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SUSTAINABLE CONSTRUCTION: CHALLENGES, CONTRIBUTION OF POLYMERS, RESEARCHES ARENA

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ABSTRACT

Sustainable development is one of the leading civilization ideas. This term means such a development that satisfies the present needs without a limitation of the possibility of satisfying the needs in the future. Sustainable development in construction is particularly important, as this branch of the industry is consuming enormous amounts of mass and energy. A new research area has been created by this idea. The new fields of investigation are involved with material, energetic, and environmental conditions, but also with such topics as protection against noise and the methods of the evaluation of the efficiency of waste materials storage. Merging the worlds of cement concrete and concrete-polymer composites opens ways to synergetic effects that support sustainable material development. Implementation of the idea of sustainable development in the construction industry will be a source of scientific and engineering inspiration for many years to come.

1. Sustainable development – a challenge for civilisation

The notion of sustainable development aspires to the role of a leading civilisational idea. Sustainable development ***"implies meeting the needs of the present without compromising the ability of future generations to meet their own needs"*** [UN, 1987]. The term is the most frequently found expression in forecasts and similar studies. It follows from philosophical premises and – in Poland – it is a constitutional prerequisite: "The Republic of Poland shall safeguard the independence and integrity of its territory and ensure the freedoms and rights of persons and citizens, security of citizens, safeguarding of Poland's national heritage, and ensure the protection of the natural environment pursuant to the principles of sustainable development." Therefore, sustainable development constitutes a principle that is to be followed by the Republic of Poland, in turn safeguarding fundamental values. In the Environmental Protection Laws, the definition of sustainable development is expanded further: ***such socio-economic development, in which – in order to equalise the opportunities to access the environment by individual communities or their members – both of contemporary generations and those still to come – a process of the integration of***

political, economic, and social actions takes place, maintaining the natural balance and continuity of vital natural processes [Wierzbicki, 1995].

Brundtland's definition of sustainable development [UN, 1987] points out some ethical and ecological aspects. Cywiński, in his philosophy of sustainability [Cywiński, 1/2007], underlines the need to generalise the definition of sustainable development and to also consider human spiritual needs. According to Cywiński, sustainable development fulfils the comprehensive, spiritual, and material needs of today's people, without limiting the ability of future generations to satisfy their own respective needs. As a consequence, engineers must be prepared to respond not only to the 'material' question of 'how' but also be able to successfully cope with the 'spiritual' challenges of 'why' [Cywiński, 7/2007].

The principle of sustainable development can also be approached from the point of view of the caution that is included in the second law of thermodynamics. In Clausius' version, the law implies that in isolated systems, processes can only occur if entropy is increased at the same time.

There have always been civilisations that have declined and fallen. In our times, the imperative of the constant growth of scale and sophistication might also bring about a disaster. Daly [Daly, 1996] formulated the following general principles of sustainability:

– renewable resources (e.g. water), including food (e.g. fish), must not be used faster than the rate at which they can be regenerated,
– non-renewable resources must not be used faster than they are replaced with renewable substitutes,
– pollution and waste must not be produced faster than they can be absorbed by nature, recycled, or rendered harmless.

The principles can be illustrated as follows (*Sustainability metric and indices*, Wikipedia.org.wiki/sustainability):

Use of resources/Production of pollution and waste	Environmental impact	Sustainability
Faster than natural regeneration	Degradation	None
Equal to regenerative potential	Balance	Steady state
Slower than regenerative potential	Regeneration	Development

Sustainable development is a life necessity. The above summary reflects a general research inspiration, comprising such areas in construction as the rationalisation of energy management (energy + mass), structural durability, maintenance, renovation, repairs, modernisation (including revitalisation), working life, reclaim and reuse, recycling and the influence on health and the environment. There is also an essential need to determine the "sustainability measures", measurement or calculation methods, and the forecasting tools for the simulation and prediction of the "development of sustainability".

2. Construction that meets the requirements of sustainable development

The construction industry uses 42% generated power and emits 35% greenhouse gases. The branch of the concrete industry alone uses 20 billion tonnes of aggregates, 1.5 billion tonnes of cement and 800 million tonnes of water per year. That is a lot of matter. Implementing the principles of sustainable development in construction is a necessity, which has found its official acknowledgment in an initiative of the European Commission (Lead Market Initiative for Europe, COM 2007 – 860; *Accelerating the Development of the Sustainable Construction Market in Europe*, ibid), which announced a draft Regulation to replace the

Directive 89/106/EEC. The regulation will introduce sustainable development for the construction industry as a seventh principal requirement, the first six being mechanical resistance, fire safety, health, safety, noise protection and energy economy: a civil structure should be designed, erected (and also used), and dismantled in line with the requirements of sustainable development. As a matter of fact, it will be a superior requirement to all others. Although stipulating the development of construction to be sustainable is defined in an ecological aspect, it is also determined by economic and social views. Sustainable construction has been classified as the second of the six development priorities. It is assumed that by the year 2020 the construction market will have been increased 3.5-fold with employment boosted by 70% [Tworek, 1/2008-04-25].
In the past "durability" stood for 'long life'. Constructions and materials were made as performing as possible, to obtain the longest possible lifespan. The effect of material production and use on the global environment was mostly not taken into account. To make an objective evaluation of the durability of products and processes and the harmlessness for the environment as a result of it, two elements must be considered. On the one hand a product can have a long lifespan, be very performing and not degrading, on the other hand a product should meet the principles of respect for nature. Only taking into account the first element would refer to the concept of durability. Also considering the second fact, the effects on nature, corresponds to the global vision of sustainability. "Sustainability" is a much wider concept than durability! One should aspire to a durable development, but in respect with nature. The aim is an optimal fulfilment of current needs, without bringing in danger the possibilities of the future generations. It is no going back to nature, but having respect for nature.
The growing awareness of the importance of the influence of construction on environmental protection issues and energy saving makes the need to satisfy the comprehensive criteria of sustainable development particularly vital for buildings and civil structures. The basis for the harmonisation of the respective European requirements should be provided by the standards that were developed by the European Committee for Standardisation CEN, Technical Committee TC 350 "Sustainability of Construction Works", in the following scope (shown in Fig. 1):

- evaluation of the effect of buildings on the natural environment,
- preparation of environmental declarations for construction materials/products,
- evaluation of the total life cycle of buildings and civil structures.

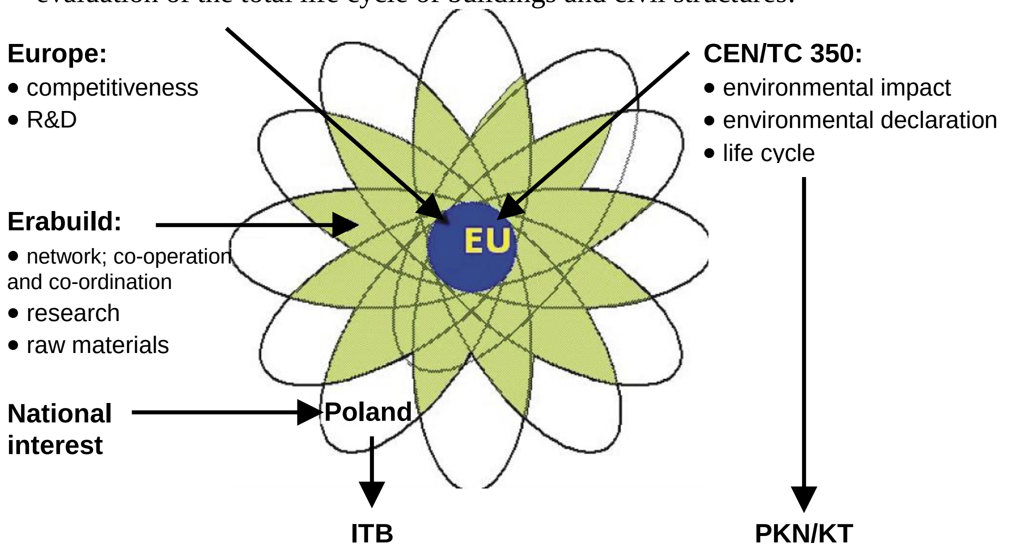

Fig.1 Activities of CEN/TC 350 as a basis for the harmonisation of requirements

3. Aspects of sustainable development

3.1Influence on the environment

For many years the influence on the environment could be solved with a certain financial effort, e.g. for acid rain and nuclear waste. For the first, the technical solution is given by a smoke gas purification plant, for the second by providing stable barriers against migration of radioactive isotopes. The concern for nature is easily translated in an economic price tag.
The greenhouse effect is a problem of another dimension, and there is no simple solution. For the moment there is even not 100% certainty about the impact of the continuous discharge of greenhouse gases (mainly CO_2, about 77 %). However, the scientific information is alarming (IPCC 2007), and calls for immediate action. The current atmospheric concentration of CO_2 is about 385 ppm, and it is rising annually at a rate of 2-3 ppm. (Hansen et al. 2008) state that today's 385 ppm is already too high to maintain the climate to which humanity, wildlife, and the rest of the biosphere are adapted. They suggest that the preservation of civilization requires that CO_2 be reduced to at most 350 ppm. Beyond 450 ppm irreversible climate changes are predicted. (IPCC 2007) states that worst effects of global warming may be avoided if annual CO_2 emissions are reduced to the 1990 level within 20 years. Because of the global size of the problem and the lack of easy solutions there is much less time left for action than assumed until now. We can not search calmly for a solution, unless science and technology find a way to solve the problem of the CO_2-emission (for example separating CO_2 out of smoke gas and storing it in underground layers; or other unknown techniques). It is necessary to look quickly for alternative solutions.
After the elimination of fossil and nuclear sources only two possible ways are left over:
-reducing the primary energy use by means of energy saving and /or the raising of energy-efficiency;
-massive use of "renewable" sources.

3.2 Energy versus exergy

The first law of thermodynamics states that energy never disappears. However this does not mean that there is no energy problem at all. We can not simply transfer one form of energy into another. Real processes only take place if entropy is created. In other words, there is only a part of the energy that can be transformed into labour (useful energy or exergy).
To preserve the future for next generations there are now three conditions to the use of exergy (Dewulf and Van Langenhove 2001):
- exergy may not be consumed faster than its development rate;
- we have to work very efficiently with the exergy sources: the less entropy we generate the more efficient the process technology;
- emissions of the exergy may not cause any danger to the eco-sphere.

There are two types of exergy sources in the eco-sphere: sources and deposits. The whole system stays working because of the continuous input of solar-exergy. Due to the sun the eco-system has renewable characteristics.
The optimum way of production is indicated in Fig. 2. The ecosystem transforms substances with a low exergy value, like water and carbon, into products of a high exergy value by photosynthesis thanks to the exergy of the sun (in the shape of photons). If the techno-sphere uses the products at a speed maximally equal to the production speed and if the emissions give again water and carbon, the circle is closed. The engine of all this is the sun-exergy, completed with earth-energy.

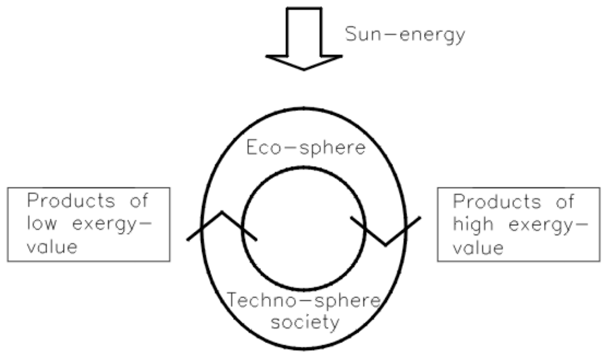

Fig. 2: The Closed Cycle approach

The conditions for such sustainable technology are:

1. use of renewable sources
2. increase of the process efficiency
3. emission restriction

4. Impact of construction industry on environment

The construction industry in Europe is the largest industrial employer, accounting for 7.5 % of total employment and 28.1 % of industrial employment in the European Union (EU) (Europe 2001). It also accounted for 9.7 % of Gross Domestic Product (GDP). The 'cradle to grave' aspects linked to the creation, use and disposal of built facilities all together constitute major environmental impacts. Construction activities consume more raw materials by weight (as much as 50 %) than any other industrial sector. The built environment, moreover, accounts for the largest share of greenhouse gas emissions (about 40 %) in terms of energy end usage. Measured by weight, construction and demolition activities also produce the largest waste stream, between 40 and 50 %, most of which though is recyclable. This means that the construction industry, and the sustainability of its products, principally buildings, faces an environmental challenge that in absolute terms is greater than that of any other industrial sector.

Table 1 gives an overview of the relative share of building materials in the European construction industry.

Table 1 : Relative share of building materials in EU-construction industry (year 2000) (15 member states, population 330 million) (de Longchamps 2002)

Construction material	Consumption [tons]	Ratio [%]
Concrete and cement based	503 000 000	71
Tiles and bricks	73 000 000	10
Timber	54 000 000	7
Iron and steel	24 000 000	3
Stone, quarry	16 000 000	2
Asphalt and bitumen	16 000 000	2
Polymers	6 850 000	0,97
(Concrete modification	486.000)	
Flat glass	5 200 000	0,73
Mineral wool	2 000 000	0,3
Copper	1 300 000	0,2
Aluminium	900 000	0,1

In the actual European Union (27 member states), total cement production in 2007 is estimated at 283 million tons, representing 10.5 % of world production, estimated at 2690 million tons in 2007.
Available data on plastics consumption are not very accurate. Other sources give a market of 8.3 million tons in construction and renovation, being 23 % of total plastics market (EuPC 2006). Polymer consumption by industry in Western Europe, in terms of end-user applications, is given in Table 2.

Table 2: Polymer end-use consumption in Western Europe (2007) (PlasticsEurope 2007)

Industry	Relative share of polymer market [%]
Packaging	37
Construction	21
Electrical/Electronic	6
Automotive	8
Others (medical, leisure, furniture, agriculture. heavy industry, toys, …)	28
Total	52.500.000 tonnes

Compared to other construction materials, the relative share of polymers is about 1 % in weight, Table 1. The available data indicate a steady increase of the use of polymers in construction. The share in weight may be only about 1 %, but in financial turnover polymers represent more than 10 % of construction industry. It is expected that polymers in construction will become the prime part of the polymer market. Moreover, due to the synergic action between polymers and cementitious matrices, the impact on performance of building materials largely overpasses the weight ratio [Van Gemert et al. 2005]
The amount of polymers, used in concrete-polymer composites, is only a minor part of the amount of polymers for modification of concrete (total consumption of 486000 tonnes in 2000), which also include water reducing agents (121500 tons of super-plasticizer in EU in 1998). The use of admixtures in concrete will further increase. In 2002 the use of admixtures was still rather limited in countries with high cement consumption like Italy, Great Britain, Russia. In countries with higher quality demands like Belgium and Switzerland, already about 80 % of ready mixed concrete contained admixtures. In France and Germany about 15 to 25 % of ready mixed concretes contained admixtures. New environmental regulations (clean working sites, low noise) and higher quality demands will require admixtures for nearly all ready mixed concretes. This evolution opens a yearly market of several millions of tonnes of admixtures. As an example, the worldwide market of plasticizers (including plasticizers for concrete, gypsum wallboard production, plastics and rubber) had a total volume of 5.5 million tons in 2004.
Minimizing the consumption of concrete through innovative architectural and structural design is one way to save cement. Specifying a 56-day strength instead of a 28-day strength for construction elements where it is allowed, can result in significant cement savings (Tool 1). Another way is to reduce the cement content of concrete mixtures through the use of blended cements, using latently hydraulic materials such as fly ash, granulated blast-furnace slag, natural or calcined pozzolans, silica fume, reactive rice-husk ash (Tool 2). A generalized use of plasticizing chemical admixtures leads to a further cement reduction (Tool 3). (Mehta and Meryman 2009) state that the combined use of tools 1 and 3 may give a reduction of 30 % in cement consumption. The diligent use of complementary cementing materials (Tool 2) can decrease clinker fraction in cement from 0.84 to 0.6, or another 28.5 %. The increased use of crop residues and industrial waste-products as alternative fuels in clinker-kilns is expected to reduce carbon dioxide emission from 0.9 to 0.8 ton per ton of clinker. In total the reduction might become about (0.7 x (2800 x 0.6 x 0.8) =) 941 million tons/year, being the 1990 emission rate. This goal is achievable, and the (secondary) resources to do so are available.

Herein the polymers are destined to contribute, by exploiting the synergies between cement and polymer (Van Gemert et al. 2005, Van Gemert et al. 2008).

5. Concrete-polymer composites and Restoration within the vision of sustainability

Because of the importance of environmental protection, energy saving and reduction of demolition waste within the vision of sustainability, restoration has become an important issue. The whole process to make a product consumes a lot of raw materials and energy. By restoration instead of new building, the environment is spared and the waste stream of building materials is diminished (Van Gemert and Poupeleer 2001).

The life cycle of a building or construction consists of three main stages, each involving a lot of energy and/or raw materials. During the production stage, building materials and construction components are manufactured. After the transportation to the site, the construction is erected. The management stage is characterized by periods of occupation and renovation until the life span is exceeded and the construction will be pulled down. All temporal stages, represented in Fig. 3, are taken into account in a life cycle analysis (LCA). LCA can be used to study and estimate the amount of energy and raw material that is consumed during the life of the construction. Renovation is an important phase that extends the life span of the construction.

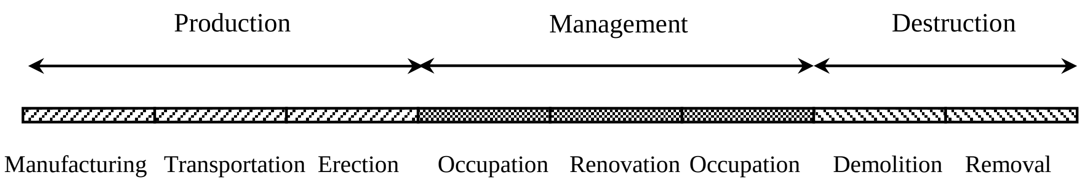

Fig. 3 Temporal stages of a construction during its life cycle (Adalberth 1997)

To understand the overall impact of renovation, a global view of all relevant elements is needed. There is a strong interaction between three domains: the techno-field, the social field and the eco-field (Dewulf and Van Langenhove 2001). The techno-field is characterized by an input, processes and an output. Raw materials are extracted from the eco-field and transformed by technological processes to products, which fulfil the needs of society. During processing and consumption of the product, emissions are possible. Fig. 4 shows the critical points that can be changed to obtain a more sustainable entity. Even from the viewpoint of sustainability, it is allowed to build. In spite of all adverse consequences and side effects, building brings a higher benefit for society (Dewulf and Van Langenhove 2001). Of course, one has to behave environment-conscious, from the winning until the waste treatment, and as stated before, try to use environment-friendly materials and manage the demolition waste.

Restoration can be a valuable solution for this problem. Conservation of structures and systems reduces the need for base materials and may limit the energy required. Also a lot of dangerous emissions can be avoided. In the scheme of Fig. 4, the construction returns to the techno-field. Different processes (treatment with a repair mortar, additional strengthening,…) restore the construction with a limited amount of materials, energy and emissions. A durable "new" product is created to serve society. The social balance is positive, because of an unchanged view or living environment, limited nuisance, less heavy transport and thus increased traffic safety…

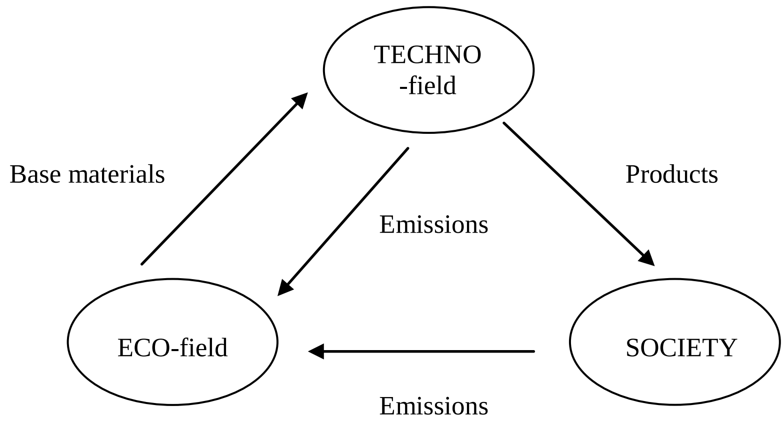

Fig. 4 The global system of techno-field, social field and eco-field

6. Sustainable construction – premises and research needs

In order to implement the concept of "construction that meets the requirements of sustainable development", first of all the requirements must be formulated specifically for the construction industry. In the year 2000, in Great Britain, a government policy for the sustainable development of construction was announced. Since that time, annual reviews have been performed to verify the policy. Nevertheless, it appears that there are still more questions than answers. In 2003, all of the sections of the report ended with a question mark [The UK Construction Industry, 2003]. In 2004, we could read the question again: *what is sustainable construction?*
The answer to the question was provided in a number of key points [Sustainable construction, 2004]:

- cost-efficient design,
- using minimum energy in construction and use,
- producing no pollution,
- preserving the nature around and in turn enhancing biodiversity,
- preserving water resources,
- providing people with comfort and respecting the local "microclimate".

The authors admit that most of these guidelines are no less than a simple business principle: minimise loss, maximise efficiency. A lack of new knowledge is distinctly felt [Czarnecki, 7/2008]. As a result, in all of the European programmes, *sustainability* is one of the leitmotifs. COST – European Co-operation in the Field of Scientific and Technical Research, which determines research directions by definition, is engaged in the following two actions:

- Action C8: Best Practice in Sustainable Urban Infrastructure [Lahti, 2006],
- Action C25: Sustainability of Constructions: Integrated Approach to Lifetime Structural Engineering [Action C25].

In 2004, RILEM – The International Union of Laboratories and Experts in Construction Materials, Systems, and Structures, Technical Committee TC-92 ECM organised an international symposium "Materials and Systems for Sustainable Development" (Kashino, 2004) under the direction of Kashino and Ohama. The symposium summed up the state of knowledge rather than attempting to solve any problems. Earlier, RILEM Technical Committee TC-165 worked on the definition of sustainable construction materials. However, their final report focused on the present situation and the technology regarding dismantling structures and the recycling of demolition waste [Hendriks, 2000]. Other attempts by RILEM in this area have been very specifically orientated, e.g. Towards Sustainable Roofing, RILEM TC-166 RMS [Towards Sustainable roofing, 2003].

Sustainable management of resources is an essential part of the latest theme (Theme 6: Environment) within the 7^{th} Framework Programme [F-P7, 20008]. In this context, it is surprising that in the policy of European Science Foundation (2007) – Looking Beyond the Endless Frontier - the concept of *sustainability* was not addressed [Van der Meulen, 2007].

7. Sustainable construction – research area

Sustainable construction is a rather rare example of a research theme in engineering. The inspiration for it did not follow from any direct practical needs, but rather from the central idea itself. Interpreting the idea, carrying out research and studies is for streamlining engineering activities. The versatility of the idea enveloped in sustainable development gave rise to a number of fundamental research directions, namely:

– material factors in the sustainable development of construction,
– energy factors in the sustainable development of construction,
– influence of a civil structure on the natural environment (ecology),
– influence of a civil structure on the internal environment (microclimate).

The first two research areas are the most extensive. An example of a direct interpretation of the research challenge contained in the concept of sustainable development is a study by K.Gertis - Director of the Fraunhofer Institute for Building Physics in Stuttgart [Gertis, 2002] that was presented at the BRI conference ”Low-energy or low-entropy buildings?” in 2002. The author states that two principal attitudes seem to have recently influenced the lines of thought of architects/building constructors:

– *absolutisation of the importance of the low-energy building,*
– *the primacy of an ecological and natural environmentally-friendly building;*

However, both terms are either undefined or vague.

As a result, Gertis states the following:

– *”natural environmentally-friendly” means a building with minimum flows of mass and energy (i.e. minimum increase of entropy),*
– *the most ”ecological” action occurs when the flows of mass and energy are minimised (ideally: zero entropy increase),*
– *a low-energy building will be essential in the future, but it will not suffice,*
– *anyone familiar with thermodynamics (c.f. Section 1) will deduce that the notion of entropy is a key one.*

It is typical that Gertis did not introduce the notion of energy in his study [Rant, 1955; Torio, 2007; Czarnecki, 2008].

Accepting sustainable development as the main guideline for progress (Table 3) results in the creation of a new research area, concerning the material factors in the development (Fig. 5). The area comprises the following existing fields:

– performance criteria of construction materials,
– methods of suitability assessment,
– modification of materials and new material solutions,
– material performance in service conditions,

as well as certain aspects of ecology, waste management, and the recycling of used construction materials for the construction industry, and reuse of building materials. The mere comparison of the amount of waste and the amount of produced building materials is enough to show that – in the decades to come – waste management in the construction industry will become a civilisational challenge, just like the repairs and modernisation of the existing assets and ensuing material needs.

Tab.3 Developments in the research areas concerning construction materials

Development factors (International Concrete, 1998)	Principal requirements (ER 89/106/EEC)	Sustainable Building, factors according to:		Research areas
		C.J.Kibert	Sustainable Building Code	
sustainable development environmental impact energy saving reduced costs of erection, maintenance, dismantling, and recycling use of highly-suitable materials; optimisation of structural solutions big and growing share of repairs and modernisation in construction works design focused on the utility of the building/civil structure	structural safety: load-bearing capacity and stability fire safety hygiene, health, and environment safety of use protection against noise and vibration energy-saving properties and thermal insulation	minimum quantity of materials used (resource conservation) maximum reuse of components possibility to renovate components or materials environmental protection health comfort of use (quality)	demand for energy and emission of CO_2 water use (dm^3/person/day) effect of used materials and products on the environment evacuation of surface runoff waste management minimised pollution health and comfort construction process and building management ecology	
Material factors in the sustainable development of construction				

The notion of sustainable development is a premise that spreads over the research and economic areas and – quite possibly – it will become a megatrend in the 21^{st} century. At the same time, the implementation of this idea is linked with finding a solution for one of the most fundamental civilisational problems – waste management, including the concept of DFR - ”design for recycling”. It seems that the programme not only aims at rectifying the errors of the past and ensuring a better future for the next generations, but it will also become a creative force of progress – ”Smart Material Systems” [Richard, 1994].
Sustainable development is a task for creating a number of balances on various levels (Fig. 6). The most general perspective refers to the society, environment, and economy. As far as the construction industry is concerned, it refers to the comprehensive concept of an environmental impact over the whole life cycle of a civil structure or building (Life Cycle Assessment, LCA). Considering the nature of the construction industry, the material factors of structural durability and reliability are particularly important.
It is a vast, and multidisciplinary, task. It may be assumed that the message of sustainable development will be one of the main keynotes of the subsequent European Programmes. Sustainable development in construction in general – and factors determining the choice of materials in sustainable constructions in particular are naturally becoming a paradigm of the research activity in the field of construction. It is an evolved consequence of the former paradigm – the principal requirements as set forth in Directive 89/106/EEC (1988).

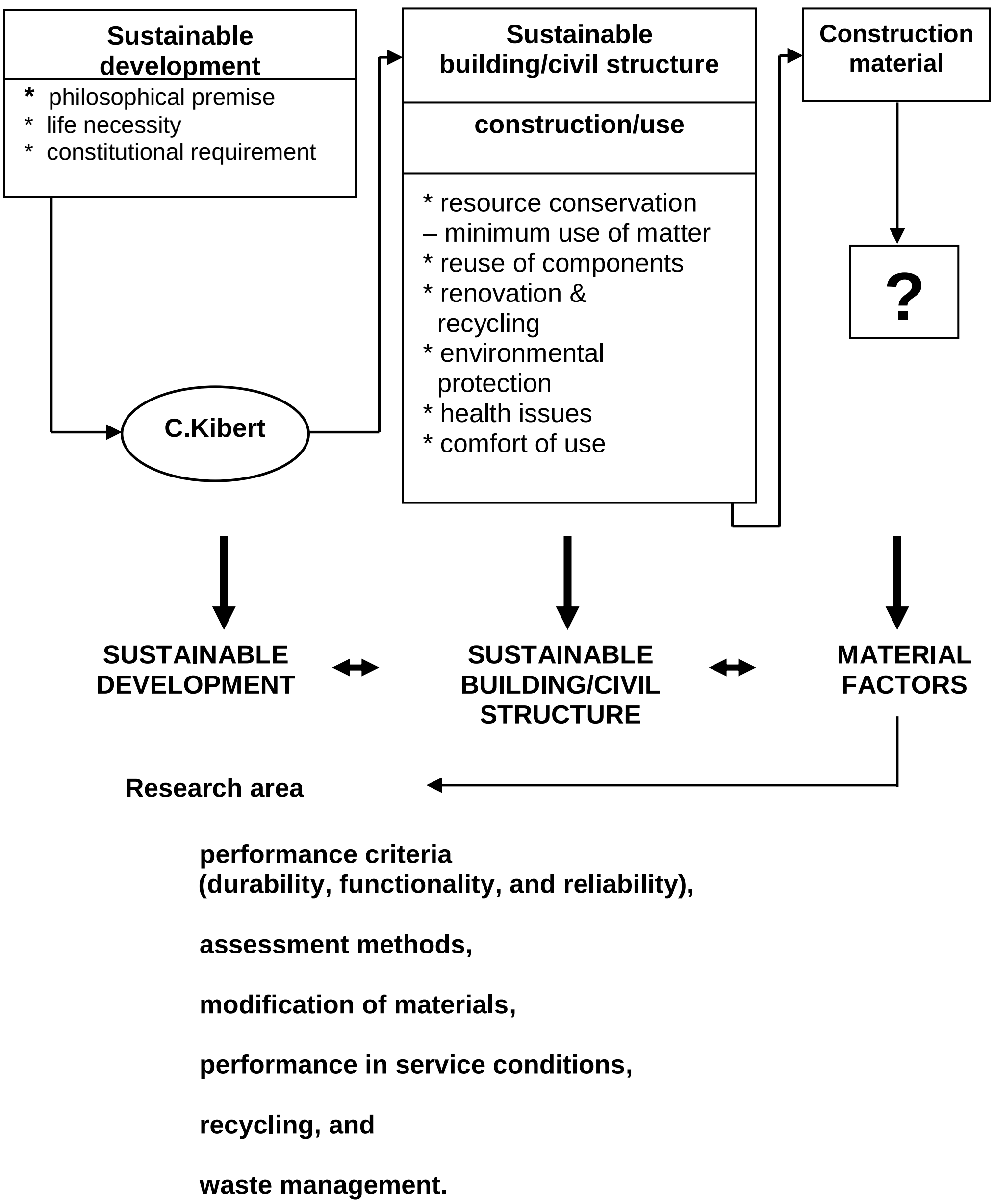

Fig. 5 Research area of the "material factors in sustainable development"

At the same time, it is a new approach, charting a new direction in the development of construction materials, which is referred to in Canada as "ISIS – Intelligent Sensing for Innovative Structures". Some elements of the new approach include the "Structural Health Monitoring" and "Building Advanced Composite Materials".

The specific nature of the construction industry makes durability and the reliability of material solutions understood as the material determinants of durability and the reliability of the construction, simply as a prerequisite. As far as the choice of materials is concerned, the central idea is their **compatibility**, which is understood as a choice of materials with regard to their physical and chemical properties so that the choice would ensure the load-bearing capacity and usability limits of each component of a given system within the designed time and conditions of use. The policy of sustainable development sets new tasks for construction materials engineers. A sustainable building or civil structure is to meet nine requirements as regards the time of the construction and period of use [Kibert, 1999; Code for sustainable Homes Dept.(...), 2006]

– minimum quantity of materials used (resource conservation), including water,
– maximum reuse of components,
– possibility to renovate or recycle,
– environment protection,
– waste management,
– minimum emission of pollutants,
– construction process management and building management,
– health aspects,
– comfort of use (quality).

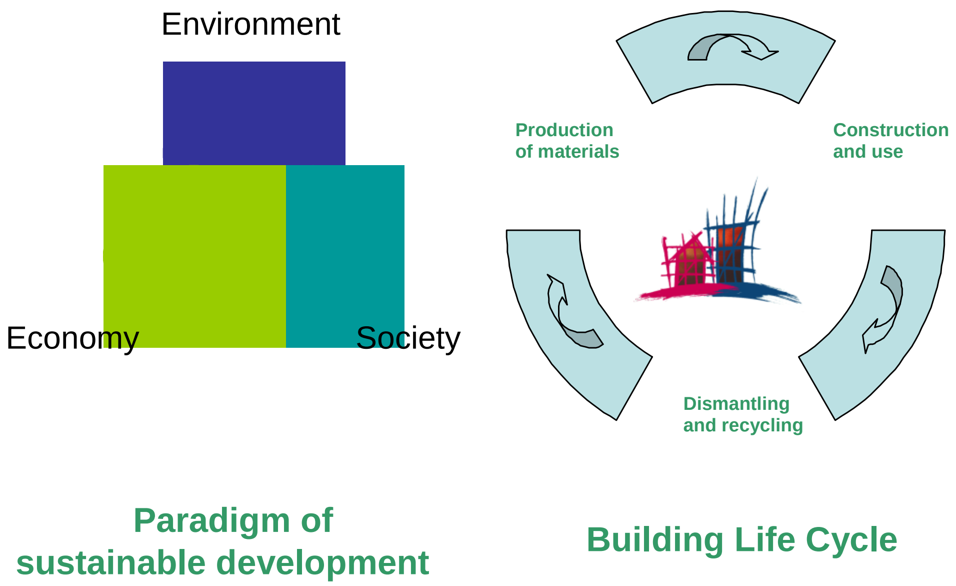

Fig. 6 Material factors in the sustainable development of construction

Recently, the survivability requirement is being increasingly brought up, especially when referring to a terrorist attack.

The task of waste management and its reuse for construction purposes became a part of the sustainable development idea. The amount of disposed and produced waste clearly shows that their reuse in the construction industry is becoming a necessity.

The research tasks, following from the concept of sustainable development, may be divided into two types:

– *intensive* – incorporating the demand for sustainable development into current research themes,
– *extensive* – creating new fields of research.

The division is vague. However, one can argue that *material factors* belong to the first type, while energy factors to the second. The *intensive* tasks face a serious problem of how to define the types and levels of criteria: the notion of usefulness must be redefined to ensure sustainable development.

8. Sustainable development vs. *performance concept*; product performance criteria

The idea of usefulness in the construction industry has a long tradition. Some aspects of the approach may be found in the Code of Hammurabi (1955 BC), and the writings of Vitruvius (dated 20-10 BC). However, only recently has there been the ***performance concept***, i.e. evaluation and selection of materials according to their usefulness, becoming increasingly appreciated throughout the construction industry. In the European standard for concrete the notion was used in the title. The idea of performance was well grasped in the US building regulations of 1925 [Gross, 1985]:

"Whenever possible, requirements should be stated in terms of performance, based upon test results for service conditions, rather than in dimensions, detailed methods, or specific materials. Otherwise new materials, or new assemblies of common materials, which would meet construction demands satisfactorily and economically, might be restricted from use, thus obstructing progress in the industry."

The above statements have not lost their validity, and – in light of the sustainable development requirements – they have even become a particularly current necessity. It is especially significant with regard to substitute material solutions (alternative raw materials), and to those construction materials and products that are based on recycled ingredients or components. Moreover, sustainable development imposes the need to consider additional requirements and/or restrictions (Fig. 7 and Tab. 4).

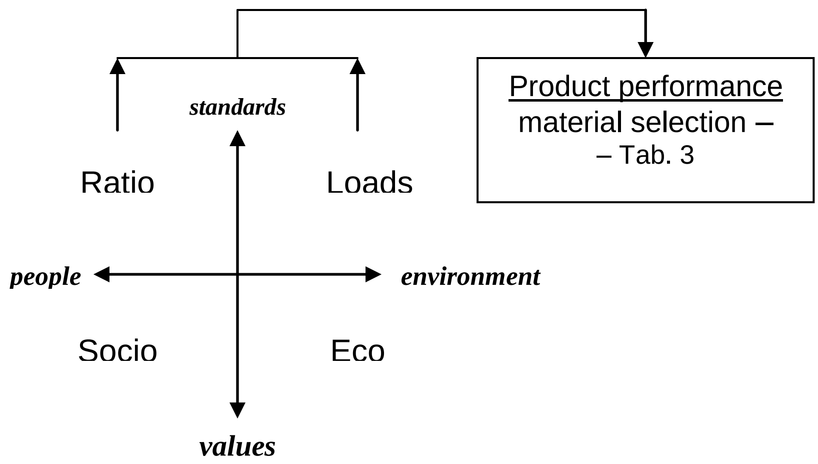

Fig. 7 Defining the performance of a construction product as a derivative of basic principles of sustainable development (Lahti, 2006)

A restriction is also a situation when certain technical properties are not used in a given application or when they are redundant, and thereby generate irrational costs (energy input). This implies that there is a need [Becker, 1999] or even an obligation to develop a new research area (and knowledge/skills) to define the performance in terms of the properly selected (type and level) technical properties. The final decision on the choice of a material solution, as a rule, will require an analysis or optimisation involving a number of criteria. There are examples of this approach in the literature, e.g. the *polyoptimal* method of designing environmentally-friendly buildings [Olędzka, 2007] considers the values of the total accumulated energy and CO_2 emission of construction materials and main technologies. It should become one of the fundamental activities of the leading research institutes in the field of the construction industry.

Tab. 4 Formulation matrix for the additional requirements to ensure sustainable material performance (Lahti, 2006)

Ecology		Economy		Social aspects		Assurance of sustainable material performance
Emission?	⇗	Cost/ performance	⇒	Joint decision making	⇗	
Use of natural resources?	⇗	Tendency to incur costs	⇗	Transparency Responsibility	⇗	
Bio-diversification?	⇗	Organisational efficiency	⇒	Safety, health, and good mental state	⇗	
Balanced system – ecology	⇗	**Balanced system – economy**	⇗	**Balanced system– social aspects**	⇗	

An example of the pursuit of a definition of *sustainable performance* is the study of A.Panek ”Metody oceny oddziaływań na środowisko obiektów budowlanych” [Methods of assessing the environmental impact of buildings, 2002], which is a manual for auditors. As part of the activities of the CEN Technical Committee TC-350 [Trinius], an extended term for “integrated building performance” was introduced (Fig. 8).

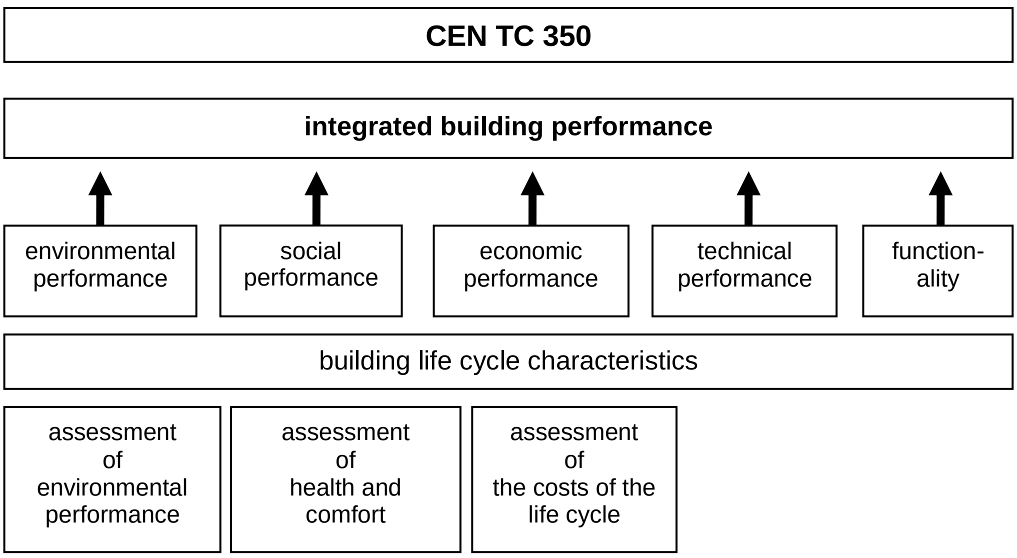

Fig. 8 A diagram representation of the term ”integrated building performance” according to CEN TC-350 [Trinius]

9. Sustainable construction industry – new fields of research

Energy factors in sustainable development have led to the creation of a few new fields of research, including a method for simulating the energy performance of buildings [Narowski, 2007; Bartkiewicz] and a method for determining the energy profile of buildings (implementation of Directive 2002/91/EC) [Kasperkiewicz, 4/2008]. New terms have been coined, e.g. a "passive building" (Adamson, Feist), i.e. a building in which a comfortable interior climate can be maintained without an active heating and cooling system. Pilot projects have been realised to respond to the new notions (www.passiv.de) along with a whole new library of software to simulate and evaluate energy and environmental effects. The number of specialised programmes is so large that a validation method had to be developed [Panek, 9/2007].

New themes within the idea of sustainability include the recycling of construction materials, such as concrete [Eguchi, 2007], and the assessment of the durability of concrete [Levy] mixed with recycled concrete aggregate. *Sustainable concrete* has proven to be a satisfying field of research [Ajdukiewicz, 3/2004; Czarnecki 2006]. Studies of concrete recycling show that the process of grinding causes such an expansion of the surface of concrete aggregate that it results in an irregular increase of carbonation intensity [Nielsen, 2006]; therefore, up to 90% of the carbon dioxide emitted while producing cement is assumed to be absorbed in this way (Fig. 9).

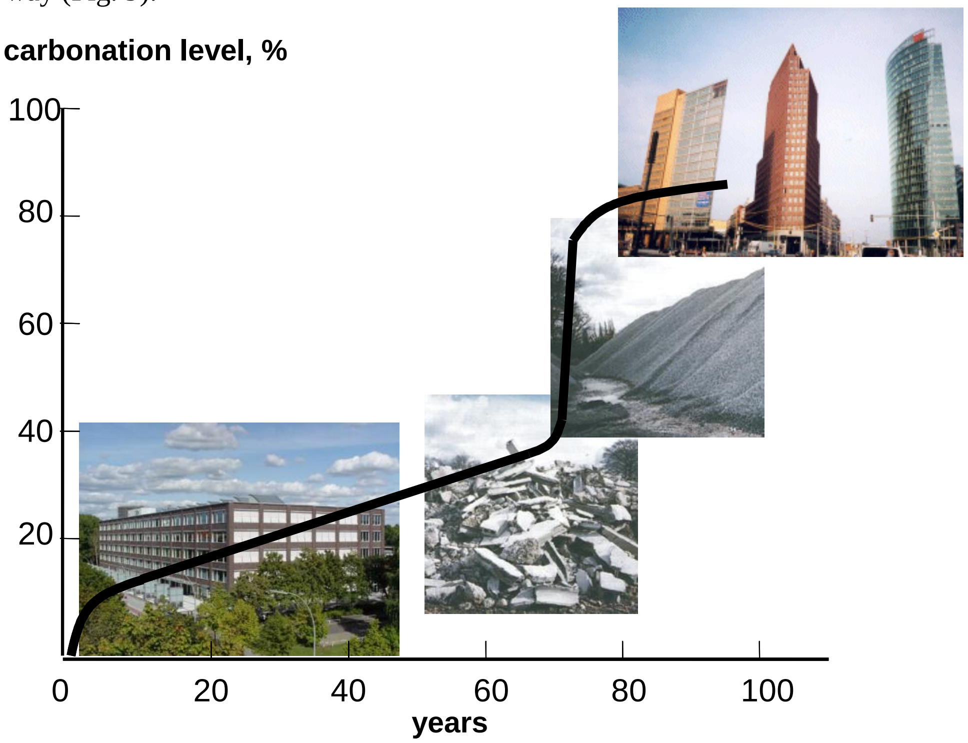

Fig. 9 Simulated carbonation of concrete, including its recycling

Sustainable development in construction opened a new research area, which is connected not only with material performance, energy factors, and environmental effects, but also protection against noise pollution and the evaluation of the storage efficiency of waste material. The introduction of the principle of sustainable development into the construction industry will provide a source of illuminating and important research inspiration for engineers for many years to come. A successful implementation of sustainable development in construction depends on the results, but it also – and to a large degree - depends on the availability of properly educated specialists. It has been found that – until now – only the British University of Strathclyde launched a *Masters' by Research in Sustainable*

Construction & Infrastructure. This should spur other universities to prepare similar relevant specialisation courses.

10. Conclusions

Considering the impact of construction industry on environment, sustainable construction procedures have to be developed. The scope of sustainability is wide, and the ambitions and goals are great. All actors in the construction process are involved, from designers to material producers, executing contractors, users. It will not be efficient, and thus from the idea itself contra-sustainable, if all partners try to improve their processes individually. Synergies have to be searched, by which materials and procedures become more efficient. Merging the fields and research areas of cement-concrete and of concrete-polymer composites opens a way to such synergetic effects. Such approach – *performance concept* requires changing attitudes in research and production, as well as of researchers and actors. New and integrated research fields have to be opened and explored. All this will need time, and most of all education. Universities and construction research institutes must become much more aware of this educational need, and take the necessary action .

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