Training Handbook: Sustainable Construction

Imprint

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In 1987 the Brundtland Commision defined Sustainability as:

A method for "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

(Brundtland Commission, 1987)

1 Introduction

The building sector accounts for 5 to 10 % of the national Gross Domestic Product (GDP) of each and every country in the world and is a major employer, with 10% of the workforce. At the same time it is responsible for 40% of all energy consumed, 50% of all natural resources used and 60% of all waste produced in the world. A sustainable construction sector is thus a key player in being able to reducing global green house gases (GHG) as well as bringing about a more sustainable world.

1.1 Sustainable construction

Sustainable construction refers to the ***adoption of building designs, construction methods and materials that are environmentally friendly.*** This not only in terms of the buildings themselves but also towards their immediate surroundings and the broader regional and global setting.

> *Sustainable Construction is "the practice of creating construction works and using processes that are environmentally responsible and resource-efficient throughout a construction works' life-cycle from initial planning approval to design, construction, operation, maintenance, renovation and deconstruction."*
>
> as defined by the Lead Market Initiative

Till date the focus on sustainable building has been on the use phase. However, as buildings become more and more energy efficient the potential for sustainability moves more and more from the use phase to the planning as well as the construction phases.

1.1.1 Dimensions of Sustainability

Sustainable construction is often referred to simply as "ecological planning" or "energy-efficient construction". However, ecology and energy efficiency are only two parts of a true holistic sustainable construction. To achieve sustainable construction all aspects of sustainability must be looked at and be based on the three pillars of sustainability, economical, ecological and socio-cultural dimensions. These three dimensions must be assessed all at the same time and to the same extent.

Sustainability must, however, also look at the technical and process qualities as well as functional and site-specific aspects. The technical properties of a building can have a strong impact on the sustainability quality. The same applies to process quality, which can strongly influence other sustainability qualities especially in the early planning phase. However, the greatest influence of process quality is within the construction phase, where the future sustainability of a building is decided, as it is here that the planned sustainable quality is actually implemented. For example, the choice of materials and or even the construction processes themselves are deciding factors in the sustainability level of a building. Last but not the least, the location or site specific aspects, including the social, political, cultural and climatic conditions, must be assessed, as a building is always a response to the conditions of its location.

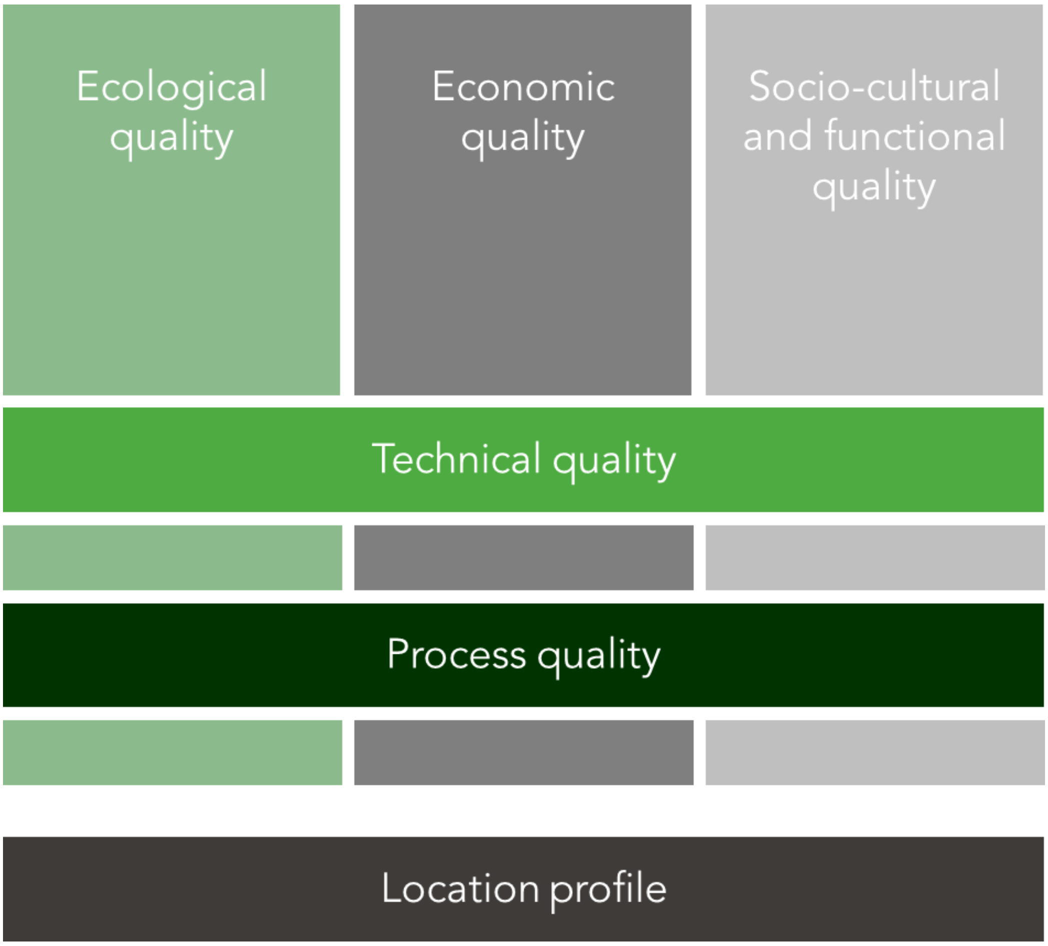

Figure 1: Holistic assessment criteria of sustainability

Source: BMUB: (2016)

It is thus only with a full holistic assessment of all of these dimensions that a future-oriented sustainable architecture be achieved.

1.1.2 Sustainable Construction Phase

Sustainable buildings are directly linked with the interest of the building owners and investors. Building owners and investors are asking more and more for sustainable and energy efficient buildings with low service and running costs. Certified sustainable buildings allow owners, investors to rate the quality and value of a building as well as its economic competiveness. The sustainable construction phase plays a key role in offering this as the use of appropriate sustainable materials and technologies as well as sustainable construction processes and a sustainable building site contribute a major part in the costs as well as the sustainability.

It also brings additional benefits, as for example it has led some construction companies to increase profits through the changing of their business models by considering novel ways of delivering their products and services to more precisely meet these customer needs for a sustainable building. Construction firms are thus increasingly using sustainable building and labelling systems, which include all aspects of the building life cycle including that of the construction phase, such as DGNB or LEED as an effective controlling risk management instrument.

Efficient resource, including material and energy, management are a must in the middle to long term if construction companies are to remain competitive. This of course with the added bonus of an image benefit. This potential for sustainable construction especially in the construction phase, although enormous, brings with it numerous drivers and barriers. Barriers to sustainable construction in the construction phase include among others:

- Technological lock-ins (e.g. use of out-dated machinery),
- Low research and development activity in the construction sector,
- Low transparency in benefits of sustainable construction
- Deficiencies in and low knowledge base,
- Fragmented market with low entry barriers,
- Risk averse attitudes by the contractors to new and sustainable innovations
- Lack of sustainable building materials and technologies
- High prices of sustainable materials and technologies with early adaptation
- Lack of willingness of public administrations to support sustainable construction

This Handbook aims to look at many of these topics and aims to offer ideas, recommendations and solutions to these so as to be a driver for sustainable construction.

2 Policies, labelling systems and standards related to sustainable construction in Europe

Standards in the construction sector are intended to assist architects, engineers, other design professionals, contractors, material producers, procurers and building owners in understanding preferences in the sustainable development, construction, maintenance and repair of buildings. Parallel to standards, reliable third party certification of materials and processes ensure transparency about the ecological and social impact of construction products while leaving room for innovation and an informed choice by the market.

2.1 Technical standards related to green construction in Europe

2.1.1 European Level

Although there are numerous polices in the European Union (EU) relating to energy efficiency there has been, to date, far less focus on sustainable buildings especially in the context of a full Life Cycle Assessment (LCA). There are, however, numerous policies that directly and indirectly influence the sustainability of a building including the construction phase.

To date, in terms of a comprehensive building assessment, methodologies or frameworks for assessing the sustainability of buildings and building products have been developed mainly by private actors. These provide the market with a working definition of a sustainable building as well as tools for its assessment. Many of these existing schemes are however not “real” policies in the traditional sense as these are of a private nature. The EU has however begun to address this and the need for an assessment tool through the development of an EU-wide voluntary standard, the CEN/TC 350.

2.1.2 CEN/TC 350 - Sustainability of construction works

The CEN/TC 350 Framework is a voluntary horizontal, standardized and harmonised method for the assessment of the sustainability, including embodied and operational environmental impacts and their aggregation (particularly for materials through a Environmental Product Declaration (EPD)), of a building and its construction works. Developed by the European Committee for Standardization (CEN), it covers aspects of new and existing construction works, for all building types, the integrated performance of buildings over its life cycle as well as standards for the EPD of construction products. Among other benefits, the standards intends to:

- Clarify the information necessary to support sustainability assessment of construction works,
- Provide a structured format for the product information so that it can be applied to the assessment of construction works,
- Provide essential elements in a strategy leading to the mitigation of climate change and other sustainability aspects, such as use of resources, through understanding the effects of decisions taken,
- Allow industry to demonstrate compliance with emerging regulations and policies.

In implementing the CEN/TC 350 a suite of standards were designed in a three tier level implementation. These being the Framework level, the Building level and the Product level. Each level covering the aspects of environmental, social and economic matters through different very specific standards. These standards lean on and incorporate existing CEN and ISO standards relating to dangerous substances, energy efficiency and sustainability in buildings and waste among others.

The European Commissions’ vision is that the CEN/TC 350 be implemented into national building regulations as well as in voluntary building assessment, certification and rating schemes. This is already partly the case with several commercial benchmarking schemes referencing CEN/TC 350 standards.

It should be pointed out that European Standards are voluntary which means that there is no automatic legal obligation to apply them. However, laws and regulations may refer to these standards and make compliance with them compulsory

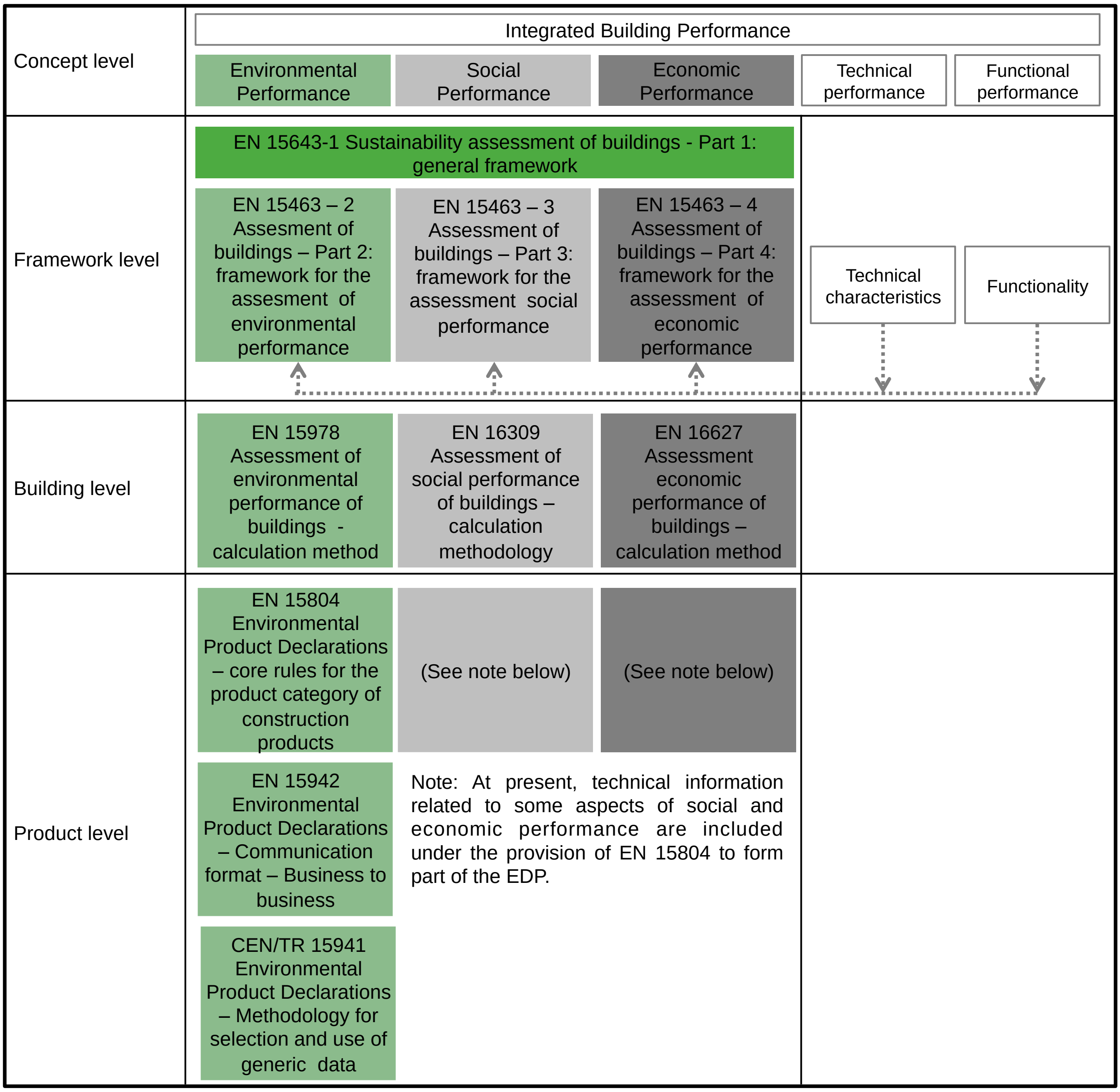

Figure 2: The different implementation levels of the CEN/TC 350 with the Framework, Building and Product levels

Source: CEN/TC 350

At the Framework Level guiding the CEN/TC 350 is the general standard:

- EN 15643-1 – Sustainability assessment of buildings – Part 1: General framework

This is followed, also at Framework Level, by the standards governing Environmental, Social and Economic Performance:

- EN 15643-2 - Assessment of buildings - Part 2: Framework for the assessment of environmental performance
- EN 15643-3 – Assessment of buildings - Part 3 Framework for the assessment of social performance
- EN 15643-4 – Assessment of buildings - Part 4 Framework for the assessment of economic performance

The second level is the Building Level which is also divided into Standards on Environmental, Social and Economic Performance:

- EN 15978:2011 – Assessment of environmental performance of buildings - Calculation method
- EN 16309:2014 - Assessment of social performance of buildings – Methods
- EN 16627:2015 - Assessment of economic performance of buildings - Calculation methods

At the Products level there are only standards grouped into the Environmental Performance, however some aspects of social and economic performance are included in the EN 15804 standard.

- EN 15804:2012+A1:2013 - Environmental product declarations. Core rules for the product category of construction products
- CEN/TR 15941:2010 - Environmental product declarations. Methodology for selection and use of generic data
- EN 15942:2011 - Environmental product declarations. Communication format business-to-business

2.1.2.1 EN 15643-1:2010 - Sustainability assessment of buildings - Part 1: General framework

This European Standard provides, in terms of environmental, social and economic performance, taking into account technical characteristics and functionality of a building, the general principles and requirements for the assessment of buildings. The assessment will quantify the contribution of the assessed construction works to sustainable construction and sustainable development. The framework applies to all types of buildings and it is relevant for the assessment of the environmental, social and economic performance of new buildings over their entire life cycle, and of existing buildings over their remaining service life and end of life stage. The standards developed under this framework do not set the rules for how the different assessment methodologies may provide valuation methods. Nor do they prescribe levels, classes or benchmarks for measuring performance.

This standard provides the general framework for the assessment. Pertaining to sustainable construction sites, the standard provides the framework for a sustainable construction including the construction phase. Construction companies need to have an understanding of this in making their works more sustainable.

2.1.2.2 EN 15643-2:2011 - Assessment of buildings - Part 2: Framework for the assessment of environmental performance

This European Standard provides the specific principles and requirements for the assessment of environmental performance of buildings taking into account technical characteristics and functionality of a building. Assessment of environmental performance is one aspect of sustainability assessment of buildings under the general framework of EN 15643-1.

Construction companies should be aware of this and have an understanding of it and how it can affect the sustainable processes on-site and make it more sustainable.

2.1.2.3 EN 15643-3:2012 - Assessment of buildings. Framework for the assessment of social performance

This European Standard provides the specific principles and requirements for the assessment of social performance of buildings taking into account technical characteristics and functionality of a building. The framework is relevant for the assessment of the social performance of new buildings over all stages of their life cycle, and of existing buildings to their end of life.

Construction companies should be aware of this and how it can affect the sustainable processes on-site.

2.1.2.4 EN 15643-4:2012 - Assessment of buildings. Framework for the assessment of economic performance

This European Standard provides general principles and requirements for the assessment of economic performance of buildings taking into account technical characteristics and functionality of a building. The assessment of economic sustainability measures the contribution of the assessed from the economic perspective to achieve sustainable buildings and sustainable development

Construction companies should be aware of this and how it can affect the sustainable processes on-site.

2.1.2.5 EN 15978:2011 - Assessment of environmental performance of buildings. Calculation method

This European Standard specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building, and gives the means for the reporting and communication of the outcome of the assessment. The standard is applicable to new and existing buildings and refurbishment projects. The standard gives:

- The description of the object of assessment,
- The system boundary that applies at the building level,
- The procedure to be used for the inventory analysis,
- The list of indicators and procedures for the calculations of these indicators,
- The requirements for presentation of the results in reporting and communication,
- The requirements for the data necessary for the calculation.

The approach to the assessment covers all stages of the building life cycle and is based on data obtained from Environmental Product Declarations (EPD), their "information modules" (prEN 15804) and other information necessary and relevant for carrying out the assessment. The assessment includes all building related construction products, processes and services. The interpretation and value judgments of the results of the assessment are not within the scope of this European Standard.

Here the assessment of the construction phase plays a role. This assessment is relative to the construction phase in that it helps to define many of the technical and functional requirements. The materials and techniques, including their impacts on the environment, on the construction site are also the basis for this assessment. This, for example, through the use of sustainable materials declared through EPDs etc. In addition, the monitoring and reporting of the construction as well as communication by , for example, the sustainability manager of construction companies, is needed to complete for the assessment.

2.1.2.6 EN 16309:2014 - Assessment of social performance of buildings – Methods

The standard provides the specific methods and requirements for the assessment of social performance of a building while taking into account the building's functionality and technical characteristics.

In this first version of the standard, the social dimension of sustainability concentrates on the assessment of aspects and impacts for the use stage of a building expressed using the following social performance categories (from EN 15643-3):

- Accessibility,
- Adaptability,
- Health and comfort,
- Impacts on the neighbourhood,
- Maintenance,
- Safety and security.

This standard does not set the rules for how building assessment schemes may provide valuation methods. Nor does it prescribe levels, classes or benchmarks of performance.

Areas relevant to the construction phase are among others the adaptability of the building, maintenance and sourcing of materials and services. i.e. the construction firm could ensure that the interiors walls are moveable or easy for dismantlement instead of permanent. Other aspects include that of maintenance where the construction companies can take measures to for the use of materials that are more durable and sustainable or construction details that make building maintenance easier. The sourcing of materials from sustainable sources i.e. Fair Stone also plays a part. This assessment is relative to the construction phase in that it helps to define many of the technical and functional requirements.

2.1.2.7 EN 16627:2015 - Assessment of economic performance of buildings - Calculation methods

This European Standard provides calculation rules for the assessment of the economic performance of new and existing buildings as one part of an assessment of the sustainability of the building. It complements the European Standard EN 15643-4.

This standard describes the methods and the rules for calculating the cash flows over the life cycle of buildings, with an emphasis on the field of life cycle costing. Principles developed in ISO 15686-5 are included, but have been adapted for sustainability assessment in the European context.

This standard describes two approaches to the calculation of economic performance:

Life Cycle Costing: Economic performance expressed in cost terms over the life cycle, taking account of negative costs related to energy exports and from re-use and recycling of parts of the building during its life cycle and at the end of life. Calculation of this indicator is mandatory for compliance with the standard.

Life cycle economic balance: Life Cycle Costing (see above) and in addition incomes over the life cycle and at the end of life. Calculation of this additional indicator is optional for compliance with the standard.

Here the costs of the construction phase play a role in the determination of the Life-Cycle-Costs. Construction firms must take care in the sustainable costs of for example materials e.g. cheap materials may not be sustainable in the long run. In addition information on costs must be provided by the construction firm for assessment.

2.1.2.8 EN 15804:2012+A1:2013 - Environmental product declarations. Core rules for the product category of construction products

This European standard provides core product category rules (PCR) for Type III environmental declarations for any construction product and construction service. NOTE: The assessment of social and economic performances at product level is not covered by this standard. The core PCR:

- Defines the parameters to be declared and the way in which they are collated and reported,
- Describes which stages of a product's life cycle are considered in the EPD and which processes are to be included in the life cycle stages,
- Defines rules for the development of scenarios,
- Includes the rules for calculating the Life Cycle Inventory and the Life Cycle Impact Assessment underlying the EPD, including the specification of the data quality to be applied,
- Includes the rules for reporting predetermined, environmental and health information, that is not covered by LCA for a product, construction process and construction service where necessary,
- Defines the conditions under which construction products can be compared based on the information provided by EPD.
- For the EPD of construction services the same rules and requirements apply as for the EPD of construction products.

This is directly relevant to the construction phase as this provides the framework for the EPD. Its implementation is useful and important for construction firms, for example, in deciding the sustainability of materials used. Although not directly relevant for construction firms unless they produce their own building products, they must however have an understanding of this as it is directly related to the sustainability of the products that the use in the construction phase.

2.1.2.9 CEN/TR 15941:2010 - Environmental product declarations. Methodology for selection and use of generic data

This Technical Report supports the development of EPDs. It assists in using generic data according to the core product category rules (EN 15804) during the preparation of EPD of construction products, processes and services in a consistent way, and also in the application of generic data in the environmental performance assessment of buildings according to EN 15978.

The application of this standard is relevant to the construction phase in that the framework for EPDs and thus the sustainability of materials and technologies is laid out within. Construction companies should be aware of this and have an understanding of it.

2.1.2.10 EN 15942:2011 - Environmental product declarations. Communication format business-to-business

This European Standard applies to all construction products and services related to buildings and works. To ensure a common understanding through consistent communication of information, the standard defines and describes the format for communication of the content defined in FprEN 15804 for business-to-business communication . This European Standard does not deal with communication between businesses and consumers.

Although not directly relevant for construction firms unless they produce their own building products, they must however have an understanding of this as it is directly related to the sustainability of the products that the use in the construction phase.

2.2 Sustainable building Labels in Europe

In addressing the sustainable built environment different assessment and labelling schemes have been developed in Europe. Although these have for the greater part a common basis of sustainability criteria such as ecological, economical and socio-cultural quality there are nevertheless difficult to compare. This is due to the fact that the details of criteria and key indicators used differ in that some might not be looked at, the depth of analysis varies and the stage and length of time measured over the life cycle also varies. Only criteria where individual impact indicators are calculated and expressed in a standardised form can there be an objective basis for comparison. The system chosen also needs to take in to account the context in which it is being used for i.e. for offices or only for residential buildings. Some of these schemes are also prescriptive (if you do this, you are ‘good’), while others are more performance-oriented (if you achieve this performance level, you are ‘efficient’). For a sustainable construction phase, the different labels give guidance and support through the criteria characteristics. They also serve as guidelines as well as tools for the quality assurance within the construction phase, for example, in the choice of materials of the sustainable process on the building site. It must be noted that, especially, with performance-based systems, as with any assessment methods of tool, there is always some disparity between predicted performance and actual performance in use. The schemes also differ in that there two main streams with a proprietary as well as open systems.

Two of the European proprietary systems, which are looked at in this report, are DGNB and BREEAM. Both of these have a central certification body, a calculation tool as well as imposed and recommended databases.

BREEAM Building Research Establishment Environmental Assessment Method	DGNB German Sustainable Building Council
BREEAM®	DGNB Deutsche Gesellschaft für Nachhaltiges Bauen German Sustainable Building Council
Topics: Management Health & Wellbeing Energy Transport Water Materials Waste Land Use & Ecology Pollution	Ecological Quality Economic Quality Sociocultural & Functional Quality Technical Quality Process Quality Location (separate assessment)

Figure 3: General comparison of two European Sustainable Building Labels

In aligning themselves with the policies and standards of the EU most of the private European sustainable building certificates including DGNB and BREEAM have aligned themselves under the standards used in the overarching CEN/TC 350 standard, see **Fehler! Verweisquelle konnte nicht gefunden werden.**.

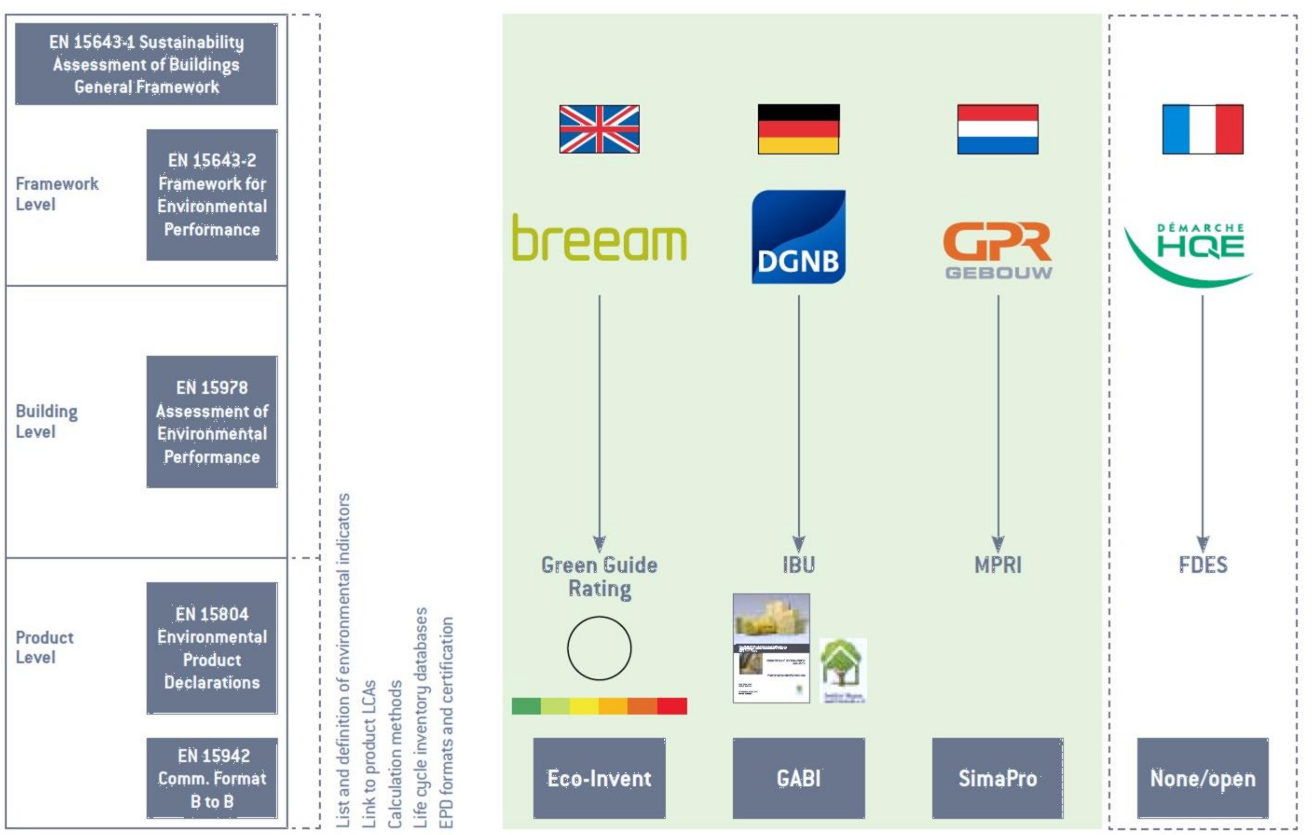

Figure 4: Comparison of private sustainable building codes and the CEN/TC 350

Source: Eurima (2012)

When choosing an evaluation scheme to rate sustainability, it is important that environmental impacts over the full life cycle of the construction work or product are considered so as to be able to deliver an unbiased and full environmental profile.

2.2.1 DGNB German Certification Scheme for Sustainable Buildings

The Deutsche Gütesiegel für Nachhaltiges Bauen (German Certification Scheme for Sustainable Buildings) or DGNB system is a holistic sustainable building assessment tool developed by the DGNB Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council).

It is a second generation certification system that provides an objective description and assesses sustainable factors holistically for different building types and urban districts. Since the launch of the German system in 2009, followed by the international system 2010, the DGNB (statistics Dec. 2016) now has over 1200 members and 2000 qualified experts in over 20 countries.

Rather than specifying individual measures, the DGNB System sets targets for assessing a building's overall performance. In doing so, it actively promotes innovative building concepts over the entire life cycle of the relevant object. It is at present the only system that certifies industrial sites. Due to its flexibility it can also be tailored precisely to various uses of a building and even to meet country-specific requirements.

A DGNB certification can be achieved in the categories of bronze, silver, gold and platinum, whereby bronze is only relevant for existing buildings. In its certification the DGNB system is especially interesting as it can be either obtained during the planning phase or after the building construction has been finished. The pre-certificate integration into the design and planning phase allows for an early optimization of the potential for construction, management, conversion and dismantling with an emphasis on optimizing costs. This approach allows projects to focus on quality from the very beginning by setting a clear definition of the sustainable goals and by providing a guideline to follow helping to raise awareness for all relevant actors.

Construction firms and architects can even use the DGNB as a controlling instrument. It is often also used as a quality management system for planning, building, using and operating buildings. It can also be used by owners and planners as a checklist, a decision-making and planning tool as well as a basis for discussion and agreement.

The DGNB has easy-to-understand categories covering all of the key aspects of sustainable building (economic, socio-cultural, environmental) as well as functional aspects (technology, processes and site). Here, too, the focus is on the entire life cycle – and therefore on the long-term quality of products used in construction. In each of the categories criteria are evaluated and scored and then multiplied by a weighting to give the relevant score for the category. In addition to ensure a balance in assessing a building the categories have different shares in the total assessment. The first four categories all have an equal share in the total assessment with 22.5%. The categories process quality with slightly less with 10% and building site being rated it on its own. This gives the DGNB system the advantage that the economical and technical aspects, which in "general" construction where the only ones looked at in details, have the same weighting as the human-centred aspects of the building of ecological and socio-cultural quality.

Note: In the next DGNB Version 2018 which is currently in review the weighting changes slightly to 22,5% in the first three, and 12,5% for technical and process quality and site quality receiving 5%

Although all aspects of the DGNB are relevant for the construction process with many interactions between the three criteria that are most closely related to the construction phase being:

- PRO 2.1 - Building Processes
- PRO 2.2 - Quality assurance of construction work
- PRO 2.3 - Orderly Commissioning

A short overview of the relevance of the different criteria to the construction phase are presented below:

Nr.	DGNB Criteria	Direct Relevance	Link to construction phase
PRO 10	**Process Quality**		
PRO 1.1	Project preparation and planning	Condition-ally	The aim is for a transparent planning process to achieve the best sustainable levels possible. Decisions made here will affect the construction phase.
PRO 1.3	Conception and optimization in planning	Condition-ally	Here the aim is for an optimised building quality. Decisions made here will affect the construction phase including the construction used, recyclability of the building, as well as maintenance friendliness of the building.
PRO 1.4	Sustainability Aspects in Tender Phase	Yes	Here the decision to the materials and technologies used in the building con-struction are made. Planners can define here the materials to be used. At the same the construction firms can look to meet and better these requirements through better suggestions of alternatives. This is of course subject to con-trols.
PRO 1.5	Documentation for Facility Management	Yes	Here the documentation for the use phase and the facility managers are made. This is extremely important as here all information of materials, tech-nologies and construction techniques used should be documented. This en-sures that the potential for a sustainable exist. This affects the later: energy consumption, maintenance, tenant use of building among others.
PRO 1.6	Method for urban planning and design	No	n.a.
PRO 20	**Quality of construction**		
PRO 2.1	Construction Site/ Construction Processes	Yes	This determines the sustainable construction phase, its environmental influ-ences the minimisation of waste materials in the construction phase and the recycling there of. It is one of the most relevant aspects for sustainability for the construction phase, especially for construction companies. Criteria in-clude: low waste, low noise, low dust and environmentally friendly construc-tion sites, including soil and water protection.
PRO 2.2	Construction Quality Assurance	Yes	The aim of this is for comprehensive documentation and quality control to ensure that a sustainable construction has taken place and to ensure that building construction defects are kept to a minimum. It is one of the most rele-vant aspects for sustainability for the construction phase, especially for con-struction companies. All materials and technologies are to be documented and controlled, including materials not covered in ENV 1.1. In addition, the use of sustainable materials and technologies does not guarantee a sustaina-ble construction phase or building as the skills and workmanship also need to be up to the standards of sustainability. Here quality controls, site visits and documentation help to ensure this.
PRO 2.3	Systematic Commissioning	Yes (par-tially)	Here all information of technologies implemented, including testing of func-tionality and protocols, in the building must be passed on to the facility man-ager to ensure that a smooth start and use of the building is guaranteed.
ENV 10	**Effects on global and local environment**		
ENV 1.1	Ecobalance - emission-related environmental impacts	Yes	Here the aim is a life cycle oriented planning which reduces the emissions related environmental impacts in all phases. The use of materials and tech-

			nologies both in the construction phase, through construction processes (on-site use of materials or production on-site), as well as in the use phase can have a direct effect on the environmental quality and thus the impacts of the building, The use of sustainable materials as declared through recognised EPDs (i.e. ÖkoBauDat) plays a central role.
ENV 1.2	Local Environment Impact	Yes	Here the aim is to reduce, remove or substitute all environmentally-damaging materials as well as their production including auxiliary materials. This is especially relevant for the construction phase, e.g. toxins from the use of non-sustainable materials can enter the bio-system, ozone-depleting products from machinery in use can enter the atmosphere. Here control of the higher risk materials is of importance. One of the relevant aspects is the VOCs within the materials. In implementing this all materials coming on to, and/or used on site must be listed, checked and recorded.
ENV 1.3	Environmentally Friendly Material Production	Yes	Here the aim is to use materials that are sustainable in sourcing, production and processing. Contractors sourcing materials need to make sure that the materials are from a sustainable source and labelled such as Forest Stewardship Council or Fair Stone
ENV 20	**Resource utilization and waste generation**		
ENV 2.1	Life Cycle Assessment - Resource Consumption	Yes	Here the complete Life-Cycle of the building is looked at. Resources (materials) used in the construction of the building play a role here. Materials that are sustainable should be used, proof of this through EPDs are critical. The waste and recyclability of the construction site is also looked at. The energy used in the production and construction phase also play a role in determining the energy consumption relative to the LCA. The more energy efficient a construction site is, the better this can become.
ENV 2.2	Drinking Water Demand and Wastewater Volume	No	n.a (However a sustainable use of water on the construction site should be implemented.)
ENV 2.3	Land use	No	n.a. (However during the construction phase, care should be taken not to impact the site through removal on soil, compacting etc.)
ECO 10	**Life Cycle Costs**		
ECO 1.1	Building-related Lifecycle Costs	Yes	Here the costs, materials, technologies and workmanship, in the construction phase play a direct role in the determination of the Life Cycle Costs, e.g. cheap materials may not be sustainable in the long run.
ECO 20	**Value Retention**		
ECO 2.1	Flexibility and Suitability for Third Party Use	No	n.a.
ECO 2.2	Marketability	No	n.a.
SOC 10	**Health, comfort and user satisfaction**		
SOC 1.1	Thermal Comfort	Conditionally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. (Only through quality control an indirect relationship)
SOC 1.2	Indoor Air Quality	Condition-	Through the use of non-conform materials (both the building and auxiliary

		ally	materials) in the construction phase, the air quality in the use phase can be affected through Volatile Organic Compounds (VOCs). If these are found at the late stage of testing it can be quite expensive for the construction firm to rectify this situation.
SOC 1.3	Acoustic Comfort	Condition-ally	(Only through quality control an indirect relationship)
SOC 1.4	Visual Comfort	Condition-ally	(Only through quality control an indirect relationship)
SOC 1.5	User Influence on Building Operation	Conditional-ly	n.a. (Information about technologies installed and their sustainable use in the use phase must be passed on by the contractor)
SOC 1.6	Quality of Indoor/Outdoor spaces	No	n.a.
SOC 1.7	Safety and Security	No	n.a.
SOC 20	**Functionality**		
SOC 2.1	Handicapped Accessibility	No	n.a.
SOC 2.2	Public Access	No	n.a.
TEC 10	**Quality of technical execution**		
TEC 1.2	Indoor Acoustics and Sound Insulation	Condition-ally	n.a. (Only through quality control an indirect relationship)
TEC 1.3	Building Envelope Quality	Condition-ally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. Quality control is for example through a blower door test. A construction geared towards the high quality of sustaina-ble building is needed to achieve this, e.g. though air tight façade or appropri-ate solutions for thermal bridging
TEC 1.4	Adaptability of technical systems	No	n.a.
TEC 1.5	Ease of Cleaning and Maintenance	Yes	Construction techniques should be made so as to ensure that need for maintenance is reduced and that cleaning is made easier. This could be: through the sustainable protection of materials through protection from rust or moisture, constructive solutions such as dripping edges, the use of materials such as flooring (i.e. with patterns) or façade that have a reduced replacement need but also includes easy access to structurally relevant constructions
TEC 1.6	Ease of Dismantling and Recycling	Yes	The ease of dismantling and recycling is decided at the latest in the construc-tion phase. Recycling friendly materials as well as a recycling friendly building construction should be chosen. All materials used should be constructed in such a way that there is an ease of separation and thus recycling. The infor-mation over materials, construction and technology used should be docu-mented and provided to the building owner/facility manager. Where possible the construction firm should make sure that the material and technology pro-ducers will take back or have systems implemented for material recycling at the end of the lifetime (“Material Leasing” or “Material Library”).
TEC 30	**Mobility**		
TEC 3.1	Mobility infrastructure	No	n.a.

SITE 10	**Site Quality**		
SITE 1.1	Site Location Conditions	No	n.a.
SITE 1.2	Public Image and Social Conditions	No	n.a.
SITE 1.3	Access to Transportation	No	(Note: Although this has little to do directly with the construction phase, a good location of a building can positively influence the transport costs of the workers)
SITE 1.4	Access to Specific-Use Facilities	No	n.a.

2.2.2 BREEAM - Building Research Establishment Environmental Assessment Methodology

The Building Research Establishment Environmental Assessment Methodology (BREEAM) is the world's oldest sustainable building rating system. Developed in the UK by the Building Research Establishment (BRE) in 1990, BREEAM is one of the largest and widely recognised sustainable building systems with over 540,000 developments and 2,230,000 buildings registered for assessment, in 77 countries, since its start in 1990. It must be noted however that around half of these being in the UK alone and 95% in the EU.

BREEAM is currently available for :

- Offices
- Retail buildings
- Educational buildings
- Healthcare buildings
- And offers a bespoke evaluation of non-standard buildings

BREEAM aims to reduce the negative effects of construction and development on the environment. Through its sustainability approach BREEAM encourages the relevant actors to build with energy efficient, low carbon and low impact design by raising their awareness to sustainability. As a sustainable building tool it can be effectively used to guide cost effective sustainable building solutions. In addition it provides the market with an easily recognised label of the buildings quality and performance. In evaluating buildings BREEAM uses recognised measures of performance, which are set against established benchmarks, to evaluate a building's specification, design, construction and use. Building can be certified in two stages, using independent, licensed assessors in the:

- Design Stage – leading to an Interim BREEAM certification
- Post Construction Stage – leading to a Final BREEAM certification

The measures used represent a broad range of categories and criteria from material, energy to ecology and are grouped into categories covering:

- Management,
- Health & Wellbeing,
- Energy,
- Transport,
- Water,
- Materials,
- Waste,
- Land Use & Ecology,
- Pollution,
- Innovation

Each of the criteria is scored and then multiplied by a weighting. On achieving minimum thresholds the building can than be certified according to BRREAM standards of 'Pass', 'Good', 'Very Good', 'Excellent' and 'Outstanding'. An international version of BREEAM is also available.

The BREAM International New Construction 2016 looks at 57 individual assessment issues. As with the DGNB a clear assignment to the construction phase is not always clear. A short overview of the relevance of the different criteria to the construction phase is presented below:

BREEAM Criteria	Relevance	Link to construction phase
Management		
Project brief and design	Yes	Here the integrated design process is encouraged for a sustainable construction including all the relevant actors. This includes among others: the installation and construction requirements and limitations, health and safety on the construction site, procurement and supply chain as well as communication strategies. Here it must be demonstrated how the sustainability of the construction including the construction phase is met. A sustainability "champion" to monitor progress is recommended.
Life cycle cost and service life planning	Yes	Here the materials and technologies used in the construction phase and their diverse costs flow back into the LCC analysis.
Responsible construction practices	Yes	One of the most relevant criteria for the construction phase this encourages a sustainable management and running of the construction site in an accountable manner. It includes, health and safety, use of sustainable timber, implementation of an environmental management system (EMS) by the construction firm, noise control, dust minimisation, waste control, implementation of pollution prevention including water management, monitoring and documentation of the site through the sustainability champion. The use, consumption and emissions of water, energy and transport are also measured and recorded. Landscaping, contouring and re-vegetation, water run-off and appropriate storage are also dealt with.
Commissioning and handover	Yes	Here information on the technologies used and commissioning need to passed on to the building owner or facility manager. It also includes quality control i.e. infra-red thermography or blower door testing and testing of the building. Quality management during the construction phase can reduce reworking and thus reduce unnecessary extra costs.
Aftercare	Yes	Here provisions must be made for an aftercare of the building to ensure that the building is running under the sustainable aspects under which it was built. This usually requires among others that the construction firm undergo a post-occupancy evaluation of the building rectify any problems that might occur. Any failures found will need to be reworked by the construction firm costing time and money.
Health and wellbeing		
Visual comfort	Conditionally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. (Only through quality control an indirect relationship.)
Indoor air quality	Conditionally	Through the use of non-conform materials, in the construction phase both for the building as well as for auxiliary materials, the air quality can be affected through VOCs. It is relevant that in if these are found at the a stage construction it can be quite expensive for the construction firm to rectify this situation.
Safe containment in laboratories	Conditionally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. (Only through quality control an indirect relationship.)
Thermal comfort	Conditionally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. (Only through quality control an indirect relationship.)
Acoustic performance	Conditionally	Here the aim for the construction phase is that the building is built according to the sustainable requirements. (Only through quality control an indirect relationship.)
Accessibility	No	n.a.

Hazards	No	n.a.
Private space	No	n.a.
Water quality	No	n.a.
Energy		
Reduction of energy use and carbon emissions	No	n.a. (However as with the building, the energy consumption on the construction site should also be reduced to that which is sustainably necessary.)
Energy monitoring	No	n.a. (However as with the building, the energy consumption on the construction site should also be monitored and from this information improved if necessary.)
External lighting	No	n.a. (However as with the building the lighting used on the building site should also be reduced to that which is sustainably necessary.)
Low carbon design	No	n.a.
Energy efficient cold storage	No	n.a.
Energy efficient transport systems	No	n.a.
Energy efficient laboratory systems	No	n.a.
Energy efficient equipment	No	n.a. (However as with the building energy efficient equipment should be used on the building site.)
Drying space	No	n.a.
Transport		
Public transport accessibility	No	n.a. (Note: Although this has little to do directly with the construction phase, a good location of a building can positively influence the transport costs of the workers)
Proximity to amenities	No	n.a.
Alternative modes of transport	No	n.a.
Maximum car parking capacity	No	n.a.
Travel plan	No	n.a.
Water		
Water consumption	No	n.a.(However as with the building, the water consumption on the construction site should also be reduced to that which is sustainably necessary.)
Water monitoring	No	n.a. (However as with the building, the water consumption on the construction site should also be monitored and from this information improved if necessary.)
Water leak detection	No	n.a.
Water efficient equipment	No	n.a.
Materials		
Life cycle impacts	Yes	Here information from the construction phase such as the materials used and their EPDs are needed as reference for the assessment of the LCA of the building.
Hard landscaping and boundary protection	Yes	Although not a standalone criteria with BREEAM the influence of the construction phase on this is quite large. Here a sustainable construction site which takes precautions to ensure that these are kept will help to ensure that the biodiversity of the site is also upheld.
Responsible sourcing of materials	Yes	Here it the responsibility of the construction firm based on the tender and specifications to

		ensure the procurement of sustainable materials is met. All materials used show that they have been sustainably sourced for example Forest Stewardship Council or Fair Stone and have the appropriate EPD labels. Broken material chains should for example not be used. All steps need to be documented.
Insulation	No	n.a. (not assessed as a standalone issue)
Designing for durability and resilience	Partially	The choice of materials made in the procurement as well as the construction can greatly influence the durability and resilience of the building. Construction techniques should be made so as to ensure that need for maintenance or replacement is reduced and that cleaning is made easier.
Material efficiency	Yes	Here the use of material efficiency is encouraged so as to minimise the use of limited materials without the compromising of structural integrity, durability or service life. Construction firms should use innovative techniques such as light weight beams and floors. The construction firm should in cooperation with planner and owner conduct an assessment and where possible make suggestions for an implementation of such techniques. In addition workshops should be held before the start of the project to promote material efficiency with all actors.
Waste		
Construction waste management	Yes	Here a construction waste management plan should be developed. This should promote reduction of material use and if not possible recycling. The provision of appropriate storage as well as separation should be provided to support this. Manufacturers’ take-back schemes should be used where possible. It also important to make sure that waste from temporary support structures are kept to a minimum.
Recycled aggregates	Yes	Here construction companies should use recycled or secondary aggregates to reduce demand for limited virgin resources.
Operational waste	No	n.a.
Speculative floor and ceiling finishes	Yes	To reduce the refitting of rooms by tenants due to speculative finishes from the building owner it is important that possible future tenants be involved as early as possible so that the construction companies can finish according to the future use, of a more sustainable use of resources.
Adaptation to climate change	No	n.a.
Functional adaptability	Partially	Here the use of materials, construction techniques etc. should be chosen that allow easy changes, demolition and replacement for example moveable interior walls instead of permanent walls.
Land use and ecology		
Site selection	Partially	Areas of a building site that are used during construction but not during the use phase can be considered used. Here care needs to be taken that after construction this is returned as far to its original state as possible. Non-construction zones should be protected to prevent damage and degradation
Ecological value of site and protection of ecological features	Yes	Areas with ecological value should not be built on or used for construction site purposes. Here measures should be taken to protect these. In addition other features such plants, trees, water courses etc. that are directly on the construction should be protected for example through barriers and soil compaction and root protection. Trees older than 10 years or

		100mm diameter should not be removed where possible.
Minimising impact on existing site ecology	No	n.a. (not applicable in BREEAM International New Construction)
Enhancing site ecology	Partially	Where it is not possible to fully protect areas measures should be made to improve the bio-diversity in others. The construction company should leave the site as found if not better in terms of bio-diversity. Biodiversity management should be included in the construction phase.
Long term impact on biodiversity	Yes	Measures under taken on the site by the construction companies should not affect long term bio-diversity. Management of protected features which are found on site should take place at the latest at the start of the construction phase. The principal contractor should nominate a bio-diversity manager. The principal contractor should train all actors on the sustainable running of as well as protection of the ecology of the site. All measures need to be documented.
Pollution		
Impact of refrigerants	No	n.a. (However as with the building the equipment used on the building site should be used, and maintained so as to prevent leakage of refrigerants)
NOx emissions	No	n.a. (However as with the building any heating equipment should be chosen with the aim to have no or low NOx emissions)
Surface water run-off	No	n.a. (However as with the building any surface runoff should be designed to avoid risk and impact to the public systems including the risk of pollution)
Reduction of night time light pollution	No	n.a. (However as with the building night time light pollution on the building site should be kept to a minimum)
Reduction of noise pollution	No	n.a. (However as with the building noise pollution from the building site should be kept to a minimum, this includes specific working hours and compliance of “rest-periods” during the night)
Innovation		
Innovation	Yes	This aims to support the innovation sustainability process on construction. This can be any sustainable material, technology or process that improves the sustainability of the construction site or building and can be replicated and demonstrated as a good practice for the wider industry.

2.3 Further standards and codes

In addition to the above-mentioned European Standards and Sustainable building System there are a number of International Standards that are relevant for a sustainable construction site. Below are listed a selection of these.

2.3.1 ISO 14000 Environmental management

ISO 14000 is a family of standards related to environmental management that exists to help organizations:

- Minimize how their operations (processes, etc.) negatively affect the environment (i.e., cause adverse changes to air, water, or land);
- Comply with applicable laws, regulations, and other environmentally oriented requirements; and
- Continually improve in the above.

ISO 14000 is similar to ISO 9000 quality management in that both pertain to the process of how a product is produced, rather than to the product itself. As with ISO 9001, certification is performed by third-party organizations rather than being awarded by ISO directly. The ISO 19011 and ISO 17021 audit standards apply when audits are being performed.

The requirements of ISO 14001 are an integral part of the European Union's Eco-Management and Audit Scheme (EMAS). EMAS's structure and material requirements are more demanding, mainly concerning performance improvement, legal compliance, and reporting duties. The current version of ISO 14001 is ISO 14001:2015 which was published in September 2015.

The ISO 14000 Standards include:

- ISO 14001 Environmental management systems - Requirements with guidance for use
- ISO 14004 Environmental management systems - General guidelines on implementation
- ISO 14006 Environmental management systems - Guidelines for incorporating ecodesign
- ISO 14015 Environmental assessment of sites and organizations
- ISO 14020 series (14020 to 14025) Environmental labels and declarations
- ISO 14030 discusses post-production environmental assessment
- ISO 14031 Environmental performance evaluation—Guidelines
- ISO 14040 series (14040 to 14049), Life Cycle Assessment, LCA, discusses pre-production planning and environment goal setting.
- ISO 14046 sets guidelines and requirements for water footprint assessments of products, processes, and organizations. Includes only air and soil emissions that impact water quality in the assessment.

> *ISO 14000 series of standards are relevant for construction companies in that it helps them to be more sustainable in their operations including the construction on-site process.*

2.3.1.1 ISO 14001: 2015 Environmental management systems - Requirements with guidance for use

The ISO 14001:2015 sets out the criteria for an environmental management system and how it can be certification to this can take place. It maps out a framework that a company or organization can follow to set up an effective environmental management system. It can be used by any organization regardless of its activity or sector.

Using ISO 14001:2015 can provide assurance to company management and employees as well as external stakeholders that environmental impact is being measured and improved.

“Requirements With Guidance For Use, is one of the most commonly recognized EMS protocols. It delineates a continual cycle of planning, implementing, reviewing and improving the processes and actions that an organization undertakes to meet its business and environmental

goals. The concept of continual improvement recognizes that problems will occur. A committed organization learns from its mistakes and prevents similar problems from recurring.“

ISO 14001 provides relevant management systems for construction firms. Using ISO 14001 also helps the companies to improve resource efficiency, reduce waste, and reduce costs. In addition certification to can be used to show compliance and assure relevant external actors of a sustainable construction process.

2.3.1.2 ISO 14006:2011 - Environmental management systems - Guidelines for incorporating ecodesign

The ISO 14006:2011 provides guidelines to assist organizations in establishing, documenting, implementing, maintaining and continually improving their management of eco-design as part of an environmental management system (EMS).

ISO 14006:2011 is intended to be used by those organizations that have implemented an EMS in accordance with ISO 14001, but can help in integrating eco-design in other management systems. The guidelines are applicable to any organization regardless of its size or activity.

ISO 14006:2011 applies to those product-related environmental aspects that the organization can control and those it can influence.

ISO 14006:2011 does not establish by itself specific environmental performance criteria, and is not intended for certification purposes.

This standard is relevant to construction as it can aid them to manage and reduce their environmental impact for a more sustainable construction practice by implementing a robust environmental management system. Construction firms that certify themselves show that they implement sustainable business methods.

2.3.1.3 ISO 14020 series (14020 to 14025) Environmental labels and declarations

This International Standard establishes guiding principles for the development and use of environmental labels and declarations. It is intended that other applicable standards in the ISO 14020 series be used in conjunction with this International Standard. Other standards currently in the ISO 14020 series are ISO 14021, ISO 14024 and ISO/TR 14025. This International Standard is not intended for use as a specification for certification and registration purposes.

Although not directly relevant for construction firms unless they produce their own building products, they must however have an understanding of this as it is directly related to the sustainability of the products that the use in the construction phase.

2.3.1.4 EN ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework

The ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard.

This standard is relevant for construction companies as it provides a framework under which the sustainability of their construction activity is assessed. Construction companies need to have an understanding of this in making their works more sustainable.

2.3.2 ISO 15392 and the related suite of International Standards for sustainability in buildings and civil engineering works

This suite of standards forms the basis in addressing specific issues and aspects of sustainability of building and civil engineering works including the construction phase. As with other similar standards these form a common framework which build upon each other and at the same time are divided under the three columns of sustainability, while meeting the requirements for technical and functional performance.

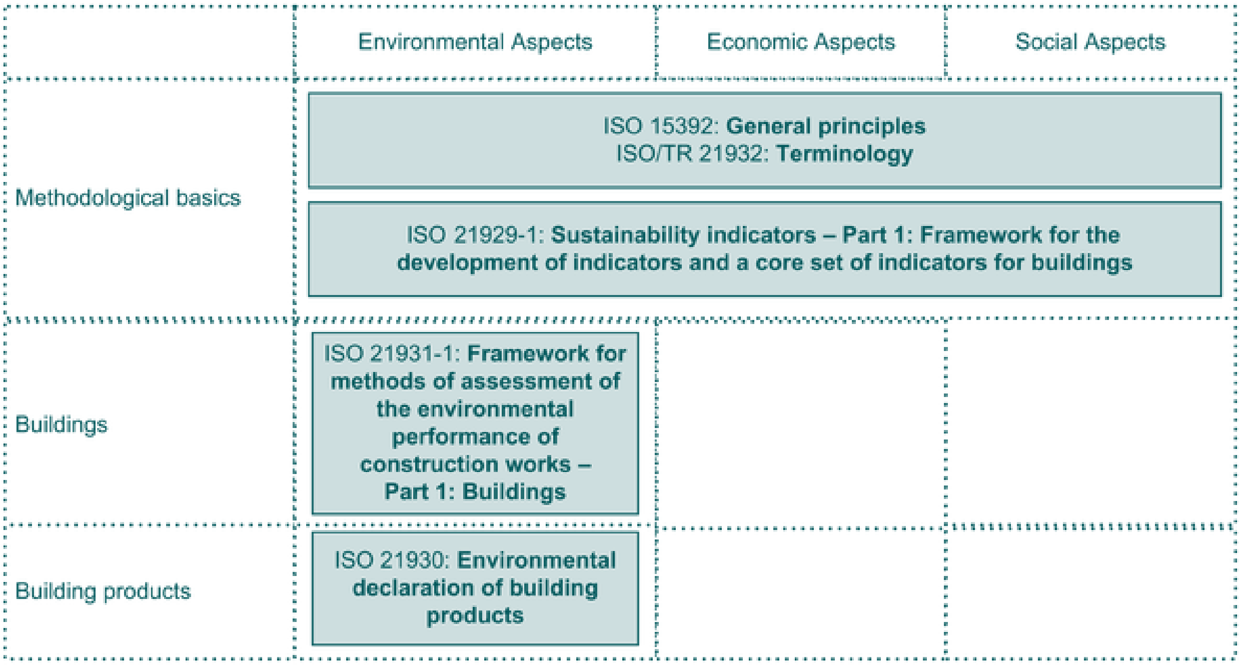

Figure 5: ISO 15392 and the related suite of International Standards for sustainability in buildings and civil engineering works

Source: ISO 15392

2.3.2.1 ISO 15392 Sustainability in building construction - General principles

ISO 15392:2008 identifies and establishes the general principles for sustainability in building construction. It is based on the concept of sustainable development as it applies to the life cycle of buildings and other construction works, from their inception to the end of life. The aim of this International Standard is to set out the objectives for sustainability in building construction and to derive general principles from these objectives.

ISO 15392:2008 is applicable to buildings and other construction works individually and collectively, as well as to the materials, products, services and processes related to the life cycle of buildings and other construction works.

ISO 15392:2008 does not provide levels (benchmarks) that can serve as the basis for sustainability claims. It is not intended to provide the basis for assessment of organizations or other stakeholders.

This is relevant for construction companies as it establishes internationally recognized principles for sustainability in building construction and establishes a common basis for communication of the information required.

2.3.2.2 ISO 21929-1:2011 Sustainability in building construction - Framework for the development of indicators and a core set of indicators for buildings

ISO 21929-1:2011 establishes a core set of indicators to take into account the use and development of sustainability indicators for assessing the sustainability performance of new or existing buildings, related to their design, construction, operation, maintenance, refurbishment and

end of life. Together, the core set of indicators provides measures to express the contribution of a building(s) to sustainability and sustainable development. These indicators represent aspects of buildings that impact on areas of protection related to sustainability and sustainable development.

This standard defines the indicators required by the contractors in their decision making of sustainability in the construction process. This for example in the procurement of sustainable materials or the indictors needed in monitoring of a sustainable construction process

2.3.2.3 ISO 21930:2007 Sustainability in building construction - Environmental declaration of building products

ISO 21930:2007 provides the principles and requirements for type III environmental product declarations (EPD) of building products. While this International Standard contains more specific requirements, it complements ISO 14025 for the EPD of building products.

It provides a framework for and the basic requirements for product category rules as defined in ISO 14025 for type III environmental declarations of building products. Type III environmental declarations for building products, as described in ISO 21930:2007, are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication under certain conditions is not precluded.

ISO 21930:2007 does not define requirements for developing type III environmental declaration programmes. Requirements for type III environmental declaration programmes are found in ISO 14025.

The working environment is not included in ISO 21930:2007 because it is normally a subject for national legislation. ISO 21930 is similar to ISO 14025 but designed specifically for building products

Although not directly relevant for construction firms unless they produce their own building products, they must however have an understanding of this as it is directly related to the sustainability of the products that the use in the construction phase.

2.3.2.4 ISO 21931-1:2010 Sustainability in building construction - framework for methods of assessment of the environmental performance of construction works

ISO 21931-1:2010 provides a general framework for improving the quality and comparability of methods for assessing the environmental performance of buildings and their related external (construction) works.

It identifies and describes issues to be taken into account in the use and development of methods of assessment of the environmental performance for new or existing buildings in their design, construction, operation, maintenance and refurbishment, and in the deconstruction stages.

This is relevant for construction companies as it provides a framework under which the sustainability of their construction activity is assessed. Construction companies need to have an understanding of this in making their works more sustainable.

2.3.3 ISO 50001 Energy Management Standard

ISO 50001:2011 specifies requirements for establishing, implementing, maintaining and improving an energy management system. Such an EMS enables an organization to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, energy use and consumption.

ISO 50001:2011 specifies requirements applicable to energy use and consumption, including: measurement, documentation and reporting, design and procurement practices for equipment, systems, processes as well as personnel that contribute to energy performance.

ISO 50001:2011 applies to all variables affecting energy performance that can be monitored and influenced by the organization. ISO 50001:2011 does not prescribe specific performance criteria with respect to energy.

ISO 50001:2011 has been designed to be used independently, but it can be aligned or integrated with other management systems.

ISO 50001:2011 is applicable to any organization wishing to ensure that it conforms to its stated energy policy and wishing to demonstrate this to others, such conformity being confirmed either by means of self-evaluation and self-declaration of conformity, or by certification of the energy management system by an external organization.

This standard is relevant to construction as it can aid to manage and reduce energy use and costs for a more sustainable construction practice by implementing a robust energy management system. Construction firms that certify themselves as ISO 50001 conform show that they implement sustainable business (energy) methods.

2.3.4 European Environmental Management System (EMAS)

The EU Eco-Management and Audit Scheme (EMAS) is a premium management instrument, which goes further than the ISO 14000. It was developed by the European Commission for companies and other organisations to evaluate, report, and improve their environmental performance. The scheme is globally applicable and open to all types of private and public organizations eager to improve its environmental performance. It spans all economic and service sectors and is applicable worldwide. It does not contain specific requirements for buildings, but can be applied by construction companies to improve their environmental performance. It is also important to note that improvement options for companies and organisations could also involve improving the building within which they are housed.

EMAS is the most credible and robust environmental management tool on the market and goes beyond the requirements of ISO 14001, the international standard for Environmental Management Systems. In Europe it is seen as a guarantee of full regulatory compliance with environmental legislation.

In order to register with EMAS, organisations must meet the requirements of the EU EMAS-Regulation. Currently, more than 4,600 organisations and more than 7,900 sites are EMAS registered.

EMAS allows construction firms to show that the implement sustainable construction practices, enhancing their credibility, transparency and reputation. Implementation helps companies to reduce their environmental impacts, strengthen legal compliance and employee involvement, and save resources and money

2.3.5 ISO/TS 12720:2014 - Sustainability in buildings and civil engineering works

ISO/TS 12720:2014 provides guidance for the application of the general principles of sustainability in buildings and civil engineering works elaborated in ISO 15392. It shows the different actors involved with the construction works how to take these principles into account in their decision-making processes in order to increase the contribution of the construction works to sustainability and sustainable development.

ISO/TS 12720:2014 provides a step-by-step approach for: encouraging the application of the general principles by all stakeholders at each stage of the project and its use, from the decision to build and the initial development of the project brief until the end-of-life of the construction works; helping interested parties to consider and/or incorporate sustainability thinking in all phases of the building's or civil engineering works' life cycle, for all relevant issues of concern, by raising key questions in relation to the general principles; understanding the outcome (effect) of the application of the general principles; and building on acquired experience to develop best practices and engendering a continuous improvement process.

ISO/TS 12720 provides construction companies guidelines for the application of general principles of sustainability in the construction phase from initial design to completion of works.

2.3.6 Level(s) Framework

The newest tool for sustainable performance rating in the EU is the Level(s) Framework. It is aimed at key actors that play a critical role in the development of building projects, including

construction and demolition management, and improving their awareness as well as knowledge of sustainable buildings. It was developed as a voluntary common framework of core indicators for the sustainability of office and residential buildings, measuring their life cycle. It is not a new standalone building certification scheme, nor does it establish performance benchmarks, but rather links the individual building's environmental impact with resource priorities at European level, using existing EN and ISO standards wherever possible.

Level(s) is the result of a broad consultation with industry and the public sector, and focuses on performance indicators across areas such as greenhouse gas emissions, resource and water efficiency as well as health and comfort. It aims to establish a 'common language' around what sustainable building means in practice – shifting the debate beyond energy performance to that of the whole life cycle of a building – from the manufacturing of the products and materials used to construct the building, right through to the building's eventual deconstruction and reuse and recycle of materials.

It is designed for ease of use, implying first implementation of the standard for first time users. It can however be adjusted according to needs to a higher level of complexity, for example from the very basic requirements to the use of more challenging performance assessment schemes and tools. This allows the Framework to:

- Provide an easy starting point to introduce sustainability and life cycle thinking into projects;
- Focus on a manageable number of essential concepts and indicators that contribute to achieving environmental policy goals;
- Support efforts to optimise building designs and their operation, with a focus on the precision of data, calculation methods and simulations;
- Support efforts to minimise gaps between design and actual performance, in terms of both measured performance and occupant satisfaction;
- Support commitments to track performance all the way from design stage through to operation and occupation of a building;
- Enable comparisons to be made between buildings in a geographical area or in a portfolio, or between design options at an early stage;
- Allow users to select between three different levels of comprehensiveness in how performance can be calculated and reported on, chosen according to the different priorities and goals of users;
- Ensure that when using these indicators, users will be working to common performance assessment methods and standards used in the EU, so as to complement and reinforce existing initiatives;

The test phase was launched in Autumn 2017 and runs until 2019

The Levels Framework provides the construction companies, in particular, the construction managers and lead contractors the necessary framework to prioritise their focus on the sustainability aspects of construction in a simple structure for ease of use. This for example through guidance notes on how to make accurate performance assessments. In addition it identifies the role that a construction company plays in quality assurance of sustainable construction through monitoring and design performance checks. As with other standards and frameworks it also includes guidelines for the optimisation of materials use, including waste reduction and recycling, sustainable material use on construction sites, and sustainable construction work

2.3.7 Kreislaufwirtschaftsgesetz (KrWG)

In implementing a sustainable environment the EU has not only looked at the construction process but also of the waste management through the European Waste Management Directive (Directive 2008/98 / EC, AbfRRL). This has since been implemented into German law in the Kreislaufwirtschaftsgesetz (KrWG). This law aims to achieve a sustainable improvement in environmental and climate protection as well as resource efficiency in waste management by strengthening waste prevention and recycling of waste.

In particular, the KrWG makes waste producers and owners take full responsibility that their waste are properly and harmlessly, and at as a high rate as possible, recycled. (In this context,

harmless means the protection of human and the environment ,especially, soil and ground water). The meaning of this law for the German building industry was/is often drastically underestimated by the construction companies themselves. Any builder, transporter, excavator, demolition contractor, etc., can always be found in any form in the position of the trash producer and / or trash owner as defined by the KrWG and thus has to fulfil its obligation for proper and harmless utilization. For example, each excavation (unless it is reused directly at the place of origin) is subject to the scope of the KrWG. Even the transport of building rubble and excavation excavations must be give in notice to relevant authorities.

The processing and storage of mineral waste, whether mobile or stationary, must also comply with the licensing requirements of the Federal Pollution Control Act. A processing or storage of waste at the place of origin is only allowed only for a period of at least 12 months, this without exemption.

Registries and proofs need to be kept, to meet the information obligations of the authorities. However, obligations for waste producers and owners do not end with the transfer of waste or disposal activities to a subcontractor or mine operator (third party). The responsibility always remains until the final completion of the utilization or until the final, safe and proper placement. The careful selection of subcontractors and disposal companies, as well as the verification of compliance with all legal requirements, is thus of utmost importance.

Failure to comply with the requirements of the KrWG is punishable by administrative offenses and severe penalties may be imposed.

The European Waste Management Directive and the national Kreislaufwirtschaftsgesetz affects the construction companies as it defines how they must treat and recycle waste making them fully responsible for this. This is achieved by promoting a sustainable use of resources including waste reduction and recycling. In addition, it can be a money saver by the promotion of only the necessary use of materials and with low waste low or no fees for waste disposal.

2.4 Sustainable Product Labelling

In order to determine the sustainability of a building the sustainability of its materials must be first determined. Information on the environmental performance of materials and technologies should be provided by producers for ease of assessment by the relevant actors using these. This must be done in a transparent way and where possible by using an independently verified life cycle assessment. By voluntarily labelling their products it is also possible for the manufacturers to further dispel any reservations with regards to their claims to health and environmental safety of their products.

2.4.1 Ecolabels and and Environmental Product Declaration

In defining standards for labelling practices the International Organization for Standardization ISO has created the ISO 14000 schema (see Chapter 2.3.1). These can be distinguished according to Typ:

- Typ I - Ecolabel (for example Blue Angel)
  - A voluntary, multiple-criteria based, third party program that awards a license which authorises the use of environmental labels on products indicating overall environmental sustainability of a product within a product category based on life cycle considerations
- Typ II - self-declaration,
  - An informative environmental self-declaration claims
- Typ III Environmental Product Declarations (EPDs).
  - A voluntary program that provide quantified environmental data of a product, under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party

A valuable tool for sustainable construction is that of a Environmental Product Declaration (EPD). EPDs provide standardised information about environmental performance of building

materials, the production process, product chains as well as information on contents, pollutants, and key environmental impact etc. among others.

In order to ensure that there is a common understanding of the criteria, clear rules and a uniform calculation must be used. Core rules for the creation of EPDs for building products and materials are set out for example in the harmonized European standard EN 15804. This provides core product category rules for the application of EPDs based on a suite of 24 indicators and their methodological background required for compliance.

Together with EN 15978 (a calculation method for the environmental performance of buildings) it provides a consistent method of measuring and reporting on the impacts. These standards provide a concrete guidance for EPD assessment tools to base their methodology on and make them interoperable.

In Europe the development of EPDs is largely lead by market forces. This especially due to the market maturity in labelling schemes and consumer awareness. This can be seen in the many mature TYP-1 labels. The following TYP 1 being examples of existing labelling:

- Blue Angel (German eco-label for eco-friendly products and services)
- EU Ecolabel (European eco-label for eco-friendly products and services)
- IBO test mark (Austrian building biology and building ecology test mark for building materials and interior furnishings)
- RAL quality associations,
- FSC
- Cradle to cradle
- GEV-Emicode (Gütegemeinschaft emission-controlled Laying materials e. V.) GuT-Teppichprüfsiegel (Gütegemeinschaft umweltfreundlicher Carpet flooring)

Figure 6: Examples of Environmental Product Declaration

Source: FSC, Blaue Engel, Cradle to Cradle, EPD Ireland

Some European Member States have however passed national legislation to regulate EPDs in accordance with EN 15804. For example, France and Belgium made it mandatory for the construction materials to comply with EN 15804.

There have also been a number of platforms offering complete databases of a wide range of materials and technologies. This too is driven by industry.

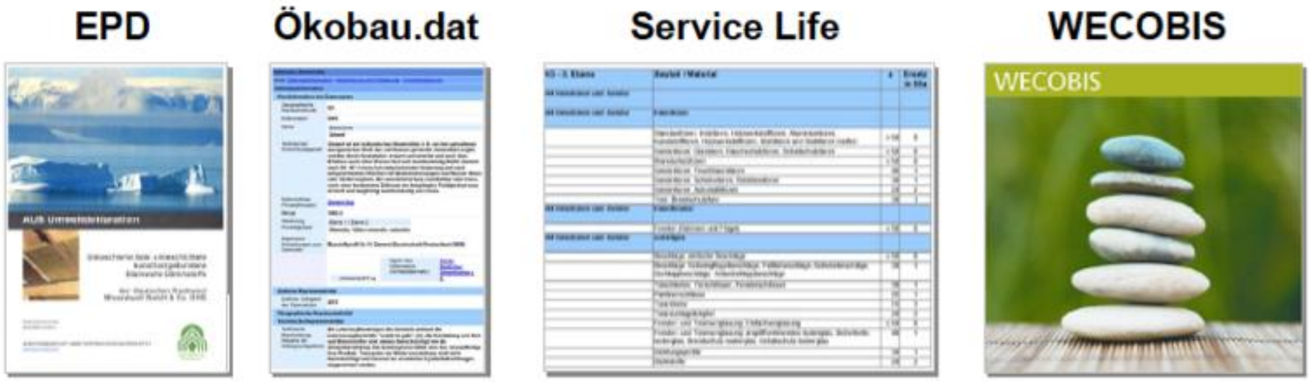

Figure 7: Examples of EPD databases

Source: EPD, Ökobaudat, Service Life, WECOBIS

However, as with the single EPDs, the need for a standardisation and common understanding among has lead to the creation of a European industry association called the ECO platform.

Although a trustworthy mechanism, a drawback of the provision of information and the certification of environmental soundness with an EPD it that it often comes with extra cost to the manufacturers. Especially since manufactures must prepare multiple EPDs for the same product to address different markets/segments and customers.

2.4.1.1 Good practice example – Material database - ÖKOBAUDAT

A well known example of a materials database in Europe is that of the German online building material database ÖKOBAUDAT. ÖKOBAUDAT was developed as a part of the research initiative "Future Building" by the Österreichisches Institut für Bauen und Ökologie GmbH, KIT – Institute for Applied Computer Science, okworx and Online Now! GmbH in cooperation with the German construction materials industry.

It provides information for eco-balances of building materials across various aspects such as use of resources, as well as global ecological impacts that cause the greenhouse effect, acid rain, smog, eutrophication etc.. The data is of a high quality and is uniform across product groups and provides eco-balance data as well as for use and exploitation paths. The ecological quality of a building using such materials and products is thus reliable.

ÖKOBAUDAT provides product group (generic) as well as product specific data based on EPDs, eco-balance tools such as eLCA. All data in ÖKOBAUDAT is in compliance with DIN EN 15804 and undergoes independent third party verification which makes it a reliable and secure data source for construction product information of environmental and health relevance.

In addition, the online database enables exportation of life-cycle analysis data for LCA tools from ÖKOBAUDAT. It also enables, through online interface, third party tools such as progressive life-cycle analysis tools etc. to query/import directly from ÖKOBAUDAT.

2.4.1.2 Good practice example - Passive House Energy Efficient Components

A different type of material and technology database that exists in Europe is that of the Passive House Energy Efficient Components. Through its very nature the extremely energy efficient building of a Passive House needs highly energy efficient building materials and systems. Such materials and technologies are however very difficult to assess.

The energy-efficiency, durability and the necessary energy parameters of materials and technologies are however frequently not accurate enough or in some cases even unrealistic as they have for example not been certified to realistic energy efficient criteria. A reliable energy consumption calculation as well as LCA is not possible with the available data.

In addressing this the Passive House Instiute, an independent certification authority, has developed standards to test and certify materials and technologies under realistic use for their suitability for use in Passive Houses. Products that carry the Certified Passive House Component seal have been tested according to uniform criteria; they are comparable in terms of their specific values, and are of excellent quality regarding energy efficiency. All components are certified and provided with labelling that they are Passive house conformant. Certified components include:

- Walls and building systems
- Low thermal bridge solutions
- Ground slab insulation systems
- Certified window frames and glazing
- Doors
- Ventilation systems
- Compact heat pump units
- Construction systems without thermal bridges
- Waste water heat recovery
- Air tight systems

The use of such materials and technologies dramatically eases the work load of the designers as well as the constructors as it helps to ensure that the buildings have been built according to highest standard.

Figure 8: Passive House suitable component label

Source: Passive House

3 Environmental Aspect of the Construction Phase

3.1 Environmental Impact of Construction

Sustainable building as well as the construction process in itself needs the assessment of the environmental impacts, of the building including the building phase, within its lifetime. For each step there should be a consideration of where materials, energy, and water are sourced, how they are sourced and consumed, and how waste is produced, from the selection of raw materials, through manufacture, use and disposal and recycling.

3.2 Environmental objectives and assessment criteria

The primary protection goal of sustainable construction should be to save resources by:

- Reducing land use,
- Maintaining and promoting biodiversity,
- Optimising the use of construction materials and products,
- Minimising energy and water consumption.

This can only be achieved by assessing the entire life cycle including all the necessary energy and material flows, from extraction to transport and installation through to demolition. The construction phase is most often forgotten in such assessments. Buildings not only emit Greenhouse Gases (GHG) during the use phase but also during the construction phase. This could be for example from equipment such as generators or building machinery and even the energy use in the builder's onsite-quarters. In addition, there are also GHG from production of building materials as well as their transport.

The production of building construction materials significantly contributes to GHG emissions (figures range between 8-15% of total GHG emissions for concrete, steel and bricks, whose cement represents 3%). Environmental effects at global and local level that result from energy used to produce building materials as well as during the construction phase must be thus included.

For each of the dimensions of sustainability looked at in any assessment, including those of technical, process and site quality, sustainability goals must be assigned. Numerous instruments such as DGNB (see Chapter 2.2.1) and BRREAM (see Chapter 2.2.2) have been developed in recent years to make these dimensions and sustainable buildings including quality as a whole comparable.

3.3 Sustainable Construction Processes

3.3.1 Landscape conservation

Construction activity on site inevitably alters the natural state of the site, especially that of green field sites. It results in damage to the existing landscape, contributes to topsoil erosion and also causes ground water pollution. It is therefore important to take measures to conserve natural biotopes, avoid site contamination and prevent construction related pollution by following the measures outlines in the subsequent subsections. It is recommended that a sustainability concept for the building site pertaining to site protection be developed

The first step in a sustainable construction phase is that of landscape conservation. Ecologically sensitive sites such as canal and riverbeds, mangroves, wetlands, marshes, as well as greenfield sites such as agricultural and forest lands should be avoided for construction as far as possible.

In the case that it is not avoidable to construct in such terrains, appropriate ecological restoration measures should be taken after carrying out a through environmental impact assessment. However, as most construction takes place in urban and semi-urban areas ecological impacts are less than for green field sites. This however does not rule out that environmental impact assessment should not take place.

For all sites it is important to enclose all areas not needed for construction. In protecting the vegetation all areas not needed for construction should be enclosed by erecting a protective fencing around root zone prior to clearing. Crowns and branching structure should be kept

clear from contact by equipment, materials and other construction activities. Vegetated buffers can also be implemented. Buffers should be marked and maintained around all resources requiring protection.

Care should be taken to protect existing trees during and post construction. Plans should be prepared to preserve and replant existing trees as necessary. Compensatory plantation or afforestation for trees that are felled for the purpose of construction should be taken up on site as far as possible and only off site as a last resort. Native trees, landscape and vegetation are preferable for replantation purposes.

Compaction of soil to a higher density than needed to a proctor density (moisture-density) within the protected zone should be avoided. Soil compaction is the largest single factor responsible for the decline of trees on construction sites. The degree of compaction depends on several factors: amount and type of pressure applied, presence and depth of surface organic litter, soil texture and structure, and soil moisture level. Techniques such as vertical mulching, soil fracturing, core venting, and radial trenching to lessen compaction such be used to reduce compaction. Care should be taken not to compact soil to a higher density then needed: 95% Proctor density (moisture – density) in improved areas for asphalt or concrete pavements, and not higher than 85% in unimproved open landscape areas that use water jet compaction[1].

The soil within the protected zone and restrict activities should not be disturbed, unless approved by an arborist or other similar competent professional or horticulture authority, etc[2].

Other strategies for landscape conservation include[3]:

- Keeping the soil grade around the trees intact
- Using soft paving technologies and pavement materials that allow percolation of water and air
- Using a single raceway or trench to run all utilities
- Irrigation on the site should be placed on the surface and should not be covered with mulch
- Building boardwalks to avoid or minimize traffic in protected areas
- Storage of building materials should not be permitted in protected areas as well as the elimination or minimization traffic in the protected areas
- Controlling competition among plants in sensitive areas

3.3.2 Soil conservation and contamination

Fertile topsoil is important to support vegetation and landscape on site. It is prone to contamination and erosion while carrying out construction activities on site. Therefore, it is important to prevent the erosion of topsoil and conserve it during construction by following applicable local or federal erosion control and sedimentation norms.

A soil conservation concept should be developed including a sedimentation control and storm water pollution prevention plan (SWPPP) before starting the construction on site as per the topography of the site with measures to control runoff, stabilize slopes and exposed soils, prevent or minimize the soil movement into drainage systems and natural areas.

Construction activities should be sequenced to restrict the disturbed area to the minimum possible at any one point of time. Protective buffer zones should be established adjacent to onsite resources such as trees, vegetation etc. that require protection by setting up fences and perimeter sediment zones before commencing construction activities.

Temporary sediment control practices include:

- Stilt fences: the sediment from runoff is filtered using a geotextile fabric or by creating a pool to allow sediment of drop out of the water column. Stilt fences can be in-

[1] Source: http://www.laparks.org/sites/default/files/forest/pdf/ProtectTrees.pdf
[2] Source: http://www.laparks.org/sites/default/files/forest/pdf/ProtectTrees.pdf
[3] Source: https://bct.eco.umass.edu/publications/articles/preserving-trees-during-construction/

stalled at downslope boundaries, as well as used for inlet protection, and around the perimeter of stockpiles.

- Fibre logs: fibres such as straw, wood chips, coconut fibre, compost, and rocks can slow down water movement and filter sediment. Fibre logs are especially useful for inlet protection, and as perimeter control where a stilt fence is infeasible.
- Rock construction: a path constructed with a bed of rocks at all the access points of the site can help to remove sediment from vehicle tires that operate in and out of the site. 1 ½ inch – 3 inch of clear aggregate is usually used and this should be cleaned and replaced periodically.
- Temporary seeding: the soil can be seeded temporarily throughout the construction period using vegetation such as rye grass, winter wheat, oats etc. to prevent soil erosion and to stabilize the soil.
- Erosion control blankets: erosion control blankets that are made of netted layers of straw, wood, coconut of synthetic fibres can prevent soil erosion by rain and runoff while holding moisture for growing vegetation.
- Mulching: wood chips, compost, straw or hay can act as a cover for disturbed soil. Mulch prevents soil erosion by rain and runoff while holding moisture for growing vegetation. Hydraulic mulches comprising of wood fibres , which are applied using hydro seeding equipment, should be used in areas with steeper slopes.
- Rock check dams: rock piles installed perpendicular across ditches, slow the flow of water and capture sediment. They should be wide enough so that the flow remains in the centre.
- Sedimentation basins and ditches: ditches and drainage can be used to prevent site runoff in sites with watercourses and wetland areas. The provision of temporary drainage and catch pits can prevent surface run-off from construction site.
- In addition appropriate sedimentation plans must be applied, with careful collection and preservation of topsoil for reuse, unless the site has been contaminated or unworthy of such storage.

Avoid soil contamination:

The treatment of the site with pesticides and herbicides can lead to toxic contamination of soil and ground water. Integrated Pest Management techniques that utilize the least toxic procedures available should thus be followed. Alternate pest control systems such as termite sand barrier, mesh barrier, use of pressure treated lumber etc. should also be considered. Alternate systems may require preventative maintenance and so building owners should be made aware and should be willing to undertake such periodic activities

3.3.3 Water contamination

Construction activity uses considerable amounts of water resources for purposes such as curing of concrete, cleaning up, etc. This can result in the water becoming contaminated before it percolates into the ground on site. Using water efficiently and reducing demand where possible conserves a valuable, universally required and frequently limited resource, it also saves money on water tariffs and indirectly reduces carbon emissions related to distribution and waste water treatment. It is estimated for example in the UK that a reduction of water consumption by each cubic meter brings with it a savings of one kilogram CO_2.

Applicable local or federal construction water pollution control norms should be followed. In addition to the SWPPP measures described in the above section, the following measures could be taken to prevent ground water contamination:

- Land disturbance should be limited and vegetation cover should not be disturbed, where possible
- Fine water sprays to control dust and dampen down the site should be used; dust spreading can also be minimized by screening the whole site, or placing fine mesh screening close to the source of dust.
- Trucks loaded with construction materials should be covered
- Stockpiles of building materials such as cement, sand, gypsum and other powdered materials in dry locations should be stored where the spillage is not washed into

waterways or drainage. These should be covered and inspected regularly for spillages.

- Non-toxic paints, solvents, pest control and herbicide treatments are to be used wherever possible.
- All drains on site should be covered and protected. The flow of water to sedimentation pits and recharge bores needs to be controlled through proper channelling of water to prevent site run off.
- Any wastewater generated from site activities in settlement tanks, screen, discharge the clean water, and dispose of remaining sludge should be collected according to environmental regulations. Waste water should be treated to meet local effluent discharge norms. Ground water is only to be recharged using treated water.
- All vehicle and equipment engines should only use low sulphur diesel oil, and incorporate the latest specifications of particulate filters and catalytic converters.

In addition to avoid contamination of water, the following measures could be taken to minimize water usage during construction:

- Provisions for rainwater harvesting should be made,
- Recycled or treated water used wherever possible
- Prevention of loss of water through evaporation during construction by using readymade materials such as pre-mixed concrete
- Minimization of the loss of water during curing.
- For the purposes of curing concrete, these specific measures could be followed:
  - Impermeable-membrane curing
    - Formwork
    - Plastic sheeting
    - Membrane-forming curing compounds
    - Internal curing compounds
  - Water curing
    - Ponding
    - Sprinkling or fog curing
    - Wet covering

3.3.4 Noise control

Noise from a construction site is not only an issue for the site itself but also the direct surroundings. The increase of noise pollution is especially problematic in the urban context. Construction activities such as excavation, drilling, hammering, loading and unloading, diesel generators, running of pumps; as well as demolition cause noise pollution within the site as well as to the surrounding areas. Measures must thus be taken to minimise unavoidable noise from construction sites. The sites and the processes that take place need to be planned, set up and operated and where possible the use latest state of the art to achieve this.

Inadequate noise protection is also a health risk for your workers!

Care should be taken to minimize noise pollution as well as to mitigate the effects due to noise pollution by considering the following measures:

- Operating times and sound reduced times must be defined and strictly adhered too.
- Applicable local or federal construction area noise pollution control norms must be followed
- “Low noise“ construction rated to RAL-UZ53 should be used
- Powered mechanical equipment, hammering, loading and unloading, erection and dismantling works must only be used within permitted hours
- Powered mechanical equipment must be enclosed using noise barriers

3.3.5 Dust control - Airborne particulate and dust

Construction activities such as excavation, drilling, hammering, loading and unloading, diesel generators, running of pumps; as well as demolition causes a lot of dust in the form of Particulate Matter 2.5 and Particulate Matter 10. These both having the potential for harmful effects when inhaled. Care should be taken to minimize airborne particulate matter and dust during

construction and demolition by following applicable local or federal construction area dust pollution control norms.

Airborne particulates can be a health risk. The reduction of dust can thus help to protect the health of workers and other persons on construction sites

Further to the local norms the following measures could be considered:

Site preparation and restoration:

- Vegetation and cover should be removed in discrete sections and not all at once,
- Earthworks, excavation and digging activities should be kept damp and, if possible, be avoided during exceptionally dry weather periods,
- Surfaces should be stabilised and/or re-vegetated as soon as possible.

During handling, storage, stockpiling and spillage:

- Unnecessary movement of dusty materials such as cement, sand and other powdered materials and keep the number of handling operations low should be avoided,
- Conveyers should be used to move materials and keep drop heights to a minimum,
- Bulk cement, bentonite and similar materials should be delivered by tanker and stored in silos,
- Indoor storage or the use wind protection sheeting for fine dry materials (less than ~3 mm in particle size) should be used,
- Dry materials (greater than ~3 mm in particle size diameter) should be stored in bunds or bunded areas
- Stockpiles of brick, aggregate and other dusty materials should be covered
- **During construction: Exteriors and outdoors**Scaffolding of the building should be enclosed using dust screens
- Water should be sprayed on earth work, debris before dumping, and before and during cutting and grinding work
- Vacuum suction should be used to collect fine and particulate matter that rises due to cutting, grinding and drilling where possible
- Enclosed debris chutes and collection bins should be provided
- A wheel washing system should be used on trucks leaving the site
- Diesel aggregates and vehicles should use low sulphur diesel oil in all vehicle and equipment engines, and incorporate the latest specifications of particulate filters and catalytic converters.
- Enclosures to minimize the spread of dust into adjacent occupied areas should be used.
- Dumping chutes should be enclosed with appropriate screens to dispose of construction and demolition debris.
- Where chutes are not provided, debris should be bagged, and kept in temporary dust control enclosures.
- Exhaust ventilation devices / system to suppress dust through the consistent and regular spraying of water at designated areas should be used.

During construction: Indoors

For indoor work areas adjacent to nearby non-sensitive occupied areas where extensive demolition or other dust-generating work is planned, the following mitigation measures should be considered:

- Appropriate signage to demarcate construction areas from adjacent spaces.
- Sticky floor mats at immediate entrances to the construction area to reduce dirt and debris transfer from the work area to surrounding halls and corridors;
- Barrier protection at the entrance to the construction area, an exhaust fan within the project area vented to the outdoors, and seal return grilles;
- The taping of all doors except those essential for access;
- The sealing of all penetrations in the demising walls prior to demolition;
- The reduction of airborne particles by spraying water during demolition

- The removal of construction debris through approved route, covered, netted, or otherwise contained to prevent dust generation, or remove during off-hours times.

Avoidance of health hazards on site during construction

- Dust pollution should be removed or reduced to a minimum as it is a health risk for workers.
- Building materials such as paints, adhesives, wall boards, and ceiling tiles that emit formaldehyde in application and use should not be used.
- Manufacturers of products containing VOCs materials should explore alternative water-based solvents to reduce or eliminate emissions of VOCs and improve environmental performance during the products use. (VOCs including formaldehyde can cause breathing difficulties, irritation and discomfort to people in the indoor environment)
- Architects, planners and construction firms need to be made aware of the risks of the materials that are used in the manufacture and processing of products - such as heavy metals, halogens, solvents, etc. - and how their use affects human health and the environmental impact of water, soil and air.
- Workers should be supplied with the appropriate Personal Protective Equipment (PPE), and provided with training to enable them to recognise the dangers of dust, and to work safely in a dusty environment.

3.4 Sustainable resource use and material efficiency in the construction phase

Globally, the construction sector accounts for 30-40 % of all material flows. This consists of both usage of virgin materials and usage of recycled materials. Sustainable resource use can be broadly classified under two categories.

- First, reduce the usage of resources, typically measured in physical units of volume or weight etc.
- Second, minimize the negative environmental impacts associated with material extraction and production, typically expressed as tonnes of GHG emissions etc.

3.4.1 Material resource efficiency

The first step in sustainable construction is the efficient use of materials, technologies and resources. The key indicator for resource efficiency in terms of virgin materials is usually resource extracted/waste generated. Other indicators used are material usage per built up area etc. These indicators should play a major part in the choice and implementation of materials and technologies.

3.4.2 Resource productivity

A more common aspect of sustainable materials use is that of resource productivity. Resource productivity describes the (unit) output that is achieved from the use of (most often) finite (unit) resources. The better the resource productivity the better the use of renewable resources and minimisation of waste. It is sometimes described in monetary terms as the monetary yield per unit resource. It is especially important in the construction phase as it brings with it the economical dilemma that a higher material usage (less recourse productivity) often brings with it a higher "value" of the building i.e. profit for the material suppliers and contractors but higher costs for the building owner. A higher resource productivity on the other hand means less overturn and thus profits for example for the materials suppliers. It is however one of the biggest drivers for developers as they aim to get as much out of the use of materials as economically possible, and hence should act as a driver for resource productivity. It is therefore, important to delink these two variables or seek more value for fewer resources.

3.4.3 Environmental impacts of resource use

The lifecycle of buildings consist of various phases ranging from extraction of raw materials, materials production, construction, usage and maintenance and finally demolition. Resources are used at various phases and it also creates waste/by-products. For example, raw materials such as sand, limestone (for cement), soil (for brick making), metals, are extracted which caus-

es considerable environmental impact in terms of mining; production and transport of building materials such as cement, steel etc. uses high amount of energy often referred to as embodied energy, and also uses other intermediary materials and catalysts which leads to GHG emissions, air and water pollution; construction phase includes the on-site construction and has the potential to cause air and ground water pollution if the site is not handled properly; finally demolition phase produces considerable amount of waste which usually ends up in landfill, unless reused or recycled effectively. Analysis such as Life Cycle Assessment/Analysis (LCA)are conducted to analyse total impact of building construction. However, the analysis are often complex and the availability of reliable data is often limited and therefore, best available proxy might be CO_2 emissions or GHG emissions and other air or water pollution indicators associated with various phases of construction. Other approaches to address sustainable use of resources is cradle to cradle approach which addresses reuse, recycling and effective waste management at every stage.

3.4.4 Resource-light construction

A simple solution for a sustainable construction and the use of less resources and energy is that of a reduction in the technologies and materials used. This might seem contradictory but can easily be achieved through light construction. It however requires a change in thinking and an innovative building process.

It is however not as the name implies only light construction but a appropriate sustainable resource efficient use of materials and technologies. That is a construction designed to the needs of the building being constructed. In achieving this it follows three basic principles:

- The use of lightweight materials that have high strength and stiffness in relation to their weight
- The use of lightweight structures that have optimal load transfer mechanisms for a structure, e.g. the avoidance of bending stresses;
- The use of lightweight system design that combines various functions in a single component

Resource-light construction requires an intense analysis of the building during the planning stage identifying material flow and the calculation of material intensities. It also needs to take into account environmental performance, mechanical properties, lifespan and maintenance requirements. Ideally it should go beyond this thinking taking into account local conditions, future needs etc. giving an integrated view of the buildings life cycle. This complete analysis then helps to identify the best materials for each specification.

A simple example of such an analysis is that of a wall. A wall in its first intention is that of a load bearing structure. This however in its function as a insulator in cold countries is not always given for example in reinforced concrete walls. The use of a bonded insulation wall construction to insulate a reinforced concrete wall might not be the most sustainable combination. Here solutions could be for example a use of highly insulated load bearing aero-concrete walls in low structures or a support and beam construction with insulation panels in higher constructions. Such solutions fulfil the load-bearing needs, the insulation needs as well as that of a sustainable use of materials.

Resource-light construction can thus only be achieved when the characteristics and interactions of all construction materials create a truly sustainable building by maximizing the reduction of material and energy consumption as well as harmful emissions to the environment.

3.5 On-Site Energy Consumption

The energy consumption in the building phase is often seen as too unimportant when weighed against the energy consumption in use phase[4]. In addition, the energy consumption over the building phase is often considered impossible to calculate. The particularities of construction, such as changing locations, amount of workers and tools used, are often seen as making it hard, if not impossible, for a consistent regulated resource and energy management on the building

site. Another reason given being that it is not possible to calculate the machines used and how they are used[4]. However, in Germany for example, studies show that energy costs in a third of all construction firms make up 5 to 10% of the total construction costs.

However, with ever increasing cost of construction, material and energy costs savings in the building phase are becoming more and more important. Measures on energy saving are the most economically efficient mitigation actions, as they often come at a negative cost. Yet, they are not systematically implemented as they face many noneconomic barriers. Decisive in the construction phase are, above all, energy supplies and greenhouse gas emissions from construction machinery, induced traffic and construction site logistics (i.e. utilization of the trucks, lighting) etc. . However, other areas such as accommodation can also play a part in on-site energy consumption.

Sustainable and thus energy efficient construction sites can only be achieved through an environmentally conscious management of operations, which records analyses and systematically reduces energy use. This includes monitoring energy use in construction plants and equipment, transport to and from site both for workers and for materials and technologies and last but not least site accommodation. The basis of a good energy management on building sites is the implementation of an energy management systems. The existing potential for savings must be systematically developed with technical, organizational and personnel measures. On such system which has been internationally recognised and is often used is that of the ISO 50001 - Energy management systems

With the implementation of a on-site energy management the first step is to prepare construction energy estimates and requirements within the construction management plan to help find avenues for energy optimization. Here a balance between time, energy and cost of construction should be arrived at.

3.5.1 Technologies

The building site should secure early, high capacity, electricity grid connection where possible. This reduces the need for running generators. If generators are needed these should be correctly sized generators, and where possible two generators of high and low capacity for daytime and night-time use should be used. In reducing electrical loads it should also be ensured that all temporary electrical installations and circuitry are energy efficient and automated. This includes appropriate lighting and lighting management. All electricity use should be monitored and managed throughout the construction phase.

To ensure that the full benefits of these technologies are realised it is essential that:

- Equipment is specified correctly
- Installers have a thorough understanding of the equipment
- Thorough commissioning is carried out
- Thorough and regular maintenance of all equipment should be made.

Unnecessary use of machines should also be avoided; plants and vehicle engines for example should not be left idling. Here a sustainable integrated construction could be of benefit through a just in time appropriate use of machinery.

The reduction of energy on-site can also be through appropriate target date planning. The natural drying of materials rather than the forced drying is an example of this. This can be achieved by planning the building appropriately so that for example that the largest amount of concrete work does not take place in the winter months. In warmer climates this can of course be in the other direction where cooling of materials such as concrete for curing uses large amounts of energy and water. Here the planning to accommodate pouring in the cooler months is more appropriate. An appropriate time between completion of the building and first occupation should also be planned to reduce the forced drying of a building.

[4] M. Helmus et al, Energiemanagement auf Baustellen, Bergsiche Unversity Wuppertal, Wuppertal

3.5.2 Training

Many of these savings can be implemented by training, organisation and sensitisation of the users. Here an easy low cost implementation for energy saving is that of the training of the workers for the efficient use of machinery. (For more information see Chapter 7 Training for sustainable construction).

3.5.3 Accommodation

An often-overlooked aspect of energy efficiency on the building site is that of the offices and accommodation used for the construction workers. This is often seen as unimportant and having high upfront costs. However mid- to long-term strategies clearly show that this is not the case. What goes as cost effective during the operating phase of a building also goes for that of the buildings used on construction sites. These are for the most not constructed just for the one site but are used by the construction firm over longer periods on numerous building sites. It is thus advisable to build or use energy efficient buildings. In Europe there has been a recent trend to extremely low energy and passive house construction buildings, by constructors thinking in the mid- to long-term and the cost savings that these bring with them. In addition in the offices and accommodation the equipment and lighting should be intelligent and efficient electrics.

3.5.3.1 Good-Practice Examples - Container Accommodation

- Max. Height: 3 Floors
- Construction: steel frame with profile sheet walls or cassette façade
- Length: 6058 - 14646 mm
- Width: 3000 - 3250 mm
- External height: 2800/3350 mm
- Insulation Wall: 0,153 W/m2K
- Insulation Roof: 0,160 W/m2K
- Insulation Floor: 0,178 W/m2K
- Period of use: > 3 Years
- Label: SIA 180

Figure 9: Energy Efficient containers in Switzerland

Source: https://fagsi.ch

3.5.3.2 Good-Practice Examples – Wooden Module Accommodation

- Max. Height: 3 Floors
- Construction: Wooden Frame with stone façade
- Length: 9600/10700/11300 mm
- Width: 2960/3035/3950 mm
- External height: 3470 mm
- Insulation Wall: 0,15 W/m2K
- Insulation Roof: 0,12 W/m2K
- Insulation Floor: 0,15 W/m2K
- Windows: 3-Glazing 0,78 W/m2K
- Label: EnEV 2014

Figure 10: Energy Efficient pre-fabricated wooden containers in Germany

3.5.4 Energy consumption from transport

Another often over looked aspect of energy efficiency on construction sites is that of transport. Studies have shown that an increase in global warming potential through transport can be more than 6% of the environmental impact of a construction material alone.

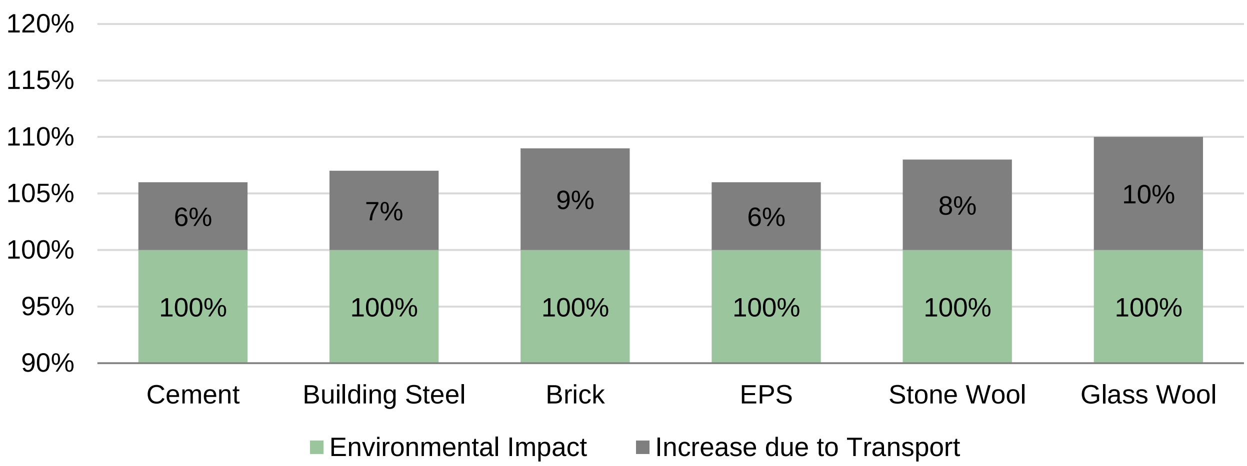

Figure 11: Global Warming Potential from transport

Optimized logistics reduces transport costs. It is thus necessary to clearly define building site logistics and the execution of processes to reduce unnecessary transport. A structured recording of the transport energy depending on the factory location, construction site and construction product should be integrated into the energy management system. A reduction of energy

consumption through transport should take into account an optimised planning of logistics both for on-site and off-site transport. Appropriate planning and delivery schedules reduce the number of times transport is needed to building sites thus reducing the CO_2 arising from transport or unnecessary running of equipment until materials are available through on-site logistics.

The maximum distance for transport of materials off-site should also be defined for each project. For building sites with large excavation works and a large number of trucks for example the resulting distance driven can be extremely high. Transport costs in the extraction sector account for around 13 % of total costs, which makes it in most cases uneconomic to transport the materials further than around 35–50 kilometres (dependent on diesel prices).

In aiding this process where possible materials should be sourced locally to reduce long transport supply chains. Checks should be made throughout the construction phase with suppliers on where and when materials are sourced. A benefit of using local materials that this adds to the local value chain making the entire construction process more sustainable and at the same time cost effective.

The provision of bus services for workers can also reduce energy costs and emissions. Although not directly energy saving for companies this can service as a bonus for workers improving the general work environment.

4 Sustainable Materials and Technologies

A major part in improving the sustainability of a building is the choice of materials and technologies. Thus a good understanding of the impact these have must be obtained from the onset. Consideration of how materials, energy and water are sourced and consumed and how waste is produced, from the selection of raw materials, through manufacture, use and disposal need to be made.

- Some materials are for example far more damaging to the environment and society than others (e.g. toxic, explosive or corrosive).
- Some materials are non-renewable or are becoming scarce (e.g. oil reserves, some metals).
- Some materials are highly resource-intensive, including energy consumption, to produce, transport or recycle (e.g. plastic is much lighter to transport than glass but more difficult to recycle in some EU countries).

The sustainability of materials in terms of the removal of the material from the environment its further processing and manufacturing, transport and construction should be taken into account. In addition this should be part of the total life cycle assessment of not only a material but a building in all its stages.

In addition the materials and their sourcing can have adverse effects on off-site sustainability for example through deforestation which can lead to erosion, higher land temperatures or air-born particles or in another example from quarrying or concrete production where indiscriminate sourcing and production can lead to air-born particle pollution.

4.1 Knowledge base

Contractors need to have a sound understanding of green materials, low VOC emitting materials, green waste management strategies, sustainable labels and certificates etc. to be able to truly participate in the integrated design approach for sustainable construction.

Material and product manufactures should take various aspects into consideration to address issues such as sustainable procurement and production processes. Key aspects of the product supply chain including differences in production processes between different countries/regions as well as other aspects such as absolute national/regional resource uses of finite resources and environmental impacts due to selected construction materials/product groups.

This information is, however, most often hard to obtain and comprehend, especially down the supply chain. Independent certification and labelling bodies, who are better equipped to this should, thus, be entrusted by manufacturers with environmental declaration of their construction products. Such environmental deceleration allows for a uniform third party assessment with an easy certification process for manufactures and a labelling that is geared towards contractors and customers with easy to understand relevant information.

4.2 Eco Balances

Eco-balances can play a part in identifying products that are not only safe for future inhabitants and users but also for the construction workers in the building phase. This could be for example if materials which might not be harmful in the use phase need harmful materials, for example solvents, in the construction phase. Here analysis tools can help to support the relevant actors in choosing the sustainably suitable materials and technologies as well as type of construction. Such tools include: guidelines and checklists, one-score screening indicators, full life cycle assessment, process simulation software, databases on materials, etc.).

Sustainable environmental assessment and labelling schemes for different building types as well as for construction products have been developed in Europe as well as all over the world. However, they are often difficult to compare, as the indicators used are not often the same. The use of standardised Environmental Product Declarations (EPDs) can help to alleviate this. EN 15804 for example provides core rules and guidelines for Environmental product declarations (EPDs) based on scientific approach to supply information on various construction products.

Tools such as these EPDs help in determining effective materials flows and processes for a cradle to cradle approach.

4.3 Construction process materials

In addition to the "global" level determined by the eco-balance, harmful effects on the local environment can also arise during the construction process. This especially when products are processed on construction sites or during building use. Here pollutants can enter waters, soil and air and can pose a risk to health due to accumulation in the food chain and pollution of indoor air. In particular, toxic effects (cancer production as well as damage to fruit and genotype) should be avoided. Theoretically in practice this is relatively easy as prohibition and requirement lists or classifications give indications of toxic effects as well as allergenic and irritant reactions. However this is not always the case.

Substance	Health effect	Occurrence
Bitumen	Suspected cancer-related substance	Paints, bitumen board, corrugated sheets, Asphalt screed, bituminized fibreboard
Phenol	Headache, dizziness, corrosive, kidney and circulatory disorders, narcotic, liver damage	Rigid insulation, synthetic resins, Dyes, glues, impregnating and Disinfectant, tar paper
Styrol	Narcotic, headache, Fatigue, depression, behavioural disorders, Blurred vision, irritation of the respiratory tract	as polystyrene for the production of thermal insulation and adhesives, Food packaging
Toluene	Aesthetic, mucous membrane irritation, disorder of the nervous system, damage to liver, kidneys and brain	Solvents in many household products occurring, especially in detergents
Vinyl chloride (VC)	Carcinogenic, connective tissue changes in lungs, liver and blood vessels	Floor coverings and windows (PVC), textiles, toys, plumbing tubes, Shutters

Figure 12: Examples of harmful substances that can be found on construction sites and their health effects

It is of utmost importance that during the construction phase (better when decided upon in the planning phase) products and the materials installed do not have adverse effects and or come with low risks. Thus, processing instructions have to be given, framework conditions and limit values set at the onset of the project in the planning phase. It is also recommended that all materials coming onsite need to be checked and approved by the quality and sustainability manager.

Experience in Europe has shown that the use of non-compliant materials leads to increased costs among others due to reworking, a larger percentage of off-cuts and waste materials.

4.4 Eco materials and technologies

In assessing the sustainability of a building the building itself is considered as the final product and the construction products are regarded as intermediate products. However these construction products must be fully assessed to assess the overall performance of the building. Certified labelling systems and standards aid greatly in this process (see Chapter 2.4 for more information). In doing this the product declaration and certification of construction materials and products require a scientific approach taking into account all factors. Although sustainable certified materials, for example, are usually less resource intensive and less polluting other factors, such as regional needs or resource sources, need to be taken into account to truly judge their real sustainability. For example certain materials can be interpreted as certified under a particular set of criteria but might not perhaps meet other ecological criteria. Wood, for example, when sourced from sustainably managed forests, can be considered an appropriate sustainable material for a single family home. However when used excessively for the building of large developments causing massive deforestation this would not be considered sustainable.

The certification processes as well as the labels thus need to take into account all factors within context such as regional factors etc. To achieve this research and development activities for eco-materials need to be increased, deployment strategies on eco-materials be implemented

and at the same time policies need to ensure that this does not lead to problem shifting or a level of use which cannot be supported by sustainable supply

4.4.1 Recycled Materials

Recycled materials are often just as or in many cases cheaper, as well as good a quality, as new materials. These should however undergo the same processes mentioned above to ensure their sustainability within each construction project.

4.4.2 Good practice example - Eco-Cement

The cement industry is one of the largest emitters of CO_2 emissions, with up to 5% of the worlds total, and requires high amounts of energy in its production. It is also the largest used manufactured material by mass and the second most used substance after water in the world. In addressing this more sustainable cements, which are comparable to the typical used standard, with lower CO_2-emissions, have been developed. Further on-going research is also focused on the development of cement that has comparable properties to Portland cement but with lower CO_2-emissions and energy consumption.

Eco-Cements for example can be a more sustainable alternative to “normal” cement. These have lower CO_2 emissions. Eco-cements also have the benefit that it hardens by sequestering CO_2 from the air. Sustainable methods of substituting Portland cement are those of using limestone, granulated blast slags and coal ash fly. Other methods include the use of industrial waste materials like slag and natural hydraulic-setting minerals such as pozzolan as clinker substitutes. These clinker substitutes represent a potential of replacing up to 50% of Portland cement clinker while maintaining similar performance. In some applications, filler contents higher than 50% in the cement can still offer satisfactory performance. The substitution of conventional clinker by up to 40% with more sustainable alternatives could reduce CO2 emissions by up to 400 million tonnes of annually. Eco-Cements although they do have the advantage that they do not need to be calcinated they do need to be activated either by adding Portland cement or so-called geopolymers or alumino silicate-cements.

One draw back at present it that although the sustainable cements do have a comparable strength to Portland cement, there is only limited information concerning other relevant properties, such as the long-term protection of steel against corrosion, porosity and frost resistance. A sustainable use of cement can however be the use of the highest strength concrete grades only where need and lower strength but more economically viable and sustainable cement in other areas.

Optimizing the mix of coarse and fine fractions of particle packing, through for example industrialised prefabrication in a controlled environment, can also reduce the use of Portland cement without the loss of performance. If this is not possible concrete should in any case not be mixed on-site but in its very worst be industrially mixed and delivered on site as needed.

Eco-cements are to date for the most still slightly more expensive than conventional cements. There has even been the case where on the higher end of the scale a CO2-neutral cement developed in Belgium with a 5% per cent higher price has not sold one tonne. Although in many areas the use of eco-cement is not taken up to due to current pricing there is still a huge potential for this. A careful life-cycle analysis in the planning phase is however recommended. It is excepted as with all innovative materials and technologies that this price will come down drastically with market uptake.

In comparison to conventional cement such as Portland cement Eco-cement has the benefit that it is fully recyclable.

4.4.3 Good practice example - Wood

In the building industry there has been a resurgence of wood as a building material as actors look for building materials that are more sustainable. Wood is being used more and more in new innovative ways, not traditionally possible, opening new possibilities. No longer is it only used as a cladding material but has in hybrid forms found new uses for example as insulation, or even in the use of high-rise structures. Synthetic wood composite blends for example offer a

material that is 100% recyclable yet more durable without losing the typical characteristics of wood, in many cases even better as water resistance and weather resistance are improved and even incorporating self-extinguishing properties. Although harder to completely recycle this can be used again in wood composites. Risks of wood, in its traditional form, such as that of structural failure and burning have been reduced or removed through innovative and hybrid use and design.

One interesting benefit of wood is that it has the potential for cascading use. Even if not recyclable the use of wood as a material in construction before being used to generate energy at the end of its life cycle helps to increase its sustainability potential. However it must be noted that only wood from sustainable sources will have a positive effect on GHG emissions.

Rhomberg"s "Life-Cycle Tower": a multi-storey tower based on wood

An interesting concept, in the use of sustainable materials and increasing resource efficiency, that is becoming more prevalent in Europe is that of the use of wood in multi-storey buildings. An example of this is the Life-Cycle Tower in Austria. Using an innovative hybrid building system, from the construction firm Rhomberg Bau, an 8 storeys 27 meter high wood hybrid building was constructed. The concept differs from comparable concepts in that the load bearing structures made of wood are not covered, saving valuable resources. This without loss of fireproofing. In addition although for the greater part was made using wood it is only used where it makes sense. Other materials are used in areas where these are more appropriate. Doubled supports of wood in the façade help to bear the vertical loads. The floors are made of a wood-cement hybrid construction. Here glue laminated timber supports beams are combined with reinforced concrete floors for an extremely stable construction.

The idea behind the building is to prove that it is possible to build a eco-innovative building that is resource and energy efficient with a 90% better CO2 emissions balance than other comparable buildings. An additional benefit is that through the modular design the construction helped to reduce the working time on-site to half of the time needed for other buildings.

5 Quality Control during the construction phase

5.1 Quality Control

The ever increasing requirements on sustainability and energy efficiency, whether through policy, regulations or at the behest of the building owner, increases the demand for high quality of execution of construction works. In the construction phase it is more the construction work itself that dominates the need for a quality control and not the easier to define technology and material control. This is due to the fact that here quality is more often due to the firm or person carrying out the task, their training, know how and implementation. Construction processes must, however, also be managed with a view of protecting the environment and resources as well as the health of all stakeholders.

5.1.1 Quality control on construction sites

The measuring and quality control of the building site during the construction phase is key to achieving the sustainable goals on a building site. The following factors, among others, can determine the quality of a building:

- Supervision of quality of construction by architects and planners
- Degree of construction site attendance on the part of planners
- Co-ordination of the construction process
- Cost control
- Comprehensive documentation of the building materials and products used in construction
- Contractor's quality management system
- Quality of project management services
- Quality assurance and integration of project management into quality assurance processes
- Training and further professional qualification of contractors

On completion of the design and planning phase a verification of completion of planning should be made. This should include a construction schedule with information on installation of all materials and technologies.

On awarding of the tender, the contractor needs to draw up a strategic plan detailing the quality of production site planning. All relevant actors should agree on this, through contracts. This ensures that the agreed sustainability qualities are also implemented in the building process in order to warrant targeted planning.

A sustainable construction phase requires that a comprehensive quality control be made to ensure that defects and damage to the building can be avoided and the targets set reached. A trained or accredited quality assurance engineer as well as energy and sustainability consultants thus need be involved on a sustainable building site. These need to be commissioned by the client before the start of the project.

On the start of construction the relevant actors, including the construction site manager, site supervisor, quality manager and relevant specialist consultants, need to monitor the implementation of the design and defined goals as well as workflow plans. This should include the materials and construction products used and must be fully documented. In aiding this process a full product lists (from the Sustainability Consultant/Auditor) must be available to the site management.

Practical experience confirms that incorrect construction workflow plans, typical but foreseeable delays or unclear definitions quickly affect building construction and thus lead to considerable deviations from the planned quality.

In order to avoid defects or damage to the building regular and comprehensive quality checks must be carried out during the building process and following completion of the building. These should include but not be limited to :

- Regular site visits (with protocols)
- Daily team meetings with daily instructions and team reports
- Mandatory protocols ('"building diary")by the site supervisor
- Photo-documentation
- Checklists of sustainable goals
- Product control of materials used on site
- Client and Quality Manager receive a form report from the quality assurance

Depending on the project and the need, quality assurance on construction sites should be provided on demand and as often as necessary. This should however, also include short-term assignments, spontaneous site visits determine action

Documentation of all materials and technologies used on site, using safety data sheets and product descriptions, must be made. Control of all products, materials and technologies entering the construction site must be made to ensure that these confirm to the sustainable goals laid out for the project. This must be constantly kept and carried on throughout the building phase until completion.

Documentation needs to be kept in a project handbook and must be presented to the building owner on completion of the project. This allows a complete chain of evidence of the construction phase as well as a reference for later facility managers of the building, for any refurbishments and extensions as well as for the deconstruction of the building.

5.1.2 Building Measurements

A major tool for quality control are on site measurements and random sampling. These include among others:

- Control of materials used through material lists
- Blower door testing
- Thermography
- The measurement for harmful substances,
- Measurement of construction site noise.

These are most often made at the end of a project. It is however advised to have one or more control measurement during the building phase rather than at the end of the project as then it is almost impossible to rectify any problems. Tests such as the blower door or harmful substances are among these.

5.1.2.1 Material lists

A product list materials used (including those not built in) should be made and presented to the quality manager. At all times materials entering the site need to be controlled and cross-checked against this list to assure that only the approved materials have been used. For all materials and technologies installed and used product certificates, such as instruction leaflets, leaflets, CE markings, etc. need to be collected and documented in the building handbook and presented to the developer on completion.

5.1.2.2 Blower Door

At least one blower door test should be made on a building at completion however it is recommended that at least one more be made, earlier in the project. The first blower door test should be completed on completion of the building envelope. On large buildings even on a partial completion of the building with a partial test in the building section where the envelope has been completed. In larger buildings this is mostly easily done according to building sectors defined by fire barriers.

The costs for a blower door test at this phase is more expensive than at the end, as some areas must for example be taped or closed. However this is only a small expense when compared to those of rectifying the problem later.

A blower door test as part of the building certification and approval is a must. All blower testing must be protocolled and the measurements recorded and passed on to the building owner as well as being protocolled in the building handbook.

A common metric for a blower door test in Europe is a minimum 1,5 1/h @ 50 pa but often better is required such as with the Passive House which lies at 0,6 1/h @ 50 pa)

5.1.2.3 Thermography

The use of thermography is recommended through the construction phase but is most effective on completion of the building. From a construction manager's point of view, infrared thermography can be a very useful tool especially due to its non-destructive nature. It aids in the detection of many construction defects including the identification of thermal and air leaks, problems with the installation of insulation and continuity, identification of thermal bridges, problems with the installation of as well as the predictive maintenance of electrical and mechanical systems, manufacturing process quality assurance among others. All infrared quality checks should of course be accompanied with a normal photo-documentation for better reference and be protocolled.

5.1.2.4 Air Quality

On-site measurement of dust and air-quality should be made during the construction phase. This is especially important to certify that the relevant standards have been upheld in terms of reduction of dust as well as VOCs on-site. It is also an active control of the materials used on site and can help to confirm that no forbidden materials have been used during construction that are difficult to re-work on completion.

On completion of the building and in order to ensure and document indoor air quality, indoor air must always be measured at least one day before furnishing begins. However this might not be enough time possible for the VOCs to naturally reduce themselves to a “normal” level. DGNB recommends that the air quality of the building should be measured 28 days after completion of the building but before the building has been occupied. This gives a measurement of the air quality including the Volatile Organic Compounds (VOCs) and can give a more reliable feedback and offers a control on the products used and if any harmful substances were used during the building process. In various sustainable building labels this is a topic with a high priority. The DGNB even goes so far that if the minimum is not met the building cannot receive a certification.

All testing must be protocolled and the measurements recorded and passed on to the building owner as well as being protocolled in the building handbook.

5.1.2.5 Thermal Bridging

Despite careful planning thermal bridges can appear in construction whether planned, tolerated or unplanned. This can be through the use of the wrong materials for example through metal instead of an appropriate material for wall brackets and façade anchors. Contractors should check all plans and documents for such problem areas and if not dealt with in these, make suggestions to rectify these problems. Where thermal bridges are to be expected the quality manager should take special care to assure that the appropriate solutions to reduce the negative impact have been reached. Thermography is an excellent tool here for quality assurance especially on completion of the building.

5.1.2.6 System Regulation including Hydraulic Adjustment

A hydraulic adjustment of both water based and air based systems need to be checked through the construction phase, at the latest on completion and certification. The breaking in and adjustment should be done by the relevant contractor and specialist to check for any problems, this of course in cooperation with the future facility manager. These need to be accompanied with a protocol for the developer and owner as well as the future facility manager.

5.1.2.7 Sound

Constant on-Site monitoring of construction noise should be made to assure that the noise levels are kept within that of regulations. On completion of the building appropriate testing of the building should be made to assure that the acoustic requirements of the building have been met. These should include building and room acoustic measurements (such as testing airborne sound, footfall sound, reverberation time).

6 Construction and demolition waste management and recycling

6.1 Waste control

As one of the most intensive users of raw materials, the building sector needs to reduce construction waste to a minimum both in the construction phase, through resource saving techniques, and in the use phase, through the use of materials with a long as possible lifecycle.

Construction waste from a building site is any material that leaves the site ultimately ending on a landfill. This can be :

- Unused materials and off-cuts
- Damaged materials and products
- Demolition waste

In the EU alone the waste from construction and demolition amounts to about 1 billion tonnes annually. Of the 70-80% of waste discarded at present much of this can be recycled. Studies show that 13% of this is new and unused materials, much of which can be reduced through careful planning. In alleviating this the European Union aims through the European Waste Management Directive (see Chapter 2.3.7) to implement a building and deconstruction recycling and recovery quota of 80%, to cover this wasted potential.

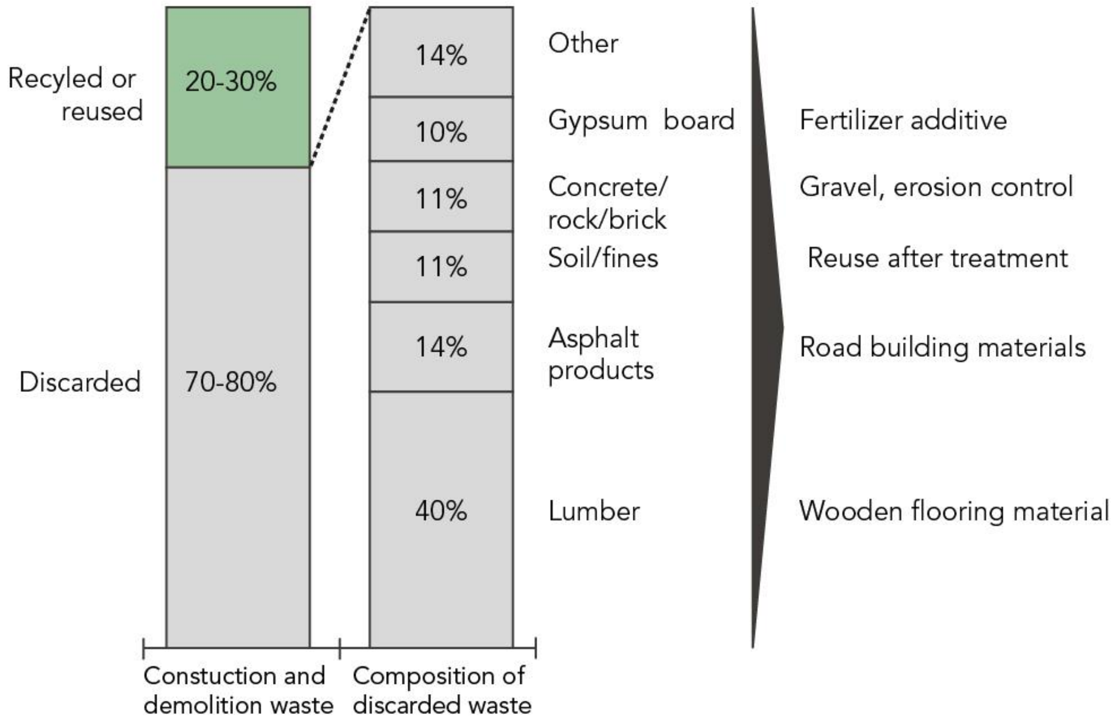

Figure 13: Construction and Demolition Waste

Source: Ellen MacArthur Foundation; World Economic Forum; The Boston Consulting Group

The first step for a sustainable waste management is the preparation and implementation of a sustainable integrated construction and demolition (C&D) waste management plan. In ensuring this a continuous monitoring for waste generation and safe disposal is needed. This involves exact calculations of materials. Tools such as BIM can play a major part in aiding this. The pre-construction phase is key to implementing a sustainable waste management plan. It is here that appropriate recyclers and waste management service providers must be identified.

With such a sustainable waste management the main focus should be of course the avoidance of any waste. Waste avoidance should be given preference over waste reduction, and the reuse of materials should have preference over recycling. Unavoidable wastes should be kept to a

minimum, for example, by designing the buildings in an environmentally friendly way, recycling-friendly construction sites and recycling in the economic cycle. This is however never completely possible and it is at design stage that waste streams should be identified, what is generated and how much. A team meeting with all contractor and subcontractors should take place at the beginning of the construction phase of the project highlighting sustainable construction including waste management. Waste and redundancy are best avoided through better coordination, thus reducing material, energy, and water use. Where only a small supply is needed, a material exchange scheme or plan can help to reduce this waste if materials need to be bought, for example, in bulk.

In addition, poor storage and site conditions can lead to a loss and damage of materials. Appropriate storage areas that meet the storage requirements needed to be identified and areas set aside for this. Such storage facilities should ensure that all materials are stored securely and are protected against excess moisture, rain and daylight. Appropriate sourcing and reduction of material loss saves money and avoid delays.

Waste can be reduced through standardisation, such as the use of room dimensions appropriate to brick size or dry board sizes, reducing off-cuts and wastage. The use of modular components: prefabrication of construction components off-site can also significantly reduce wastage on-site; providing that the modules have been correctly sized.

Training of workers can also improve accuracy and appropriate use pertaining to the use of building materials, which also reduces wastage. Training and excellent workmanship also reduces the amount of rework needed on a project and thus reduces construction waste. Other benefits of excellent workmanship include a minimisation of on-site concrete dust or dust from plasterboard or wood works. Incentives and rewards can also help to promote sustainable construction.

Many materials thrown away as waste can still be used. Here either a use on other projects, or a take-back/buy-back agreements from the manufacturers, with a possible refund or selling them to a third party is possible and a monetary gain. A large part of waste is packaging. Here communication should be made with suppliers to reduce this, if not take back, and to recycle packaging. Materials that cannot be returned or have been partly used i.e. for formwork can be salvaged and be reused on site, off site etc. Appropriate demolition waste and excavated earth can also be used for example again in levelling and filling of the site.

Waste that can be recycled needs to be identified early in the process to reduce mixed waste and contamination. Here segregation and storage of waste in demarcated bins to ensure reusing and recycling of waste materials can improve the process. Provisions for onsite segregation of materials as well as possible reuse or recycling need to be taken into account and relevant areas set aside for this. It is here that precautions are needed to ensure the safe disposal of hazardous C&D waste to avoid these ending in landfills.

It would be recommend that a materials exchange programme be developed to exchange and use or reuse building materials. Such programmes, such as the Nemsitt in Hungary, are already being implemented in Europe. Here an online platform allows for the use and reuse of building materials and components. Searchable by 12 construction material categories and region it allows the construction firm to easily find the appropriate materials for their needs.

Waste reduction also saves money! Each tonne reduced means a reduction in removal fees and landfill taxes. In addition, the waste management service industry often provide better rates for segregation of materials, which can also encourage waste reduction. Fly-tipping of building material is also a major cost to community's and often results in higher landfill taxes or other taxes.

An evaluation of all projects should be made on completion so as to reduce waste and costs in the future. This should include estimated waste, waste flows and removal. Waste and redundancy are avoided through better coordination, thus reducing material, energy, and water use.

6.1.1 Good Practice Example – recycling of aggregates and gravel.

In a case study for the city of Zurich, Switzerland, it was found that about 80% of deconstruction material is recycled (AWEL 2010). Most of this material however is used as an inferior

building material. The other 20% is disposed of in landfills. Currently, almost all types of recycled concretes have slightly worse attributes than concretes made from primary gravel. However, if this is properly accounted for in the planning of a construction project, even recycled concretes can be used in structurally relevant parts of a building. Nevertheless, this would require some rethinking in the building industry. Therefore, the Amt für Abfall, Wasser, Energie und Luft (AWEL) (Office for Waste, Water, Energy and Air) has created the Swiss information initiative –Kies für Generationen (gravel for generations; own interpretation). The purpose of this initiative is to spread knowledge on the use of recycled materials and to enhance the information exchange between science and industry (AWEL, 2010).

6.1.2 Good Practice Example - Site Waste Management Plan UK

A good practice example of construction waste management is that of England where according to regulation projects over 300,000 £ are required to implement a Site Waste Management Plan (SWMP). It must be prepared before work begins and is a prerequisite for receiving planning approval. This plan allows among others for :

- A better use of resources - materials and products:
- Minimisation of the amount of waste being produced:
- Recovery of valuable materials:
- Reduction of costs and increase profit:
- Planning for waste minimisation and management:
- Prevention/reduction of fly-tipping

This SWMP allows the industry to be more sustainable as well as cost effective. This throughout its value chain and in addition it discourages construction firms who do not comply through strict penalties. These can be from up to 50,000 £ for a summary conviction and an unlimited fine on conviction.

The whole value chain is part of the SWMP including architects, project managers, suppliers, clients, waste managers and construction firms, who must all act accordingly.

The SWMP requires that a responsible person, who must be named and who will maintain the plan. Any transfer of responsibility should be recorded in the SWMP. A clear chain of responsibility that confirms ownership of elements within the SWMP also needs to be defined. The responsible person must:

- Define a chain of responsibility,
- Monitor the SWMP requirements of individual contracts,
- Ensure appropriate waste recovery and recycling at an authorised site,
- Inform everyone working on the site of their responsibilities,
- Agree to report back on progress,
- Identify any compliance issues.

According to the Basic SWMP plan, for projects between 300,000 and 500,000 £, all waste must be recorded according to European Waste Catalogue Codes. The licensed operators who remove waste must be named and a record made of all transfers and consignment notes and where the waste is being taken. In addition, this must be monitored throughout the construction phase and be updated as needed.

The Advanced SWMP, above 500,000 £, sees further that the projects have a formal review every 6 months, data is collected for auditing and monitoring, a record is kept of the types and quantities of waste and how these are treated i.e. reused or recycled. In addition a comparison needs to be made between actual and projected waste and within three months of the project completion date a report needs to be made on any deviation as well as an estimate on cost savings.

In a responsible SWMP all actors should know about their wastes and how these can be reduced and where if not possible be disposed. In doing this it needs to be clearly stipulated in the terms of contract how waste management and waste minimisation can be implemented. This however needs an early and integrated planning where designers are responsible for using standardised systems and sizes and must plan for waste minimisation as well as an efficient building site process. Other methods are a planning for a sustainable deconstruction.

The SWMP is regulated by the Environmental Agency and Local Authorities.

6.2 Deconstruction and recyclability

As mentioned above buildings and building sites are one of the major sources of waste. Deconstruction and recyclability of any building should thus be planned from the start. Designing for deconstruction also has a huge potential for the reduction of waste. The recyclable building is a concept just coming into trend that could make the urban mining of the future much easier. It means that the end-of-life deconstruction of the building is already taken into account in the design.

De-construction and recyclability is also a market changer in Europe. Companies have come to realise that if they designed their products in such a way as to enable easy recycling, it also made sense that they be the ones doing the recycling creating a cradle-to- cradle supply chain. As a result of this many construction firms in Europe have expanded their logistic departments to include that of reverse logistics creating an entire new sub-market.

Construction firms should thus take in two account, if not already in the call for bids for a sustainable construction, whether materials can be deconstructed or if they are constructed so that they are bonded and not recyclable. If the latter is the case they should then suggest alternatives to improve recyclability.

Construction processes must be revaluated and alternatives for techniques such as substance joining be reworked or alternatives such as mechanical fixing be proposed. The processes involved in dealing with the product/service when it has reached the end of its life, which might be during demolition or renovation for services, structural and cosmetic products like piping, wiring, lintels, windows and wall coverings or replacement for mechanical/electrical products like heating and ventilation, should also be taken into account. Materials should be chosen that are easy to modify in the future and so that demolition works can be undertaken with a minimum of waste. The use of modular components can aid this process. Construction firms should also play a part by understanding the complexities of this and a future recyclability of materials. Any building is a potential source of valuable building material at the end of its lifecycle. Some say even a possible material bank!

Note: not all bonded construction is not necessary unsustainable, for example if it must be used, reinforced concrete can be recycled with an average expenditure of effort.

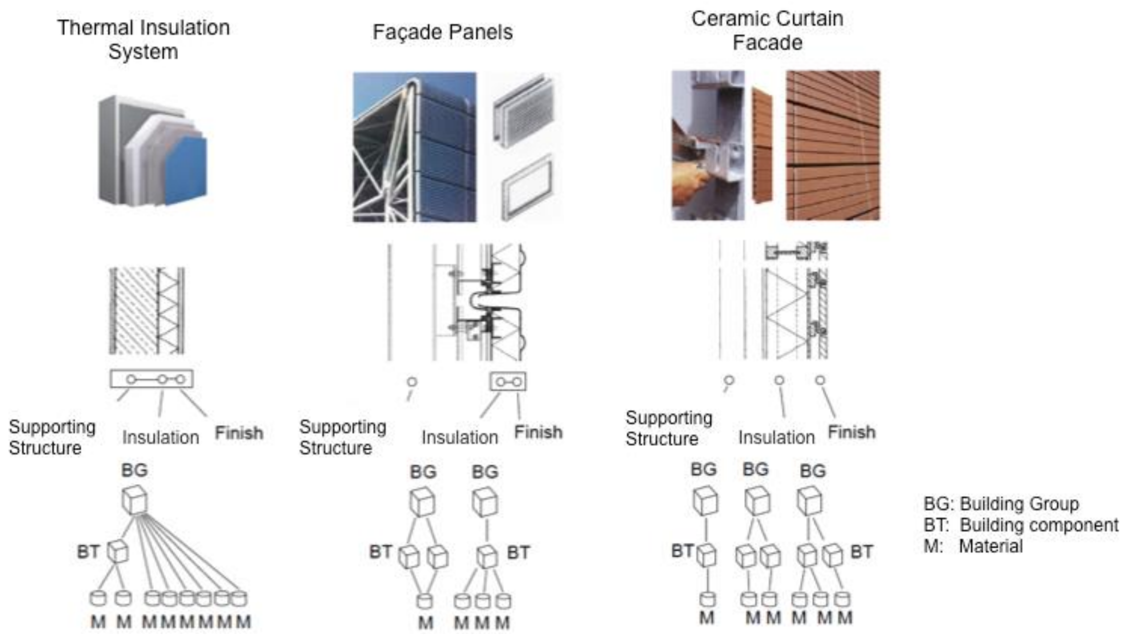

Figure 14: Building design for a sustainable deconstruction

Source: Valentin Brenner, ILEK Diplomarbeit 2010

Local planners and regulators also need take into account the availability of recycling and disposing facilities when encouraging or requiring selective demolition. Moreover, incentives to the construction sector are needed to expand their capacities and interest for using secondary materials. There is a need to better understand these dynamics to enable informed policy guidance

A building or a product's life usually spans several decades and consequently the end of life opportunities are likely to change, in terms of future regulation, market forces and treatment. To aid future recyclability or urban mining efforts, governments should set up monitoring mechanisms to keep track of which materials were contained in the building stock. This could include the creation of databases to help facilitate recycling activities, develop better norms and standards, and better disseminate best practices and routines. Such a database should include information about the material composition of the built environment to enable better material re-use, recycling, and refining. In addition buildings should have a compulsory resource inventory, which lists the amount and types of materials it contains, as well as the information necessary for their recovery.

Systems and tools, such as those provided by DGNB (an excel based tool), to evaluate and compare construction and construction techniques and their sustainability and recyclability should be developed to aid the construction firms.

6.2.1 Good practice example – Recycling by prefabrication company from Japan: Sekisui Heim

An interesting concept is that of the prefabrication company from Japan: Sekisui Heim. Sekisui Heim sells and guarantees that they buy back the buildings at the end of their lifecycle. These buildings are fully recyclable and are seen as a "Bank" for materials. This was only achieved through a full control of the building process. Constructed in the their prefabrication factories, waste is reduced, reused on-demand or connected to a recycling system. The buildings are all modular and can easily be set up and dismantled unit by unit by fasting or easing the joints of the steel frame units. The dismantled units are then either reused or dismantled in the companies own dismantling factory. Upon dismantling and inspection components are sold for use in further constructions. The buyers are matched with sellers though a web based platform. Such innovative processes offer opportunities for a highly efficient component circulation, reverses logistics and remanufacturing system and a more sustainable construction.

6.2.2 Good practice example - Case Study, The recyclable building

An example of a fully recyclable building is that of the R128 House in Germany. Located in the southern city of Stuttgart it was designed and built in 2000 by the German architect and engineer Werner Sobek. This building was designed pertaining to the „Triple Zero" concept of Werner Sobek's. This is a fully sustainable concept with the buildings built to be a Zero Energy, Zero Emission and Zero Waste.

Built on a small and steep piece of land, it is completely glazed and has no interior walls giving the user the impression that they are living in nature. The building also demonstrates resource light construction through the choice and use of materials as well as the innovative design needed to develop resource-efficient buildings. The building was built using an innovative modular design and a prefabricated construction. This allowed it not only to be built quickly but allows for a complete recycling. Columns and beams were bolted on-site and the floors were prefabricated plastic covered wood panels, placed between the beams without screws or bolts making the recyclability easier. The primary structure rests on 12 bolted steel columns linked by rails in two directions. The secondary structure is that of the triple-glazed windows of the façade. This system allowed for a reduction of materials used. All elements, load bearing and non-loading bearing as well as the façade are constructed either through screws or bolts and if not through other easy to separate connections. There was no plastering use and also no composite materials. This allows a complete deconstruction to the single elements. Designed to cleverly use passive solar gains the building is a zero-energy house generating all the energy it needs producing zero CO_2 emissions. Electricity is provided by photovoltaic cells.

Figure 15: West elevation of the R128 House

Source: UT Solar Decathlon 2009 Werner Sobek.

7 Training for sustainable construction

7.1 Training

Some of the most critical barriers on construction sites are those of deficits in the knowledge base, skills as well as social factors (e.g. risk averse attitudes in the construction sector and the lack of awareness). Sustainable construction is thus not only about enhanced research and technology supply, but also about the development of competencies, about an active knowledge and skills enhancement and about the creation of lead markets. A sustainable construction thus needs a trained and knowledgeable work force.

This is however, for various reasons, most often lacking. In most European countries, for example, there is a shortage of skilled building workers needed to meet the 2020 goals. To achieve the 2020 goals 3,9 and 4,6 million workers would require up-skilling on energy efficiency or renewable energy sources by 2020. On-site construction and product manufacturers will be confronted with the need for skilled labour, especially regarding near sustainable buildings, it thus requires new specialist skills and know-how. A future oriented training of the workers is thus not only for the SME but also for a country´s sustainable goals of utmost importance.

Training schemes need to address the issues of sustainable building as well as the transfer and cross-trade knowledge and skills. The training also needs to be adapted and constantly updated to the reflect the changing demands and technological evolution. For future reference proof of training should of course be documented.

For each building project, prior to the commencement of construction, a meeting should be held with all the relevant actors. Here all actors including sub-contractors need to be given the sustainability objectives and targets. This should be a detailed introduction covering all aspects. It is here that verification of the training of the building construction team should be made. If necessary it is recommended that further training is given to all actors so as to be able complete the tasks as needed (before the start of project). Carpenters and joiners, bricklayers and stonemasons and building electricians are the most frequently mentioned occupations identified as requiring additional training.

As the hiring of external consultants can be costly, the focus should be on the training of the construction companies own “resources”, their own current workforce. It will be cheaper, in the long term, for larger public construction firms to train their own employees, to tender innovative building solutions, rather than building a new workforce. However, this is most often not possible for sub-contractors. It is of utmost importance for contractors to aid sub-contractors in the training if they are not able to do this themselves. Contractors must come to realise that they too are responsible for the work of the sub-contractors. This can be done through the establishment of a long-term cooperation between the contractor and sub-contractor for example through a framework agreement.

In many countries and regions, there are also public or publicly funded organizations offering training and support in the areas of sustainable and energy-efficient construction and innovative tendering models. An example of this is the BUILD UP Skills Program in Europe. As a part of the European Commission's Energy Efficiency Plan and funded by the Intelligent Energy Europe (IEE) programme, it is a strategic European initiative to stimulate the training of craftspeople and other on-site workers in the building sector on the topics of energy efficiency and renewable energy.

Governments can also contribute to capacity building through the provision of vocational training, by creating municipal-level agencies for SME start-up development and management, such as “Enterprise Advice Bureaus”, and by encouraging SMEs to engage with large corporations.

7.1.1 Good Practice – Supply Chain Sustainability School

The UK Supply Chain Sustainability School, which offers a common and collaborative approach to addressing sustainability within the supply chain, is a partly publicly funded free virtual learning program with matched funding from industry, launched in 2012.

The aim of the program is to help construction suppliers and subcontractors develop their organisations' sustainability knowledge and competence.

Match Funding was provided by some of the industry's largest contractors and materials & equipment suppliers (Aggregate Industries, Kier, Lend Lease, Morgan Sindall,Sir Robert McAlpine, Skanska, Willmott Dixon), showing that the interest in the training of all actors in the construction phase, in sustainable building, is of great importance. The school is aimed, in part, at addressing the barriers that SMEs often do not have the resources to be able to address these issues.

The training gives the relevant actors a common approach as well as the tools needed for an understating and implementation of sustainable construction. It was designed to be used by any supplier or sub-contractor in the construction supply chain, regardless of company size, who want to develop their sustainability credentials and help to build a more sustainable supply chain for the industry.

The core training is through an online tool with bespoke e-learning modules and other web-based resources to suit a wide variety of requirements. It helps the relevant actor to assess their strengths and weaknesses and areas which can be developed through the tool. The school however offers face-to-face learning including regional supplier days and training workshops.

Since its start it already has 6,000 members, exceeding the original target of 800, with over three quarters of these from SMSEs.

7.1.2 Good Practice - Dual vocational training in Germany[5]

Vocational courses are single job-specific courses typically taught in high school career and technical education programs or technical colleges. Graduates of such training programs most often find jobs easier than comparable general education graduates at a similar level mostly due to the fact they are better skilled to the task at hand and thus are more relevant to the employers needs (Thompson 2013).

The Dual-Vocational System is a popular, well recognised qualification method in Germany. Germany has, in part due to this training, a higher than average proportion of persons with upper secondary level qualifications of 58.7%, the EU average being 46.6%. This is also in part due to the fact that, in many professions in Germany, it is recognised as a professional qualification by the relevant professional boards. These professions are called regulated professions. For example, medical professions, legal professions, teachers at state schools, public service professions as well as many professions in the construction industry are regulated.

With the demand for sustainable construction many construction vocational programs have also introduced sustainable green building content as core aspects of the training. High demand has also led to the creation of new training programmes specifically on sustainable and green building construction.

In total there are around 350 officially recognized dual-vocational training programmes. The German vocational training offers training in the basic areas of construction in:

- Civil Engineering (Underground)
- Civil Engineering (Above ground)
- Interiors and Finishings

In addition there are careers that are overlapping with the building industry, these being:

- Commercial Trades
- Trades involving Construction machines

Unlike pure vocational or other higher learning, a school leaving certificate is not a pre-requisite for a dual-vocational training as the requirements for the qualifications needed are made by the companies themselves. However, the better the qualifications the better the chance that a trainee might be taken by a company. (Note: Other forms of training in Germany

[5] https://berufenet.arbeitsagentur.de/berufenet/faces/index?path=null/reglementierteBerufe

such School-based vocational training or dual-vocational degree however require a school leaving degree or university entrance qualification respectively). Dual-training programs start either on the 1st of August or 1st of September each year to be able to take up the school leavers directly after the summer.

Depending on the training the time varies but last usually between two to three and half years. During this period the trainee spends either one to two days a week or blocks of several weeks at once at a vocational school (Berufsschule) for theoretical training with the rest consisting of practical on the job training. The rest of the time is spent with on-site training.

During the vocational training participants are paid for their work from the first day, during their on-the- job training, by the companies that they are working for. On average the salary is around 795 Euros gross[6]. This varies depending on region and training. Salary increases with every year further training. This of course, among other things, as the longer the trainee learns, as well as works for a company, the more productive they become. In addition holidays of up to 24 days are granted under the system, however these can only be taken in the vocational school holidays.

Examinations are held after the first half of the training as a learning control and proof of on the job skill learning. Further final exams are held at the end of the training.

At the end of the training the participants are fully qualified for their profession and around two thirds of all trainees are hired by the companies at which they do their training. This is due to the fact that both parties benefit from this schemes as both sides already know the other, their operation and the training has covered the needs of both parties. This prospect, of trainees being hired on completion of a vocational training, being very high is one of the reasons for its popularity in Germany[6]

[6] Cologne Institute for Economic Research,2007, Vocational Training in Germany, Cologne, Germany

8 Sustainable building construction costs and cost reduction

The cost of building materials and the competition for innovative building components are currently not considered strong incentives to eco-innovate. Yet as the sector with the largest material requirements, material costs are relevant to the construction sector. Indeed, around 73% of companies[7] have experienced increasing material costs over the last 5 years (increases were dramatic for 21% of companies) and 89% expect material cost increases in the coming 5 to 10 years. One can thus expect increasing efforts towards reducing material costs in the coming years.

Figure 16: Rising construction and building costs

In the past the lack of demand for eco-innovative buildings (user-investor dilemma) was seen as one of the strongest barriers to eco-innovation in the sector. This may be enhanced by split incentives between building owners and building users to invest in, for instance, energy-efficiency technologies with a long payback period (Schartinger 2010).

> *“Investing in buildings and infrastructure provides an opportunity to tackling the central challenges facing the global community: reigniting growth, creating and maintaining jobs, delivering on the Sustainable Development Goals and reducing climate risk in line with the Paris Agreement.”*
>
> Global Alliance for Buildings and Construction

Experts foresee that the situation regarding demand will improve in time; the relevance of this barrier is expected to decrease substantially in 2015 and 2030.

Rising energy prices, material costs and taxes on waste disposal are expected to be a driver of eco-innovation and thus promoting the use of sustainable and recycled materials and at the same time saving all actors unnecessary expenses.

Costs determine economic decision-making, but often in an imperfect way. Ideally, cost not only need to tell the 'ecological truth', but also need to capture other unwanted and indirect effects. Examples may include:

[7] eco-innovation observatory (2011): Resource-efficent construction.

- Building materials are relatively cheap, environmentally sound materials too expensive;
- Refurbishing is too expensive because it is labour-intensive and requires specific skills;
- Secondary materials / re-used construction materials are usually not competitive and faced with high volatility;
- Scarcity of materials for energy and resource-efficient technologies; here one needs to take into account the volatility of raw material prices that make rational expectations for future prices more difficult;
- Lack of financial incentive to invest specifically in eco-innovations. This may be due to a lack of investment support, tax advantages, public support, etc.

There has also been an overall trend towards the reduction in design and construction costs associated with sustainable building as building codes around the world become stricter, supply chains for green materials and technologies mature and the industry becomes more skilled at delivering sustainable buildings. This can be seen for example in Europe, where according to Eurobarometer, 86% of companies had introduced at least one change in the past 5 years to reduce material costs.

Research shows that sustainable building is not necessarily more expensive than conventional building techniques. This especially when cost strategies; program management and environmental strategies are integrated into the entire building process.

Sustainable building is a world driver - not a cost-driver

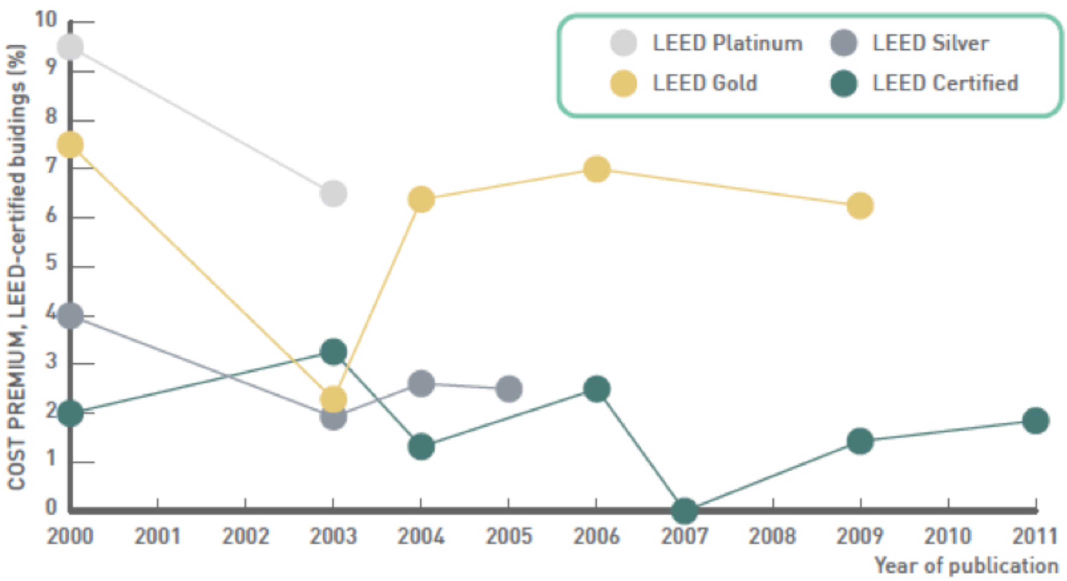

Figure 17: Reported cost premiums associated with LEED (in the USA)

Source: World Green Building Council (2013)

Sustainable buildings can now be delivered at a prices comparable to those of conventional buildings and the extra "sustainability" costs can be recouped through operational costs savings and, with the right design features, through more a more productive workplace. Sometimes the costs are even lower than that of conventional buildings. Even when there is a cost premium this not typically as high as perceived, which can be as high as 30%[8] more. In fact they have been documented, in research by the World Sustainable building Council, **Fehler!**

[8] Gomez, S. (2008). "Is the Client Willing to Pay to Occupy a Greener Building?" Improving Energy Efficiency in Commercial Buildings Conference.

Verweisquelle konnte nicht gefunden werden., to be in the range of -0.42 to 12.5%, (Note: the 12.5% in the study was for a zero carbon building with pilot character.) However the majority lies in the 0% to 4% range, of course with the highest certification this being higher, with ranges being from 0% to 10%. Additional costs, for construction, for DGNB certification are 0 to 4% (in comparison LEED lies at 0 to 7%). It must however be noted that these costs are offset by the decrease in long-term life cycle costs.

The increase in skills, tools and supply chain maturity have meant that the costs associated with achieving certification have decreased and will continue to decrease as sustainable building becomes more mainstream. It can also be clearly seen in **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.** that with the market maturity the prices decrease more and more.

On strange side effect seen in Europe is that a sustainably constructed building can take half the time to build, saving substantially on total building costs. In Lichtenberg for example the “Slimbouwen” (slim building) projects have not qualified for subsidies because they were too efficient to build.

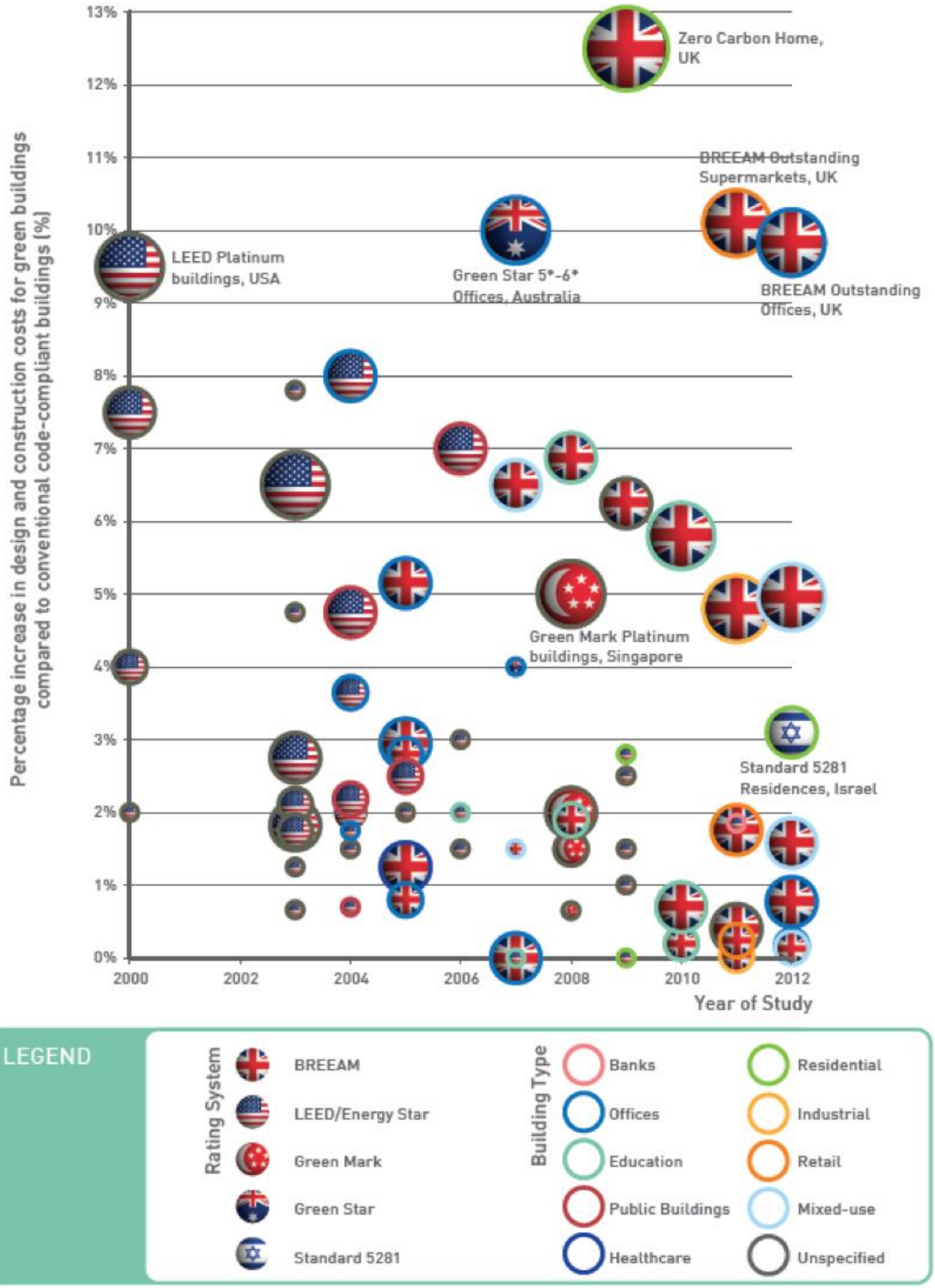

Figure 18: Reported cost premiums for sustainable buildings

Source: World Green Building Council (2013)

8.1 Design and planning phase

Cost-benefit analyses must be based on total costs including those not commonly associated with this such as noise and air quality pollution, and risks of project delay. However life-cycle costs cannot always be accurately calculated – bids should be informed by them, not based on them.

Sustainable green strategies should also be adopted in this phase and included them in the budget, to avoid more expensive bolt-on strategies at a later date.

8.2 Materials

In the design and planning phase as well as in the procurement and construction phases great influence can be made on the costs on the choice of materials and their sustainability. For example some materials, which are cheaper in the purchase, may not be sustainable as well as ecologically viable as their replacement cycle is so short that in the lifetime of the building they do not present a sustainable and economically viable alternative. However, according to the Eurobarometer study, prices for building materials are not considered strong incentives to innovate or to search for more environmentally friendly substitutes. This is however expected to change in the future as sustainable materials become for central in respect to the 2020, 2030 Sustainable Development Goals and 2050 Energy Roadmap 2050 goals of the European union.

Prices of sustainable materials are however coming down. This can be seen in LEED **Fehler! Verweisquelle konnte nicht gefunden werden.**, BRREAM **Fehler! Verweisquelle konnte nicht gefunden werden.** and Passive House studies that with market maturity the prices decrease more and more.

It is, however, extremely important than when sustainable materials are more expensive than conventional materials the life-cycle costs are closely analysed. More than often the life-cycle costs of sustainable materials are a lot more cost effective over the long run. This is a huge benefit for the building owner and user. Here a close cooperation is needed with the building developer/owner as they might be willing to pay a higher upfront cost for a long-term cost effective solution.

8.3 Construction phase

A sustainable integrated design process can also aid in the reduction of costs by streamlining the construction process making work more efficient and offering a cost-effective delivery of projects. This however means the right combination of actors. Care should be taken to hire the right sub-contractors and specialists as needed. Call backs and re-working takes time and uses extra resources, both costing more in the long run.

Materials and labour are sometimes purchased separately so that there is often no incentive for companies active in building to dramatically reduce costs. This seems to reflect poor mid- to long-term financial strategies of many actors within the construction industry and should be addressed.

Energy efficient technologies for building sites also hold a large potential for energy cost reduction. Innovation capacities of the construction industry to date have been lacking. This for example in that the industry has been particularly lagging in buying, developing and using more efficient technologies for their own use on construction sites despite the energy and cost saving potential.

The reduction of transport can also save money. Transport from local suppliers as well as just in time delivery and waste transport to local landfills can save enormous costs. The extraction sector for example has transport costs on average amounting to around 13 % of total costs, making the economical transport of materials limited to a maximum distance of around 35–50 kilometres (dependent on diesel prices). The same goes for the transport of wastes to landfills.

8.4 Recycling and waste reduction

Designing for a sustaible resoucre efficient building is also a cost effective strategy. Designing a product for ease of dismantling at its ‘end of life’ for example, could reduce manufacturing

costs through for example, reducing the number and variety of screws and other fastenings. Reduction of waste is also cost effective both from the perspective of reducing the loss of an investement already made and from the recdution of costs due to landfill fees and taxes.

8.5 Construction companies and their sustainable investments

In staying competitive, construction firms have an inherent incentive to gain price or quality advantages over their competitors. This is most commonly done through the improvement and streamlining of processes and enhancement of their services and products. This brings with if however certain risks, associated with for example the expenses for new technologies or for research and development ('sunk costs') as market success is uncertain

As a traditional conservative industry, construction companies tend to “wait and see” rather than be a “first mover” as they tend to benefit most from the pioneer's efforts in market development. This especially as expectations about future demand are real uncertainties and lack of consumer acceptance and awareness tend to promote this. However, construction companies, construction contractors and their sub-contractors cannot be top-tier companies in today’s business environment if they are not responding to the market’s demand for sustainable buildings and energy efficiency improvements.

Moreover, many sustainable practices, such as green and environmentally responsible construction site management, soil and run-off management, waste management handling and practices, etc. can only be carried out by construction companies who have prepared, trained and equipped themselves for this. With the change in the market demand to sustainable buildings, with its associated use of environmentally friendly materials and sustainable construction practices, so to will the demand for companies who can offer this rise. This especially with a higher customer satisfaction with higher quality and better completion times through the sustainable integrated construction process. Construction companies with sustainable construction practices will thus be more likely to be involved in a higher percentage of sustainable building projects due to the nature of their work. The contractor’s ability to bid for sustainable projects due to their know-how, for example through training, is a monetary benefit.

Sustainability has led some companies to increase profits through changing their business models by considering novel ways of delivering their products and services to more precisely meet customer needs. This being as simple as reducing the weight of a product (for example hollow floors) while maintaining functionality cutting the costs for materials as well as for transport. Another example of this is castellated steel beams which can use 25–50% less steel than traditional ‘I’ beams and reduce cost by an average of €44 per metre. Conversely, being able to offer a product with demonstrably improved environmental performance can also give increased competitive advantage where markets are experiencing growing expectation for “greener” products.

Implementing sustainable construction can seem daunting for construction companies but by understanding their role and how the four main areas of sustainability can be implemented and that the effort is only relative with many the benefits it is a clear win-win scenario for the implementation of sustainable construction practices

9 The sustainable construction phase

9.1 Relevant Actors and roles

The construction industry has a huge variation in the actors and their roles engaged in the building process. These work side by side, with a high rate of interdependency and complexity of tasks in varying collaborations for the duration of a project. This can be seen from the first acquisition of an appropriate building site through design and planning, construction, use phase and decommissioning. All are influenced by the incentives in the markets they operate, and respond to outer factors such the wishes of the developers, availability of materials, know-how of sub-contractors as well as to government regulation where it affects their activities. This is not different in a sustainable construction.

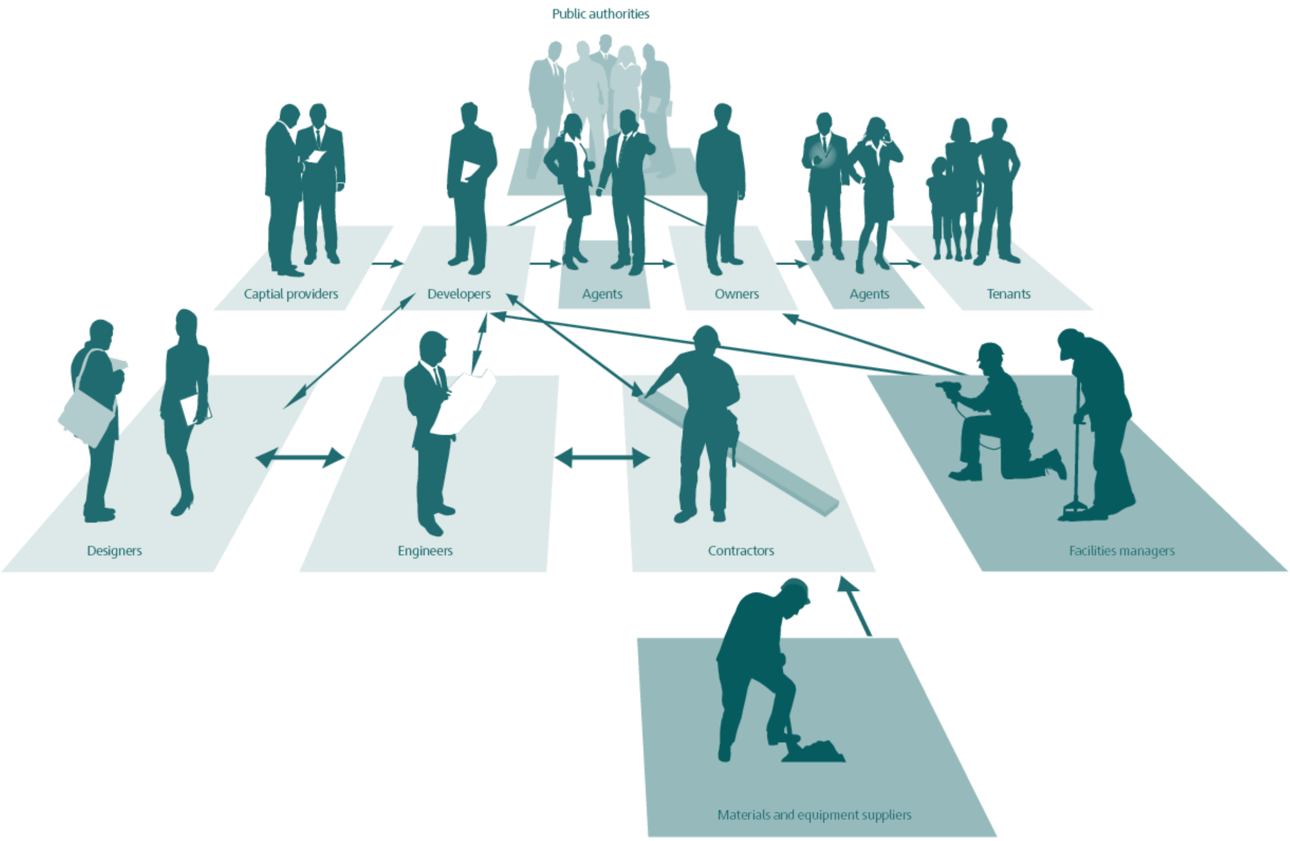

Figure 19: The most significant commercial relationships in the construction and building sector

Source: WBCSD, 2007

In most markets, the construction is carried out by the private sector, ranging from informal, micro-enterprises, small and medium enterprises (SMEs) to multinational companies. The market is however most defined by the amount of relatively small players in many discrete segments or specialties. Even the largest construction projects rely, to a large extent, on a myriad of small and medium enterprises (SMEs) as suppliers and subcontractors, contributing to aspects of the design, providing and transporting materials and offering specialist skills onsite.

These relationships are extremely complex and the interactions are constantly varying throughout the building process. Figure 19 shows a simplified schematic view of the main commercial relationships, illustrating the complexity of interaction between these stakeholders. All of these actors must work together on complex tasks and are highly interdependent of each other. This complex interaction is perhaps one of the greatest barriers to sustainability in the building supply chain. On many projects there is often a fragmentation of tasks, poor levels

of co-operation, lack of mutual respect, and lost opportunities for an optimum use of resources. This often due to a lack of alignment between the actors, each working with their own targets and motivations under pressure of deadlines and budget constraints. This often translates into conflicting priorities and motivations due to the lack of integration between the actors. In the long term it reinforces a tendency for short-term financial criteria to dominate decision-making.

It is thus paramount in any successful building project and more so in a sustainable building project to have an appropriate team with the right qualifications. A sustainable building construction needs an early involvement of all partners. An integrated team process should involve among others:

- Developers
    - Owner / Client
- Designer, Planners and Engineers
    - Architect
    - Landscape Architect
    - Engineers
    - Programmers
    - Interior Designer
- Contractors
    - Sub-Contractors
    - Specialists (Security, Telecom, Acoustics)
- Material & Equipment Suppliers
- Operations and Maintenance Personnel
- Other Stakeholders
    - Community Members
    - Real Estate Buyer
    - Tenants
- Others....

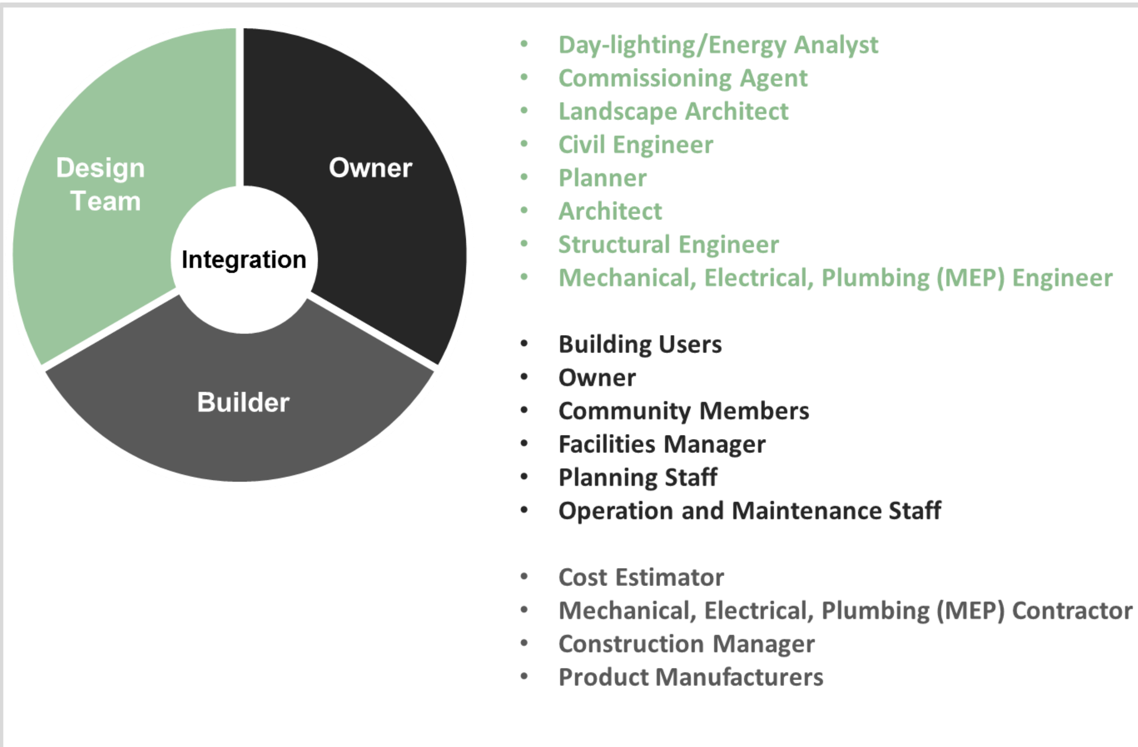

Figure 20: Overview of possible actors

Source: Guide to Integrated Design and Delivery

9.2 Sustainable building processes

Buildings need to be sustainably designed to achieve sustainable construction. Wherever possible best practice should be adopted whether this be tools, standards or processes. Of course, this needs a degree of flexibility for example, in that the sustainability concept allows new or alternative processes, tools, technologies and standards.

At the start of any construction project a robust sustainability concept should be developed which covers all aspects of the environmental, social and economic factors. A set of measurable and deliverable goals should be set. These must be embedded into the planning, procurement briefs, construction implementation as well as documentation. Goals can for example be:

- Reduction in emissions
- Reduction of energy consumption
- Minimisation of waste
- Use of local sustainable materials
- Recycling of materials and use of recycled materials
- Sustainable return of materials used to the natural material cycle
- Reduction of consumption of equipment resources
- Reduction of potable water use
- Avoidance of transport costs (of building materials and components used)
- Protection of natural spaces
- Space-saving construction

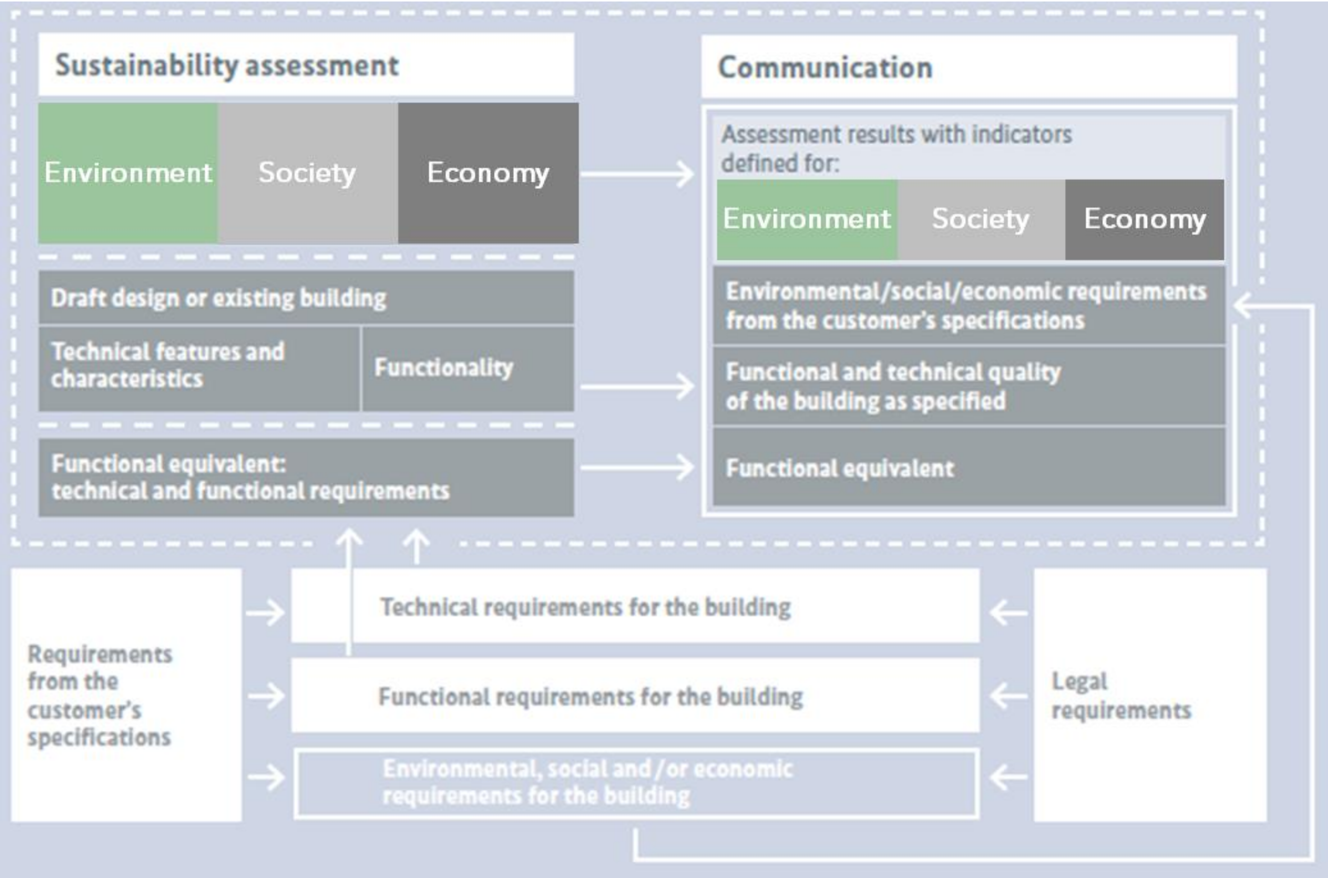

Figure 21: Flowchart of a sustainable building process

Source: BMUB (2016)

9.2.1 Prerequisite from other building phases - Design and planning

The design and planning stage holds the greatest potential for an influence and impact for a sustainable construction phase. It is also here that the most influence can be made in the costs of a project especially in terms of its sustainability.

Critical decisions made here ensure a sustainable building as well as a reduction of its environmental impact. This for example by deciding building materials to minimise impact, while considering aspects such as where do they come from, what are their production methods etc. reuse and recycling potential, disposal mechanisms etc. One example of this being where the choice of the structural system changes the amount of materials used as well as the energy (embodied energy) used in the construction.

If a high quality sustainable construction is to be achieved, it is strongly recommended, if not a prerequisite, that the contract is awarded to companies that have demonstrated their suitability in terms of reliability, expertise and performance. In starting a sustainable construction project qualified design and engineering consultants should thus be requested to submit request for proposals to offer design services through either public or private procurement policies.

On awarding of the contract design strategies should be formulated, by developing environmental objectives and relevant design strategies and assessing the feasibility and desirability of these. During the final planning phase, the targeted sustainability qualities must be described in as much detail as possible so that quality losses during tendering are kept to a minimum. After the lead designers finalize the conception design, all other consultants including architectural, building services, and structural engineers provide further technical specifications for the project. At this stage decisions are taken on key specifications for example, materials, finishes, systems, equipment etc. based on their quantities, capital costs and running costs etc. These specifications are finalised after multiple iterations to meet the project objectives before beginning construction on site.

An integration of construction firms should be also made as early as possible. Where possible already in the design and planning phase as it is here that sustainable materials and their their procurement, site planning, sustainable site operations and waste management and a future recyclability are best planned.

9.2.2 Start of Construction Phase

Construction activities, prior to the start of construction, begin with the mobilisation of all the necessary actors, materials and technologies. Here all the required contracts and arrangements, including procurement of most materials, equipment and services must be secured. Conventionally, construction would not begin until the greater part of the design and specifications have been completed, however, some aspects of design and specifications, for example, materials, finishes and equipment suppliers etc. are typically completed during the construction phase. At this early stage, designers and engineers may be consulting about design queries and amendments and changes in the tendering and procurement in finding the most sustainable path for the building construction.

Constructors will have sustainable standards and environmental product obligations as laid out in the tender and contract. This however is not necessarily down the value chain. Here there is a need for more communication, clearly defining sustainability goals especially with the subcontractors. Sustainable constructions processes must thus be clearly defined in order to meet these obligations on all levels. All processes need to be coordinated by the lead contractor, including that of material control and planning, efficiency of construction processes, waste management and plant and energy source selection. Where needed specialist contractors who are better suited for the work should be used. Wastage through mistakes and reworking by contractors not fully specialised lead to higher costs in the long run.

Procurement can then thus be used as a tool to guide and drive the goals.

Equally important is the use of appropriate control procedures to monitor and evaluate adherence to the given objectives and indicators. Thus to ensure that the sustainable planning is implemented, whereby the generally higher requirements of sustainable concepts also require further quality control measures. In addition to the control of the applied building materials and

their corresponding declaration, the execution qualities (e.g. air-tightness, design of the insulation) must also be monitored with suitable measures.

The promotion of innovation should not end with the signing of the contract. Incentives for ongoing improvements and innovations during the contract period by the contractors should be included in the clauses of the building contracts. Some examples being:

- Set bonus payments for (over) achievement of key indicators (e.g. energy efficiency, use of recycled products, waste reduction, and transportation),
- Include a profit-sharing clause, which allows contracting authorities and subcontractors to benefit on savings on the planned costs,
- Establish an “Innovation Fund " in contracts where savings through innovation (e.g. LED lighting) are equally shared between contractor and sub-contractor,
- Provide options for contract renewals for innovative planning change,
- Include a "technology renewal clause" in the contract that obliges the company to periodically renew old technologies or with the introduction of new technologies. Of course within reasonable economical payback times,
- Promote best available technology, to switch to energy efficient and sustainable technologies. This can be linked to bonus payments or penalties to ensure that the application of the best available technology is guaranteed from the start of the project.

Supplier Relationship Management is also becoming increasingly important for sustainable construction. Contractors who build long-term relationships with suppliers encourage them to develop and implement materials and innovative technologies.

9.2.3 Sustainable materials and material procurement

Unless guided by developer policies laid out in the tender, the lead contractor selects material & equipment suppliers to meet the design specifications; decisions which directly impact on resource sustainability. Decisions pertaining to materials and processes that are not necessarily used in the construction of the building but only to aid the construction process such as the selection of formworks, material control and planning, efficiency of construction processes, construction site and waste management, energy source selection etc. are taken by the lead contractor. They may not always be optimal or cause an impact to the environment unless, guided by the sustainable policies of the developer.

The environmental impacts of material and technologies chosen should be assessed throughout the product/service lifecycle. Independent material certification and Eco-labels as well as sourcing certification helps to aid this and can be used to specify requirements. Suppliers should however be given the opportunity to prove, via other means, that the materials and technologies to be supplied meet the environmental criteria in the tender documents. This could be through test reports or information provided by the manufacturer.

During the specification process, construction products must be specified with a view to their use – based on the requirements from the standardised or approved ratings and classes – and in detail with a view to their environmental and health-related properties. Standard EN 15804: ‘Sustainability of construction works – Environmental Product Declarations - Core rules for the product category of construction products’ offers guidance for the harmonisation of tools and methods in ensuring selection and procuring materials with minimum life cycle impact.

Some non-architectural materials are typically specified during the construction stage, including plasterboard and formworks (e.g. timber). These too must be included in a resource efficient and sustainable construction site as well as in the procurement of materials.

The procurement process and supply chains of construction materials are often complex and are sometimes international in their scope resulting in higher risk of negative social, economic and environmental impacts. Therefore, selection and procurement of construction materials affects embodied energy of buildings as well as the life cycle impacts.

It is also important to consider the credentials of the manufacturers and suppliers. Most large European construction businesses, retailers, utility companies, public authorities and governmental organisations require their suppliers and sub-contractors to demonstrate that they are

managing their environmental impacts. For example, there are a number of certification and accreditation schemes for the responsible sourcing of materials, such as Forestry Stewardship Council for timber.

Purchases of materials should be so that delivery is just in time for the required building phase. This saves space on the building site which would for example could otherwise be left untouched or in its natural state. It also helps to reduce the danger of site contamination as well as damage or spoilage to the materials themselves. Materials stored on site such wood or textiles could for example be damaged or spoilt due to their long storage here. One benefit of just-in-time delivery is the economic benefit for the cash flow within the construction process.

Good Practice example of sustainable material procurement

Skanska one of the world´s largest construction firms, which sees itself as a leader in sustainability, requires that all suppliers and sub-contractors adhere to their sustainability vision and requirements for a sustainable construction. All products, materials and technologies must be sourced or produced according to these requirements. They go so far as that they “will only do business with responsible suppliers and subcontractors who understand the nature of the products, materials and services they are supplying, and who recognise their responsibility to protect the environment…”. [9]

9.2.4 Optimisation of the interaction between trades

A smooth construction process is often hampered by disparity between the subcontractor’s goals and the goals of a stable sustainable construction process for the project as a whole. This is often made worse as the work flows, especially between the trades, are difficult to describe and depict in a transparent manner.

All project actors should have an understanding of the project, its sustainability goals and that fact that this is a key driver. Studies have shown that work flow can be improved by providing both process and product visualization directly on site for all actors. This should show how the maintenance of work flow stability can be maintained, enable the negotiation and commitment between teams, encourage and support a lean production planning, with sophisticated pull flow control, as well as how to implement effective communication. Supporting documents, standards etc. should be provided to provide clear guidance and the monitoring as well possible the possible penalties on non-compliance be made clear and laid out in the contracts as well as procurement documents.

An example of a poor interaction between trades is that of envelope insulation. Here a poor communication between the insulator, painter and plasterer can lead to insulation boards not laid on joint (but with gaping joints). This then can lead to defects and structural damage and presents a heat bridge leading to mould formation, heat losses, penetration of moisture increased, increased heating costs. At the end of the day the general contractor is responsible for this and need to rework the façade. It leads thus not only to a loss for the contractor but to the developer/owner, as well being unsustainable due increase in materials and energy.

An optimisation of the interaction between the trades call also lead to sustainable practices such just-in-time purchase and delivery of materials for the required building stage. This reduces delays and thus costs in a project.

An example of an appropriate tool to address the interaction between the trades is that of the use of BIM which provides a powerful platform for visualizing work flow in control systems that also enable pull flow and deeper collaboration between teams on and off site.

9.2.5 Waste reduction

One of the most important factors contributing for a sustainable construction phase lie in the reduction of waste, noise, dust, soil and water protection and emission reduction as well opti-

[9] Source: EDECON, Eco-design for the construction industry, South Hampton, United Kingdom

misation of material use as well as the use sustainable material. (For more detailed information see Chapter 6 Construction and demolition waste management and recycling)

9.2.6 Quality Control

Quality control is needed to implement the sustainable goals which were set out already in the design and planning phase. In setting the goals an excellent monitoring and audit process is needed through appropriate tools. Self assessment tools which are recognised and well tested help to make this process easier. The monitoring as well as the strategy and tools should be clear and transparent (For more detailed information see Chapter 5 Quality Control during the construction phase)

9.2.7 Completion of the construction Phase

The construction stage can only be considered (conditionally) finished and the site handed back to the developer after the issue of a certificate of completion by the contractor, following appropriate inspections, commissioning and testing. Following this there is a period of defects liability, within which any defects are rectified and thereafter a final certificate is issued indicating the completion of the construction works. The certificate is often accompanied by the building or O&M manual. Such documentation on a sustainable building site is a must. It shows that the project has met the requirements as laid out by standards, norms and the building developer/owners wishes as well containing the schedule of tasks for operation and further maintenance.

9.3 Optimisation of the sustainable building process

9.3.1 Integrated Sustainable Design process

Building construction is a complex process, this process is further complicated in green and energy efficient buildings and even more so when the entire building phase of a building is to be made more green and energy efficient. Traditional, and conventional, design-bid-build contracts bring with them many shortcomings including:

- Projects take longer to complete since all the design work needs to be finalized before the contractor is procured.
- Knowledge is lost in the hand-offs between project phases.
- Different firms and individuals enter projects at different phases and take responsibility for only what falls in their area of expertise or responsibility
- Adversarial relationships develop because separate contracts create competing incentives for team members.
- Any cost savings from selecting contractors based on the lowest bid are offset by extra costs incurred in change orders, construction rework, litigation, or reduced quality.
- Performance outcomes in terms of energy and water efficiency and occupant comfort fall far short of what is cost-effectively achievable.

An integrated sustainable design process answers these shortcomings and can be seen as paramount in achieving this sustainable construction phase. The integrated design process considers building components and sub-systems collectively, along with their potential interactions, to achieve synergies. Here it is fundamental to understand that the core to whole building' design is that all building systems are interdependent.

This integrated design process is a deviation from the typical planning and design process of relying on various actors, such as the expertise of specialists, who work somewhat isolated from each other. It requires relevant actors be involved as early as possible.

Before delving into pre-design, integrated projects begin with a kick-off meeting to explore values. Such a meeting may last several hours or even several days, depending on the size and complexity of the project, but the team members must explore the values that underlie the project and agree in their alignment to them. It is here that a review of the each actors roles and responsibilities before construction should be made.

All important building processes and building technologies uses must be studied in regard to their material resource and energy consumption and interlinkages, if necessary back to the design and planning stages. It is only then that an optimised planning and management of the building phase can be implemented.

The requirements for a sustainable building must be recorded in all tenders and contracts and must be binding to ensure utmost quality on building sites.

Every project is unique and so the importance of each of those issues will be different. But one design element should never become the sole driving force behind a project or it will fail to meet its 'holistic' objectives in the short- and long-term.

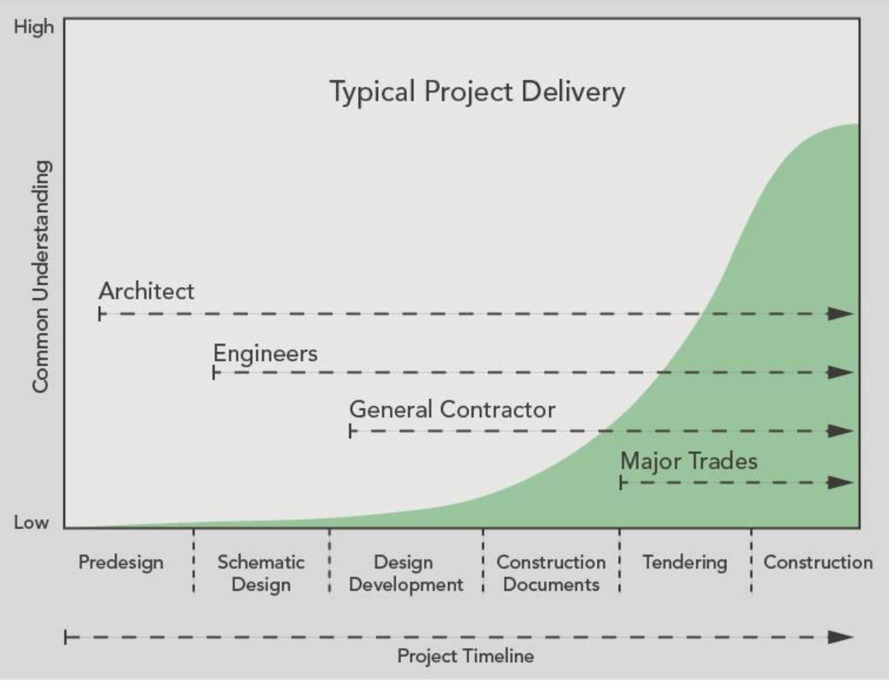

Figure 22: Typical project Design and Delivery

Source: CEC (2015)

Quite some effort is needed to maintain the necessary high level of collaboration in an integrated team. Optimising the planning workflow is the basis for implementing sustainable buildings. In the integrated design and delivery approach owners or developers play a critical role in the integrated design and delivery by adhering to this approach from the project outset. It is essential that the project owner becomes a team member from the pre-design phase. The owner takes a more active role beginning with the team selection, by being open to a new business models and associated increased capital costs, and constantly engages with the project team. This spares the architect the responsibility of controlling communication with the owner and instead the architect coordinates with the contractor and educates the whole team about the significant and interconnectedness of design decisions.

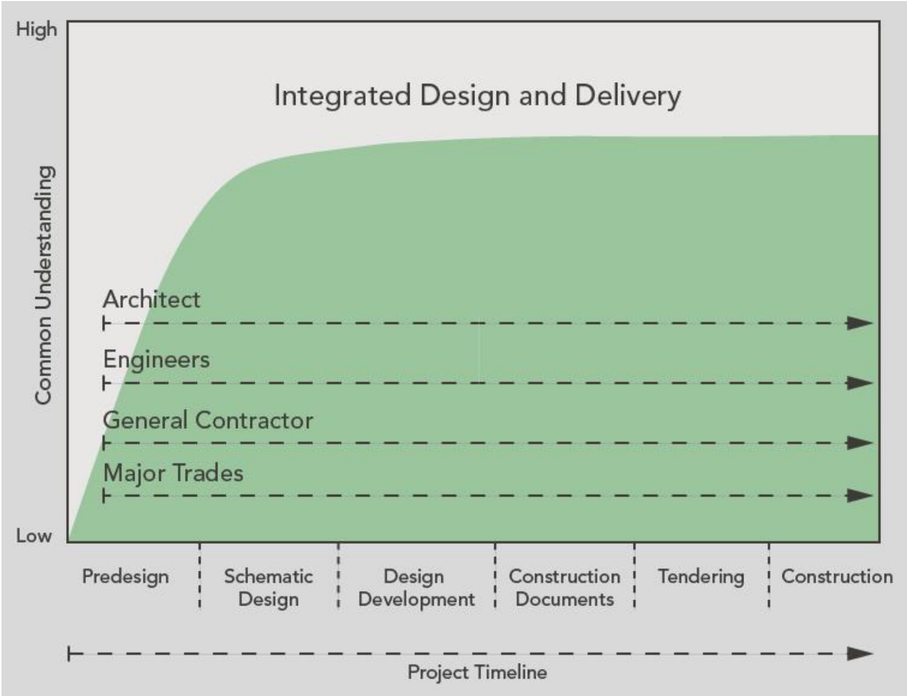

Figure 23: Integrated Design and Delivery

Source: CEC (2015)

The general contractor is also usually selected early in the design process to provide inputs on cost, constructability, engage in alignment workshops etc.. This to understand and meet the expectations during design and thereby avoiding any major changes during construction. Integrated design requires a high level of detail and this early integration helps to ensure this. This also saves time and frustration down the line during construction.

In addition to the architect and general contractor, it is also important to involve the services of different trades required early in the design process. Tradespeople can often, from experience, point out the errors in details by looking at the architectural drawings. By involving them from early on in the design process helps to incorporate any required changes to the design, ensure completion of construction documents so that all tradesmen begin construction with a full understanding of the installations. A study estimated that this can save 7 to 11% of construction costs through the prevention of rework and delays.

Figure 24: Tools for an integrated sustainable construction process

Source: World Economic Forum (2016)

A project facilitator or project manager may be employed for the length of the project to improve and sustain the collaboration between different stakeholders. Standard operation procedures should also be established to provide a continuous feedback loop to reduce changes and to avoid unnecessary delays, which ultimately cuts costs. The bigger and less experienced the team, the more intensive and hands-on the facilitation has to be.

Designers and builders come with various levels of skill and experience in collaborative work. Where necessary an on-going coaching, facilitation, and support are essential to maintaining a high-functioning team.

9.3.1.1 Good practise example - Lean Construction

Lean/Integrated Project Delivery (Lean/IPD) is a response to address construction labour efficiency/productivity, which has been falling since the 1960s. At present, 70% of projects are over budget and delivered late. Lean/IPD has been derived from the lean manufacturing principles with emphasis on value for the customer, controlled flow process, and perfection, pioneered by Toyota. This process encourages collaboration and offers an entry point and synergies with the integrated design and delivery process.

To that end, many Lean practices could be useful tools in an integrated project: The Last Planner® System consists of layers of increasingly detailed schedules that help effect a more reliable production schedule during construction, created by "collaborative pull scheduling;" Just-in-time Delivery offers a system that minimizes materials waste and storage problems; and Root Cause Analysis offers a collaborative problem-solving tool. These tools and more may all be incorporated into the construction process, but a focus on early alignment and participatory input in early design are still needed to ensure that they are successful.

Lean Construction has since been developed as a production management approach with trademarked techniques to maximize value and minimize waste in construction, through organizations such as the Lean Construction Institute

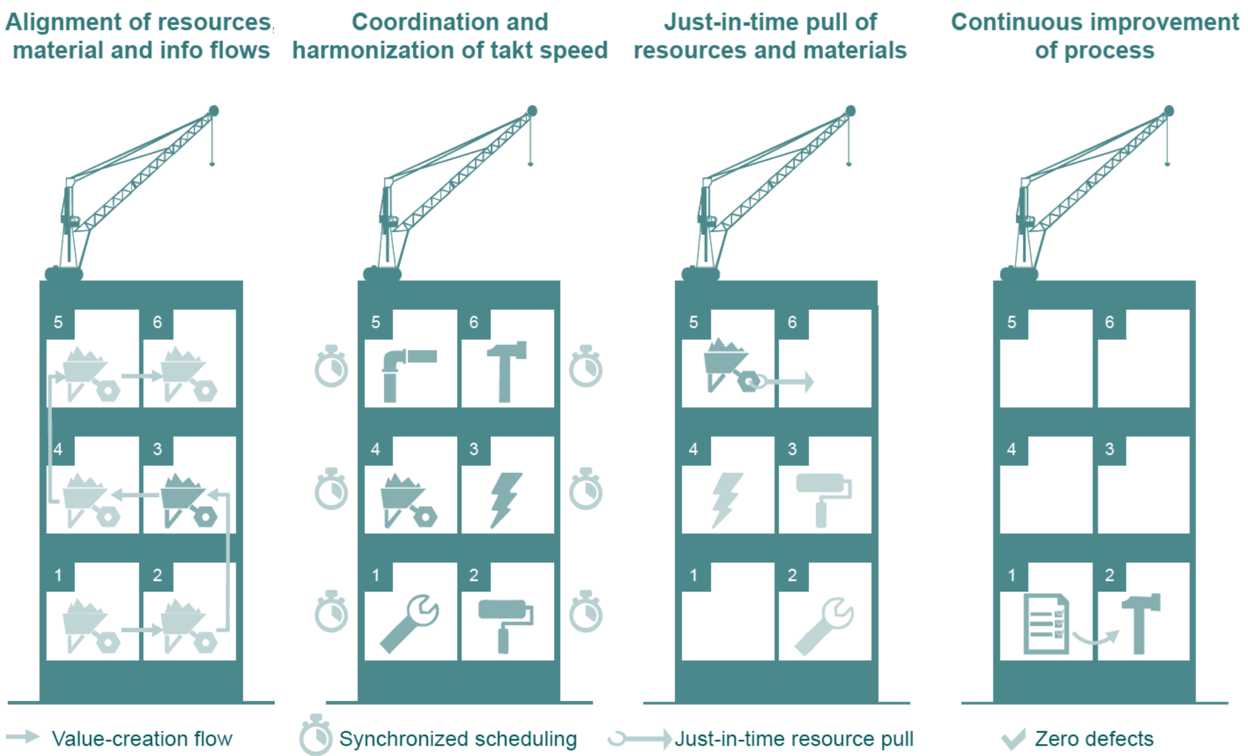

Figure 25: Steps of a lean construction phase

Source: World Economic Forum (2016)

9.3.2 9.3.2 Pre-fabrication and Industrialized construction

Construction is one of the few industries that to date still uses a singular component approach in its implementation. Other industries, such as the automobile, have converted to an industrialized style of fabrication and production. This is mainly due to the fact that buildings for the most part are bespoke in design, each one unique.

> *Industrialised building has been defined as "a building technology where modern systematized methods of design, production planning and control as well as mechanised and automated manufacture are applied"*
>
> International Council for Research and Innovation in Building and Construction

The traditional construction industry is very conservative with poor diffusion of knowledge and adoption and application of innovative sustainable building techniques. A change is however needed in the industry as the largest group of actors, defined by MSEs and MMEs, do not readily find motivation towards industrialisation and the associated resource efficiency and sustainability.

However, a higher level of industrialisation brings with it multiple benefits such as resource savings and productivity, efficient cooperation, reduction of waste, minimizing occupational health hazards, enhance rate of construction and methodological demolition. This, with higher ecological and economical savings.

New technological advances are also already pushing this sector into the main stream. Advances in ICT, robotic and intelligence are creating more efficient options for customization. Combined with digitalisation it is the path to a full Construction 4.0, the fourth industrial revolution, offering economical and resource efficient construction.

Pre-fabrication and industrialized construction has already be seen on building sites with mechanization of parts of the on-site construction process and the prefabrication of building components. It however does not necessarily mean mass production of pre-fab construction elements, but can be the application of technologies in construction processes that become increasingly mechanized and automatized. It could also be the strategy of the automobile industry where locally-based factories integrated into a distributed and flexible factory network can deliver pre-fabricated bespoke components just on time

These new advances are also helping to break the monotony that surrounds the prefabricated construction by offering ease of customization and implementation. Products can be designed to suit customization and aimed at user-centred innovations.

It is expected that in the future pre-fabrication and industrialisation will bring about a radical change in the building industry with sustainable economical buildings with flexible designs, ease of construction and deconstruction and remanufacturing, all built in a fraction of the time as previously done – as seen in other industrialised sectors.

9.3.3 BIM in the sustainable building construction – Road to Construction 4.0

Even with diverse sustainable building standards and tools the tracking of a sustainable construction is still lacking. In current design, construction and facility management tools do not provide enough information on the building, its components and materials as well as the possibility to analyse these. Traditional methods require a huge human resource consumption, which renders this costly and time-consuming. Owners for example face several challenges when trying to contain costs and deliver on schedule. Over 60% of major capital programs fail to meet cost and schedule targets. 30% of construction cost is rework. 55% of maintenance remains reactive. Building Information Management (BIM) offers a tool that can alleviate this problem. The use of BIM is also the first step towards Construction 4.0, the fourth industrial revolution, bringing with it a sustainable, industrialised and digitised building industry.

BIM is a "digital representation of the physical and functional properties of a building that provides information about the building as a unified knowledge base, providing a reliable basis for decision-making throughout the lifecycle, from early planning to demolition." With BIM, a digital model of the building can be passed from the architect to the contractor and then to the owner or operator, without loss of information.

BIM offers the developers, architects and engineers the possibility to have a virtual model containing all relevant information on a building and its environmental, economic performance among other things.

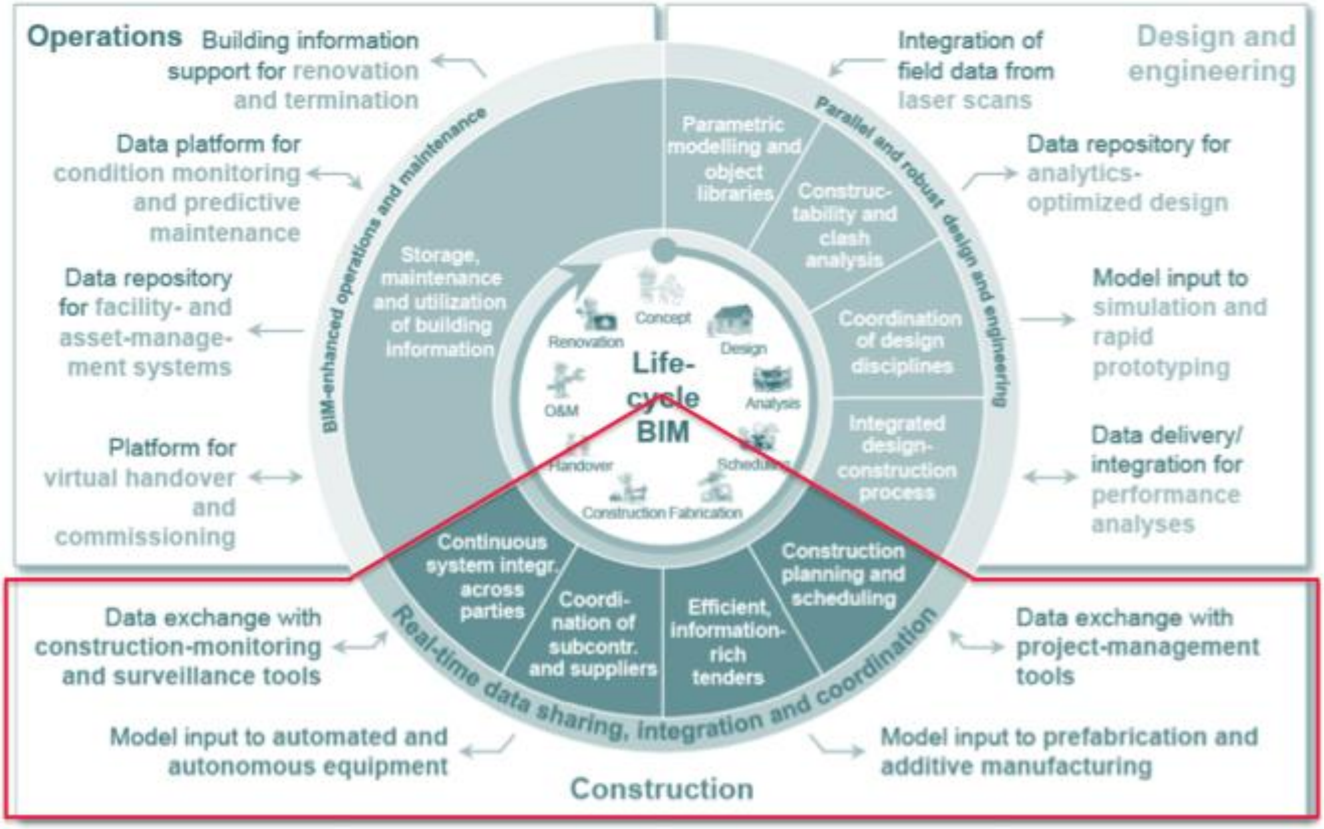

Figure 26: Uses of BIM in the construction phase

Source: World Economic Forum (2016)

This allows a quick and efficient tool to aim in the development of an appropriate building and monitor it throughout it various phases. It addition, it allows for an analyst of the feasibility of a project, which helps to design structures that reduce waste and optimise energy use. It also allows an appropriate planning giving the relevant actors the possibility to evaluate sustainable alternatives to those originally planned i.e. through use of different materials. Just in time planning is also greatly improved by being able to create accurate scheduling timetables and calculate, and ultimately reduce, the costs of a building project. The interoperable nature of BIM aids in the collaboration and communication amongst the relevant actors and provides information required by a manager throughout each phase of the building's life cycle. It also can optimise overall construction time by highlighting bottlenecks and site constraints during construction work.

The costs and cost effectiveness, as well as the LCA ,of a building can also be easily calculated using BIM and can be dynamically updated during the relevant phases. Bailey et al. (2008) reported that integration of BIM within the process may not only reduce design and documentation time, but can minimise the effort, time, and money required during the various construction phases. In France it was estimated by contractors that BIM achieved a faster approval time and permit issuing and at the same time a reduced construction time. According to a 2007 Stanford study, BIM provides an estimated 40 % reduction in unbudgeted changes, provides cost estimates within 3 % of traditional estimates but generating the estimate 80 % faster, results in contract savings up to 10 % with the use of clash detection, and reduces project time by 7 % [10]. A study by McGraw-Hill Construction (2014)[11] showed that 97% of all contractors using

[10] CIFE. 2007. VDC USE in 2007: Significant value, dramatic growth, and apparent business opportunity. Center for Integrated Facility Engineering Technical Report #TR171.

[11] McGraw-Hill Construction (2014): Smart Market Report: Green BIM, The Business Value of BIM for Construction in Major Global Markets

BIM in Germany have a positive return on this investment. The largest percentage even estimated that the return of investment was between 10% to 25.

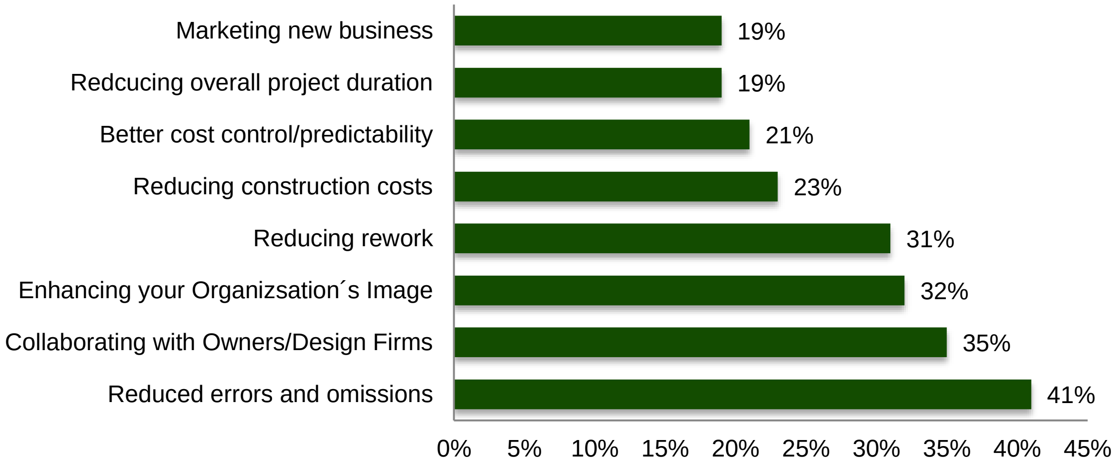

Figure 27: Contractors citing the benefits of BIM

Source: McGraw-Hill Construction (2014)

The ability to label and sort model objects by status is required when design information is instantly available to site. Digital signatures need to be sorted to approve models being issued to site. Laser scanning for example integrated with BIM offers a greater accuracy on building sites and control of the building process. Coordination of project work can also be improved through the scanning of building elements resulting in a correct delivery and that on time. An example of this is complex ductwork that can be pre-planned, pre-fabricated and the correct elements delivered on-site and in-time for their relevant implementation/construction.

Model driven prefabrication also stands to benefit greatly from BIM. This accelerating the modular building industry and at the same time keeping costs low yet allowing for a greater variation of module types and at the same time optimizing material usage and reducing material waste. It also allows constructors to manufacture and build more complex assemblies as easy as standardized products.

Through better coordination of processes onsite energy efficiency on building sites can also be reduced.

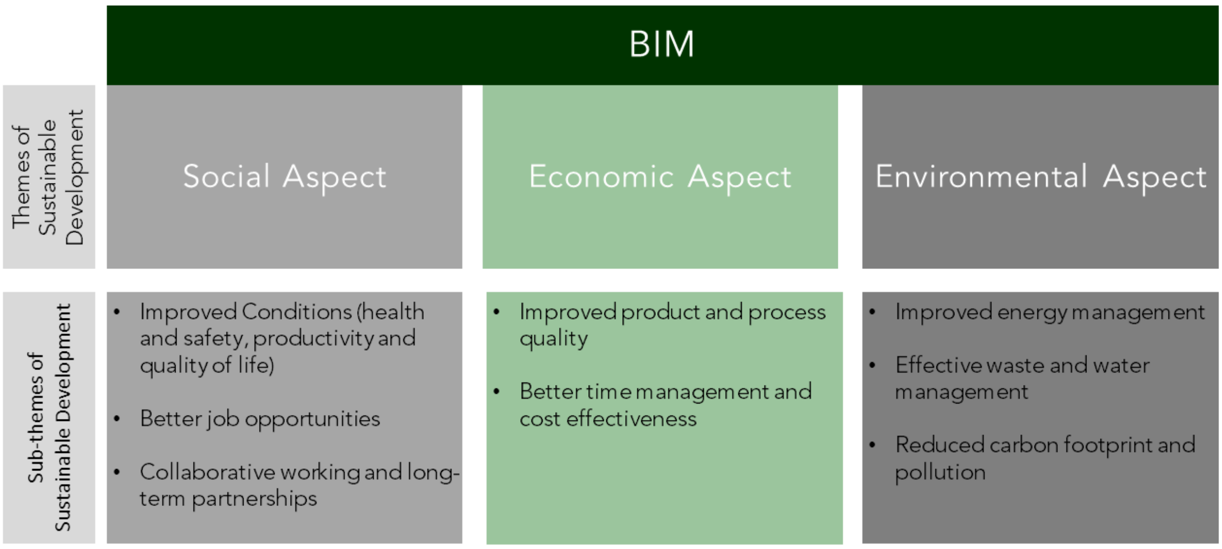

Figure 28: The influence of BIM on sustainable development

BIM offers the possibility for waste reduction through tracking of any changes as well as use of materials but more importantly gives exact amounts of materials needed and thus influences the ordering of materials.

An unexpected benefit of BIM is that of a better safety on the building site. Due to an integrated planning, delivery on time and improved business processes and it is estimated that safety on building sites is positively impacted.

BIM is also a method that is increasingly being used in Europe. In the EC Science for Environment Policy Brief on BIM (2012) it was recommended that in order to improve the sustainability of building projects, that design and construction professionals would benefit from more education about the potential benefits of BIM use and steps should be taken to improve information exchange. There is however great room for improvement; in one study it was found that contractors and those engaged in design-build projects saw BIM as an effective tool to help improve sustainability. It was however not the case for architects and respondents from companies engaged in the traditional method for project delivery, with separate entities for the design and construction phases. Industry customs also weigh heavily and need to be recognized when enforcing ambitious BIM requirements in procurement of small subcontractors. Therefore, in order to improve the sustainability of building projects, the study suggested that design and construction professionals would benefit from more education about the potential benefits of BIM use and steps should be taken to improve information exchange

Nevertheless the use of practical tools such as BIM should thus be promoted to aid the sustainable construction process. This by assisting professionals (such as architects, designers, consultants) in predicting the outcome(s) of a building before construction to minimise its impact on the environment throughout its lifecycle. BIM based software tools can support sustainable design and export building information and data related to materials, room volumes, furthermore, into sustainable building extensible markup language (gbXML) and Industry Foundation Classes (IFC).

Note: The Sustainable building XML schema (gbXML) is an open schema developed to facilitate transfer of building data stored in Building Information Models (BIM) to engineering analysis tools

It is thus a life cycle decision-making tool and supply collaboration throughout all phases, improve construction and procurement processes and aid project and later facility management. Actors using BIM find it particularly useful for sustainable and sustainable building construction. According to McGraw-Hill Construction[12] 27% of BIM practitioners see BIM as highly applicable for use in green retrofits.

9.3.3.1 Good Practice Example - New Karolinska Hospital

The New Karolinska Solna (NKS) Hospital is a hospital located in Stockholm Sweden. It is considered to be the world’s largest public-private partnerships, involving an overall investment of $3.0 billion (including $1.6 billion for construction). Construction started in 2010 and is expected to be completed by 2017.

In addition to the core hospital building, the project includes a parking garage, re-search building, technology building (to handle the energy supply and deliveries for the hospital), cancer treatment (radiation building), as well as new roads connecting the buildings and an entrance to a new subway station. On completion, the hospital – will cover 320,000 square metres – and will have over 12,000 rooms, 35 operating theatres and 17 magnetic resonance imaging (MRI) units. Located in the north of Stockholm, the integrated hospital and research complex will then contribute crucially to the development of the new Hagastaden neighbourhood.

[12] McGraw-Hill Construction (2010): Smart Market Report: Green BIM, How Building Informaiton Modeling is Contributing to Green Design and Construction

Figure 29: The New Karolinska Hospital during construction

Source: World Economic Forum (2017)

The hospital is and was under considerable public as well as medial scrutiny due to the significant public investment and the institution's global reputation. As a result, all parties involved are under considerable pressure to complete the project on time and on budget. To complicate matters, construction had to take place without disrupting the normal operations of the old Karolinska University Hospital and the research-focused Karolinska Institute, which are located nearby. Meeting the relevant noise, dust and traffic level requirements for example was no easy task.

BIM was contractually mandated in the project agreement for both design and facility management. The hospital intends to use an advanced BIM across the entire lifecycle, not only for design but for its facility management in the operation phase as well as for a future deconstruction. The integrated building process made an excellent communication and coordination a priority. At peak more than 300 designers were working full time on the project and almost 2000 workers were on site. For better coordination and communication a link between the 3D Model and the Database was used for storage of the hand over document. This enabled the actors to „click" an object and access the relevant documents. The BIM model is linked to an environmental library, with all relevant information about all materials used in the building; it expedited environmental certification, and it can track materials for future replacement. Ownership of design information was not an issue.

Care was taken that even the small contractors and sub-contractors were involved from the start in BIM. Suppliers and sub-contractors were educated on the benefits of BIM and provided training courses to enable them to use it effectively. Where needed further training was provided by the main contractor. In addition personal was rotated across countries, projects and project phases to enhance knowledge transfer. This ensured a close integrated building process.

The whole project was carried out from a sustainability perspective. The construction process was carefully detailed planning for sustainability. Prioritisation was made for the use of locally produced, recycled and low-emission materials as well as FSC-certified wood. In addition the construction waste was systematically analysed with the aim to reduce it to zero. In 2010, only 5% went to landfill through on-Site crushing for recycling of building waste. Hybrid and lower-emission trucks were also used to further reduce emissions.

The building achieved a LEED Gold as well as Swedish Green Label Gold award.

The lessons learned from the New Karolinska Hospital included:

- Rotate personal across countries, projects and project phases to enhance knowledge transfer
- Deploy BIM across the project´s entire lifecycle and its stakeholders to maximise benefits
- Educate suppliers and sub-contractors on the benefits of BIM and provide training courses to enable them to use it effectively
- Ownership of design information was not an issue.
- IT infrastructure requirements needs to be properly investigated before project start.
- Design exchange formats need to be properly tested.
- Use of models on site have exploded with new hardware. Usage is sometimes hard to predict.
- Ability to label and sort model objects by status is required when design information is being instantly available to site. Digital signatures need to be sorted to approve models being issued to site.
- Define content of as-built model. Do we really need to asset code/model ”everything”?.
- A broad and sweeping contractual requirement is harder to enforce throughout the project.
- Do not underestimate the many ”small” design-build contractors. How will their deliveries be included in the BIM model?
- Industry customs weigh heavily and need to be recognized when enforcing ambitious BIM requirements in procurement of small subcontractors.
- Facility Management usage for the as built model put much higher requirements on level of detail and accuracy. New methods needed, eg. laser scanning.
- Long project deliveries requires a neutral interface and generic objects.

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