



# Sustainability of earth building materials – Environmental product declarations as an instrument of competition in building material industry

Horst Schroeder<sup>1</sup>, Manfred Lemke<sup>1</sup>

<sup>1</sup>Dachverband Lehm e.V. DVL, Weimar, Germany

## ABSTRACT

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The evaluation of the building process in terms of their environmental impact in all life cycle phases of a building leads to the key principle of sustainable building: the analysis of the life cycle of the materials used in a building. The goal of this analysis is to reduce waste and keep the environmental impact as low as possible by “closing” the cycle. During an inventory, the entire life cycle is assessed. This includes the sourcing and extracting of the raw material, the use of the raw material to produce building products, elements and structures, the use in finished buildings including emission of pollutants, decay and maintenance, and, finally, the demolition of the building and the recycling of the demolition materials. Transportation between the individual phases as well as production-related material and energy flows are also included in this evaluation.

Several European and national norms and regulations define core rules and a special instrument for the evaluation of the sustainable quality of a building product based on a quantitative analysis of the life cycle of the materials used in a building: the Environmental Product Declaration EPD. These documents are voluntary standards, commitments or guarantees for building products. They are provided by producers, organizations and quality assurance associations in order to establish the “environmental performance” of buildings in the form of a certificate. Such declarations must fully include all phases of the life cycle of a product by describing the environmental impact during production and use as well as possible health hazards for the users.

Until now, EPDs for earth building products do not exist. This paper will give current information about a project for developing EPDs for earth mortars and earth blocks started by the German Dachverband Lehm e.V. (DVL).

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## KEYWORDS

*Sustainability, environmental impact, building material industry*

## 1. SUSTAINABLE BUILDING

In the Brundtland Commission report to the United Nations World Commission on Environment and Development entitled "Our Common Future" (1987) the term "sustainability" was first used to describe a lasting development of humankind. Sustainable development ensures that it "meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNO, 1987).

The building process always has a more or less severe impact on natural resources and cycles. To apply the term "sustainability" to construction means that in all phases of the life of a building, and with respect to the users' requirements, the use of existing resources and the environmental impact need to be minimized. Traditionally, during the construction process, the main assessment focused on function and design, structural engineering, material technology and building practice. Today, the building process is increasingly seen as an optimization task where user demands and environmental requirements by the legislature need to be in harmony. Therefore, the term "sustainable development" comprises three aspects which must be considered as equals over an appropriated period of time (BMVBS, 2011):

- ecology,
- economy, and
- user demands (socio-cultural concerns / functional quality / health).

Additionally, all buildings constructed according to the requirements of sustainable building must meet predefined technical parameters and corresponding quality levels in terms of planning and construction for each of the three aspects. Ecological and economic aspects are better

defined as user demands. Several current EU-funded research projects are focused on the use stage of building materials. They intend to improve functional qualities and the impact on health of building materials, elements and structures by improved moisture buffering properties with clay as component in pre-fabricated elements (Thomson et al. 2015), reduced VOC (volatile organic compounds) emission and higher energy savings in use at lower costs [www.eco-see.eu, www.h-house-project.eu, www.isobioproject.eu].

In Germany, the general requirements placed on building materials and building elements with regard to their technical quality are regulated by the Model Building Code for the States of the Federal Republic of Germany (Musterbauordnung für die Länder der Bundesrepublik Deutschland - MBO). According to the MBO, building products, materials, elements and systems are produced for permanent installation in structures. "Building products are only to be used if the structures they are used in, along with proper maintenance over a time period which is proportionate to its purpose, meet the requirements of this law or are suitable for their intended use based on this law" (MBO, §3.2).

The MBO lists the following aspects as the main requirements for the building materials' and building elements' *suitability for use*:

- mechanical strength and stability,
- fire protection,
- hygiene, health and environmental protection,
- safety in use,
- sound insulation,
- energy conservation and heat insulation.

The Regulation of the European Parliament and of the Council for "Laying down harmonized

conditions for the marketing of construction products" published in March 2011 (Europäisches Parlament; Rat der Europäischen Union, 2011) introduces an additional requirement: *the sustainable use of natural resources*. According to the regulation, buildings must be designed, built and demolished after their use in a manner which facilitates the sustainable use of natural resources and guarantees the following:

- The building, its building materials and building elements need to be recyclable after demolition.
- The building must be durable.
- Environmentally friendly raw materials and secondary building materials must be used in the construction of the building.

This regulation also requires the national governments of the EU to apply principles of sustainable development to building activities in their respective countries. In order to establish sustainable development it is necessary to explicitly formulate *protection objectives* regarding the environment, economy and the users' interests. Examples of general protection objectives are the avoidance of harmful substances, a reduction in the use of energy as well as land and resources, and the prevention of waste through material recovery. Based on the knowledge of cause and effect relationships, *action strategies* need to be derived from the protection objectives. These strategies should target three levels: raw and building materials, building construction, and surroundings (Glücklich, 2005). The *effects* caused by the building process on these levels need to be described through indicators and by defining assessment standards.

Standards for the assessment of the sustainability of buildings in terms of their environmental,

social and economic qualities are specified in the DIN EN 15643 group of standards. Whereas the ISO 21929-1 international standard defines a framework for the development of indicators and for the compilation of core indicators for buildings, ISO 15392 formulates general principles for sustainable building.

## 2. THE LIFE CYCLE AND MATERIAL CYCLE OF A BUILDING

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The evaluation of the action strategies described above in terms of their environmental impact in all life cycle phases of a building leads to the key principle of sustainable building: the analysis of the life cycle of the materials used in a building. The goal of this analysis is to reduce waste and keep the environmental impact as low as possible by "closing" the cycle. During an inventory, the entire life cycle is assessed. This includes the sourcing and extracting of the raw material, the use of the material to produce building products, elements and structures, the use in the finished building including its indoor environmental properties, the life span with maintenance, and, finally, the demolition of the building and the recycling of the demolition materials. Transportation between the individual phases as well as production-related material and energy flows are also included in this evaluation. When passing through each phase of the life cycle the building material needs to meet the requirements of sustainable building defined in Chapter 1. These requirements are described with the help of relevant parameters which are determined through standardized testing procedures. For example, a building material needs to have adequate compressive strength to be suitable for load-bearing construction or proof low VOC (volatile organic compounds)

emission in use according to EN ISO 16000 et.al. Meeting the test criteria ensures that the required qualities for a certain life cycle phase have been attained after completing this stage. Only then is the building material or building element suitable for use.

Figure 1 shows the life cycle model for earth as a building material (Dachverband Lehm e.V., 2004) (Schroeder, 2016). After passing through each life cycle phase, the earthen material attains a new quality: raw soil becomes soil for construction; construction soil is processed into earth building materials etc. By reusing recycled earthen materials the life cycle becomes self-sustaining.

### 3. ENVIRONMENTAL MANAGEMENT AND LIFE CYCLE ASSESSMENT

Environmental management is part of the management system of an organization. It develops action strategies for environmental protection at the company level as well as the

official authority level in order to ensure the environmental compatibility of the products and processes developed by the company and its staff performance.

The term life cycle assessment describes the systematic, quantitative analysis of the environmental impact of products throughout their lives in the form of ecological assessment results. Here, "environmental impact" refers to the use of resources as well as the environmental effects of emissions at every phase in a product's lifetime. The results of the analysis make it possible to find measures for reducing the environmental impact or for comparing different products.

The life cycle assessment has become a generally accepted methodological approach for the quantitative evaluation of the sustainability of building materials and building products.

On a European level, the following standards for conducting a life cycle assessment are currently available:

DIN EN ISO 14040:2009-11 Environmental management - Life cycle assessment - Principles

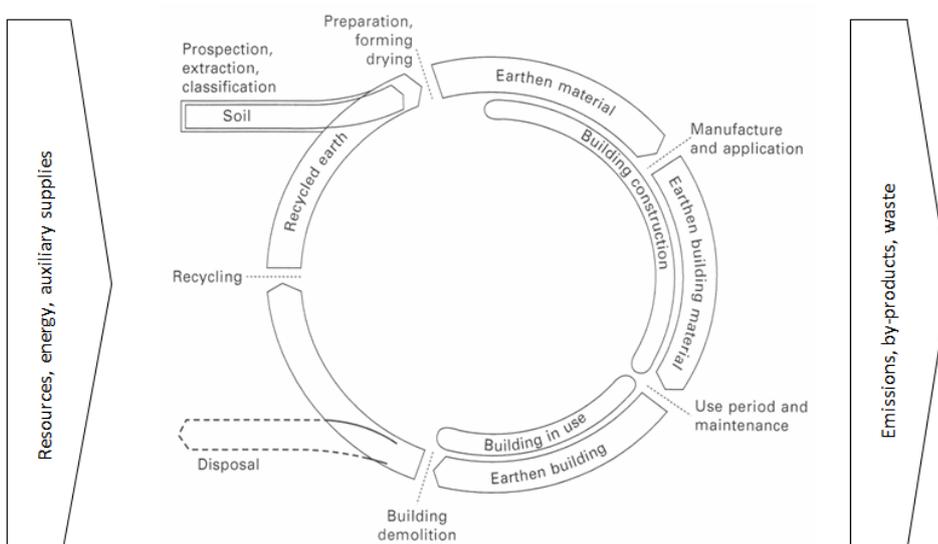


Figure 1.

Life cycle of earth as a building material (Dachverband Lehm e.V., 2004) (Schroeder, 2016)

and framework,  
DIN EN ISO 14044:2006-10 Environmental  
management - Life cycle assessment -  
Requirements and guidelines.

According to DIN EN ISO 14040 the life cycle assessment consists of four phases. These phases correspond to each other and cannot be viewed separately:

- defining goal and scope,
- life cycle inventory analysis,
- impact assessment,
- interpretation.

### 3.1 DEFINING GOAL AND SCOPE

A determination of the goal and scope must define the use and function of a product and its general life cycle from raw material sourcing to disposal. Figure 1 shows this cycle for earthen materials.

In terms of building materials and building products, this phase is used to select and define different material and construction options. To facilitate this process, so-called *functional units* are determined to serve as a reference (such as a quantity unit of a building material or a sample building as a product-specific size). The results of the analysis of the environmental impact can then refer to these functional units. Product units which are to be compared need to match exactly in terms of their functions. For example, render and plaster should be compared as kg per m<sup>2</sup> coverage and insulation material as m<sup>3</sup> needed per W/m<sup>2</sup>K.

At the beginning, the *system boundaries* need to be determined by deciding which indicators to include in the analysis and which to leave out. "From cradle to factory gate" and "from

cradle to grave" are typical examples of system boundaries. The selection of these indicators can influence the result of the life cycle assessment.

### 3.2 LIFE CYCLE INVENTORY ANALYSIS

During the life cycle inventory analysis phase the defined material and construction variations within the determined system boundaries are established for the relevant material and energy flows. The life cycle inventory analysis contains information on all relevant consumption of raw materials and energy, the kind and quantity of emissions and harmful substances and, if applicable, all quantities of waste generated throughout the entire lifetime of the materials and buildings. This initial information needs to be obtained from the manufacturer. The determined material quantities are linked with their environmental impact during the impact assessment phase. The life cycle inventory analysis itself does not include an evaluation. Collection of the required data can be very time-consuming unless existing databases can be used.

*Primary Energy Intensity*. The energy expenditure needed for the production of building materials including the production and transportation of the source materials is an important indicator for the selection of "ecological" building materials. This energy expenditure is called the "primary energy intensity" (PEI) and is mainly related to the system boundary "from cradle to factory gate". When it comes to meeting energy needs, the available energy includes renewable (e.g. biomass), inexhaustible (e.g. sun) and non-renewable (e.g. fossil fuels) sources. The supply of non-renewable energy sources is limited and they should, therefore, be used sparingly. When determining the PEI, the amount of non-

renewable energy sources is identified. This also makes the PEI a measurement for the environmental impact "use of energy resources" category.

Applied to traditional earth building, the manual processing of suitable excavation material into earth building materials and structures on the building site was and still is the ideal situation as far as the PEI is concerned. Particularly the fact that no transportation of the earth building material was required resulted in a PEI of practically zero.

Modern earth building, however, is largely mechanized and characterized by the physical separation of building material production and product use on the building site. This automatically leads to energy consumption and transportation. Long-distance transportation and the resulting high specific energy consumption have a negative impact on an ecological assessment of building materials, e.g. in the case of artificial drying. Tab. 1 shows the PEI for common modes of transport according to (Glücklich,2005):

Mode of transport	PEI [kWh/tkm]
Rail	0.43
Passenger car Western Europe	1.43
Truck 40 metric tons	0.72
Truck 28 metric tons	1.00
Truck 16 metric tons	1.45
Van < 3.5 metric tons	3.10
Cargo ship overseas	0.04
Cargo ship inland waterways	0.27

Table 1.

*Energy use of common modes of transport*

In terms of their PEI, earth building materials are still unrivaled compared to the main conventional building materials. This is even true when additives with a high embodied energy are used. A selection can be seen in Tab. 2 (Umweltbundesamt et al., 1982):

Building material	PEI [kWh/m <sup>3</sup> ]
Earth	0 - 30
Straw panels	5
Wood, domestic	300
Derived timber products	800 - 1,500
Fired bricks	500 - 900
Cement	1,700
Standard concrete	450 - 500
Sand-lime bricks	350
Sheet glass	15,000
Steel	63,000
Aluminum	195,000
Polyethylene PE	7,600 - 13,100
PVC	13,000

Table 2.

*Primary energy intensity for selected building materials*

*Cumulative energy demand.* The cumulative energy demand encompasses the energy demand of a building over its entire lifetime (system boundary "from cradle to grave"). According to VDI guideline 4600: 2012-01 it is estimated with the help of specific assumptions and scenarios. The corresponding environmental impacts are compared to this energy demand.

Frequently, the PEI of a building material or a building technique is only used for a comparative evaluation. A realistic assessment, however, needs to take all phases in the life of a building into consideration because the actual production of a building material and the construction of a

building represent relatively short time periods. Therefore, the advantage of a "low PEI" of an earth building material might come at the expense of the durability of the structure or a higher maintenance requirement. Insulating materials with a higher PEI can offset this "disadvantage" by reducing the required energy for heating, thereby lowering emissions for the entire lifetime of the building. In addition to the positive environmental impact, these materials can therefore also offer financial advantages to the owner. As a result, the determination of how long a building will be in use becomes an additional important system boundary which has an effect on the number of required maintenance cycles for the building element or material layers.

### 3.3 IMPACT ASSESSMENT

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In this phase, the material and energy flows collected during the life cycle inventory analysis are evaluated in terms of their environmental impact on the basis of selected indicators and defined system boundaries: The causes are compared to the impacts.

Currently, a number of computer programs containing databases of relevant values can be used for calculating the impact assessment. The data analysis must be carried out according to defined standards. The programs GaBi ([www.gabi-software.com](http://www.gabi-software.com)), EcoInvent ([www.ecoinvent.ch](http://www.ecoinvent.ch), approx. 4,500 data files) and WECOBIS ([www.wecobis.de](http://www.wecobis.de) of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) are examples of commonly used environmental databases. The latter has been available since January 2015. It is structured based on the criteria of DIN EN 15804 and currently contains approx. 1,300 data files which also cover earth plaster, earth blocks and rammed earth.

### 3.4 INTERPRETATION

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Depending on the specific situation, the final interpretation of the calculated results can be carried out in different ways, such as:

- a comparison of suggested design variations (preferred variation),
- ecological impact assessment (hazards),
- impact in relation to already existing environmental pollution.

Today, life cycle assessments are indispensable for environmental decision making, for example when trying to determine binding regulations for orders of magnitude for decreasing CO<sub>2</sub> emissions in relevant documents on an international level. Environmental goals can only be achieved if they are defined as guidelines in appropriate standards and regulations. This also includes product standards in the field of building materials. The technical information sheets "Technische Merkblätter 02 - 04" (Dachverband Lehm e.V, Tm 02, 2011), (Dachverband Lehm e.V, Tm 03, 2011) (Dachverband Lehm e.V, Tm 04, 2011) published in 2011 by the German Association for Building with Earth include a procedure for determining the CO<sub>2</sub>-equivalent value on the basis of DIN EN ISO 14040. Appropriate procedures have been included in DIN standards for earth blocks and earth mortars (DIN 18945 - 47) as optional tests (Appendix A). A life cycle assessment requires a significant effort during the planning stage as well as the willingness to add sustainable building concepts to conventional planning operations. Often, a lack of sufficient data poses a problem. Although the indicators mentioned above allow for a very detailed description of ecological impact categories, there are still harmful environmental effects which are generally known but, so far, have

not been able to be measured quantitatively. The reference accuracy of correlations for indicators which have already been defined also remains questionable. Finally, the reliability of the life cycle inventory data collected in the available environmental databases must be examined. This more or less limits the validity of each result. On the other hand, life cycle assessments are already a suitable tool for checking if seemingly feasible, ecologically founded arguments can hold up in reality. However, the necessary fundamentals and instruments need to be improved further.

### 3.5 ENVIRONMENTAL PRODUCT DECLARATIONS AND CERTIFICATION OF BUILDINGS

The life cycle analysis according to DIN EN ISO 14040 provides systematic and standardized data for recording energy demands and environmental consumption as well as their environmental impacts over the total life cycle of a building.

In addition, the *environmental performance* of a building according to the principles of sustainable building comprises its technical quality, functional aspects, socio-cultural criteria as well as location, e.g. transportation infrastructure. Finally, costs are an important consideration for the client. These aspects exceed a "pure" life cycle analysis.

Two instruments have been developed for analyzing the environmental performance of a building product:

- environmental labels / environmental declarations for *manufacturers* of building products,
- environmental building certificates for

*owners/clients.*

*Environmental Product Declarations.* Currently, three categories of environmental labeling are available to manufacturers of building products:

- Type I environmental labeling according to DIN EN ISO 14024 consists of symbols or logos which have been awarded by external bodies for outstanding environmental performance. The eco-labels "Blue Angel" and "natureplus" are typical examples. Several earth building products carry the latter (nature plus, e. W.).
- Type II environmental labeling according to DIN EN ISO 14021 consists of environmental declarations by the producers themselves. This means that the producers are responsible for their own declarations which they can have verified by external bodies.
- Type III environmental labeling according to DIN EN ISO 14025 consists of voluntary standards, commitments or guarantees for building products. They are provided by producers, organizations and quality assurance associations in order to establish the "environmental performance" of buildings in the form of a certificate awarded by external bodies. This type of label is known as an Environmental Product Declaration (EPD).

The following standards currently exist for the development of EPDs for building products:

- DIN EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products,
- DIN EN 15942 Sustainability of construction works - Environmental product declarations - Communication format business-to-business
- DIN EN ISO 14025 Environmental labels and declarations - Type III environmental declarations - Principles and procedures,
- ISO 21930 Sustainability in building construction

Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Production of raw materials	Transport	Production	Transport	Construction / installation	Use	Maintenance	Repair	Replacement	Rebuilding / renovation	Company - related energy consumption	Company - related water consumption	Demolition	Transport	Waste management	Disposal	Re-using, recovering and , recycling potential

- Environmental declaration of building products. Such declarations must include all phases of the life cycle of a product by describing the environmental impact during production and use as well as possible health hazards for the users. In order to meet these requirements, a standardized assessment diagram has been developed. It consists of the four life cycle phases (stages) which need to be declared as well as column D which records benefits and loads (consumption) (DIN EN 15804) (Tab. 3).

EPDs have become instruments for the selection of products with regard to the environment. They stimulate the use of environmentally friendly products through competition and help to protect the safety and health of consumers by keeping unsafe products off the market.

Earth building materials are inherently environmentally friendly because they do not pose any health risks and have a low PEI compared to other building materials (Tab. 2). Currently, producers of mineral building materials with higher PEIs are providing certified EPDs according to DIN ISO EN 14025 for building materials containing lime, gypsum and cement based on requirements

**Table 3.**

*Assessment diagram for EPD life cycle phases according to DIN EN 15804*

by their respective industry organizations. When assessing the emissions of greenhouse gases, described by the CO<sub>2</sub>-equivalent (GWP), producers take advantage of the trade-off, for example by "consuming" CO<sub>2</sub> during the carbonation of lime or by "recovering energy" from waste instead of using fossil fuels. In this manner, producers can reduce the "sustainability gap" between their conventional materials and earth building materials. This emphasizes how environmental product declarations are increasingly assuming the role of a competitive tool on the building material market. There are now life cycle assessments for industrially produced, naturally moist earth mortars which, with regard to their manufacturing process (from raw material to delivery ex works), have an energy balance value that is 5 to 10 times lower than that of building materials made of lime and gypsum (Lemke, 2012).

*Certification of buildings.* Nowadays, home owners must account for the environmental performance of their houses during the use phase with regard to energy consumption. The Energy Conservation Regulation EnEV 2014 (4. Zweite Verordnung zur Änderung der Energieeinsparverordnung (EnEV 2009) v. 18.11.2013.) requires owners to present an energy pass to anyone interested in renting or purchasing.

However, energy consumption only represents a partial aspect of the environmental performance of a building. Currently, the following standards can be applied in a comprehensive quantitative assessment of the environmental performance of buildings:

DIN EN 15978 Sustainability of construction works - Assessment of environmental performance - Calculation method,

DIN EN 16309 Sustainability of construction works - Assessment of social performance - Calculation methodology,

DIN EN 16627 Sustainability of construction works - Assessment of economical performance - Calculation method.

These standards use the assessment diagram for EPDs according to DIN EN 15804 (Tab. 3).

A number of organizations and associations have developed systems for the certification of the environmental performance of buildings based on criteria catalogs which are more extensive than those found in DIN EN 15804. An example is the certification of buildings issued by the German Sustainable Building Council (DGNB - Deutschen Gesellschaft für Nachhaltiges Bauen) (Deutsche Gesellschaft für Nachhaltiges Bauen, 2012). This system uses a core catalog of six quality categories with additional weighted partial criteria: ecology, economy, socio-cultural and functional aspects, and technical criteria (amounting to 22.5 % each), as well as

process quality (amounting to 10 % of the total assessment). The category "location" is included in the total assessment indirectly. For compliance with each quality category, external auditors award combined points leading to the quality seals "bronze", "silver" and "gold".

The German government has decided to make it mandatory to apply the principles of sustainable building to all future federal building projects by using a rating system called "Sustainable Building for Federal Buildings" (Nachhaltiges Bauen für Bundesgebäude - BNB), published by the Federal Ministry of Transport, Building and Urban Development (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2010) (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2011). Federal buildings are thereby intended to serve as role models.

## CONCLUSION

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Until now, certified EPDs for earth building products do not exist. Producers of industrially manufactured earth building materials have to become aware of the fact that the given environmental credibility of earth products will not suffice in the future. To remain successful in an increasingly competitive market, appropriate EPDs for earth building materials need to be drawn up. The German Dachverband Lehm e.V. (DVL) has, therefore, initiated a project for developing EPDs for earth mortars and earth blocks.

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