's requirement and behaviour (including load forecast)

Multi-criteria smart building and district management systems are implemented to continuously adapt the performance of the building to the constraints (occupancy, weather, user behaviour, etc.), thereby making sure that energy efficiency does not compromise other performance criteria (occupant's comfort, health, wellbeing and security), as well as the building's functionality. Comfort tolerances are set up to maximise the optimisation potential (for example the building does not operate at a constant indoor temperature, but within a 'comfort zone'). This is achieved by simulation based control of the building linked in real time with BEMS which sample and predict the best whole building outcome every few minutes. End-users should also be part of this optimisation process: new multimodal context-aware interfaces and devices would make the in-house network as 'user-friendly' as possible, thanks to a right combination of intelligent and interoperable (manual) services, relying on new techniques of man-machine interactions (ambient intelligence, augmented/dual reality, tangible interfaces, robots, etc.). 'User-proof' solutions are implemented to make such systems robust enough. A building integrated approach implies that the user is taken into account in the design constraints of new or refurbished buildings. Feedback on criteria, such as comfort, accessibility and acoustics in energy efficient buildings, cultural heritage value, are therefore required to make also new buildings/refurbishments specifications more robust and gain more flexibility.

Reduce the excess of unused, difficult to understand and not accessible information and data on real energy performance of buildings

The existing information on real energy performance of buildings is currently either not accessible and difficult to understand due to excess of data (in most cases not useful data) or is too fragmented, resulting on data management systems which are not used or poorly interpretable. The final aim of any monitoring systems is to gather the minimum necessary data to provide information to the management system that are able to optimise the general performance of all systems in the building to produce the minimum energy demand and maximum financial return from all renewable energy sources present in the building. Demonstration of research developments is fragmented and not comprehensive, resulting in incomparable results. Test bed demonstration sites require a common approach and data monitoring strategy to make the resulting information useful for the research community.

Energy performance based contracts grow steadily

The actual building energy performance in operation would be compared with the designed performance and the commissioning performance. Contracts should have clearly defined terms and liabilities, in order to:

- Provide a clear definition of the guaranteed energy performance and standardised reliable methods and tools to measure and monitor it;
- Prevent from potential negative rebound effects;
- Anticipate issues related to end-user's behaviour (in particular 'Do It Yourself'), since end-users may tamper with the energy equipment or the envelope, beyond the contractor's control.

The actual performances of energy efficient buildings and districts are used as benchmarks by the construction sector for future constructions and refurbishments

Feedbacks and lessons learned from the energy efficient buildings and districts in operation should be used to support energy efficient deployment within the building sector. Techniques are therefore needed to measure and maximise the use value of new technologies and components within the building value chain: a high use value should accelerate the deployment of energy efficient solutions.

END OF LIFE

Building deconstruction practices must evolve from demolition to selective demolition and deconstruction/dismantling

When considering the destruction of a building, the common practice was the full demolition, mainly through knock-down. In the perspective of resource efficiency and sustainability of buildings, building destruction practices must evolve towards more sustainable approaches:

- Building deconstruction (or dismantling) should allow for a high rate of reuse of building components and the recycling of building materials, but at high additional costs;
- Selective deconstruction allows reusing and recycling only partially, (but the most critical components and material), at limited extra expenses.

The choice between demolition/deconstruction or rehabilitation must be based on informed decision-making processes

Selecting rehabilitation or demolition/deconstruction of a building is a complex process. It must be backed by reliable energy consumption estimations, taking into account the expected energy/resource performances of the rehabilitated building, the embodied energy/resources of the materials and process costs for construction and demolition/deconstruction, the reuse/recycling potential of building components material. Life Cycle Assessment and Life Cycle Costing approaches must provide the appropriate support. As mentioned in the design phase, the rehabilitation or conversion of a building into a new use depends on the direct building environment. In particular, the district level must be considered in the optimisation process: connection with neighbour buildings, (particularly important in the case of districts of historic value) existence of energy infrastructures, phasing with other rehabilitation works.

Sustainable and profitable exit markets must be created and enabled for reuse or recycled materials

Stating that the whole building value chain must integrate reuse and recycling considerations in its assessment processes relies on a fundamental assumption: reused parts and recycled material would indeed be reused and recycled. Today, the market for reused parts and recycled is very limited, very far from what is requested to reach the objectives of the EC Waste Directive in 2020.

This is clearly due to:

- A lack of technical solutions enabling a more widespread use of recycled material in like-to-like applications, e.g. concrete for structural applications (multi-storey dwellings) based on large volume fractions of recycled concrete fine (i.e. sand) and coarse aggregates;

- Missing cost-effective technological solutions to separate composite construction materials, such as (fibre) reinforced concrete;

- Limited consideration of 'easiness to deconstruct' during the design phase;

- A lack of insurance schemes to guarantee the performances of recycled products and material over time. Such measures are compulsory to allow for the recycled markets uptake.

A second aspect related to recycling practices is the acceptability, which can play either in favour of or against recycling and reuse. The use of recycled products and material can be perceived as 'fashionable' and support the trend. But in parallel aesthetical considerations can also prevent from reuse ('second hand' appearance).

CROSS-CUTTING AND INTEGRATION

Research and innovation must be better linked to speed up the market uptake of promising solutions (= pre-normative research)

The energy transition[76] in the building sector is slowed down by obstacles that are linked with technology, processes and the integration of technology and process. Innovation implementation is therefore critical, and the driver should be the realisation of increasingly more ambitious energy concepts in successive waves, allowing the different players to learn from past waves, to prepare for the next wave and to scale up and replicate building projects both in terms of quantity and quality. A key success factor for this transition process itself lies in the new role of individuals, from construction managers to skill workers, to foster collective approaches of building construction and refurbishment.

76 Energy Transition of a Sector in the Netherlands, *I.J. Opstelten, Dr R. Weterings, Drs. F.A. Versteeg Energy research Centre of the Netherlands, TNO, FORGOOD (2009).*

Standardisation

Key challenges include:

- Various building codes and other regulatory standards exist across Europe. Better coordination would open wider markets for innovative products;
- EPDs (European Product Declarations) would show all relevant data in a standardised manner for quick integration in product databases for ecological data. Regularly updates are mandatory, e.g. if changes of the assessment occur. All major ecological, social and cultural aspects have to be part of it, when corresponding effects exist (impartial checking);
- Harmonised BIM and BACS Standards.

Comparable labelling (with respect to different regions)

A new European mechanism for energy labelling of buildings, building components (materials, envelope components, energy equipment) and associated processes (construction) must be found. Regional aspects (different climates) must be considered.

Major social, demographic and climate evolutions by 2050 must be anticipated

Energy efficient buildings of the future would have to anticipate and adapt to major changes, such as:

- Climate change;
- A growing and increasingly urban population (resulting in a urban sprawl issue);
- A growing concern for the preservation of historic value areas;
- An ageing population with changing needs (e.g. accessibility, ageing in place);
- An economy undergoing frequent crises and impacting the purchasing power;
- A shift from building ownership to renting;
- Smarter technologies and growing ICT culture.

The use value of buildings based on an in-depth understanding of users' behaviour must be scientifically assessed and taken into account over the whole building life cycle

A better monitoring, analysis and modelling (especially in the design phase) of **end users' behaviours** is required to make new buildings/refurbishments specifications more robust ('user-proof'), to possibly influence users' patterns and to give more flexibility and adaptability in order to cope with demographic trends. This relates to the **different values that users give to a building** (perception of comfort, usefulness and usability of solutions and services, perception of historic value, acceptance of new technologies and building constraints, etc). In particular, refurbishment projects must deal with complex users' perceptions. Managing occupants' expectations and perceptions of benefits[77] can reveal quite difficult. Analysing and modelling the user's behaviour and perception of the building value would rely on collecting:

- Data on use value coming from field experience (i.e. from the management of existing buildings);
- Feedback on constraints, such as comfort, preservation of historic value, accessibility and acoustics in energy efficient buildings.

New techniques need also to be validated and spread to address quantified assessment issues:

- Experimental methodologies for 'in vitro' validation (modular testing facilities, able to reproduce a wide variety of living habitat boundary conditions);
- In vivo experiments with adequate panels of real life end-users, to assess the implication and adoption by the end users under quasi real life conditions and to measure acceptance levels.

A holistic optimisation framework is required to minimise CO_2 emission, energy consumption and cost of ownership, where Life Cycle Assessment supports decision-making a teach stage of the building value chain

Optimising the energy/resource performances of a building, taking account of all the processes and material/components involved, over its full lifetime, is a very complex, multi-criteria optimisation issue. The assessment of various building design options requires considering in parallel three physical levels:

- The building material level, where durability issues, embodied CO_2 and recycling potential, must be addressed;
- The building component level, where the component reuse is the main challenge;
- The whole-building level, in operation (with its energy performances monitored and optimised on the long term), including maintenance (durability and ageing of components) and up to the end of life (with the various options from knock down to selective or full deconstruction, refurbishment, preservation and conversion).

A key concept for CO_2/resource optimisation is the **embodied energy**. In recent decades the operational energy in buildings (lighting, heating, cooling, etc.) was accepted to be the major part while the embodied energy represented only a small fraction (10-15 %). Consequently, much effort was made towards the reduction of the operational energy by increasing the energy efficiency of buildings. However, as the target is to significantly reduce operational energy, the percentage of the embodied energy in the total energy of buildings would becomes increasingly important and therefore life cycle approaches need to be considered when developing new materials, components and processes that consider CO_2, energy, water and other sustainable principles. The critical issue for design 'eco-optimisation' is therefore to arbitrage

77 For instance, following to refurbishing, the degradation in only one aspect of a user's environment is likely to outweigh all achieved improvements, in terms of users' perception of benefits. (*A Climatic Envelope Extension of an Office Building – Perception and Reality of the Change in Environmental Conditions*, Jentsch et all, 2006).

between the expected operational performances of the building solution, and the embodied energy of all material, components and processes involved. This impacts numerous steps of the building value chain, as described below. During the **design phase,** the following must be taken into account:

- The performance of building system as a whole;
- The integration of reused or recycled material in the building;
- The reusability/recyclability potential of the components and material that would compose the building;
- The building's refurbishment or conversion possibilities when reaching its end of life ('the greenest building is the one that is already built'[78];
- The building's dismantling possibilities so as to ease the reuse of components ('design to dismantle').

At the level of the **structure and envelope** of the building, this translates into:

- The sustainability of the materials/components fabrication processes (concrete, cement, wood, glazing, insulation materials);
- The durability of the materials and components (including stability of properties over time) and their sustainability (renewable, biodegradable materials);
- The recyclability and reusability of the materials and components;
- The content in recycled material (for instance from building wastes used in structural materials);
- The embodied CO_2 of the respective material/system solutions;

In this context of issues, geopolymer materials seems to be suitable for the substitution of traditional building materials, because of their greater durability and capacity of employ many wastes and by-products as raw materials.

- The real performances of the integrated envelope (different from the sum of the performances of the single components);
- The preservation of the cultural heritage in case of refurbishing (a real challenge for structural engineers who must partner with owners, architects and developers);
- The source of procurement (local sourcing to minimise transportation).

78 Elefante, Carl (2007). *The Greenest Building Is...One That Is Already Built*. Forum Journal. Vol 21, No 4.

It implies that structural engineers and material engineers have to work together: for the time being, the material manufacturer is generally involved too late in the construction process to inform on the selection of the structural materials. At the **construction stage**, more efficient construction practices must be developed to reduce material requirements, and minimise CO_2 emissions during the transport of materials and the construction process: new ways of constructing have to be invented (e.g. optimise between offsite prefabricating and onsite construction to optimise CO_2 and cost). At the **building's end of life**, reliable evaluation methods and tools are required to arbitrage between 'knock down', (selective) deconstruction, preservation of historic value elements and rehabilitation. Overall, enabling the proper optimisation of CO_2/resource in buildings requires to be backed by a set of tools and methodologies that allow comparing alternative building design options data bases against their costs of ownership and possibly additional value streams. Life Cycle Thinking provides a series of tools that ease this complex task of integrating sustainability concepts all along the building value chain. **Life Cycle Assessment**[79] in particular is recognised to provide the best framework currently available for assessing the potential environmental impacts of components and systems. It however requires a harmonised set of approaches: existing approaches should be benchmarked before being finally adapted to ensure they are reliable, affordable, and widespread amongst the stakeholders.

The deployment of Building Information Models and Building Automation (BASCS) makes planning and realisation and utilisation of energy efficient solutions more cost-efficient and enable the engagement of constructors and manufacturers

Key challenges include:

- Manufacturers would strive for cost reduction through standardisation and prefabrication of complete subsystems at factory level, a trend which has shown tremendous cost reductions at increased performance;

79 http://lct.jrc.ec.europa.eu

- Constructors would favour creativity and dedicated solutions to take into account the specifications of each building and the use value of the occupants: the return on investment might not be then the only purchase criterion;

- Engineering bureaus may be in a position to offer both options which differentiate by architectural options.

At any rate, it would be the integration of technologies into a reliable construction process that would deliver the performance expected by design, within the value constraints imposed by the final client.

Resource efficiency in buildings must integrate a district dimension with smart grids

When seeking for optimisation, the building process would have to go beyond the building scale and integrate also the district level, which can bring both constraints and opportunities for synergy. Buildings can indeed collaborate at a district/neighbourhood scale and interact at a city-wide level with the smart grid and energy networks. District morphology, ultra local micro climates in urban areas, district electrical, heating and cooling networks, connection with neighbour buildings for optimised energy management (with energy trading and energy storage pooling), support to peak load shaving for the electricity grid, time phasing with other works are as many elements that can influence the building design and performance optimisation. The right balance also has to be found between a highly decentralised electricity production and a centralised micro-production. To promote an integrated and coherent approach and reduce construction costs, construction processes should likewise have, when relevant, a district dimension. Here district means either a geographical district, or a 'virtual' district, i.e. buildings belonging to the same category (e.g. governmental buildings). The district approach allows the contractor implementing standardised construction processes to tend towards mass production, with only minor customisations required. Even the urban planning scale can be considered with regards to energy flow management: buildings with complementary energy demands may be located close to each other and/or designed to fulfil multiple functions. GIS[80] and Spatial Data Infrastructure can help to consider a broader dimension. This would require flexible and robust solutions as well as intense collaboration between institutions at local/regional level (city management, governmental bodies, energy agencies …) based on a systemic optimisation of energy resources/waste needs at district level. Finally, one must note that even end users' behaviours can be impacted by the district dimension: for instance, reactive facades in the surroundings can cause discomfort to the occupants of a building and lead to misbehaviours.

The shift in mind set required for collaborative optimisation should be supported by innovative education and training techniques

Training and education would be a critical way to:

- Improve the collaboration between architects, engineers and contractors for resource efficient design, and between contractors and structural engineers to favour innovation at material level;

80 Geographical Information System.

- Increase the level of skills in the different professions, so as to deal with new technologies, tools and methods, preservation of any potential historic value and integration needs;
- Increase the level of responsibilities of the different stakeholders by addressing contractual issues, and spreading insurance and performance guarantee approaches;
- Improve the awareness of the public with regards to energy/resource efficiency issues, thus increasing their acceptability by end-users.

Innovation processes dealing with the whole building value chain are able to facilitate the integration of novel technologies and construction processes

Integration can be facilitated by several innovative ways of addressing the different steps of the building life cycle. Let us mention for instance:

- Pre-normative research;
- Standardisation;
- A European mechanism for energy labelling of buildings, building components (materials, envelope components, energy equipment) and associated processes (construction);
- Public procurement improvements.

Networked cooperation involving laboratories to accelerate innovation

The national dimension of building codes and regulations prevent researchers and innovators to learn from each other on the basis of real construction experiences. The European dimension of technology and construction process optimisation would benefit from intense networking at all points in the value chain so that good and poor experience can be shared to accelerate innovation processes.

APPENDIX 4 — Summary of cross-ETP priorities by Building-up project

The Building Up Roadmap includes eight Cross-Platform (CP) collaboration areas in research and innovation considered of interest by several ETPs and having high impact for the energy efficiency in the built environment. These are the following:

- *CP1. Performance Based Approach for building components, including sustainable design, Life Cycle Analysis;*
- *CP2. Multi-material composites;*
- *CP3. Healthy indoor environment (including air quality, ventilation, lighting, acoustic performance);*
- *CP4. Electricity generation and storage materials and systems (e.g. storage systems including building integrated energy technologies);*
- *CP5. Thermal generation and storage materials and systems (e.g. storage systems including building integrated energy technologies);*
- *CP6. Advanced thermal insulation construction materials for new buildings and existing buildings (e.g. aerogel, nanofoams, vacuum insulation panels);*
- *CP7. Building materials recyclability and reuse of components;*
- *CP8. Renewable resource-based products.*

The following tables report 2020 targets and research and innovation topics for each identified cross-platform area.

TARGETS	RESEARCH AND INNOVATION TOPICS
CP1 Performance Based Approach for building components, including sustainable design, Life Cycle Analysis	
1) All building components meet an eco-design approach (including LCA) covering the whole chain of the building life (material production, construction, use, recycling); 2) To assure higher energy efficiency and advanced building performance (e.g. acoustic, seismic, etc.).	• Agreement on common understanding (boundaries) and handing back to national standards; • Common methodology based on existing Life Cycle Analysis /LCA studies (CEN TC 350 based); • Systemic approach for all energy usages (energy, water…) taking into account their mutual interaction; • Link with future modifications of Eco-design EU directive; • Design tools for optimisation of buildings and building components; • Building design tools for architects allowing for real time building eco-design; • Development of new devices for reduction of water consumption.
CP2 Multi material and composites	
1) To provide multifunctional materials from: • Assembling of materials and/or components having different functions to obtain new elements enabling the exploitation of these different functionalities; • Producing composite materials enabling to exploit new functionalities; 2) To increase the use of building waste into recycled composites; 3) To develop composites consisting of renewable source matrix and fibre materials.	• Low-cost processing technologies for composite materials production and for components assembling; • New production processes for fibres — easy application methods; • Bio-mimetic technologies: need for better understanding of surface interaction on nano scale; Multi-scale modelling from atom to system; development of Chemical coupling agents and binders.

TARGETS	RESEARCH AND INNOVATION TOPICS
CP3 Healthy and comfortable indoor environment (including air quality, ventilation, lighting, acoustic, etc.)	
1) Availability of validated planning and measuring tools for Indoor Environmental Quality; 2) To improve comfort levels in buildings and houses, including historical buildings through highly energy-efficient and financially affordable internal components; 3) Active functions are integrated into the building; 4) All used materials have near zero harmful emissions (e.g. Reducing the Volatile Organic Compound (VOC) content of building materials).	• New and accurate IEQ assessment and planning tools; • Better understanding of VOC release. Better control over acoustics. Better control over moisture; • Empirical and reliable epidemiological data on correlation between buildings and human health; • Improved aesthetic room concept • Low-E insulating glazing, coatings, vacuum glazing and aerogel for reduced U value. Electrochromic, thermochromic or photochromic properties for G value control; • Multifunctional glazing; • Improvement of building material properties in order to maximise human comfort; • Establishing a methodological guide for the energetic rehabilitation of historic buildings; • Efficient, comfortable indoor lighting (Flexible Lighting based on LEDs — Development of LED integrated coated textiles); • Materials/systems with integrated failure warning; • Reducing the Volatile Organic Compound (VOC) content of building materials.
CP4 Electric generation and storage materials and systems (e.g. storage systems including building integrated energy technologies)	
1) System and components need to be optimised (cost and energy) and their performance evaluated correctly. Tools for modelling new energy generating system performances need to be designed and developed; 2) Availability of new technologies and systems for electric energy storage and electric generation.	• New testing procedures, identification of new performances for new existing materials (e.g. with reference also to adaptive performances); • Holistic, intelligent & predictive energy control systems; • Fuel cells for static applications; • Smart grid solutions to fully enable distributed energy generation. Demand response solutions to fully exploit energy production at local level; • Building Integrated PV, producing energy to be stored in either batteries or hydrogen through electrolysis.
CP5 Thermal generation and storage materials and systems (e.g. storage systems including building integrated energy technologies)	
1) Advancement to total building integration (e.g. in plaster, windows, tiles, etc.): to increase aesthetics and integration flexibility, efficiency, cost, quality insurance, plug and play development. Market implementation; 2) Availability of new technologies, systems and processes for energy storage and heating and cooling management; 3) Further development of advanced nanotechnology.	• Need for modelling behaviour and properties of building integrated thermal technology (e.g. Development of flexible high efficiency solar thermal collectors); • Validation of thermal energy generation through advanced modelling tools; • To explore the potential for demand side management opportunities associated with the storage of energy in the thermal mass of buildings; • Research on new technologies for chemical composition of storage materials and efficient integration of existing ones.

TARGETS	RESEARCH AND INNOVATION TOPICS
CP6 Advanced thermal insulation construction materials for new buildings and existing buildings	
1) Availability of insulation materials with highly enhanced properties ($\lambda < 0.03$ W/m*k, improved durability, low cost, recyclability) especially for retrofitting; 2) Availability of components with very high insulated materials, eco innovative, easy to install.	• Development of new cost-effective energy-efficient insulating materials from renewable sources or waste materials; • Development of materials that enable to create insulation materials with active properties; • Evolution of materials with $\lambda < 0.03$ W/m*k (e.g. nanofoams or silica aerogels); • Cost-effective large volume manufacturing • Cost-effective analysis on pilot test demonstration in public/administrative buildings • To determine the environmental tradeoffs between using insulation and sophisticated building techniques to control indoor climate in buildings with energy using heating/cooling and ventilation systems; • Integration of insulated materials in traditional products for large application; innovative solution for retrofit; thermal insulation, with good vapour permeability; • Improved material combinations in a layered and structured facade construction, IR absorption and reflection on demand in combination with insulation and switchable U-values.
CP7 Building materials recyclability and reuse of components	
1) Reduction of the amount of down cycling, considering cost and energy issues; 2) Design implementation of recycling and reuse of materials and techniques in construction; 3) Establishment of deconstruction processes and guidelines for existing buildings.	• Development of solutions to recycle and reuse the light part of construction materials, including thermal recycling; Increase the uptake by the manufacturing chain; • Research on the recyclability of different types of demolition products; • Better adhesives and other methods allowing disassembly of boded structures / assemblies; • Optimisation of recyclability properties of materials for new buildings; • Building concepts with high fraction of material replacement where needed; clear separation of functionality layers in buildings; • Building concepts with very low resource input: low emissions recycling options; • Specific trainings to companies and end-users in order to improve recycling and re-using skills and techniques; • Information management and traceability.

TARGETS	RESEARCH AND INNOVATION TOPICS
CP8 Renewable resource-based products	
1) Availability of renewable (bio-based) construction materials and systems as alternatives to fossil and mineral based products for sheathings as well as advanced insulation products with improved performance and cost-effectiveness; 2) Availability of bio-based treatments such as paints, adhesives and modification for high performance renewable products.	• Creation of new value chains considering the complete life cycle (possibility of re-using etc.); • Optimisation of natural fibres for insulations in order to ensure durability; • Advanced research on biotechnology and new bio-based materials such as plastics for barriers, pipes etc. and foams for insulation; • Creation of new value chains.

APPENDIX 5 — Summary of Technology Roadmap from ICT4E2B Forum

The roadmap for ICT supported energy efficiency of buildings can be summarised in simple terms as follows:

- Short term: ICT enables the connectivity and interoperability of individual buildings and networks and is used to ensure that existing and new buildings meet the current and emerging requirements for energy efficiency defined in relation to the surrounding infrastructure and climate;

- Medium term: Design, production, retrofitting, operation, use and demolition are empowered and enabled by re-configuration, optimisation, and access to real-time information, decision support and interoperability with easy to use interfaces;

- Long term: ICT enables and supports new business models and processes driven by energy efficiency. Buildings have evolved from energy consumers to ‘prosumers’ (producer + consumer).

The roadmap is structured in five main technology areas:

Main category	Subcategory
1. Tools for EE design and production	• Design • Production management • Modelling • Performance estimation
2. Intelligent control	• Automation & control • Monitoring • Quality of service • Wireless sensor networks
3. User awareness & decision support	• Performance management • Visualisation of energy use • Behavioural change
4. Energy management & trading	• Building energy management • District energy management • Smart grids and the built environment
5. Integration technologies	• Process integration • System integration • Knowledge sharing • Interoperability & standards

The following figures depict the specific roadmaps developed per each technology area.

Figure 14. Roadmap 1: Tools for EE design and production management

	From s-o-t-a to short term	From short to medium term	From medium to long term
Drivers	Increasing EE requirements from regulations and users.	Enhanced regulations for EE of buildings. Integration of renewable energy sources.	EE driven business.
Barriers	Lack of interoperability. Unavailability of EE data about materials and products.	Incompatibility of business incentives for design vs. whole life cycle performance. Simulation tools are not fully interoperable with design tools.	Prevailing business models focusing on delivery costs instead of value to client.
Impacts	Compliance at lowest cost.	EE services, Life cycle optimised buildings.	Branding EE design and production services.

State of the art	Short term		Medium term	Long term	Vision
Design: Discipline-oriented analysis and configuration management tools. CAD with discipline specific applications.	Enhancement of existing design tools with EE features, EE aspects to catalogues of materials and products	Tools for EE conceptual design, model-based CAD tools, interoperable interfaces	Intelligent product catalogues, semantic search, libraries of best practices and reference design solutions, visualisations of EE design alternatives, long term archival and revival of BIM and other digital data, tools for validation of EE-compliance to building codes.	Tools for configuration, management, self-optimising models, contractual and legal validity of BIM, and digital information.	Integration of various functions, tools and communication between stakeholders. Contractual practices including valid verification of EE. Self-learning design system. Validation and certification of simulation software tools. Contracts based on models and life cycle EE performance.
Production management: Tools for scheduling, costing, procurement, logistics.		Material and product tracking systems, e.g. RFID, WSN etc.	Tools to optimise production EE as part of life cycle, collaboration platform for concurrent building engineering, model-based product design and production, agreeing and integrating information flows across the value network.	Tools for rapid and flexible project team formation, contract configuration and management, model driven workflows, model-based as-built information available for operation and maintenance.	
Modelling: Document oriented tools.	Enhancing current BIM models (IFC) with standardised EE attributes. Model analysis and validation tools for energy efficiency modelling of building energy profiles.		Enhancement of data models (ontologies) to cover EE aspects. Modelling of local energy generation related to buildings: PVs, wind power, RES, storage etc., modelling of user profiles.	BIM servers for collaborative BIM based design. Integration of design models (BIM) with operational near-real-time information, integration of building and district level models.	
Performance estimation: Numerous distinct tools for cost estimation, life cycle assessment and energy simulation.	Definition of EE performance indicators, easy input from tools for simulation, reduced time.		Standardise performance indicators at European level, performance estimation tools, comparison of performance information at the different stages of design-production-operation, development of test cases for simulation software tools.	Tools to estimate EE in a quantified and verifiable way — sufficient for performance based contracts, models, methods and tools to estimate EE performance of urban districts consisting of buildings, local generation and storage, interacting with energy grids, use of test cases to develop validation/ certification process.	

Figure 15. Roadmap 2: Intelligent control

	From s-o-t-a to short term	From short to medium term	From medium to long term
Drivers	Increasing EE requirements. Dynamic energy prices.	Local production and storage of energy.	Regulations and standards for energy efficiency.
Barriers	Focus is more on capital investment than operational cost/savings during lifecycle. ROI must be proven before investment decisions, which hindrances the launch of new products. Lack of interoperability between actors.	Insufficient interoperability. Security and privacy concerns.	End-user acceptance.
Impacts	Increased demand for a Building Management System (BMS).	Sustained energy efficiency.	Improved district energy management.

State of the art	Short term	Medium term	Long term	Vision
Automation and Control: Standardised solutions for control.	Coordinating algorithms between applications.	Predictive control considering weather forecast, make building controls responsive to smart-grid interactivity.	Generate optimal building controls from BIM, optimal controls on district and city level, equipment manufacturers provide dynamic models of their products enabling simulation.	Collaborating subsystems and optimal predictive control. Collaborating buildings on district and city level and interaction with the smart grid. Self-diagnostics systems with high degree of monitoring while protecting privacy of individuals. Building controls are derived and tuned based on dynamic building models that through simulation show the nominal energy consumption.
Monitoring: Monitoring as a standard component in a modern BMS and measurements used for building control stored in trend logs.	Decrease production and deployment cost of basic communicating meters.	Increased data collection while protecting the privacy of individuals, embed more intelligence in sensors for local analysis.	Sensors are built in the fabric of the building.	
Quality of service: Basic self-diagnosis commonly available in automation control products. Large quantity of self-diagnosing functionality with associated alarms.	Enforce that detected problems get attended, develop real-time algorithms for energy-efficiency diagnosis.	Embed self-diagnosis in sensors, self-diagnosing equipment detecting suboptimal energy performance.	Use of virtual reality for diagnosis and repair. Inclusion of sensors and diagnostics in building materials	
Wireless sensor networks: Wireless technologies for building automation available, but there's a lack of interoperability between different vendors.	Develop communication standards ensuring multi-vendor interoperability and supporting battery-less low-power devices, establish cost-effective deployment procedures.	Define standardised roles and services for sensors, automatically adapting network topology.		

Figure 16. Roadmap 3: User awareness and decision support

	From s-o-t-a to short term	From short to medium term	From medium to long term
Drivers	Cost reductions.	user-driven demand for applications and services.	Social Pressure.
Barriers	Lack of data related to energy use profiles Concerns over privacy and security.	Lack of European standards and common metrics. Lack of multi-disciplinary approaches/ solutions to EE.	People's habits, lack of integration in social applications.
Impacts	ICT is be combined with non-ICT tools in line with energy efficiency measures available to users	Users and owners make informed decisions about the building and its use.	Life cycle optimised buildings. Users as active players in energy market.

State of the art	Short term	Medium term	Long term	Vision
Performance Management: Standardised indicators available for assessing energy performance of buildings, systems and components. Performance audits, labelling and continuous commissioning are supported by recorded data of real time performance.	Technologies that are capable of balancing the levels of automation and individual choice, performance database. Interoperability between BMS and real-time diagnostics system, for comparing estimated (designed) and observed (actual) performance.	Parameterisation of the intelligent BMS by using specific energy based knowledge management system. Integration of personal energy use between different building contexts, privacy and security.	Heterogeneity of the system, definition of common standards and metrics at European level. Combination of ICT tools with non-ICT tools for obtaining an effective assessment of the energy consumption.	There are smart, fun and easy to use and effective energy management tools, which exploit real time energy consumption/ production information and help the different stakeholders to achieve their tasks while being energy efficient at building level. Visualisation of energy use anytime anywhere with management capabilities and integration in multi-domain applications and services. Energy analytics and decision support systems that provide useful suggestions to change habits to decrease energy consumption and costs.
Visualisation of energy use	Attractive and understandable energy visualisation display, identification of the level of individual knowledge that each user must have about the buildings in which he lives or works in.	Organise training sessions and e-learning websites for user involvement, integration of building services with user's needs and interactions.	Exploit 'social pressure' as a driver for motivating users on energy efficiency themes; integrate with social applications and services.	
Behavioural change: Technologies are available to be used improving the level of user awareness.	Real-time Internet accessibility to control building energy-related processes, development of energy bank database.	Increasing involvement of building users and owner on the use of BMS. Reduce technological costs and learning curve for end users.	Daily energy consumption plan act to follow the scheduled activities planned by the users and to support end users energy decision during the whole building life.	

Figure 17. Roadmap 4: Energy management and trading

	From s-o-t-a to short term	From short to medium term	From medium to long term
Drivers	Stakeholder and technology driven	Economic reasons e.g. increased energy prices, user-demand	Policy/Regulation at EU level; realisation of an EU-wide open energy market
Barriers	Technology, market, social barriers	Acceptance of ICT tools for enabling stakeholders; integration in business	Business adaption and availability of value added and self-sustained services
Impacts	Significant impact in BEMS	Significant impact in District Energy Management	Integration with Smart Grid and the Building Environment at smart city level

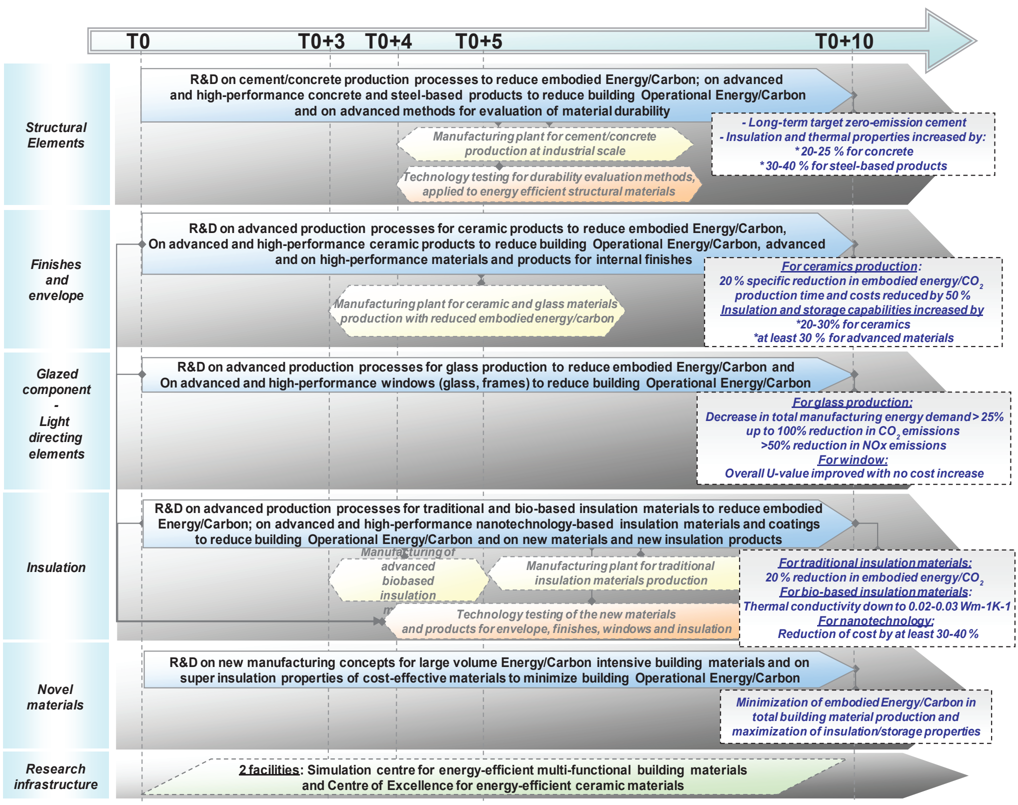
State of the art	Short term	Medium term	Long term	Vision
Building Energy Management: Isolated solutions(not interoperable) available dealing with energy management in buildings. Limited number of smart appliances available.	Smart metering, adoption of basic open and interoperable solutions, service wrapping of existing functionalities, information exchange between building's subsystems, enhancing and extending existing energy management.	Deployment of intelligent devices, provision of (mobile) Internet based user services, adjustment of the building behaviour to users' plans. Analytics offer better view on building processes and better management can be achieved.	Provision of complex user services, real-time fully automated energy management and adjustment to dynamic conditions and user needs, collaboration with other buildings and systems.	Flexible building energy management adjustable to user's as well as external needs. Integration of intelligent devices and accurate monitoring &forecasting by context information integration. Interoperable energy management solutions beyond standalone systems/buildings. Real-time energy management depending on Key Performance Indicators (e.g. cost, efficiency, etc.). Participation in Real-time Demand-Response approaches — new revenue generation. Buildings collaborate with their users and the local district for energy efficiency. Collaboration of buildings with each-other, smart city infrastructure and participation in energy markets Towards autonomic smart buildings with self-management, self-monitoring, self-healing and self-optimisation.
District Energy Management: Some District Energy Monitoring solutions are available (not real-time), hardly any energy services for the citizens	Energy monitoring at district level, opening of functionalities and provision of basic energy services.	District-wide Energy services for end-users, deployment of district-wide energy management (DR), citizen energy services and best practices, privacy and security assessment tools.	Real-time adjustment and optimisation of district's energy management to conform to KPIs, full integration with all parts of the smart city (including public infrastructure, transportation etc.), energy simulation and detailed modelling availability for districts.	
Smart Grid and the Building Environment: Smart metering is an issue under development, energy monitoring services for citizens.	Smart metering, energy awareness via monitoring services, sharing of information.	User participation on district energy marketplaces, value added energy business services, best practices and models	Real-time demand-response solutions, participation of prosumers to groups and free energy trade, automated Intelligent Energy management for virtual groups of buildings/users, market-driven energy services.	

Figure 18. Roadmap 5: Integration technologies

	From s-o-t-a to short term	From short to medium term	From medium to long term
Drivers	Increase citizen awareness on EEB.	Costs savings benefits	Increase demand for energy consumption prediction.
Barriers	Lack of knowledge about building lifecycle energy management and difficulty to adapt new technological solutions to existing buildings.	Too much property protocols and communications standards coexisting in the market.	Access to the knowledge generated in all the fields related to energy efficiency in buildings.
Impacts	New business opportunities for ICT, energy and building sectors. Change of mentality regarding the importance of EEB. Better implementation of building lifecycle.	Achieve a standardisation regarding communications and protocols to ease the interoperability and the communication among different devices. Implementation of smart grids.	Share of knowledge among all the stakeholders involved in energy efficiency. New algorithms to plan and forecast the consumption in buildings.

State of the art	Short term	Medium term	Long term	Vision
Process integration: Rude applications to integrate different roles in a project.	Improvement of the rude applications existing in the market.	Centralised application able to control parallel processes done by different kinds of experts works in a project.	Development of smart common workflows.	New applications to support parallel processes, smooth and smart workflow and tight control allowing different kind of experts work together.
System integration: Coexistence of various communication protocols and devices.	Systems integration from building level to neighbourhood level.	Networked Embedded software to devices is needed to control the consumption of buildings using diagnostics methods.	Systems to predict future consumptions and plan them are also a wide field to be investigated.	Early detection of anomalous energy consumption and/or malfunction of networked devices by using embedded diagnostics methods.
Interoperability and standards: Non interoperability among devices and non-complete standards.	Agreement on the protocols and communications that fit better with the needs of the vendors and the existing devices.	Advancement of technology standards development and general adoption by most of the vendors.	All the devices inside and outside the buildings would share the same protocols.	Cost reduction for installing EE devices and reduction of problem interoperability among EE devices by using standardised data models and real-time communication protocols.
Knowledge sharing: Different allocations for knowledge share and difficulty to find it.	Use of common forums and collaboration spaces to share the knowledge.	Development of a knowledge sharing platform among construction, energy and ICT stakeholders.	Improvement of seek methods in the common platform to allow a good access to the information related to EEB.	Definition of a 'one shop point' platform that collects information coming from construction, energy and ICT fields and allows the sharing among stakeholders from these fields.

APPENDIX 6 — Overview of the Materials Roadmap (SET PLAN)



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With a yearly turnover above € 1.2 trillion in 2011, the European construction sector, including its extended value chain (e.g. material and equipment manufacturers, construction and service companies), is the largest European single activity (10% of GDP) and the biggest industrial employer. Moreover, the built environment affects the quality of life and work of all EU-citizens. Since buildings use 40 % of total EU energy consumption and generate 36% of greenhouse gases in Europe, by reducing its CO_2 emissions by at least 80% and its energy consumption by as much as 50%, the construction sector is today on its critical path to help decarbonise the European economy by 2050.

This multiannual roadmap for the years 2014-2020 sets a vision and outlines routes towards a high-tech building industry, which turns energy efficiency into a sustainable business. This roadmap proposes research and innovation priorities openly agreed amongst the wide community of stakeholders across Europe, after an extensive public consultation.

The Public-Private Partnership (PPP) on Energy-efficient Buildings launched in December 2008 under the European Economic Recovery Plan managed to attract high industrial participation and helped to innovate the building sector. Under the new EU framework programme Horizon 2020, a contractual PPP on Energy-efficient Buildings will aim to develop affordable breakthrough technologies and solutions at building and district scale, facilitating the road towards future smart cities.

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