Requirements for Sustainable Construction Materials and Components

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Abstract
Under the focus of construction material stewardship, negative environmental impacts in construction arise, among others, due to various construction waste streams. With this respect, efforts in practice as well as in science are undertaken to foster the development of new construction materials, paying respect to the requirements set by the need for a sustainable development. In the paper, outcomes of a Delphi study among experts with experience in the field of architecture supported by a literature study are presented. In particular, requirements for construction materials will be elaborated. Thereby, the focus is drawn to the ecological as well as economic dimension of sustainability. Ecological aspects attached to construction materials stewardship comprise required characteristics of construction materials with respect to environmentally friendly behavior during and after use. In contrast, economic factors focus on, among others, cost and flexibility. A third category was raised by the target group: "architectural and engineering requirements" which are however only briefly addressed and the paper.

Keywords:
Construction materials, life-cycle, sustainability, requirements

1 INTRODUCTION

Under the focus of construction material stewardship, the construction industry is characterized by a high material intensity due to the heterogeneous mix of construction materials and components inherent in buildings and the related construction and demolition waste streams.

The tremendous impact of the construction industry becomes obvious considering aspects like resource deterioration as well as congestion of landfills. Additionally, negative environmental impacts arise due to various construction waste streams. With this respect, efforts in practice as well as in science are undertaken to analyze current construction materials and to foster the development of new construction materials, paying respect to the requirements set by the need for a sustainable development.

In the paper, the focus is drawn to the ecological as well as the economic dimension of sustainability. Thereby, ecologic aspects attached to construction materials stewardship comprise required characteristics of materials in order to avoid negative ecological impact. In contrast, economic factors focus on cost but also quality factors and associated terms like eco balancing and life cycle costing. Therefore, the whole life cycle of a construction material has to be taken into consideration.

Furthermore the paper will elaborate on the outcome of a Delphi study on sustainable construction materials among experts with experience in the field of architecture.

2 IMPACT OF THE CONSTRUCTION INDUSTRY

The negative effects of construction activities can be categorized as follows [1]:

- Resource deterioration: depletion of forest resources by the use of timber; dereliction of land caused by quarrying; extraction of sand, clay and other deposits such as limestone; use of energy in the production and transportation of materials and in site construction activity;
- Physical disruption of ecosystems and long-term climatic changes: diversion of natural waterways caused by dams, loss of flora and fauna, and upsetting of the ecological balance with possible

health hazards; noise pollution caused by buildings in urban areas; affection of stability of fragile hillsides by highway construction;

- Chemical pollution: particles released in the production and transportation of materials such as cement and quarry products; pollutants produced in the production of building materials; fibers released during working with asbestos products; accidental spillage of chemicals on site and careless disposal of waste.

It becomes obvious that the construction industry must actively react in a positive manner to environmental issues. Actions to be undertaken include [2,3]:

- Arresting the depletion of resources, e. g. timber and clay, through economic use of resources as well as recovery of materials and the use of renewable varieties;
- preventing and arresting pollution by a proper waste management, the development and use of non-polluting materials, as well as by applying suitable techniques for construction, maintenance and demolition; low pollution or no-waste technologies;
- exploring energy sources for the extraction of raw materials and the production of materials, the construction activity as well as for the use, maintenance and deconstruction of buildings.

In addition the environmental factors, the economic component of construction materials has to be taken into consideration as well; i.e. environmentally sound construction materials will only find widespread use if its economically reasonable to use these materials for the construction contractors (apart from laws and regulations in force).

3 RELATED WORK

Intensive research has already been undertaken with respect to the sustainability of buildings, its components and materials. Thereby, the focus of research mainly addressed the sustainability of buildings or its components in terms of ecological impact throughout the whole life cycle. The most common measures used were energy use and embodied energy.

3.1 Sustainability of buildings

Analysis and research on life-cycle energy and embodied energy use or the related energy efficiency of buildings were undertaken, for instance, by Chen et al. [4] for a residential building in Hong Kong, by Yohanis and Norton [5] for a single-storey office building in the UK, by Sartori and Hestnes [6] as a review for conventional and low-energy buildings, by Thormark [7] as life-cycle analysis of a building including recycling potentials, by Scheuer et al. [8] undertaking a life-cycle energy and environmental performance analysis of a new university building, as well as by Meillaud et al. [9] who evaluate a building using the emergy method.

3.2 Sustainability of building components

Components were addressed by Weir and Muneer [10] with an energy and environmental impact analysis of double-glazed windows, by Wilson and Young [11] on the embodied energy payback period of photovoltaic installations in the U.K., and by Crawford et al. [12] as life-cycle energy analysis of building integrated photovoltaic systems.

3.3 Sustainability of building materials

Furthermore, building materials were addressed by, e.g., Harris [13] introducing a quantitative approach to the assessment of the environmental impact of building materials, by Huberman and Pearlmutter [14] as life-cycle energy analysis of building materials in the Negev desert, by Venkatarama Reddy and Jagadish [15] for the embodied energy of common and alternative building materials, by Morel et al. [16] who address the use of local materials and its impact on the environmental impact of construction, by Cole and Rousseau [17] using indices for building materials referring to energy and air pollution, as well as by Abeysundara et al. [18] who present a matrix for selecting sustainable materials for buildings in Sri Lanka on a life-cycle perspective.

4 DIMENSIONS OF SUSTAINABILITY OF MATERIALS

As can be seen, research most commonly focused on the analysis of the environmental performance of buildings, its components and materials using energy measures. However, looking at the three columns of sustainability materials – ecological, economic, and social dimension – a much wider scope which should be considered within the context of sustainability of building materials occurs. Thereby, requirements for building materials with respect to sustainability have not only to be considered but also need to be classified according to these dimensions. However, due to the interdependencies of some requirements (e.g. well-being as social mean also includes the use of non-hazardous-materials which is most often referred to as ecologic aspects) overlapping of the dimensions occurs.

Hence, the criteria named in the following can by no means classified exclusively as ecologic, economic or social. However, the illustrations given put special emphasize on the most suitable dimension with respect to the highest correlation of impact on the sustainability of building materials and components. Thereby, it is not note, that in addition to the requirements mentioned, sustainable materials and components still have to comply to requirements regarding safety (such as health protection), quality (e.g. durability, resistance), and DIN norms.

4.1 Ecological Requirements

Ecological requirements raised by the experts interviewed were:

- Recyclability
- Contamination

- Insulation and thermal conductivity
- Deconstructability

Recyclability

The construction industry is the second largest consumer of raw materials after the food processing industry [19]. Construction materials are highly diversified and accumulate in huge amounts at the end of the life cycle either of the material or of the building or its components. In Germany, the Waste Management and Recycling Act (KrW-/AbfG) [20] defines a hierarchy for waste treatment. The highest priority is assigned to the avoidance of waste. Second ranked is recovery or recycling of materials (§4). However, construction materials can still not lead back into the material cycle without any processing, or even have to be disposed off. Hence, the ability of recycling of a construction material is a prerequisite for the establishment of closed-loop material flows.

However, a prerequisite for the recycling of the construction materials is the existence of incentives for the disposal at recovery facility. Hence, the user has to be provided with a functioning and affordable, or even beneficial in terms of refund, take back system. Unfortunately, due to the high costs associated with such a take back system for C&D waste leads to a draw back in the establishment of these systems in the construction industry, which, naturally would have to pay for it [21].

Contamination

The aspect of contamination refers to the environmental burden caused by construction materials but also to its impact on the well being and health of the living environment. In the past, construction materials were used for interiors without giving cause to possible negative effects. However, nowadays, several of the construction materials used in the past are now known to be hazardous to health and environment. Among these substances are asbestos, polychlorinated biphenyls (PCB), polychlorinated terphenyl (PCT), polynuclear aromatic hydrocarbons (PAH), as well as wood preservatives like lindan and pentachlorophenol (PCP). The use of numerous substances is already interdicted, however, the number of negative symptoms caused by indoor algerns and toxins in the interior of buildings has risen significantly [22].

Thereby, to avoid energy loss in buildings, building envelops, doors and windows are tried to be sealed as good as possible. If these buildings do not have appropriate ventilation, the concentration of indoor pollution increases.

With this respect, the Construction Products Directive contains regulations not only about building materials. testing and approval but also contains requirements regarding hygiene, health and environmental protection on a European basis, which are, however not yet being implemented into guidelines and norms. Hence, the implementation of health and environmental protection is only at its beginning [22]. Standardized methods for the assessment and approval of contaminant content of construction materials are still missing. Particularly in Germany, steps are taken by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety who fund projects undertaken by the German « Öko-Insitut » as well as by the « Deutsches Institut für Bautechnik (DIBt) » which is a member of the EOTA (European Organisation for Technical Approvals) and of UEAtc (The European Union of Agrément).

Insulation and thermal conductivity

The requirements for construction materials with respect to insulation and thermal conductivity are permanently increasing. Especially in the field of retrofitting, a high potential exists with respect to high insulation with at the same time low material thickness. Not only indoor emissions can be decreased with improved insulation and thermal conductivity, but also costs for heating might be decreased which strongly interrelates with economic requirements [22].

Not only with respect to heat but also with respect to noise, insulation is considered to be an important criterion for sustainable construction materials and components. However, it is claimed that although efforts to protect people from noise have been undertaken, the situation has not significantly improved during the last years [22]. Here as well, overlapping of the ecological as well as social dimension of sustainability occur, as increased exposure to noise might lead to health damages. Noise decreasing actions might include the use of sound absorbing walls, doors, windows and roofs.

Deconstructability

Already in the ancient world, buildings had been deconstructed and construction materials had been recovered and reused. For example, one can find columns from every epoch of the Greek architecture in the cistern of Istanbul [23]. For the easy deconstruction, however, single components are not only needed to be designed for deconstruction, but also compound materials have to be easy resolvable and enable a non-destructive deconstruction.

Compound materials as used in practice are not always sustainability in terms of resolvability and non-destructibility. A proposed solution is to foster prefabricated building and modular housing.

4.2 Economic Requirements

Economic requirements as perceived to be important for the experts interviewed comprise:

- Availability
- Manufacturing and price
- Flexibility
- Life time expectancy

Thereby, these requirements are not only achievable in terms of cost savings but also with respect to time savings during construction projects.

Availability

The availability of construction materials has a strong impact on costs as well as on the construction time of a building. Thereby, on the one hand, a high availability reduces purchasing effort and on the other hand leads to quick lead times, even if orders are made on short notice. Low availability would present an obstacle for construction contractors to use these materials. Furthermore, the availability refers to local aspects. It might be beneficial to use local materials rather than materials which have to be delivered from far distances, with respect to transportation effort and costs (which in turn is beneficial for the environment due to reduced emissions during transport) [19].

Manufacturing and price

In addition to a high availability, construction materials and components ought to be cheap in production, hence, should not be significantly or even cheaper than its less sustainable substitutes. Keeping the idea of closed-loop material cycles in mind, subsidies for the use of recycled or renewable raw materials should be encouraged, whereas the price for primary resources should be increased, which however, has a positive impact on the environment.

Flexibility and multiple purposes

The flexibility of construction materials addressed the opportunity to be able to use the materials for different purposes. The high flexibility could lead to an increase in the demand for a particular construction material, hence, to a larger production, and, hence, the realization of cost reductions due to economies of scale. Prices could decrease and the demand for these sustainable materials would increase as result of market mechanisms.

Life time expectancy

Although high life time expectancy might as well be an ecological requirement in terms of reduced material use due to longer replacement intervals, construction materials and components with a long life cycle and low maintenance effort reduce investments for maintenance, replacement and renovation.

4.3 Further Requirements

Based on the practical experiences of the experts participating in the Delphi study, a third category was raised: “architectural and engineering requirements”. These aspects consider characteristics which are related to the use of construction materials for particular design and engineering purposes. These aspects, besides the ecological and economic requirements, where mentioned to be significantly important for future efforts to develop sustainable construction materials and components. Thereby, it is to note that these requirements are also related to economical as well as ecological requirements.

Especially for façades, a high durability with low maintenance was required. In practice, developments for self cleaning coatings exist [23].

Also the bearing capacity plays a role by the development of sustainable construction materials in the future. Despite materials already existing, a high bearing capacity with smaller cross-sections for easy handling and more innovative design of buildings were mentioned to be important too.

5 SUMMARY

In the paper, results of a Delphi study among experts with practical background in architecture were presented. With this respect, the requirements for sustainable construction materials and components could not be classified as solely ecological or economic. However, the most appropriate dimension was chosen. A high emphasis was put on the economic requirements by the experts, though ecological requirements are usually put in the foreground in research about the sustainability of construction materials and components.

Nevertheless, the existence of these requirements does not ensure sustainability of construction materials and components itself. Approaches and methods have to be applied to examine and proof whether and to what extend the requirements are fulfilled. Different methods existing are, for instance, quality management, eco balancing, labeling and life cycle analysis. These would have to be further analysed regarding their scope and suitability for the different criteria.

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