DRAFT

Energy-efficient Buildings PPP beyond 2013

Research & Innovation Roadmap

July 2012

NOTE: This document is a first draft resulting from the work of the Ad-hoc Industrial Advisory Group of the Energy-efficient Buildings PPP (http://ec.europa.eu/research/industrial_technologies/ad-hoc-eeb_en.html). This draft roadmap aims to update the research and innovation priorities to align the industry long term plans with the content of Horizon 2020 proposal, where a clear research line on "Technologies enabling Energy-efficient buildings" has been proposed by the European Commission. A revision of this document after consultation of the wide stakeholders' community is expected in the coming months. For any information, please contact **stefano.carosio@dappolonia.it** or visit **www.e2b-ei.eu**.
Please send your feedback before October 1, 2012 through the feedback form available at http://www.ectp.org/enewsportal

Worth at least 1.3 trillion Euros of yearly turnover (2010), the European building sector and its extended value chain (material and equipment manufacturers, construction and service companies) is on the critical path to decarbonize the European economy by 2050. It must enable reducing its CO_2 emissions by 90% and its energy consumption by as much as 50%. This is a unique opportunity for sustainable business growth provided that products (new or refurbished buildings) and related services are affordable and of durable quality, in line with several past or future European Directives. Yet, together with the 2050 deadlines, such Directives are putting more constraints onto a sector which is directly impacted by the on-going financial and economic crisis (less purchasing power, but also potentially increasing building costs due to more stringent requirements to meet building energy performances). The time frame left to develop innovative technology and business models in line with the 2050 ambitions is narrowing down to less than 10 years.

E2BA acknowledges the proposal of the European Commission to include research and innovation activities in the Horizon 2020 proposal, in continuation with the current EeB PPP. Its extension over 2014-2020 will both amplify and accelerate the collaborative research and innovation efforts implemented since 2004 at European level, in order to comply with energy demand reduction in buildings. It reinforces the value chain optimization approach initiated in the EeB PPP which will require more dedicated R&D and innovation activities covering each of the following components of the value chain:

- design and commissioning with novel approaches to narrow down the gaps existing between performance by design and performance when built,
- structural parts where material processing innovations will allow further reducing the CO_2 embodied footprint of the structural components over the life cycle of new buildings,
- building envelopes, which protect the build environment from external aggressions while reducing space heating/cooling demands by a smart use of renewable energies with the help of thermal storage,
- energy equipment (heating, cooling, lighting, ventilation) and their control systems which have to be sized down since energy demand is lowered, but must also be user centric to optimize in real time energy demand and supply,
- construction processes where combining pre-manufacturing of critical components and self-inspection/automation of construction tasks increases quality and productivity of construction workers,
- building energy management systems able to optimize supply and demand according to price signals sent to consumers, but also energy cooperation between buildings at district level,
- end of life optimisation in view of recycling/reusing demolition wastes.

But reaching affordability and durability in performances requires both research in novel technologies and construction solutions as well as systemic integration and innovative processes both at buildings and district scale. A similar value chain approach is proposed for implementation: it should yield further material and energy gains, increases in worker productivity , reduced optimized interface costs and new business models to deliver affordable building solutions with durable performances (energy, aesthetics, indoor comfort, accessibility, etc.), thus guaranteeing business replication. Indeed this roadmap is not only about research but it covers significantly non technological aspects which are fundamental for market take-up as business models, standards, innovation friendly procurement etc., fully in line with the ambition and scope of Horizon 2020.

Overall, the proposed Research and Innovation activities aim at increasing the speed at which the whole construction sector and extended value chain reaches industrial and business maturity by 2030, thanks to:

- the delivery of new or refurbished user-centric building/districts in line with specific national commitments towards realistic 2050 decarbonisation pathways,
- the implementation of European quality standards encompassing the whole life cycle of buildings, thus guaranteeing sustainable building performances,
- the valuation not only of dramatically improved energy performances but also of the aesthetics, comfort or accessibility criteria which are all purchase criteria,
- the ability to implement long term energy performance guarantee contracts, either on the energy bills at building level or on energy invoices at district level thanks to the implementation of local energy production that make such districts energy positive .

Reaching such enabling capabilities helps the building sector shaping a renewed skilled work force (up to 1 million new jobs created[1]), capable of meeting a minimum depth refurbishment (60% reduction in energy demand for all buildings by 2025) and an adequate rate of renovation (up to a yearly 4% of the foreseen 2020 building stock), which are both needed to reach the 2050 ambitions safely. It also allows setting by 2020 European energy performance standards for all new buildings at a near zero energy demand over a full year.

The proposed roadmap shapes upgraded research and innovation activities as well as priorities to reach a set of new 2020 targets in line with the 2050 decarbonisation goals. It also addresses the integration of promising research results obtained over the current EeB PPP: demonstrations followed by industrialization by industry will allow integration in our built environment and future smart cities contributing to keep EU decarbonisation goals in line with the original agenda.

A budget of 2.1 billion Euros over 2014-2020 is proposed to support this acceleration which is equally shared between industry and the European Commission. Additional industrial investments will progressively be needed to bring the prototype resulting from such new innovation activities to the market as well as launch proper education programmes, for instance. The expected leverage factor reaches 4, a figure based on a dedicated analysis of each value chain segment and of past experiences of E2BA members. There are however 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. A better use of cohesion and structural funds is another element of commitment. Structural Funds are needed to complement local financial needs in terms of full scale demonstrations of the developed technologies: such funds should be able to contribute to the field validation of industrialised technologies and processes as earlier as 2014, thus accelerating further the deployment of innovation throughout EU-27 and creating synergies with the running wave of projects within the EeB PPP.

[1] See BPIE study's deep scenario, (2011) Europe's buildings under the microscope

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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: Greenhouse gases
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
LEED: Leadership in Energy and Environmental Design
MVD: Model View Definitions
PPP: Public-Private Partnerships
RD&D: Research, Development and Demonstration
RFID: Radio Frequency Identification

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. 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.

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, …).

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);

[2] See "Intelligent Building Envelopes - Architectural Concept & Applications for Daylighting Quality", Annemie Wyckman, 2005

- 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.

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. For construction materials such as steel and concrete, 'embodied carbon' will be used instead of 'embodied energy'.

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]**:** group of adjacent buildings.

Reuse
In this document, the term 'reuse' has a broad sense which covers:
1) 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;
2) 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
   - Downcycling: to produce new materials /products of lesser quality and reduced functionality
   - Upcycling: 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 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.

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).

[3] Source: CSTB
[4] Source : NREL
[5] Source: CSTB
[6] From EU project 'European Smart Cities'

PART I: VISION 2030

1 Introduction

The preparation of this Draft Roadmap has been driven by industry in the framework of the Ad-hoc Industrial Advisory Group set-up within the running EeB PPP. The private sector is represented by the **European "Energy Efficient Buildings Association" (E2BA)**, as industrial interlocutor of the European Commission in the EeB PPP, represented by DG RTD (Themes NMP and ENV), DG Energy and DG INFSO. E2BA has started the review of the achievements of projects and updating of the EeB PPP roadmap since mid 2011, openly awarding a contract[7] to identify future research and innovation priorities as well as engaging all its members in this exercise. These are the starting elements of this draft roadmap to set the research priorities beyond 2013 with a specific focus in 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" has been proposed by EC. In this framework an extensive review of running research and demonstration projects at EU and member states level has been performed, combined with close contacts with other major initiatives at EU scale such as the **SET Plan and its Smart Cities initiative**, the **Intelligent Energy** and **Eco-innovation** programmes under the CIP framework, the **InnoEnergy Knowledge and Innovation Community** (KIC) running under the European Institute for Innovation and Technology (EIT), the **Lead Market** initiative 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 have been limited at this stage at the level of E2BA, bilateral contacts with stakeholders from the above mentioned initiatives as well as the experts community mobilised within the framework of the ICT4E2B Forum project (www.ict4e2b.eu), 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) engaged within the framework of the Building-Up project (www.buildingup-e2b.eu).

In Part 1 the main drivers, pillars and **strategic objectives** at the basis of the roadmap are presented, highlighting the need to address existing buildings and overcome a potential market failure through research and innovation on technologies and integrated solutions for buildings and districts. In Part 2 the **overall structure of the roadmap** is presented following a value chain approach. Specific **challenges, barriers, targets and innovation drivers are then presented for each segment and area of the value chain** concurring to the identification of the research and innovation targets and priorities capable of mobilising innovative and high impact projects, including an overview of the investments associated with the broader implementation of the roadmap. In line with the Horizon 2020 strategy, the identified **priorities include all those horizontal non technological aspects 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 strategy. **KPIs and the expected logic to monitor progress** is provided jointly with a preliminary analysis of the

[7] E2BA 2020 Research & Innovation Roadmap, Technofi (www.symple.tm.fr), June 2012

expected leverage effect both on mobilised investments by industry to bring results to market in the competitive stages of the innovation chain as well as on those indirect aspects as education and effective use of resources at local scale in line with the "smart specialisation" strategy. Appendix 1 provides a detailed description of the research and innovation targets or priority areas.

2 Importance of the building sector for the European economy

Construction is a lucrative sector for the European economy. It accounts for 6.3% of the GDP, and as much as 10% when counting related industries, such as the manufacture of construction products, architecture and engineering. It is the **largest European single activity and industrial employer**, directly involving nearly 20 million people within more than 3 million enterprises, 95% of which being SMEs with less than 20 people. In 2010, the sector's turnover[8] was close to 1.2 trillion € for EU27. Moreover, the European Construction Industry Federation (FIEC) estimates that 41.7 million workers in the EU depend, directly or indirectly, on the construction sector[9]. 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 activities in the construction sector (see Figure 1).

Figure 1 : EU-27 & EA-17 Construction output (production index[10]), 2000-2010, annual data, 2005=100, Source: Eurostat

The onsite construction sector has experienced sharp drops in both turnover and orders, followed by drops in the number of persons employed and salaries, in turn impacting other subsectors like the manufacturing of construction materials and distribution channels. In 2011, **the sector continued 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[11].

8 Source: FIEC annual report 2011

10 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.

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11 Source: Eurostat News Release 58/2012 – 18 April 2012

3 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 CO2 emissions and for about half of the CO2 emissions which are not covered by the Emission Trading System).
In this framework, **the building industry will 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"[12] 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 about 90% of its CO_2 emissions, since 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 (technology manufacturers, construction companies, and energy service companies):

1. How to make the routes to reach the 2050 goals realistic when complying with intermediate targets by 2020[13] ?
2. How to reduce the risk of potential market failures ahead?

3.1 The critical role of refurbishment

Tackling refurbishment of existing building is a top priority; it is expected that, by 2050, about half of the existing building stock in 2012 will be still operational. In 2011, the Buildings Performance Institute Europe's (BPIE)[14] study emphasized the critical role of refurbishment, when considering various pathways to achieve the 2050 building sector decarbonisation goals. The proposed pathways[15] 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).

By combining different refurbishment rates with different refurbishment depth 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.

[12] Meaning the technology manufacturers, the construction companies, the energy companies and the building users
[13] 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.
[14] 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 Peformance of Buildings Directive (EPBD).
[15] 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.

Table 1 - Scenarios (Source: BPIE 2011)

	Current	Deep Scenario	Two-Stage Scenario
Building sector GHG emissions reduction by 2050 (compared to 2010 level)[16]	72%	90%	91%
Average depth of refurbishment	9%	68%	71%
Average rate of refurbishment	1%	2.5%	3.3%

Nevertheless, the BPIE study has not addressed the impact of a third critical parameter discussed earlier: the **district dimensions** which could possibly relax either one of the above trajectory parameters, since allowing for cross building energy cooperation and/or smart energy generation and use within districts. At any rate, deep refurbishment will 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)

3.2 Avoiding the risk of a market failure

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

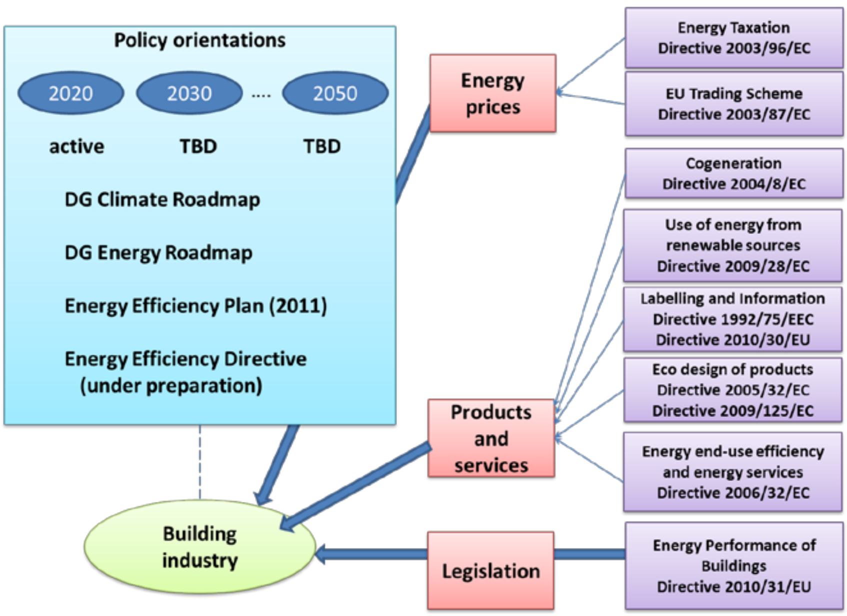


Figure 2: European regulations and policy strategies impacting the building industry

The above policy strategies and regulations are implemented with very little public funds: they are first supposed to drive the behaviour of market players in the expected directions. Yet, there is evidence that **market players do not implement the expected behavioural changes**. The measured rate of refurbishment as of to-day is still much lower than the one which should be observed to remain in line with the above future 2050 ambitions. To-day buildings are renovated every 30 to 40

[16] the GHG targets in the roadmap are compared to 1990 levels, but 2010 emissions are already lower, so reducing 90% compared to 2010 is even overachieving the target.

years on average[17] (EC, 2012), and every 60 to 80 years in the Mediterranean regions[18]. 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.[19]

The probability of a market failure is therefore rising: very stringent Directive targets are set, whereas the building sector is unable to transform them into opportunities, either because the supply is not adequate (too expensive) or the demand is not ready (too high upfront investment costs). Reducing the probability of a major market failure requires that all the stakeholders of the building sector (manufacturers, constructors, energy service companies) 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 stock. And 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 will deliver savings if and only if their building integration has been 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 optimize 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 upon users' behaviour. Moreover, several other building use values can hardly be monetized (acoustic comfort, indoor air quality, improved accessibility ….).
    - **how much is traded in refurbishment?** Energy consumption is still poorly metered in buildings. The other use values (acoustic comfort, indoor air quality, etc.…) can hardly, if ever, be measured.
    - **how is refurbishment trade organized?** A myriad of market players 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.

[17] EC, 2012. European Commission. European Commission Directorate-General for Energy. Consultation Paper Financial support for energy efficiency in buildings. Brussels, February 2012.
[18] 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/)
[19] See for instance: Jakob, M., 2007. The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners. CEPE Working Paper No. 56.
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.

4 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),
- The **total costs** required for developing and implementing the product or construction process (cheap).

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. Policy implementation at EU level will certainly favour affordable costs and quality (durable energy efficiency of buildings): time will be left aside since constructors aim at being the most affordable possible to sell and the most durable to be considered as performance achievers. And policy makers will follow along the same lines: affordability means the arrival of a demand-driven market whereas durable quality further guarantees that energy savings will last long after new or refurbished buildings have been commissioned. Thus, **the 2050 deadline to reach full decarbonisation remains under question**.

This is why **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, while involving all the value chain players including SMEs. 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 [20]
- **SMEs which represent 95% of the players in the value chain are engaged** since the early stages, developing skills and know-how that will be instrumental to achieve the expected energy efficient performance at building and operation stage.

[20] and triggered by affordable prices and value creation for the users that can go beyond mere energy savings

5 The running EeB PPP and the need to extend its ambition beyond 2013

The EeB PPP was launched as part of the economic recovery plan in 2008. The EeB PPP uses existing FP7 mechanisms whilst providing a midterm approach to R&D activities. It brings together various Directorates Generals (DGs): DG Research and Innovation (RTD) – Nano, Materials and Processes (NMP) and Environment (ENV)-, DG Energy and DG Information Society and Media (INFSO) 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[21] 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&Building followed by Operation) as stated here below,
- knowledge gained in the first "wave" feeding also the second at the design stage, realising a continuous implementation process (see Figure 4 below).

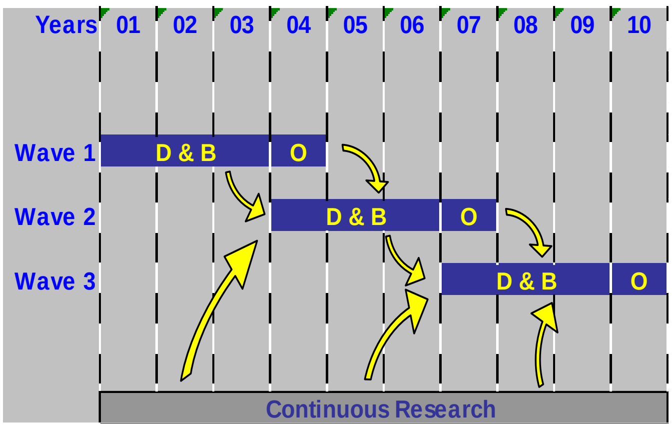


Figure 4 - Wave action along the roadmap (D&B: Design&Building; O: Operation)

As a result of this "wave action" industry expect 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 EeB PPP);
- **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 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. This long term approach has mobilised heavily industry

[21] EeB PPP "Research priorities for the definition of a multi-annual roadmap and longer term strategy", July 2009

with over 50% participation in calls and SME involvement beyond 30%, figures which are well above business as usual in collaborative research projects under the framework programme.

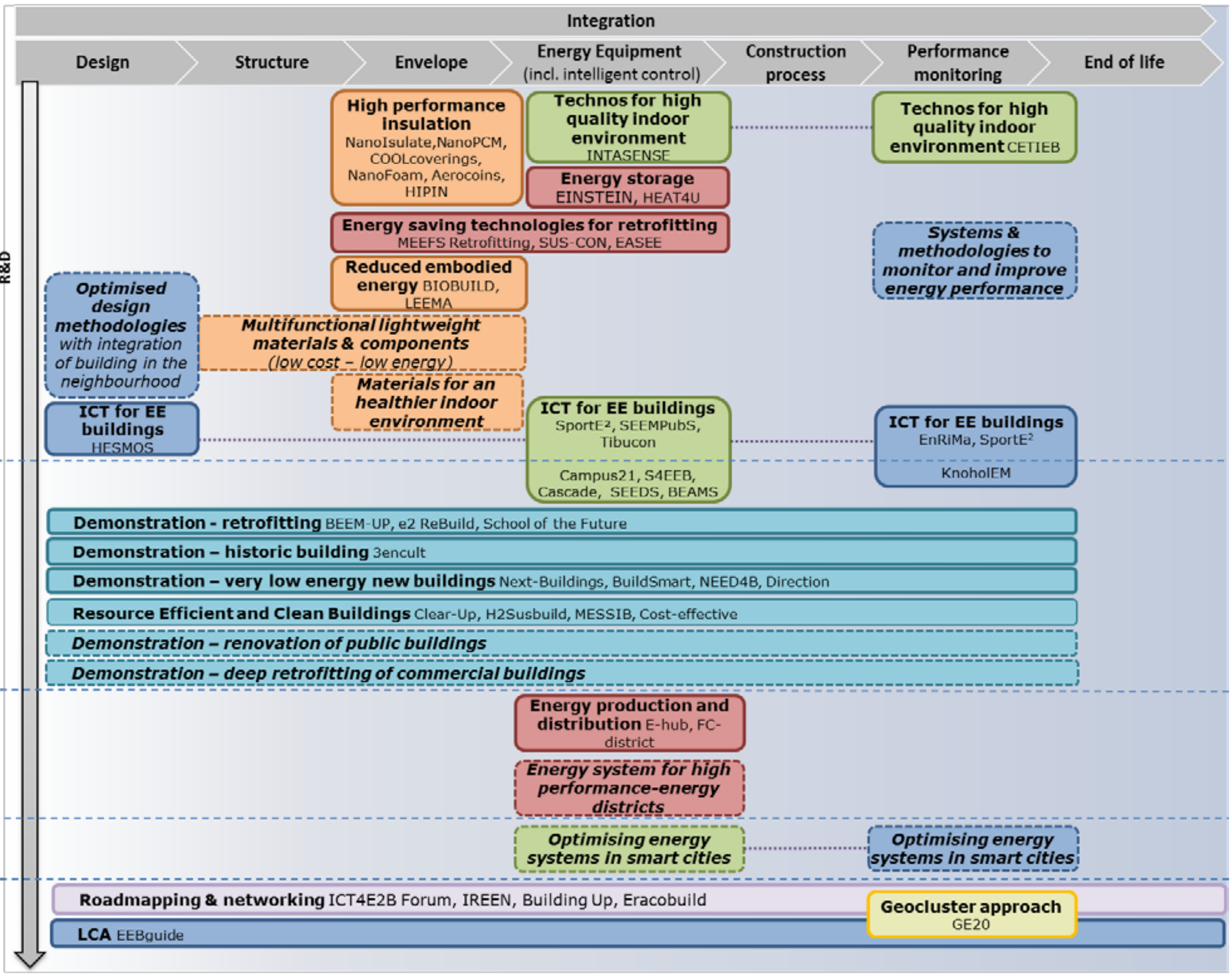
A review of the different running projects[22] has highlighted some of the innovations under development, such as:

- **Nanotechnology coatings** to substantially improve Near Infrared Reflective properties of the building envelope
- **Integrated Air Quality Sensors** for Energy Efficient Environment Control
- **Tools to improve Indoor Environment** in Retrofitted Energy Efficient Buildings
- Operational Guidance for performing **Life Cycle Assessment** Studies of the Energy efficient Buildings Initiative
- Sustainable, Innovative and **Energy-Efficient Concrete**
- High Performance **Bio-composites** for Buildings
- Component and systems for buildings: **multi-functional façade panels**, ETICS systems, etc.
- Components and systems for districts: Solid oxide fuel cells (SOFC) as **energy storage solutions** part of a district network
- Computer processable, **standardized building and user friendly models**
- **Energy control hardware** and reasoning capability to both improve energy consumption and the quality of the internal environment
- **Building Energy Management System** (BEMS) based on self-leaning techniques and wireless technologies with innovative behaviour modelling
- Optimized **Energy Management systems** through pervasive sensor networks and intelligent adaptive technologies, as a function of the external environmental climate, and the interaction with occupants
- Development of ultra low power units to control **Heating Ventilation and Air Conditioning** (HVAC) system through hybrid power harvesting unit
- Close existing gaps between intelligent building and facilities data providing the results of **energy performance simulation** calculations in design and in facilities management to decision makers.
- Providing new methods and services that integrate data obtained via control systems with a **virtual building model**
- Approaches to the envelope – walls and roof – or façade development with the integration of **multifunctional energy modules**.
- **Thermal energy storage**, compact heat storage, energy hubs to solve mismatch between energy transport, conversion and storage and energy management are key issues under study.
- Development of new **business models** to identify different routes to market; commercialisation of energy management concepts; consultancy for E-neutral districts.

Figure 5 below presents an **E2BA mapping of the projects** launched since 2008[23] at EU level and clustered according to the value chain. There is a clear **lack of activities on the construction process**, which may impair the final performance on either new or refurbished buildings. There is also a lack of research on **end of life** and innovative **integration pathways**, with **design** issues only partially covered so far.

[22] "Impact of the Energy-efficient Buildings PPP", Report from the Workshop held on 14-15 March 2012

[23] Only the FP7 project listed in Cordis have been mapped. Recently funded projects (or projects still in negotiation) will have to be added.



Key

- Forums, collaborative platforms
- Integrated approach
- Electronics, metrology, automation & control
- Modelling and computer science
- Materials
- Energy technologies
- Data management

- *Plain line: 2010 and 2011 EeB-related FP7 calls and corresponding funded projects. Only the FP7 project listed in Cordis have been mapped. Recently funded projects (or projects still in negotiation) are not considered.*
- *Dotted line: expected upcoming FP7 calls*

Figure 5: Mapping of FP7 projects related to Energy Efficient Building

In this framework, the table below summarizes the Strengths, Weaknesses, Opportunities and Threats (SWOT) for the existing EeB PPP as seen by industry.

STRENGTH	WEAKNESSES
- Multidisciplinary approach with the whole value chain addressed - Implementation of RD&D consortia who cover the whole length of the value chain - Strong involvement of industry and in particular SMEs due to long term planning with more focus and coherence - Clustering activities among projects to maximise impact - Networking arena to openly exchange at proposal preparation and project execution levels - Technological and non technological barriers are both tackled in projects, since the early stages of the innovation chain, creating future partnership among large players and SMEs to deploy solutions - Strong synergy and complementarity with initiatives funded under the CIP Programme, DG Energy demo projects and the EIT KIC Innoenergy - Transforming barriers and regulatory constraints into innovation opportunities - Fostering the creation of innovative supply chains, which are user centric according to the difficulty of implementing refurbishment strategies[24]	- Critical mass of resources not yet reached to allow self-propagation onto the next research and innovation waves - Although non technological barriers are covered in the current EeB PPP, the roadmap was aligned with FP7 ambition and lacks the integrated vision of Horizon 2020 along the innovation chain - RD&D approaches not enough user centric - RD&D on construction processes and end of life poorly addressed in running projects - Although statistics show a coverage of the vast majority of EU-27 countries, some Member States worried about the visibility and transparency of the PPP - The demonstration of the feedback from research projects bringing innovative technologies to integration projects is yet to be done
OPPORTUNITIES	**THREATS**
- Improved management by the EC and the industry to maximise impacts, building on lessons learnt - Growing participation in calls and more industrial partners from the EU willing to join - Horizon 2020 integrated vision along the innovation chain provide a good balance of research and innovation activities to reduce time to market in line with industry needs - Enable the market breakthrough of energy efficiency technologies, enabling commercial market forces to drive the substantial public benefits; - Integrate research, development and demonstration, and focus on achieving long-term sustainability and industrial competitive targets for cost, performance and durability and overcome critical technology bottlenecks - Reach the critical mass of research and innovation efforts to give confidence to industry, public and private investors, decision-makers and other stakeholders to embark on a long-term programme - Make the most of new market opportunities opened to reach 2050 decarbonisation goals - The diversity of possible futures pushes industry to be ready with several technology and process "building blocks" to respond to any of the potential scenarios - Refurbishment becomes more and more attractive with the increasing price of energy, the internalization of CO_2 costs and the valuation of other benefits like increased comfort, accessibility , etc.. - Demonstrate the advantages of industrial co-operation, taking into account regulatory framework and creating conditions for industries towards medium to longer term market deployment in Europe, boosting their economic sustainability - Proven success on the European market builds further opportunity on the world market - Strengthen the current and future potential role of the construction sector and associated extended value chain in addressing the current challenges of employment creation, sustainability and energy efficiency - Raising understanding, awareness and collaboration among all the stakeholders about the actual and future role of the modern and knowledge based construction industry - Reorganizing and stimulating innovative procurement of buildings and ordering of technology/services	- The lasting economic and financial crisis reduces the investment capabilities of industrial players and SMEs - Doing nothing will leave new opportunities to non-European competitors - Keeping the present innovation pace will impact the 2050 deadline inevitably - The maturity of innovative products is not reached early enough to make the refurbishment market go from a supply to a demand market: new regulations to make refurbishment compulsory are promoted leading to demand overheating - Lack of enough skills to keep the refurbishment pace high enough to meet the 2050 deadlines: prices increase due to a lack of supply - Diminishing public support at EU and Member State levels which refocuses industrial players on short term issues - Energy efficient buildings and districts are tackled by a mix of large players developing and integrating globally optimised technologies and solutions with a strong involvement of SMEs in the different steps of the value adding chain and in particular in construction, operation and maintenance at local scale with direct impact on employment. Moving to business as usual with FP tools and funding instruments will stop the current momentum associated with the running EeB PPP before a critical mass is reached.

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

The extension of the EeB PPP beyond 2013 will henceforth **accelerate the innovation pace of the on-going projects** (be ready earlier to meet performance targets) and **implement a long term "wave action" strategy** to integrate validated technologies into the day to day supply of the value chain. The results and knowledge gained in the first "wave" of R&D project financed within the EeB PPP will feed the next project waves, leading to demonstrations, a prerequisite to prepare scaling-up and replication of the validated concepts.

Overall, and in coherence with the initiatives Building up[25] and ICT4E2B Forum[26] supported by the European Commission, **a sequence of new waves from 2014 on[27] is required**:

- **Validated technology components and processes are integrated** into the value chain for full demonstrations, thus creating progressively new market conditions where building owners are ready to invest into an affordable built environment having lower energy demand and lower GHG emission footprints over their whole life cycle,
- **New technology building blocks and construction processes are validated** to reinforce the above integration waves through other innovative integration processes: such integration processes must indeed become even more user centric (building users lean on "fool proof" user interfaces that prevent the misuse of buildings, while improving optimal indoor air-quality and comfort), but also construction worker centric (construction workers must work more collectively, while being able to monitor the quality of their tasks through self-inspection commitments that guarantee intermediate performances, and therefore faster commissioning of more and more complex construction projects)
- **Each Research and Innovation activity supports both Climate and Energy policies** set at European level for the full decarbonisation by 2050 of the European economy.

This analysis clearly show an **added value for industry in teaming up with EC in bringing forward the current PPP beyond 2013**, keeping the overall ambition to share a long term programme which will lead to growth and job creation while enabling the solution of relevant societal challenges. In this respect the industry vision till 2030 and the associated strategic objectives are described in the following chapter.

6 Overall Vision till 2030 and strategic objectives

Our ambition is to drive the **creation of an innovative high-tech energy efficiency industry extending the scope of the running EeB PPP beyond 2013**. This ambition is based on the successes achieved so far by the running EeB PPP and the opportunities highlighted in the previous chapter. Connecting construction industry to other built environment system suppliers will 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 paradigm shift, **EU companies will 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.

[25] http://www.buildingup-e2b.eu/

[26] www.ict4e2b.eu

[27] Two parallel road mapping exercises have prepared the above conclusions (BUILDING UP and ICT4E2B)

In line with the ambitious 2050 targets, we expect that already in 2030 the **entire value chain will produce advanced systems, solutions and high value services for intelligent and sustainable buildings and districts**. The long term strategic objectives include:

- most buildings and districts become **energy neutral**, and have a zero C02 emissions. A significant number of buildings would then be energy positive, thus becoming real power plants, integrating renewable energy sources, clean distributed generation technologies and smart grids at district level.
- industry will employ **highly skilled individuals capable of efficiently, safely and quickly carry through construction processes**. This means an extended value chain and collaborative "assembly" line delivering adaptive and multifunctional energy and resource efficient buildings and districts solutions.
- **unemployment is kept low as skilled local jobs will be created through an effective and dynamic matching of demand and supply**. Public Private Partnerships will indeed cover the entire innovation chain, fostering performance based contracting and innovation friendly procurement practices. This will be achieved with sustainable financial incentives schemes on the demand side. On the supply side, systemic technical solutions optimised at European scale will be integrated locally.
- **urban planning and smart cities implementation leverage on these novel solutions at building and district scale**, creating the basis for intelligent connections between buildings and districts and all urban resources.
- such globally competitive energy efficiency industry is able to **deliver new business opportunities, jobs and solutions**. In terms of environmental impacts, greenhouse gas emissions are reduced to 80-95% below 1990 levels, as required by the Energy Roadmap 2050 (COM(2011) 885/2). In addition, the use of renewable energy and efficiency technologies is extended as required by the Strategic Energy Technology Plan, the energy efficiency plan and the recast of the EPBD.

Indeed in Europe, each Member State with its own building stock is faced with a combination of four implementation options (see Figure 6) to comply with the challenges ahead, inevitably mixing rehabilitations and construction of new buildings, viz.:

1. increase significantly the rate of **high performance, deep rehabilitation of commercial and residential buildings**, while lowering the costs of rehabilitation,
2. increase the **overall depth of rehabilitation** by favoring district rehabilitation in priority[28],
3. **valorize energy production and use within new districts** to make these districts " energy positive",
4. **scrap all poorly insulated buildings and replace them** by high performance buildings (energy neutral and, when possible, energy positive).

[28] see for instance the 25 kWh primary energy /m2/year and below target value, taken in France for the demonstration projects to be funded and operated by 2015

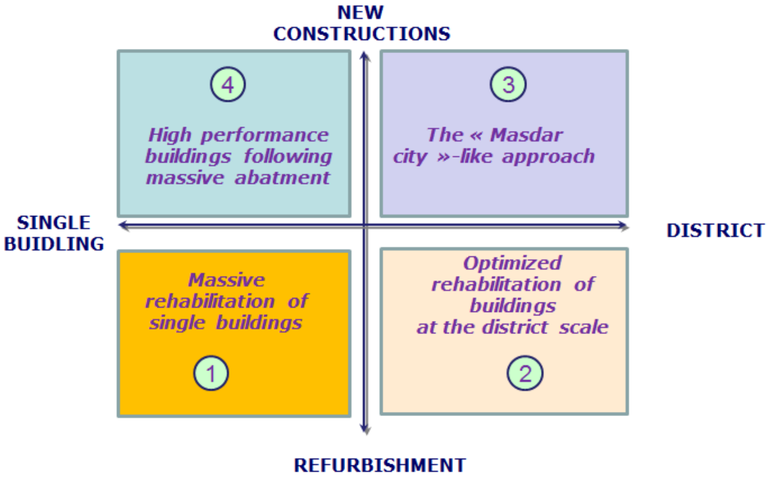


Figure 6: Representation of the resulting four scenarios

Member States have a reduced set of optimization parameters to address properly these options:

- the spatial scale chosen for energy demand optimization (single building versus district). The **district dimension** provides new energy optimization possibilities, for instance through the connection to existing grids (electricity, heat and cooling networks), via the design and operation of a set of buildings as components of an integrated energy system, which can in turn contribute to improved peak load management.
- the rate of new constructions versus the rate of refurbishment which in turn is conditioned by:
  - the **depth of refurbishment versus the new building energy performance level** (set by law)
  - the split between **technology-based (energy demand) and behaviour-based (energy use) solutions**, whatever the project under scrutiny

Implementing pathways at the right pace to make innovation breakthroughs possible requires the building sector to go through a profound mutation before 2030 which shape a vision as described below:

Vision 2030

By 2030, increased and faster collective research and innovation has allowed 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 national commitments towards 2050
- working 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 aesthetics, acoustics, accessibility or comfort as purchase criteria for end users
- **committing to long term performance guaranteed contracts** on the energy bills

In doing so, industry aims at introducing as most technology and market flexibility as possible for the benefits of policy makers and investors when facing the decarbonisation of the building sector. Any mix of the above four scenarios can then be addressed by the building industry in the next 40 years, **industrial maturity being reached by 2030**.

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 EeB PPP beyond 2013 in line with the 2030 vision to develop and to validate a set of innovative integrated to novel tools, technology and process components covering the whole value chain. They will then be integrated to meet future market conditions, 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[29],
- **Reorganizing and stimulating innovative procurement** of buildings and ordering of technology/services.

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 management in the construction sector has become a prerequisite to develop a building stock that is technically and economically optimized: 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[30] must be given birth, which are dedicated to collaboration between players from different disciplines to contribute to the realization of buildings with energy-ambitious goals.

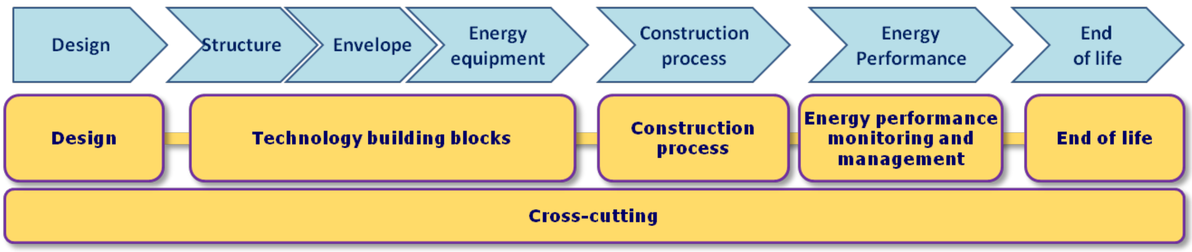


Figure 7: representation of the segmentation of the value chain

The whole value chain will be involved in this continuous optimization process which follows three major steps:

<u>Step 1</u>: **From design to commissioning** of new or refurbished buildings, the optimization consists in picking amongst 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.

<u>Step 2</u>: During this life cycle, **robust user-centric energy management systems** ensure that the initial GHG emissions targets are continuously met thanks to adaptive energy management tools able to correct for or modify behaviours of users. Only natural ageing of technology can impact the initial energy performance at commissioning.

<u>Step 3</u>: The next refurbishment involves another optimisation approach where the **investment for refurbishment can be recovered through further savings on the cost of ownership**.

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

[30] "Energy Leap long term program" TNO (2011)

This optimisation approach requires that all the stakeholders perform according to **quality rules** where interfaces and responsibilities between any of them are transparently exchanged:

- **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 will probably widen when the more stringent building code standards for 2020 are in place).
- **Structural parts of a building can be mechanically and thermally optimized with sophisticated tools**: the focus must now be put on the embedded CO_2 which comes from the materials (cement, steel,…). This CO_2 will become the most prominent part of GHG emissions as the share of energy neutral building grows.
- The **building envelope** becomes the most critical part when it comes to energy efficient building:
    - for **new buildings**, materials and energy equipment integration already allows reaching very low energy demand. Yet, the investment costs have to be further reduced while taking care of several other design constraints (acoustics, fire, seismic, air quality, adaptation requirements for ageing population,...). In the long run, active envelope could make buildings energy positive by, for instance, smartly managing solar fluxes onto the building.
    - for **refurbishment**, the diversity of architectures and climates in Europe requires a whole value chain innovation process where design, technology choice and construction are even more intertwined than for new 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
- **The energy equipment must adapt to the lower unit energy demand from more energy efficient buildings**, which requires sizing down to-day 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 storage (heat and electricity), refrigeration and building integrated solutions.
- **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 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 test for air tightness) which, in turn, require collective work in the field,
    - **Continuous improvement processes** as part of a quality process which increase energy and comfort performances for new and refurbished buildings,
    - **Training** of workers on the impacts of a wrong installation on the final energy performances.
- **Performance monitoring (both at commissioning and during the building life) is mandatory**: it enables users to oversee and control their own consumption, allows detecting potential misuses of buildings due to a lack of awareness of the users,, potential disorders and/or pathologies of the monitored building. Moreover, conditional maintenance approaches can

bring added value in guaranteed performance contracts. New IT solutions and embedded sensors will come from other field of use (transportation for instance) as pervasive technologies that will be user centric,

- **End of life**: building demolition is an environmental issue which will grow under the pressure of deeper refurbishment. It can be addressed, both at design (reusable components) and demolition levels (reusable materials). The building industry is already involved in significant waste recovery (with a focus on metal and plastics). Innovation is expected in view of contributing both to the lowering of embedded CO_2 and resource efficiency,
- **Integration processes and cross cutting activities** allow merging the best available technologies and processes to optimize both costs and performances of new or refurbished buildings.

This Research and Innovation Roadmap provides dedicated R&D trajectories for each element of the value chain of the building sector (see Figure 8): progressive market availability of technologies and processes will come from large scale demonstrations. They will 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 optimization at building or even district level, and data sharing to help minimizing the interface risks inherent to any such complex system optimization process.

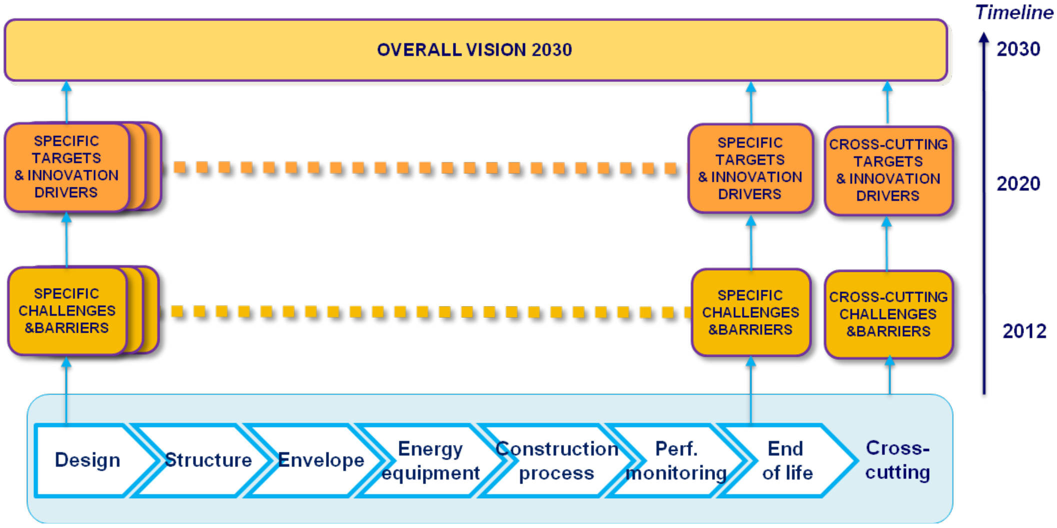


Figure 8: Road mapping process

2 Overview of the industrial needs: state of the art and drivers to meet the 2050 long term goals

2.1 Main drivers per element of the value chain

2.1.1 Design

- **Emerging standards for BIM (Building Information Modelling) deployment**[31]

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/

[31] 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).

Model View Definitions) approach are also on their way towards ISO standardization. This provides further grounds for in-depth cross-disciplinary collaboration and information sharing. Public clients are supporting IFC[32], helping leading software vendors to increase their investment on the matter. Though, the deployment of IFC in BIM is a long-term trend that will really succeed only far beyond 2020, and conditioned by large investment from the BIM vendors.

- **Recognized market value of LCA-based green building certification[33]**

The most widely recognized environmental assessment methodologies in the construction industry (LEED, BREEAM, HQE) use LCA approaches. So far, LCA databases that are applicable for the 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[34]. CABA[35] indicated a few years ago that while, on average, the cost of an office infrastructure amounts to 10$/square foot, the yearly cost of the work force amounts to 100$/square foot. In their recent report on the Solid-State Lightingmarket, 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[36] and should become one of the major drivers next to energy efficiency.

- **Growing interaction between building and electricity grid, and between user and grid**

Building design will more and more benefit from evolving electricity distribution networks which integrate more decentralized and renewable energy sources, as well as emerging flexibility in the consumers' demand (demand response schemes). Electrical and thermal loads of building will less and less be a burden for the local grid (e.g. adding to the peak load). Rather, energy management systems in buildings will support electricity management, thanks to the increased flexibility in energy consumption behaviours.

2.1.2 Structure

- **Coherent GHG emission abatement**

In line with Europe's 20-20-20 target[37], 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

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

[33]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

[34]« Rethinking the Design Process », Energy Studies in Buildings Laboratory, University of Oregon, and Konstrukt 2006

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

[36]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

[37] 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

cement (already more than 3 billion tons/y worldwide) as well as concrete contributes to the on-going increase of worldwide CO_2 emissions. 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.

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

Due to the decreasing availability of traditional raw materials, such as natural sands and aggregates, accompanied by the growing public awareness to protect remaining resources (river beds), alternative solutions have to be identified and developed.

- **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 will contribute realising this.

2.1.3 Envelope

- **The development of mass customization and standardization**

Recent market trends show a shift towards mass customization and standardization[38] (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 materials and technologies provide the user with additional value (higher thermal comfort due to more friendly wall surface temperatures, high efficient insulation, aesthetics, acoustics, 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 and ultra-thin or elastic ceramics as 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 Modeling 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).

2.1.4 Energy Equipment

- **World Competition for heating and cooling equipment**

The global market for heating and cooling is very large, the yearly market for cooling being worth as much as USD 70 billion in 2008[39]. 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**Erreur ! Signet non défini.**). OECD countries dominate the market for space and water heating, but not for cooling,

[38] See *Building Envelope Technology Roadmap, a 20-year industry plan for building envelopes*, DoE, 2001.
[39]EIA (2011).Technology Roadmap. Energy-efficient Buildings: Heating and Cooling Equipment

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 will increase the need for a holistic energy management approach at building and district level. There is economic evidence that energy consumption optimization 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.

2.1.5 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 are more aware of the sustainable principles. 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.

2.1.6 Performance monitoring and management

- **The "smart cities" initiative**[40]

This initiative supports at European level cities and regions which take ambitious and pioneering measures to progress by 2020 towards a 40% reduction of greenhouse gas emissions, thanks to the sustainable use and production of energy, based on systemic approaches and organizational innovation. 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 have been initialized with the support of professional organizations[41]. They know that a change of mindset is needed at contract level: usual "best effort" approaches will be progressively replaced by "commitment contracts", including energy refurbishment contracts. Insurance systems have started implementing the appropriate legal framework onto which construction companies can lean to sign future contracts.

- **Overcoming poor building operations on a daily basis**

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

[40] European Initiative on Smart Cities, see http://setis.ec.europa.eu/about-setis/technology-roadmap/european-initiative-on-smart-cities

[41] 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

2.1.7 End of life

- **Public sector procurement**

Government procurement procedures will 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 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 e.V.[42]) 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 will 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.

2.2 Cross-cutting drivers

- **EC regulations**

The **European Commission Roadmap to a Resource Efficient Europe** (COM(2011) 571) targets that by 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The life-cycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient, and policies for renovating the existing building stock will 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 will 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 **proposal for a Directive on energy efficiency**, 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 of waste prevention. The revised Directive has laid down a five-step hierarchy of waste management

[42] 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.

options: Waste prevention; Preparing for re-use; Recycling; Recovery (including energy recovery); and Safe disposal, as a last resort. With regards to building, the directive states that "the preparing for re-use, 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 regarding the envelope**: return on investment optimization 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 **optimization 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 optimize 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[43] 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 attached to 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 favor 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 have 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 optimization
- more and more demanding customers and end-users, able to compare construction services and products prices on internet;
- "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;

[43] http://www.salvoweb.com/

- DIY[44] 'experts' who prefer to do part of the construction works by themselves and like to 'customise' and adapt their home to their changing needs;
- organizations in commercial and offices buildings who 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 CO2 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, such as 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 , interoperability of IT tools are topics which could be covered at a faster pace once such Research Centres have been networked to address them.

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

3.1 Design

3.1.1 Challenges

The design of energy/resource efficient building (new or to be refurbished) must involve all stakeholders within a collaborative approach, allowing for more iterative steps

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*.

Collaborative design implies shared data, practices and tools with proper training and education

A **knowledge-based approach to collaborative design** allows designers accessing the right information and provides performances of real cases, thanks to:

- interoperable data bases to manage economic assessment,
- building Information Modelling 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[45] open standards),
- harmonized 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 to foster:

- collaboration between architect, engineers and contractors for resource efficient designs,
- collaboration between contractors and structural engineers to favour innovation at material level.

Eco design is required to ensure sustainable performances of buildings based on its use value

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),

[44] Do It Yourself
[45] IFC : Industry Foundation Classes

- the building components' reuse, and recycling potential, (including options from knock down to selective or full deconstruction, refurbishment and conversion),
- and the building material durability and recycling potential.

The complex multi-criteria optimization process covers:
- the environmental impact (minimization of CO_2 emissions),
- the **value for the user** (internalizing aesthetics, accessibility, increased comfort and productivity, preservation of cultural heritage, public health).

Energy/resource efficient building design tools 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[46].

Optimal design will progressively include the district dimension when appropriate

District morphology, local micro climates in urban areas, electrical/heating network configurations, connections with neighbour buildings for energy management, phasing with other local works can influence the optimal design.

3.1.2 Barriers

The table below summarizes the barriers which may prevent the design players meet the above challenges.

BARRIERS SPECIFIC TO BUILDING DESIGN	
Technical/ Technological	▪ 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
Industrial	▪ Software vendors still hesitate to invest in BIM interoperability[47] due to the lack of demand in having compatible BIM ▪ IFC, IFD[48], IDM/MVD[49] limitations
Economic	▪ Time constraints impact iterative design in terms of energy efficiency
Societal	▪ Resistance to change ▪ Considerations for cultural heritage buildings
Organizational	▪ Building Information Modelling makes responsibility sharing fuzzy ▪ Lack of Experts on combined BIM and IFC knowledge
Regulatory	▪ IFC certification suffers low quality ▪ Regulating qualitative issues is difficult

[47]For instance, the "Screening national building regulations" report 2011 distinguishes different national regulatory approaches such as the "Anglo-Saxon model" with generic basic requirements, voluntary guidance and standards and advice-based building control officers; the "Germanic model" based on detailed regulation and strict control and registration of professionals and artisans; the "Napoleonic model" based on decennial liability and insurance with technical control bureau; or else the "Nordic model" focusing on self-regulation and self-assessment at the level of builders and building owners… (See PRC Bouwcentrum International, Delft University of Technology, February 2011)
[48] International Framework for Dictionaries
[49] IDM/MVD: Information Delivery Manual / Model View Definitions

3.1.3 Research and Innovation Targets

DESIGN TARGET

1. ***A multi-scale cross-disciplinary approach fostering interactions among players (including software suite and training) is set up for the design of energy efficient buildings and districts in Europe***
2. ***Improved building management tools cover the whole lifecycle from sourcing to building construction, refurbishing and end-of-life***
3. ***A validated European cross-disciplinary "design for affordable sustainability" framework supports new and refurbished construction projects which minimize building GHG emissions AND their cost of ownership***

3.2 Structure

3.2.1 Challenges

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 to the construction, maintenance and demolition of the building[50]. For some office buildings, it has been reported[51] 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[52]. 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 annual rate of over 3 billion tons per year[53], enough to produce over 10 billion cubic meters – around 25 billion tons – of concrete[54]. The development of composite cements with largely reduced clinker contents is consequently a key driver for reducing the overall embodied CO_2 of building structures at a European and worldwide level by up to 50 % is. The fabrication of these cement types relies on incorporating into the cement significant amounts of industrial inorganic by-products and/or residue streams, such as ground granulated blast furnace slag or fly ashes from coal fired power plants. Blending with limestone or – to a minor extend – with alternative components, such as recycled concrete fines or slags from the non-ferrous metal production, may also contribute to reducing embodied CO_2.

[50] Berge, B. (2009) The ecology of building materials, 2nd edn. Architectural Press, Oxford
[51]Dimoudi, A., Tompa, C. (2008) Energy and environmental indicators related to construction of office buildingsResources Conservation and Recycling 53:86-95
[52]WBSCD and EIA (2009). Cement Technology Roadmap 2009: Carbon emissions reductions up to 2050
[53]World statistical review 1999 – 2009, CEMBUREAU. Cement production, trade and consumption data
[54]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

- **Use of timber** 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 minimizing transportation related CO_2 emissions.
- **Use of reclaimed materials**, especially steel sections, from demolition sites

3.2.2 Barriers

The table below summarizes the barriers which may prevent the structure materials players meet the above challenges.

BARRIERS SPECIFIC TO THE BUILDING STRUCTURE	
Technical/ Technological	▪ Innovative structural materials with low embodied CO2 possessing same performance parameters that state-of-the-art technology and to be produced on a multi-million t or m³ scale are not available
Industrial	▪ Characterization methods and standards for eco construction materials are missing
Economic	▪ Costs of future low CO2 solutions need to be competitive with state-of-the art technology to enable market penetration
Societal	▪ The trust of the construction sector towards new materials is poor ▪ The contribution of structural engineers to energy efficiency is underestimated
Organizational	▪ Structural eco products and solutions are lacking visibility
Regulatory	▪ Codes and regulations need to evolve and become supportive regarding the use of eco materials

3.2.3 Research and Innovation Targets

STRUCTURE TARGET

Affordable, adaptable and durable structural systems have a significantly reduced embodied CO_2 content

3.3 Envelope

3.3.1 Challenges

Envelope is a critical element to reach the 2050 decarbonisation goals, indeed according to US DoE[55] estimation, the building envelope impacts 57% of the building thermal loads.

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

Envelope design constraints include acoustics, seismic, fire resistance, indoor air quality, thermal comfort, energy performance, legislation, aesthetics, cultural heritage, availability of products, regional differences, etc…. and, of course, costs and energy harvesting. Envelope optimization 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,

[55] *Building Technologies Program, Roadmap overview*, Marc LaFrance, Buildings XI Conference DOE Roadmap Meeting, December 2010

comfort and energy harvesting). A wide range of methodologies and tools[56] are being developed. They are yet difficult to benchmark (different coverage – for instance only HVAC optimization- 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 optimize the integration of new materials and components in the envelope.

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 minimize thermal bridges, whatever the building's age, all of it optimized in terms of final costs and energy harvesting. Energy harvesting optimization 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.

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

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

- 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,
- radiation control (cool roofs, …),
- materials for switchable glazing (smart windows),
- improved concrete: Concrete based on composite cement used in connection with innovative insulation solutions is another possible approach to improve energy and resource efficiency.

Envelopes can progressively adapt to their environment (internal and external)

Building envelopes can also contribute to the indoor quality and comfort, since embedded in the energy management at building level (storage), in connection with the Building Energy Management Systems (BEMS). The "smart building envelope" will "adapt to its environment by means of perception, reasoning and action"[57], viz:

- handling variations (i.e. provide an acceptable response to regular variations[58], 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 optimization),

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[56] 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

[57] See *Intelligent Building Envelopes - Architectural Concept & Applications for Daylighting Quality*, AnnemieWyckman, 2005

[58] 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.

- 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.

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[59]. It can address acoustics, comfort, lighting, which have (or have not) an impact on energy performance and indoor air quality. The envelope is used to improve the indoor air quality by implementing potential ventilation systems that enhances the general energy performance of the building and internal comfort. 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[60] causing low intrusiveness in the general functionalities of the building.

Manufacturers and construction companies are in the driving seat for further performance regulations beyond 2020

So far, manufacturers and construction companies have been lagging behind directives. If new regulations come into the picture to enforce further decarbonisation, it is essential that manufacturers and construction companies are in the driving seat to set the level of future deployment parameters (refurbishment depth and rate) which make regulatory approaches obsolete together with policy makers.

3.3.2 Barriers

The table below summarizes the barriers which may prevent the players from meeting the above challenges.

BARRIERS SPECIFIC TO THE ENVELOPE	
Technical/ Technological	▪ Meeting the design performances of integrated envelopes still difficult ▪ Assessing the contribution of each envelope component to the system performance over time still difficult ▪ The detection of users' misbehaviour very limited ▪ Data on material characteristics and energy needs are lacking
Industrial	▪ Industrialization of building envelope solutions still very costly ▪ Characterisation methods and standards lack high volume / high performance eco construction materials
Economic	▪ The selection of envelope solutions still driven by investment costs and building codes

[59]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)

[60]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.

	▪ Integrating the envelope components still costly to meet the final performance targets ▪ Return on investment for refurbishment projects not attractive ▪ High intrusiveness in refurbishment intervention
Societal	▪ Building owners not enough open to make sustainable choices ▪ High intrusiveness in refurbishment intervention ▪ new multifunctional components require continuous education of craftsmen which is often not the case.
Organizational	▪ 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.
Regulatory	▪ differences in national standards slow components standardization ▪ Guarantee and insurance schemes for refurbishment ▪ regulations for public decision promote lowest prices, not best performances

3.3.3 Research and Innovation Targets

ENVELOPE TARGETS

1. ***Energy efficient envelopes combine easy to integrate materials and components to lower building energy demand***
2. ***User-centric envelopes maximize the envelope value, including improved aesthetics, acoustic and lighting comfort, quality of indoor environment***
3. ***Envelopes are adaptable to a dynamic and complex environment***
4. ***Envelopes are able to integrate generation and conversion of incoming solar radiations***

3.4 Energy equipment

3.4.1 Challenges

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 will be used, as much as possible, when it is available from renewable sources. Energy storage will 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 changes in energy networks, management systems and also in appliances, energy equipment and their control systems. Within each building, energy consuming equipment (ventilation, space heating and cooling, domestic hot water and lighting) will be appliances with individual high energy performances: they are integrated, interconnected and controlled in order to optimise their efficiency in real time. Ventilation systems will 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 will 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. Future buildings will be able to communicate with each other and their environment. They will 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 will 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 will contribute to manage the mismatch between local centralized generation and instant demand, allowing bidirectional exchange with generation, storage, and demand. Systems capable of operating with low temperature networks will be used. Thermal storage systems, both passive, such as wall mass, and active, such as hot water storage, or thermochemical heat which stores heat with very low loses in chemical bonds, will also be used to manage the gap between renewable systems and user demand. 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 socio-economic 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 will be effective at European level, 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.

Envelope and energy equipment are synergistically integrated into building design

Building envelope and energy equipment will progressively merge to ensure optimised energy management. The envelope, controlled by innovative BEMS, can store and release energy to minimise energy peak demand.

3.4.2 Barriers

The table below summarizes the barriers which may prevent energy equipment players from meeting the above challenges.

BARRIERS SPECIFIC TO THE ENERGY EQUIPEMENT	
Technical/ Technological	▪ Energy equipment is insufficiently interoperable ▪ Energy efficient heating, cooling and generating systems are difficult to integrate ▪ 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
Societal	▪ Public acceptance of smart metering ▪ Public acceptance of mechanical equipment, such as ventilation system, automatic lighting etc. ▪ End-users' behaviour is poorly understood
Organizational	▪ 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

3.4.3 Research and Innovation Targets

ENERGY EQUIPMENT TARGETS

1. ***Energy efficient, interoperable and scalable HVAC, energy generation and lighting solutions in line with energy consumption standards are available for integration into new and refurbished buildings***
2. ***Minimum European energy performance standards, certification and labeling schemes are applied to building-integrated, interoperable energy-using and energy-generating equipment***
3. ***User-centric multi-scale BEMS allow improving the level of users' awareness and optimizing energy demand at buildings and district levels***
4. ***Energy management systems and management protocols are available to optimize energy generation, storage and distribution at district level***

3.5 Construction process

3.5.1 Challenges

Worker-centric construction processes are durable, adaptable, with better productivityand 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 will compromise the final performance of the building, despite all efforts done during the design and the structure and envelope engineering steps, and will 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 and acoustics 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 become a more collective process

Ensuring high energy efficiency in buildings will 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 involvement in renovation processes will 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 utilization 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 of measured **energy performance** to meet pre-set contractual values
- guarantee of 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 will rely on shared tools, data and practices in order

i) to meet the guarantee of performance,
ii) 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. ICT solutions, such as 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. pre-cast 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.

3.5.2 Barriers

The table below summarizes the barriers which may prevent construction players from meeting the above challenges.

BARRIERS SPECIFIC TO THE CONSTRUCTION PROCESS	
Technical/ technological	▪ Methods for energy related self-inspection are still lacking
Industrial	▪ The construction industry is not yet fully ready for prefabrication away from the construction site
Economic	▪ Upfront investment costs are high for new construction

	technologies ▪ Refurbishing costs are high
Societal	▪ Concerns about health and safety of the workers may slow down the pace of the refurbishing process
Organizational	▪ The building sector is slow to adopt new technologies and lacks the skilled workforce to meet the refurbishment rate
Regulatory	▪ National codes and regulations can be barriers for new comers

3.5.3 Research and Innovation Targets

CONSTRUCTION PROCESS TARGETS

1. ***Self-inspection techniques support the commitment of each worker to meet intermediate performance targets for the built environment***
2. ***Interoperable, safe and cost-effective solutions and quality driven management approaches help workers meet more stringent quality criteria***
3. ***Advanced and automated processes that favour the use of prefabricated modular solutions are available to ease new building and refurbishing high performance works***
4. ***Appropriate training schemes to continuously improve on worker skills are set up***

3.6 Performance monitoring and management

3.6.1 Challenges

Energy performance will be monitored 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 will be to better understand the dynamic changes in energy use. Sensing techniques, possibly coupled with dynamic building 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.

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. The interaction and interconnection of different systems creates not only reliable, secure and safety systems, but also systems giving users more comfort and added value (smart city concept thinking).

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 is able to optimize 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 a 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 will 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 building energy performance is continuously optimised to meet performance criteria and evolving user's requirement and behaviour (including load forecast)

Multi-criteria smart building management systems are implemented to continuously adapt the performance of the building to the constraints (occupancy, weather, user behavior, 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 maximize the optimization 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 will 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.

Measurements of use value are integrated into the design of equipment and buildings

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, are therefore required to make new buildings/refurbishments specifications more robust (user-proof) and gain more flexibility during the life of the buildings (more adaptability to the constraints, comfort tolerance). Real-life data on the performance of operating energy efficient buildings (and the way this performance is perceived by the end-users, or use value) is needed to provide such information.

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

Feedbacks and lessons learned from the energy efficient buildings 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.

3.6.2 Barriers

The table below summarizes the barriers which may prevent the players from meeting the above challenges.

BARRIERS SPECIFIC TO THE ENERGY PERFORMANCE MONITORING AND MANAGEMENT	
Technical/ Technological	▪ Low cost and low maintenance sensors are still lacking ▪ Energy performance monitoring systems with advanced functionalities is not yet available ▪ Energy equipment is insufficiently interoperable
Economic	▪ Innovative energy performance monitoring equipment is too expensive
Societal	▪ Public acceptability of performance monitoring is lacking ▪ The use value and behaviour of end-users is poorly understood
Regulatory	▪ Legislation to frame appropriate energy metering in buildings is needed ▪ European legislation on energy management and trading at district level is needed

3.6.3 Research and Innovation Targets

ENERGY PERFORMANCE MONITORING AND MANAGEMENT TARGETS

1. ***A European framework on energy performance metering and analysis, going beyond the IPMVP standard (International Performance Measurement and Verification Protocol) favors guaranteed performance contracts***
2. ***Conditional maintenance techniques are deployed to maximize building energy use efficiency***
3. ***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***

3.7 Building's end of life

3.7.1 Challenges

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 optimization process: connection with neighbour buildings, 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 will 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 recyclate 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).

3.7.2 Barriers

The table below summarizes the barriers which may prevent the players meet the above challenges.

BARRIERS SPECIFIC TO BUILDING’S END OF LIFE	
Technical/ Technological	▪ Technical solutions for producing construction materials and prefabricated elements based on recycled material (like-to-like applications) are uncommon ▪ Cost-efficient beneficiation technologies are lacking ▪ “Contaminating” finishes limit dismantling and reuse ▪ Changes in material characteristics prevent from recycling and reuse
Economic	▪ Deconstruction/dismantling is costly
Organizational	▪ Lack of 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

3.7.3 Research and Innovation Targets

END-OF-LIFE TARGET
Innovative paths allow increasing the further utilisation of construction components and materials

3.8 Cross-cutting challenges and targets along the whole building value chain

Beyond the challenges identified at each value chain step, some critical issues relate to the integration of these value chain steps 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 will become the critical process to meet ambitious energy efficiency in the building sector. Current integration processes can take care of validated prototypes coming from the on-going EeB PPP. Yet, new integration processes are needed to implement large scale demonstrations up to 2025, but also to minimize industrialization costs of the validated solutions up to 2025.

3.8.1 Challenges

Research and innovation must be better linked to speed up the market uptake of promising solutions

The energy transition[61] 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 realization 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.

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

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

- climate change,
- a growing and increasingly urban population (resulting in a urban sprawl issue),
- 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, acceptance of new technologies and building constraints, etc). In particular, refurbishment projects must deal with complex users'

[61]ENERGY TRANSITION OF A SECTOR IN THE NETHERLANDS*Dr. I.J. Opstelten, Dr. R. Weterings, Drs. F.A. Versteeg Energy research Centre of the Netherlands, TNO, FORGOOD (2009)*

perceptions. Managing occupants' expectations and perceptions of benefits[62] can reveal quite difficult. Analysing and modelling the user's behaviour and perception of the building value will 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, 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 optimization framework is required to minimize CO_2 emission, energy consumption and cost of ownership, where Life Cycle Assessment supports decision-making at each stage of the building value chain

Optimizing 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 optimization issue. The assessment of various building design options requires considering in parallel three physical levels:

- the building material level, where durability issues, embodied CO2 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 and conversion).

A key concept for CO_2/resource optimization 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 has been 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 will 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-optimization" is therefore to arbitrage 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.

At 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 will 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"63),

[62] 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)

[63]Elefante, Carl (2007). The Greenest Building Is…One That Is Already Built. Forum Journal.Vol 21, No 4.

- 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, 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 CO2 of the respective material / system solutions
- 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)

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 minimize CO_2 emissions during the transport of materials and the construction process: new ways of constructing have to be invented (e.g. optimize between offsite prefabricating and onsite construction to optimize 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, and rehabilitation. Overall, enabling the proper optimization 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**[64] in particular is recognized to provide the best framework currently available for assessing the potential environmental impacts of components and systems. It however requires a harmonized 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 makes energy efficient solutions affordable and enable the engagement of constructors and manufacturers

Several points of view about energy efficient buildings will prevail:

- Manufacturers will strive for cost reduction through standardization and prefabrication of complete subsystems at factory level, a trend which has shown tremendous cost reductions at increased performance
- Constructors will favour creativity and dedicated solutions to take 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 in fine by architectural options.

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

[64] http://lct.jrc.ec.europa.eu

Resource efficiency in buildings must integrate a district dimension

When seeking for optimization, the building process will 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 optimized 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 optimization. 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 can mean either a geographical district, or a 'virtual' district, i.e. buildings belonging to a same category (e.g. governmental buildings). The district approach allows the contractor to implement 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[65] and Spatial Data Infrastructure can help to consider a broader dimension.
This will 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 optimization 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 optimization should be supported by innovative education and training techniques

Training and education will 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,
- Increase the level of skills in the different professions, so as to deal with new technologies, tools and methods, 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,
- Standardization,
- A European mechanism for energy labelling of buildings, building components (materials, envelope components, energy equipment) and associated processes (construction),
- Public procurement improvements.

[65] Geographical Information System

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 optimization 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.

3.8.2 Barriers

The table below summarizes the barriers which may prevent the players from meeting the above challenges.

CROSS CUTTING BARRIERS
Coordination between 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

3.8.3 Research and Innovation Targets

CROSS CUTTING TARGETS

1. ***A supply chain of adaptable refurbishment solutions is structured taking into account the use value of building users in districts***
2. ***The systemic integration of components and sub-systems (e.g. structure, envelope, energy equipment) covers the whole building value chain***
3. ***Cross-cutting innovation topics are addressed to speed-up the innovation take-up at Member State level (pre-normative research, procurement management, standardization, energy labelling)***

4 Priorities over 2014-2020: timeline, scale of resources and proposed investment distribution

The proposed roadmap is intended to guide the implementation of an industry lead research and innovation programme in the period 2014-2020 to reach a set of new targets in line with the industry 2030 vision and EU decarbonisation goals. It also addresses the integration of promising research results obtained over the current EeB PPP as its natural prosecution in line with the original long term strategy and “wave action” strategy: demonstrations followed by industrialization by industry will allow integration in our built environment and future smart cities in line with industry 2030 vision highlighted in Part 1.

An overall budget of 2.1 billion Euros over 2014-2020 is proposed to support this acceleration 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 EeB PPP and associated industry mobilization 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 will 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 and the cross cutting activities has been 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 9), in line with the analysis of the current project portfolio provided in Part 1.

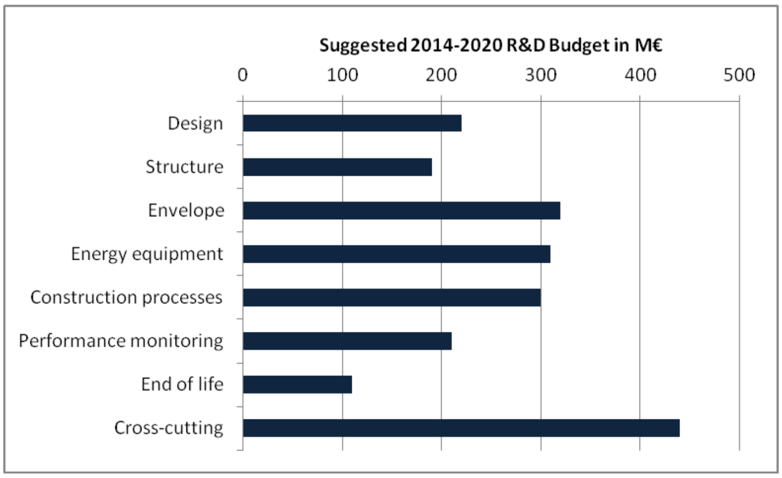

Figure 9: Proposed breakdown of the EeB PPP budget in the period 2014-2020 per step of the building value chain

It must be emphasized that **a larger industry co-funding is expected in the construction process, cross cutting activities and performance monitoring and management**: the innovations will be tested on real life buildings (both new and refurbished, with probably districts concerned by a combination of both) for which EC funds will cover only the innovative part of the real life project.

With regards to demonstration activities, it is assumed that at least **30 % of the total budget proposed will be concerned with full scale demonstrations** (over 650 million Euros), addressing every step of the value chain, and with special implementation in cross cutting activities that integrate all these steps together. This is in line with the H2020 overall objectives to bring innovations close to the market, tackling also non technological barriers.

PART III: EXPECTED IMPACTS

1 Expected impacts on industry and society

As reported in February 2012 within the consultation paper "Financial support for energy efficiency in buildings" by DG Energy, buildings are central to the EU's energy efficiency policy, as nearly 40%[66] of final energy consumption (and 36% of greenhouse gas emissions) is in houses, offices, shops and other buildings. Moreover, **buildings provide the second largest untapped cost-effective potential for energy savings after the energy sector**. Within this framework which sets the challenges and the opportunities to create an impact, this roadmap is built on key pillars which foster **systemic innovations to deliver new technologies and solutions which would accelerate the transformation of our buildings and districts in decentralised energy producing blocks**. This is based on a **coherent and multidisciplinary programme ambition, covering research and technological progress while tackling also innovative business models and services, standardisation, innovation friendly procurement**, to name a few. All these non technological aspects are centred around building users, introducing **social innovations**, as well as users of the technologies and systems along the value chain. This includes **education for the future skilled workers** and the European society at large. Beyond industrial competitiveness and employment, this roadmap introduces a number of potential benefits for the environment, the climate and our secure supply of energy which are summarised in the following chapters.

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**[67].

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**[68]. According to the Ecorys report[69], 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**,
- Closer customer and end user relations and process innovation,
- **Professionalization** of the clients,
- Access to **applied research and technology transfer** such as new technologies, materials, smart and eco-efficient solutions and buildings,

[66] In 2008. See "Energy, transport and environment indicators, 2010 edition", Eurostat
[67] Ecorys (2011) FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – Sustainable Competitiveness of the Construction Sector. Final report
[68] Ecorys (2011) FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – Sustainable Competitiveness of the Construction Sector. Final report
[69] Ecorys (2011) FWC Sector Competitiveness Studies N° B1/ENTR/06/054 – Sustainable Competitiveness of the Construction Sector. Final report

- New **service models** to complement actual construction, retrofitting and renovation activities, which allows 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 present PPP will 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 present PPP will 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 is 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 will generate a demand for new energy efficient buildings, a mature refurbishment market required to meet the 2050 decarbonisation goals leads approximately to an **additional 60 billion Euros/year** ambitions[70] 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 thanks 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.

The overarching goal of this roadmap is to reach **industrial marketing for energy efficient buildings by 2030** through the extension of the running EeB PPP beyond 2013, identifying research and innovation priorities to be addressed in the period 2014-2020. 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 (60% and beyond).

Europe is not on track to achieve its energy efficiency goals by 2020. Calculations show that the reduction of energy consumption would be below 10%[71] instead of the 20% targeted figure by 2020. Two recent studies[72] 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 587 billion € for the period 2011-2020. This translates into an investment need of around 60 billion € per year to realize this savings

[70] Eichhammer, W. et al.: Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. 2009; 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

[71] See for instance the EC communication SEC(2011)277

[72] Eichhammer, W. et al.: Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. 2009; 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

potential[73] 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 soon as 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**[74]. 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 where productivity has decreased.

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**[75]. According to the BPIE study[76], 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 per year. 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[77] states that "investments in improved energy efficiency in buildings could generate an additional 2-3.5 million jobs in Europe and the United States alone".

The French Ministry for Ecology, Energy, Sustainable Development and Spatial Planning estimates that for every 1 million Euros of investment in property-related thermal renovation, 14.2 jobs are created or maintained in the field of energy performance-related work[78]. **Applying these numbers to the above-identified investment need of 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 at up to 2 million jobs based on data from the building sector. **As the construction sector is in general highly locally oriented[79], this means that job creation in this sector will have a high impact on local employment.**

The availability of a long term roadmap and the possible extension of the eeB PPP 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

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[73] Consultation Paper: "Financial Support for Energy Efficiency in Buildings"

[74] 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.*

[75] Communication from the Commission “The Competitiveness of the Construction Industry”, COM(97) 539 of 4/11/1997

[76] BPIE (2011) Europe’s buildings under the microscope

[77] Green Economy Report 2011, United Nations Environment Programme

[78] Plan européen pour la relance économique COM(2008) 800 final Mesure n°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

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

from outside of the EU. A key feature of the construction sector is indeed that employment generated is indeed rather local and this will provide a clear boost to local economies which are struggling in the crisis time, thus **fostering smart specialisation**.

1.3 Energy, climate and environment and associated EU policy implementation

The role of EU institutions in supporting energy savings in buildings is likely to be similar to the role they played for renewable energy deployment:

- To ensure that commitments are taken at national level towards the implementation of the new building construction standards and deeper building refurbishment targets.
- To facilitate the arrival of more instruments aimed to steer the refurbishment of buildings: this is, for instance, the purpose of **carbon price internalization** into the building refurbishment decisions. Currently, carbon price is still not completely internalized by market players: refurbishment decisions are biased towards fossil fuels, which is inconsistent with the EU climate and energy objectives. The recent EU Energy Tax Directive proposal is a first step in this direction. Moreover, **technology standards and labelling of building refurbishment technologies**, products and materials at EU level are a route to be explored in order to avoid that national regulations for building materials and products create barriers for the internal market . Last, but not least, **EU energy performance certificate schemes** could support energy performance regulations of buildings. The proposed Energy Efficiency Directive introduces stricter requirements; these certificates could also be expressed in greenhouse gas emissions to be aligned with the 2050 building sector goals. Only a few Member States are taking emissions reduction in consideration.
- To develop the building refurbishment market, which is still supply-driven and addresses shallow refurbishments, in order to make it **more demand-driven by addressing not only energy savings but also other user's benefits**, such as comfort, aesthetics or health, as well the minimum refurbishment depth required for GHG emission abatement. The Energy Service Directive took a first step towards an EU framework by introducing the concepts of accreditation, standardized contracting, and measurement and verification protocols for energy savings. Such verification protocols could be extended to other values that can be less monetized.

The purpose of the present Research and Innovation Roadmap is to complement such EU pathways by preparing the building sector (technology manufacturers, construction companies and energy utilities) to be in line with the 2050 decarbonisation goals: **the economic inertia of this sector requires that technology building blocks and construction be prepared to respond to the above market needs**.

1.3.1 Compliance with the EU 2050 decarbonisation goals

As anticipated, reaching the 2050 decarbonisation goals requires that:

- **performance standards** for new buildings be reached at affordable costs: In many European Member States, a first set of targets by 2020 have been set for zero energy buildings, which would be the norm beyond 2020,
- **energy refurbishment** of buildings: both the rate and the depth (from shallow to deep energy refurbishment) must continue increasing significantly beyond 2020 (with several scenario mix which could be reached according to Member States own building stock).

The present Research & Innovation Roadmap aims at initiating a learning curve for the three main critical pieces of the value chain:

- **the building envelope,** which is critical to reach depth of refurbishment beyond 70% (whereas most of the national roadmaps have promoted energy savings on buildings around 30%, which is interpreted by the players as the target for the refurbishment depth),
- **the construction process,** which must be of a sufficient quality to narrow the gap between performance by design and performance at commissioning. It requires increasing the skills of workers and increasing productivity to keep costs down, while developing self-inspection techniques that support collective approaches of energy efficient buildings,
- **the development of Energy Management Systems,** that are user-centric enough to allow energy saving potential measured at commissioning being kept along the lifecycle of the new or refurbished buildings.

The role of the learning curve has been exemplified in the study performed by Fraunhofer ISI (2009)[80]. It shows that decreasing manufacturing costs and increased construction worker skills are of paramount of importance. The case of double glazing windows is illustrative: the price of double glazing windows decreased by a factor of two, despite higher technical and innovative content as well as insulation performances.

1.3.2 Compliance with the 2020 energy policy goals

Overall, most of the **Member States that have implemented stringent energy savings regulations for buildings by 2010 are already lagging behind targets**:

- on the refurbishment rate (the economic crisis slows down investments),
- on the refurbishment depth (shallow refurbishment is encouraged by aggressive supply policies from manufacturers).

Moreover, the **construction of new buildings is already stuck to the 2020 standards**. For instance, in France, the growth of external insulation is very steep: 4 Mm² in 2009, 12 Mm² in 2011 notwithstanding the economic crisis. This growth is drawn in part by the new building standards: 30% of low energy private houses and 50% of collective housing are using such new technologies for the French building sector. It is therefore very likely that by 2015 most of the players will be involved in construction projects for new buildings at the standards set for 2020; but the contribution to lower energy consumption by 2020 will be lower than expected due to lagging refurbishment players.

- **Improved security of supply**

Whatever the scenarios implemented at national level to reach the 2050 decarbonisation goals, all of them improve the security of supply either by reducing the energy demand of buildings, or by using more renewables in the energy mix that favours carbon free energy production, or both.

- **Improved efficiency of energy markets**

The main improvement addressed by the present roadmap is to **develop all the technology building blocks required to make performance guaranteed contracts a reality**, whatever the types of buildings (new or refurbished), and to propose adequate integration processes which will facilitate investments by building owners. Even though observed refurbishment rates are still behind schedule, there is a high probability that smart regulations will be developed to support players in the value chain taking the right decisions towards energy efficient buildings as illustrated below. For instance, European energy performance certificate schemes, in line with the Energy Efficiency Directive, could be promoted where Member States could subscribe to[81]. The key element is the contracting of

[80] "Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA countries" EC Service Contract TREN/D1/239-2006/507-66640

[81] « How to refurbish all buildings by 2050 ? » THINK Topic 7, Final report, May 2012 (to appear)

performance on the use value which covers not only energy but also comfort (acoustic, thermal), health (indoor air quality), accessibility (ageing population), etc… The present roadmap provides a full toolbox to make the regulation on outputs as depicted above possible, involving several business options which could be tested in real life demonstrations.

- **Improved sustainability of the EU energy system**

This roadmap includes **GHG emission abatement from the building sector**, which goes beyond mere energy savings in buildings. This can be reached addressing:

- the use of **renewable energy sources** (for instance photovoltaic electricity production or, thermal solar generation of hot water)
- **heat and coooling networks** using either biomass or geothermal energy sources
- the **district dimension** in the overall optimization of energy fluxes within and between buildings: this space dimension allows more renewable generation schemes to be implemented (such as geothermal or wind electricity production),
- the **coupling of smart districts with smart grids**, where buildings can contribute to peak load management in order to avoid using standing reserves working on fossil fuels, and where renewable electricity can be used on site to support electric cars.

Moreover, this Research & Innovation Roadmap addresses the **embodied CO_2 content of construction materials.** The ambition is to address the development of new standards which should give Europe a world leadership in construction materials.

2 Additionality to existing activities and European added value

2.1 *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:

1. 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,
2. 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,
3. 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 EeB PPP clearly showed that collaborative Research and Innovation activities around an industry lead 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 applies also today and despite the successful achievements so far it has been 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 improvements in this current roadmap that is well aligned to the Horizon 2020 objectives while addressing additional research areas not fully covered in the running EeB PPP.
- **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 will 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 EeB PPP 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 then be tested in the larger Smart Cities framework when available. Furthermore current non technological barriers are tackled since 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.

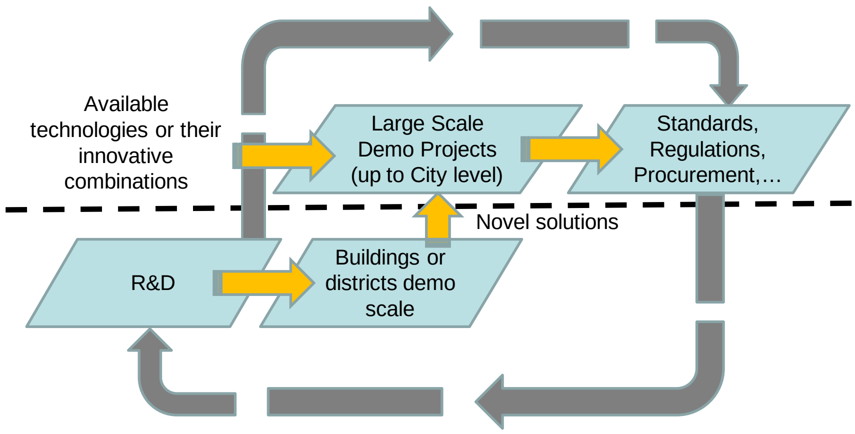

Figure 10: Additionality and complementary of EeB PPP beyond 2013 within the framework of the broader Smart Cities strategy

2.2 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 EeB PPP**, 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 specially for buildings renovation. Still there is a danger of 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 will 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 EeB PPP 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 will 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 a better chance of success, given the trans-national nature of the technologies and systemic solutions to be developed, and also the need to achieve finally the critical mass of players and resources. The intervention of the European Commission will 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 will arise from the close research cooperation and the trans-national demonstration projects. **This standardisation will open a wider market and promote competition**. This Research & Innovation Roadmap has been conceived so as to encourage the **Member States to pursue complementary initiatives at national level**, in the spirit of reinforcing the European Research Area - indeed the very intention of the extension of the EeB PPP initiative beyond 2013 is to leverage these national and regional programmes to make best use of the combined efforts. **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 Figure 11 below where the contribution of the research and innovation activities within the framework of the extended EeB PPP 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.

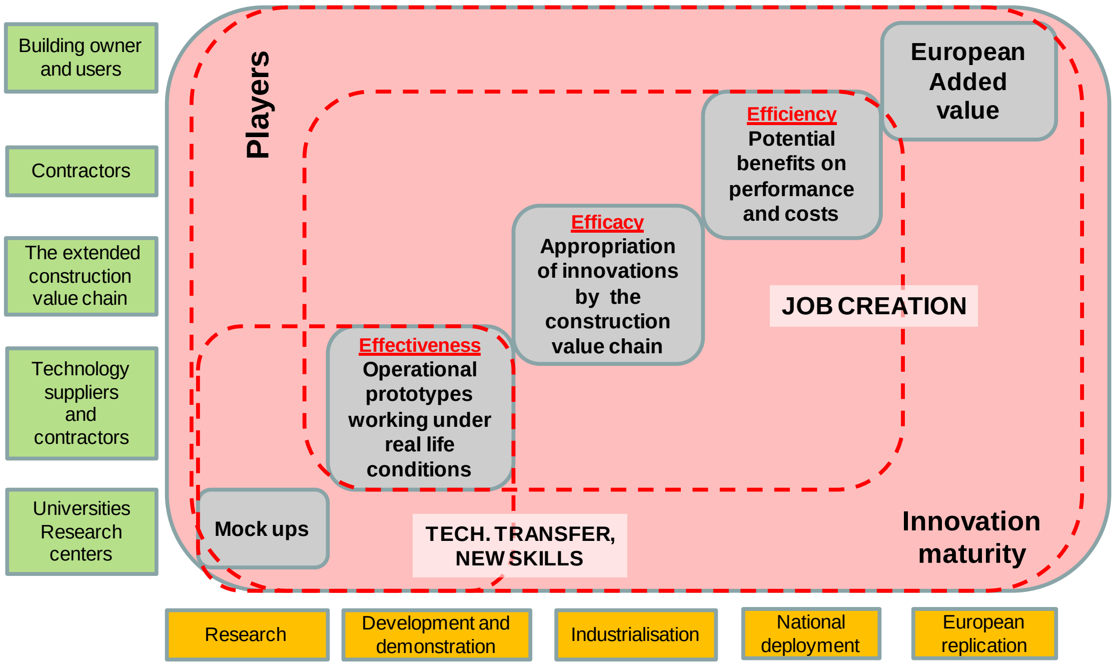

Figure 11: The intended innovation model and the European added value, EeB PPP beyond 2013 covering the initial steps of the innovation chain

Indeed our roadmap to extend the EeB PPP 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 affects 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 will be analyzed,
- Activities will be developed within national and international certification bodies.,
- The standardisation of components and systems developed will contribute to a wider uptake of the technologies by SMEs as well as a wider deployment in the market,
- R&D effort in standardisation will 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 concerns 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 will 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) will be reinforced as well as private industrial banks at European, national and regional level.

The involvement in this roadmapping exercise of organisations active in the EIT KIC Inno-energy initiative has also contributed to consider properly **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.

2.3 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 co-ordinating 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.

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 partnership, 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 lead role in defining the programme priorities and timelines, set against commercialization targets for cost and performance – with **milestones and KPIs to take strategic decisions and mobilize 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 more dynamic and efficient implementation.

The following benefits are expected from the extension of the running EeB PPP beyond 2013, based on lessons learnt and experience 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 into 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[82] at EU level.

3 Expected impact of achieving the specific research and innovation objectives: Key Performance Indicators

The table below summarizes the **expected direct outcomes for the players in the value chain and relevant Key Performance Indicators** (KPIs).

Segment of the value chain	Key Performance Indicators	Expected outcomes for the building players
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
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	• Prefabricated solutions to reduce investments at constant quality • Durable high performance solutions for new buildings that minimizes cost of

[82] « How to refurbish all buildings by 2050 ? » THINK Topic 7, Final report, June 2012

	building of same type and function (measured in kWh/m² floor area/year)	ownership • Active envelope available at affordable costs • Refurbishment processes involving standard envelope configurations built on purpose
ENERGY EQUIPMENT	• Financially attractive zero energy districts possible in Europe • 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 optimization 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 maximize 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 AND MANAGEMENT	• 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: - Sound business models with end-	• Higher productivity of players along the value chain

	users ready to purchase innovations based on criteria which may go beyond energy savings (comfort, accessibility, aesthetics, ….) - Scalability/replication of innovations proven via full-scale demonstrations - 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)	• Validated business models to ensure replication before 2025 • Industrialisation costs of validated technologies under control • Industrial making before 2025

4 Scale of the resources involved and ability to leverage additional investments in research and innovation

According to the 2011 Industrial R&D Scoreboard[83], 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 (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 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 1,405M€ (0,6% of net sales, figures calculated for 34 companies),
- With regards to the "**Household goods and home construction**", R&D investment amounted to 1,377M€ (2,1% of net sales, figures calculated for 19 companies),
- R&D investment was higher for "**Electrical components and equipment**" (5,903M€, 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 EeB PPP 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 in Figure 12, which is expected ultimately to generate a leverage for additional private investments:

- **During real life demonstrations** in support of the validation of integration processes,
- **During the industrialization** phases which remain indispensable on industry side to reach the first sales of commercial products or services.

Quantifying the leverage factors 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

[83] http://iri.jrc.ec.europa.eu/research/scoreboard_2011.htm

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 industry before reaching significant revenues out of innovative products.

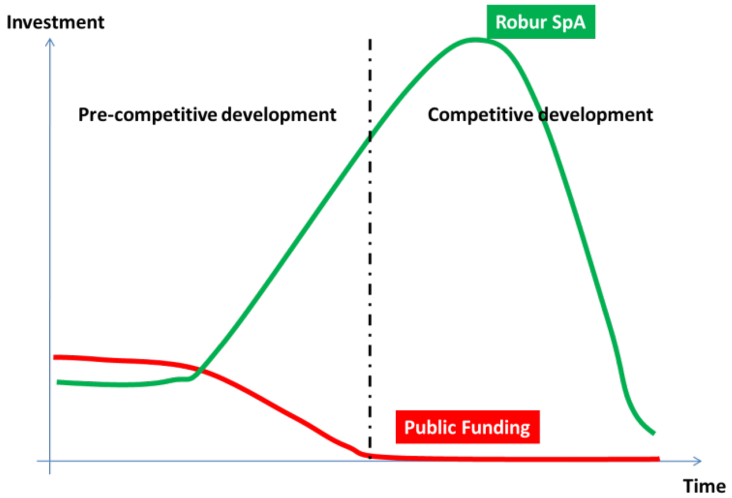

Figure 12: Leverage factor: an example

The following estimates have been made by E2BA for each of the value chain elements considered in this roadmap, considering the proposed budget of 2100 M€ for the extension of the EeB PPP beyond 2013.

	% of total Research and Innovation	Total Research and Innovation investments (pre-competitive)	Industrialisation (competitive) investments (M€)
Design	10%	220	700
Structure	10%	190	800
Envelope	15%	320	1 500
Energy equipment	15%	310	2 000
Construction processes	15%	300	950
Performance monitoring	10%	210	600
End of life	5%	110	200
Integration	20%	440	1 500
TOTAL		2 100	8 250

The expected **leverage factor,** based on the budget allocation per element of the value chain (and excluding the direct leverage coming from real life demonstrations which will support the real life validation of innovative technologies and processes), **is therefore evaluated to be conservatively a factor 4**. There are however 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. A **better use of cohesion and structural funds** is another element of commitment. Structural Funds are needed to complement local financial needs in terms of full scale demonstrations of the developed technologies: such funds should be able to contribute to the field validation of industrialised technologies and processes as earlier as 2014, thus accelerating further the deployment of innovation throughout EU27 and creating synergies with the running wave of projects within the EeB PPP.

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 world-wide level. This will require for instance benchmarking with other programmes implemented in US, Australia, Russia, etc.

6 Proposed arrangements to monitor and assess progress towards achieving the desired impacts

Fast implementation and performance feedback are keys issues of the PPP, and represent a **fourth major pillar in building up the long term strategy** expected as a natural continuation of the running EeB PPP. 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 program progress with the help of an appropriate set of KPIs. **Three levels of Key Performance Indicators** are proposed (see Figure 14):

"Level 1" KPIs address the completion of the overall PPP goals (Vision 2030), in connection with the EC climate and energy policies based on the three pillars (sustainability, security of supply, and competitive energy markets).

	EU Climate & Energy policy		
Benefits brought by the Building value chain to building users	Sustainability	Security of Supply	Competitive markets
All new districts at least energy neutral by 2030	X	X	
Deep refurbishment of existing buildings and districts	X	X	
Productivity increase of the building value chain			X
Reduced embodied CO2 per M_2 of new floor space	X		
User centric BEMs in high performance buildings and districts	X	X	X

"Level 2" KPIs aim at monitoring the PPP progress and measuring how the specific research and innovation targets defined by 2020 are met. These indicators are listed in Chapter 3 of Part 3 of the document.

"Level 3" PKIs allow monitoring the success of each project to be funded under the PPP. They will be defined by each project as ad-hoc KPIs in support of the level 2 KPI that describe the expected outcomes of the PPP.

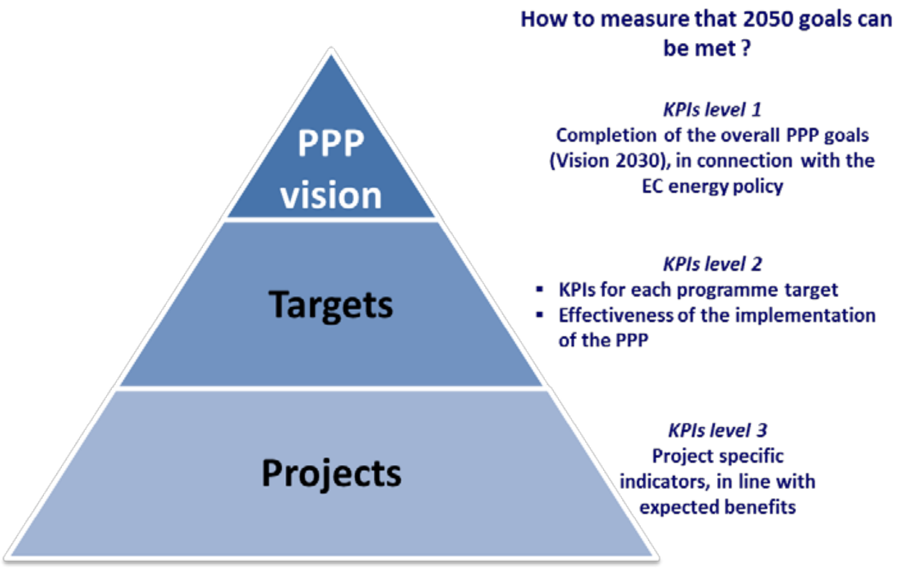

Figure 13 : The different levels of KPIs

APPENDIX 1
RESEARCH AND INNOVATION TARGETS AND PRIORITY AREAS PER EACH ELEMENT OF THE VALUE CHAIN

DESIGN

Target 1: A multi-scale cross-disciplinary 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 will be able to integrate different spatial dimensions from the building (micro scale) to the district, and to urban planning (macro scale), so as 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.

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.

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.

Target 2: Improved building management tools cover the whole lifecycle 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 Modeling (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,
- 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 will 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.

Target 3: A validated European cross-disciplinary "design for affordable sustainability" framework supports new and refurbished construction projects which minimize building GHG emissions AND their cost of ownership

A holistic approach must be developed to optimize both the CO_2 content AND building costs[84], 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 (structure, material) and construction processes in order to:

- **For new buildings:**
  - reduce the overall CO_2 content and environmental impact of materials used in the structure
  - reduce the cost of the structure by using materials more efficiently (design and construction principles),
  - simplify the assembly of structural components and of the envelope during the construction process and provide optimised interface between the structure and the envelope,
  - provide adaptability to changing demands on the space,
  - comply with building codes and standards (resistance to fire, earthquakes, humidity, etc.).
- **For refurbishment**
  - facilitate the interactions between players,
  - provide methodologies and tools supporting refurbishment design,
  - clarify the certification processes,
  - share information on the technological performances,
  - develop business models.
- **For buildings end-of-life:**
  - select demolition or deconstruction optionsin a transparent way,
  - take into account the dismantling issues at the building design stage, including LCA approaches[85],
  - identify and disseminate good practices for deconstruction.

STRUCTURE

Future materials must demonstrate a significantly reduced level of embodied carbon via a systematic carbon footprint assessment. Besides their reduced embodied carbon, materials will also:

- 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 within the structure subsystem and with the other subsystems (envelope in particular) during the construction process)
- be responsibly sourced[86],
- be non-toxic (low VOC and hazardous substances emissions level),
- be recyclable or reusable,
- have a high durability and stability over very long period of times.

[84] 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.
[85]The same idea applies at the building component level: designing for reuse/recycling.
[86] See BES 6001 certification in the UK for example

ENVELOPE

Energy efficient buildings will use envelopes that are durable, adaptable, user-centric and cost effective. Envelopes become more resistant to external (climate, fire) and internal aggressions (moisture): they require less maintenance and allow for easier and better-quality maintenance work. The ageing of components is better understood which allows appraising their loss of performance over time.

Target 1: Energy efficient envelopes combine easy to integrate materials and components to lower building energy demand

Materials are critical to envelope both for insulating properties but also for anchoring the resulting envelope onto existing or new structural elements. Mass manufacturing including pre-fabrication must be investigated to lower manufacturing costs and ease building integration processes.

Target 2: User centric envelopes maximize 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.

Target 3: 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[87] ("Perception, Reasoning, Action"). Envelopes also facilitate the future renovation or conversion of the whole or part of the building:

- 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 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.

Target 4: 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.

[87] See *Intelligent Building Envelopes - Architectural Concept & Applications for Daylighting Quality*, AnnemieWyckman, 2005

ENERGY EQUIPMENT

Target 1: Energy efficient, interoperable and scalable HVAC, lighting and energy solutions in line with energy consumption standards are available for integration into new and refurbished buildings

Energy consuming equipment (e.g. HVAC and lighting) become more and more energy efficient, and adapted to the size and type of buildings (commercial or residential), either new or refurbished. Decentralized energy equipment has to be sized down and re-optimized since less operational energy is needed in energy efficient buildings. Energy equipment needs to be designed to an optimal energy efficient level, with a specific attention paid first to **heating** and then to **cooling**: using a scaled-down heating system based on heat pump at full load is more efficient than underusing an oversized fossil boiler at part load. However, depending on the equipment and application, the optimal size will 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 hot domestic 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.

Target 2: Minimum European energy performance standards, certification and labeling 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. Standardized national and international testing and evaluation procedures for specific technologies will 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** must expand for:

- HVAC components, in particular systems for space heating based on heat pump 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 (heat pumps, solar water heating systems),
- Lighting,
- Direct current networks inside buildings to reduce losses by eliminating AC/DC conversion and increase level of control,
- Energy storage equipment (electricity, heat and cool).

Objective and transparent labelling[88] of energy related products needs to be accelerated, in order to build on the impacts of the EU Appliance Labelling[89].
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[90].

Target 3: User-centric multi-scale BEMS allow improving the level of users' awareness and optimizing 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 maximizes 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 ('idiot proven') users' interfaces take into account users' behaviours and tolerate users' behaviour changes.

Target 4: Energy management systems and management protocols are available to optimize energy generation, storage and distribution at district level

Individual homes and buildings optimization 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 optimize the distribution of locally generated and stored energy and to minimize 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).

CONSTRUCTION PROCESS

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

[88]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.

[89] 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.)

[90] 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.

Target 1: 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 will be quantified during commissioning. Let us mention air tightness of buildings, where all contractors are briefed and must report damages to the air tightness barriers on a ''no fault'' basis, the contractual responsibility for the global building performance being born by the main contractor.

Target 2: 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 data bases to describe the building's main features, and collect quality control information at intermediate milestones of the construction process.

Target 3: Advanced and automated processes that favor 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 customization 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 will need to be developed, tested and implemented considering the use of dedicated handling tools and automated machines which are deployed in parallel to assist workers in reducing time to deploy and increasing quality standards. These new processes will require additional training and definition of new emerging risks.

Target 4: Appropriate training schemes to continuously improve on worker skills are set up

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 specialized 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, minimization 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.

PERFORMANCE MONITORING AND MANAGEMENT

Target 1: 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 have 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 2050. This European wide approach must go beyond than the IPMVP methodology which is very US centric and has proven 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 optimize the whole system and will monitor the user's behavior 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 mayor key factor influencing the overall energy performance of the building, performance-based contracts reduce risks and facilitate implementation.

Target 2: Conditional maintenance techniques are deployed to maximize building energy use efficiency

Condition-based maintenance requires extensive instrumentation of energy equipment[91], and data processing tools at BEMS level to produce real-time diagnosis of building working conditions and energy performances. It will 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.

Target 3: 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** have to be developed in parallel. These pilot sites will measure the actual impact of the energy efficient solutions on users' behaviour and will integrate the users' feedback with respect to these various solutions. Using methodologies similar to clinical studies (e.g. placebo groups), the pilots will directly involve end-users sorted by profiles (age, activity, type of building, etc.).

[91] 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

The observatory[92]will monitor energy performance involving 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 will record and centralize energy performance data and global cost data of exemplary buildings that are representative of larger segments of the stock. Each record will 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) will constitute the scientific background for effective policy making and allow monitoring the progress of such policies and addressing adjustments where necessary. Roadmaps for building stock renovation can be set up with optimized 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 will undergo renovation in a given area in a given period, hence facilitating customized mass production and industrialization. This knowledge base will also serve as a reference data to crosscheck results from building simulation tools, but also a calibration/performance objective for future real constructions. This observatory will also foster an online community to share and rank energy information to compare performance data.[93]

END OF LIFE

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 re-use, recycling and other type of recovery[94]. This requires:

- technical solutions and markets for large scale re-use 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, and
- possibly some innovative financial support schemes.

Achieving that target and promoting viable business models require:

- a clear procedure for the characterization of concrete and demolition waste in order to acknowledge their ability to be reused or recycled in new components,
- 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.

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[92] 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.

[93] ICT supported Energy Efficiency in Construction – Strategic Research Roadmap and Implementation Recommendations, 2010, REEB consortium.

[94] EC Waste Directive related abstract: *"the preparing for re-use, 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."*

CROSS-CUTTING ACTIVITIES

Target 1: 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 customized to account for local specificities (climate conditions, geographical constraints, cultural habits, architectural and aesthetical coherence at district level) or regulations. A trade-off must be found between the possibilities of standardizing 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 inhabitants and users has to be taken into account at building and district level: users' feedback on different criteria, such as wellbeing, comfort, accessibility, aesthetics and acoustics 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.).

Target 2: The systemic integration of components and sub-systems (e.g. structure, envelope, energy equipment) 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. Between these component 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.

Target 3: Cross-cutting innovation topics are addressed to speed up innovation take-up at Member State level (pre-normative research, procurement management, standardization, energy labelling)

Integration covers more than technology and business model issues. National programmes show that pre-normative activities, public procurement management and standardisation issues will be raised and will require dedicated collective approaches. Energy Labelling in all aspects of the built environment will 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.