

## EMBODIED ENERGY IN FAÇADE DESIGN

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**This article gives a short introduction to the recent development of sustainability in the built environment and shows the potential of embodied energy to reduce the impact this sector has on nature. The applications of ecological information are introduced and commented on according to their potential. An excerpt of strategies is given at the end.**

### **Sustainability in the built environment**

In the last millennia mankind has learned to cultivate the broad variety of resources nature offers. The dimension of consumption increased with the industrialization and interfered with a stable system, thus causing change, which is unpredictable, irreversible and potentially constrains the living standard society has reached. While the massive influence on nature took place in the last three hundred years, consciousness about that effect developed in the second half of last century. In the past fifty years, politically and socially motivated environmentalism has become a new focus.

The growing respect for nature and its integration into decision-making processes on different levels (individual, industrial, political) are stimulated by various aspects. Extreme weather conditions, increasing energy prices and the subsequent energy revolution have raised a new awareness for nature, which shows the dependence on a well-functioning ecosystem. The social pressure has now reached a level at which the industry has to react with ecologically friendly products. Transported by media, the topic of environmental protection has been widely discussed. Today's society is well informed about the reciprocal effect of consumption and environmental impact. Hence, environmentalism has become a marketing topic.

Today this increased sensitivity for nature is evident in everyday life. The building industry is affected in a special way since it deals with half the global resources and is responsible for more than the half of the global waste. Additionally, the emission and land use contribute essentially immensely to the impact mankind has on nature. Three

groups of parameters navigate the amount of environmental impact in the constructive context. The energy and emissions used for transportation, operational energy and the energy bound in the building substance, the so-called embodied energy.

Legal regulations in the building sector define minimum standards for operating energy consumption, and thereby control the use of natural resources. The building industry became increasingly aware of this correlation in the last 50 years and reacted on different levels. The respect for nature originates from a political left oriented group, while the oil crisis made it tangible for the broader population, and the IPCC report illustrated the urgency of reducing emissions. The building sector reacted with regulation on passive heat loss and limited the amount of energy to operate a building. Beginning in the 70s, the regulation became stricter over time so that now architects and planners are facing the introduction of the 2010/31/EU directive in 2020, which requires all new constructions to be nearly zero energy buildings. While today 30 years of operational energy equal the energy for the construction and demolition (assuming EnEV 2007 standard and massive construction method), this ratio will drastically change when nearly zero energy is used to operate the building. Including the ecological performance of the building substance is increasingly becoming a part of common practise. The green building certificates consider embodied energy and support its application. This tendency will develop substantially in the next decades. When a building regularly generates a high level of comfort with nearly zero energy, the building material will define the ecological quality of buildings!

### **Embodied energy as a potential to optimize the relation of built and natural environment**

Apart from turning resources into energy carriers, processing resources into building components offers a hitherto mostly ignored potential for climate protection. Since energy is needed for every step of the production chain, (for example to make bricks from clay,) this energy must flow into a holistic consideration. The sum of all amounts of energy used in the production process yields the ecological footprint of a product. While operating energy exclusively relates to the utilizations phase, embodied energy includes the energy needed for the production and deconstruction phases. Linking both amounts of energy allows for a holistic examination of the ecological potential in the building sector.

Calculating embodied energy is done on the basis of a Life Cycle Analysis (LCA). This method is based on ISO 14040 and ISO 14044, which regulate the framework, define terms and the calculation procedure. The goal of a LCA is to identify and analyze the environmental impact resulting from the production all the way to the disposal of a particular product. It consists of a compilation and assessment of the input and output influences, and potential environmental impact of a product system throughout its entire life cycle. Depending on the life cycle impact assessment model, the indicators vary. In the building industry the factors most frequently considered are embodied energy in mega joule and global warming potential in kilogram CO<sub>2</sub> equivalent. This quantification serves to indicate the environmental impact. The use of embodied energy aims at the comparison of solutions in order to identify a more or less ecologically beneficial solution. It does not serve to define absolute judgement.

The instrument LCA can identify potential by comparing different variations against each other and determine the one with the most beneficial qualities. This helps to understand the relation between planning decisions and environmental impact. Naming solutions with the lowest amount of embodied energy helps to optimize the usage of resources and to limit the amount of emission as often resource consumption and emission pollution correlate. The design, the construction method and the materialization influence the amount of embodied energy spent for a building and each phase offers a potential to optimize this. In order to exploit the building substance's potential, embodied energy has become a relevant parameter in the architectural planning process.

### **The relevance of the facade**

A building requires resources and emits gases during all life stages. The erection includes the materials, which form the building substance. The operational energy uses resources as energy carrier to generate heat and electricity for a high level of comfort. Additionally, in this phase materials are exchanged or repaired, which is part of the building's maintenance. The demolition process requires effort to deconstruct and demolish the building substance. Some of the materials can be reused or recycled. This can have a positive effect on the consumption of primary resources of the next material cycle and helps to reduce the waste amount.

The distribution of embodied energy for building elements differs with each building. Generally speaking, the structure bounds most of the energy, as it is the heaviest building element. LCA works mass-related. Hence,

with mass the embodied energy increases. The difference between a concrete and steel structure is not significant and so the optimization potential is limited. The façade contributes around one third of the amount of embodied energy (again generally speaking). The essential difference to the other building elements lies in its variety. The broad possibilities of massive, skeleton, rear or modular façade and the materialization with natural stone, wood elements, metal sheets or synthetic materials influence the embodied energy essentially. Here lies a significant potential that when utilised strategically, contributes not only to a contemporary perception of architecture, but can reduce the environmental load the building sector bears today.

Following this thought, it is not only a duty to reduce the natural impairment but an architectural challenge to generate a high level of quality with what is withdrawn from nature. This relation between expended energy and generated quality defines sustainable solutions. It imperatively emphasises the exploitation of the qualitative potential, which is the drive of architects and is filled with content by each planner individually.

### **LCA application in the building industry**

For non-LCA professionals, information on embodied energy for construction material is available in different formats. The information can be accessed on material-basis for example in Environmental Product Declaration EPDs or in a compilation of LCA results in form of a database. It can be part of interactive database or Building information modelling BIM.

**Single material-based LCA information – Environmental product declaration according to ISO 14025:** Material-based LCA express ecological information related to one kilogram, one cubic metre or one square metre of material. Generally, one document contains information about one product or product group. For the material-based LCA information the Type III label *Environmental Product Declaration* EPD is of special relevance as it presents ecological information on a reliable and readable basis. (The definition Type III follows the ISO 14025.)

LCA is designed to compare different solutions against each other and to identify the one with the least ecological impact. In order to do so, the investigation of the ecological impact has to have the same basis. The same phases have to be assessed, the same system borders have to be chosen and the same processes need to be in- or excluded. In order to generate a fair comparison, *Product Category Rules* (PCR) regulate these

parameters for each product category group. The structure and content is regulated in ISO 14025. The PCRs are developed by the institutes, which issue the certification in cooperation with industry partners. The content of a PCR is displayed in the box below. (Figure 1) The application of the PCRs helps increase the comparability and, as a result, has supported the acceptance of LCA data.

EPD was introduced by the Swedish *environdec*, after which several European institutes followed (Marino 2012). The *German Institute Construction and Environment e. V.* (IBU) published EPDs in over 20 categories relating to the building sector (Peters 2012). Companies can approach an institute like IBU or *environdec*. The IBU requires an LCA conducted with the Software GaBi or Simapro. If a PCR is available, the LCA will be conducted according to that, if not, a PCR will be developed. The institute itself does not carry out the LCA itself but is the holder of the certificate. An external reviewer is required to check the compliance the ISO 14040 and the PCR. By doing so, the ISO 14025 criteria third party review is fulfilled. Currently in the Netherlands the MRPI, along with others, is developing guidelines according to the ISO 14025 and prEN15804 (introduced in the following) standards for conduction an EPD.

The aim of an EPD is described as the following: «*present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function*». (Labelling” 2006) With EPD based on the ISO 14025 a format was introduced that communicates the amount of resource and energy used in the production of a product. The main element is the presentation of LCA results for products in a condensed and readable format.

A product is assessed by volume, mass or area. LCA results for products are displayed along with other physical properties. The EPD has a descriptive character and does neither judge the results nor translate them into a benchmark system. In the last two decades the demand for EPD increased significantly because EPDs deliver a relevant input for material criteria the Type I building certificates.

Even more reliability is achieved with the *EN 15804:2012 Sustainability of construction works-environmental product declaration- core rules for the production category rules of construction products*. It regulates PCR for products in the building context. It defines more precisely the parameter of the rules. An essential part is the adoption to the phases of a building product's life cycle. The norm considers production, construction, usage, end of life stage as well the benefits and loads for the next product system (Figure 2).

<i>PCR content</i>	
1	Product definition
2	Base materials
3	Manufacturing of the product
4	Product processing
5	Condition when in use
6	Singular effects
7	End of life phase
8	Life cycle assessment
9	Evidence

**Fig. 1**  
Paragraphs of PCR

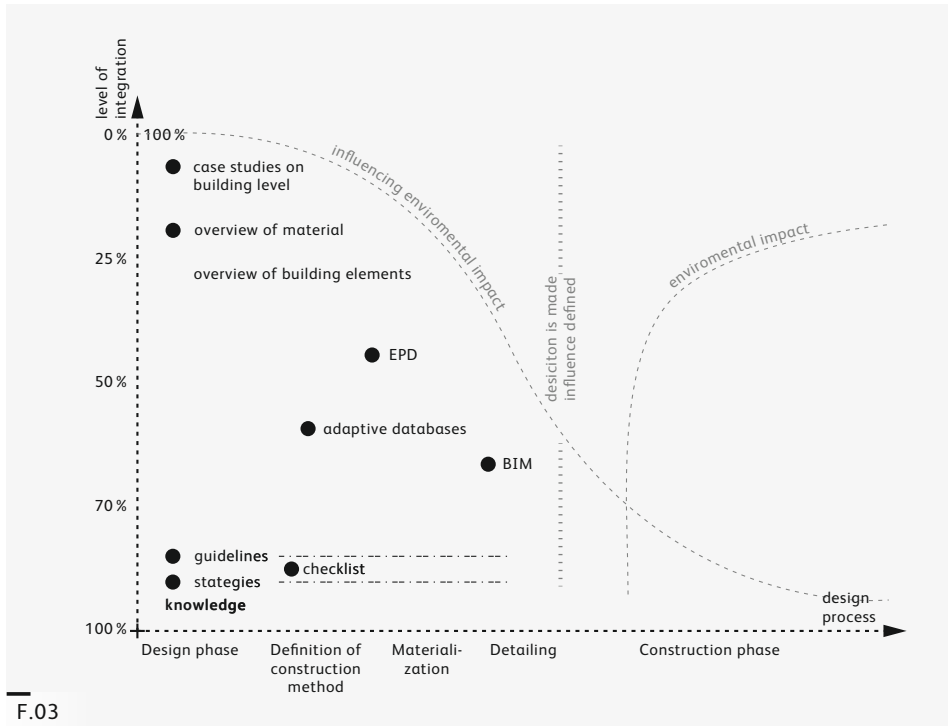
**Fig. 2**  
LCA phases according to EN 15804

<i>PCR phases according to EN 15804:2012</i>		cradle to gate	cradle to grave
<i>Production stage</i>	A1 raw material supply	mandatory	mandatory
	A2 transport		
	A3 manufacturing		
<i>Construction stage</i>	A4 transport	optional	
	A5 construction/installation process		
<i>Usage stage</i>	B1 use		
	B2 maintenance including transport		
	B3 repair and transport		
	B4 replacement including transport		
	B5 refurbishment including transport		
	B6 operational energy use		
	B7 operational water use		
<i>End of life stage</i>	C1 de-construction demolition		
	C2 transport		
	C3 re-use recycling		
	C4 final disposal		
<i>Benefits and loads for the next product system</i>	D re-use recovery and recycling potential		optional

**Databases:** A compilation of LCA data can be found in databases. A range of databases are available, some of them freely accessible. Several databases were published in XML-format, which offers the advantage of easy access without the necessity of software and a quick and sufficient overview. Material comparison on the bases of mass and volume can easily be made based on this type of information. Some databases contain LCA information from literature (for example the Inventory of Carbon & Energy conducted by Bath University or Econum, a compendium of Swiss data published by Econum GmbH) and others display assessment results. Researched databases have to be used with care since the background information is not always available and the calculation conditions might vary. Databases published by LCA conducting companies tend to give more information about the assessment, which makes the application more easily. The German Government offers several free databases available under [www.nachhaltigesbauen.de](http://www.nachhaltigesbauen.de), like *Wecobis* or *Ökobau.dat* (Kerz 2012). The *Ökobau.dat* was compiled by the LCA company *PE International* and published by the German Government in 2008. It is available as xml format and in so-called ILCD format, which the European Commission, Joint Research Centre defined. Both formats do not require professional software. While the database gives quick information, the ILCD file informs on included life phases, end of life scenarios and validity. This information is necessary to understand the origin and scope of the LCA data and helps the sufficient implementation.

**Interactive databases:** Interactive databases contain a database and a simple calculation web-based tool (with no software installation required.) The ecological impact of for example 1 m<sup>2</sup> façade can be calculate by the thickness of each layer. Different material for layers is provided. With very little effort different solutions can be compared with each other. The simple way of operating the interactive databases makes them interesting for a quick material comparison but the background information (data quality) needs to be transparent.

**Building information model BIM:** The software-based *Building information modelling* (BIM) organizes physical or financial information and relates its to the building substance. CAD developer like Autodesk included BIM in the software product Revit as well Computerwork in Vectorworks. The idea behind BIM is to save all the calculation but have them within the program. By this, changes can be implemented more easily. LCA data is



F.03

available as mass related so the software can easily include LCA information. BIM is a relatively young product and it has to overcome some beginner's obstacles like organisation of building elements in groups. While the concept sounds rather simple, the implementation of LCA data in BIM is not common yet.

A similar concept can be found in the planning software for façade construction. For example Wicona and Schüco use tools with integrated LCA of a façade product. BIM is very close to the planning process and requires a lot of planning information. Corrective planning follows the identification of critical planning decision. This iterative process can involve high effort.

**Overview:** From the architect's perspective ecological information about building materials is accessible but quite complex. The characteristics of the architectural planning process do not easily allow for the integration of additional information due to its permanent tight time schedule. Added parameters need to be very efficient in order to become part of the planning routine.

Ecological information is available on single material level, in the format of databases or integrated in CAD software. Like described earlier, they

**Fig. 3**  
Administrative building for Roche Diagnostics AG, 2008–11, Rotkreuz, Burckhardt Partners

impact the grade of environmental performance to different extent. *Figure 3* shows these various formats of LCA information and indicates the level of influence planning has on the actual environmental impact. Decisions in the early design phase are the most important ones. This decreases with proceeding planning phases since the steering possibilities become more limited. While general information, like published in case studies, is very interesting, practical information on ecological impact and sufficient planning advice is needed to become relevant for the planning process for example given in the guidelines and strategies.

### **Consequences for facade design**

The potential for the reduction of the environmental impact of the building sectors is evident when considering the resource flows which are controlled by the planning of the erection, operation and demolition of a building. Though information is available, it lacks integration into the architectural planning process. The architect and planner have to have the ecological parameter in the right planning phase in the appropriate form. Single information on material is not sufficient to become part of the planning routine. BIM includes an iterative process, which requires detailed planning for a corrective solution and by that a high planning effort. Architects and planners need to understand the embodied energy's mode of action. This contains different parameter for each planning phase. While the design phase defines the cubature and by that the façade area, the construction method determines the amount of material that will be installed. Additionally, the way of jointing is decided and by doing so, the possible end of life scenario. The environmental burden will increase with extensive material use. In the materialization phase the choice of material finalizes the amount of embodied energy.

Strategies and guidelines contain comprehensive knowledge in a simple format. The general character is appropriate for the uncertainties, which are typical for the design phase. Various interdependencies can be identified from the evaluation of LCA on product-, building element and building level. Here three important ones of mentioned.

- 1 The grade of sustainability is a relation which can be optimized in two direction: quality and environmental impact
- 2 LCA is mass based. With less material consumption the embodied energy figures decrease.
- 3 All phases of a material are relevant to address all environmental dimensions (resource consumption, emission and waste production)

**F.04**

In the design phase the cubature is defined and with this the amount of embodied energy in the building skin.



Especially for facade design the determined duration of a building should be reflected in the construction method. The shorter a façade will be used for, the less energy it should bind. In the planning process the end of life should be considered and functional advantages should be weighed against the potential reuse or recycling capabilities. The format of LCA data needs to be suitable for the architectural planning process in order to exploit the potential in optimizing resource consumption and limiting emission and waste production.

### References

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The broad variety of construction method and the materialization bear potential to realize high quality architecture with low embodied energy (Academy Mont-Cenis)



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