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Sustainability of earth building materials – Environmental product declarations as a competition instrument in the building material industry

Sustainable Building

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 [1]:

- 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 prefabricated elements [2], 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). 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 [3] 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 [4]. The *effects* caused by the building process on these levels

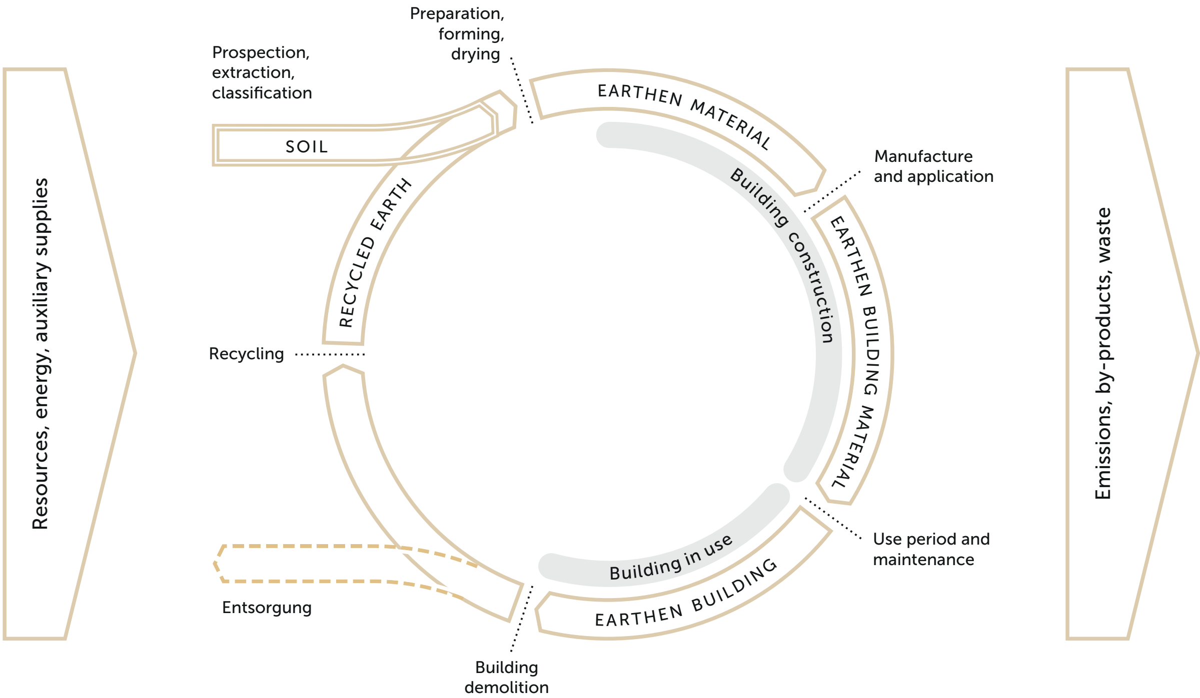

Figure 1 Life cycle of earth as a building material [5] [6]

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.

The life cycle and material cycle of a building

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 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, its 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 evaluated.

When passing through each phase of the life cycle the building material needs to meet the requirements of sustainable building. 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 loadbearing 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 [5]. 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.

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 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.

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^2 coverage and insulation material as m^3 needed per W/m^2K.

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.

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.

Impact assessment

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*), EcoInvent (*www.ecoinvent.ch*, approx. 4,500 data files) and WECOBIS (*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.

Interpretation

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 variants (preferred variants),
- 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_2-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" [7], [8], [9] published in 2011 by the German Dachverband Lehm e.V. (DVL) include a procedure for determining the CO_2-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).

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 labelling** 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 [10].

- **Type II environmental labelling** according to DIN EN ISO 14021 consists of environmental declarations by the producers themselves. This means

Table 1 Assessment diagram for EPD life cycle phases according to DIN EN 15804

	PRODUCT STAGE
A1	Production of raw materials
A2	Transport
A3	Production
	CONSTRUCTION PROCESS STAGE
A4	Transport
A5	Construction/installation
	USE STAGE
B1	Use
B2	Maintenance
B3	Repair
B4	Replacement
B5	Rebuilding/renovation
B6	Company-related energy consumption
B7	Company-related water consumption
	END-OF-LIFE STAGE
C1	Demolition
C2	Transport
C3	Waste management
C4	Disposal
	BENEFITS AND LOADS
D	Re-using, recovering and, recycling potential

that the producers are responsible for their own declarations which they can have verified by external bodies.

- **Type III environmental labelling** 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 – 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) (Table 1).

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 Primary Energy Intensity PEI compared to other building materials. 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 by their respective industry organizations. When assessing the emissions of greenhouse gases, described by the CO_2-equivalent (GWP), producers take advantage of the trade-off, for example by "consuming" CO_2 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 [11].

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 [12] 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 (Table 1).

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) [13]. 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 [14] [1]. Federal buildings are thereby intended to serve as role models.

Conclusion

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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