IOP Conf. Series: Materials Science and Engineering **442** (2018) 012013 doi:10.1088/1757-899X/442/1/012013

Contribution of concrete structures to sustainability – challenge for the future

Petr Hajek

Czech Technical University in Prague, Czech Republic

E-mail: petr.hajek@fsv.cvut.cz

Abstract. New situation in natural and socio-economic environment requires new technical solutions for construction of new and reconstruction and modernization of existing structures. Structures and all built environment should be better prepared for new conditions – they should be sustainable and resilient. Concrete gradually becomes building material with high potential for new technical solutions resulting in needed environmental impact reduction and consequent social and economic improvement. The paper presents potential contribution of concrete and concrete structures to solution of Sustainability Development Goals specified in UN 2030 Agenda for Sustainable Development and brings basic principles of implementation of sustainability approach into fib Model Code 2020.

Keywords: sustainability, concrete structures, environmental impact, resilience, SDG

1. Background and context

Conditions for life on the Earth are changing. Biodiversity including human life is affected by climate changes, decrease of quality of environment and depletion of natural resources. Changes of these conditions is innate and everlasting process. Although Earth goes through natural regular cycles of warming and cooling, human activities evidently accelerated these climate changes. Global climate changes are now happening faster than anticipated. The impacts of climate changes include warming temperatures, changes in precipitation, rising sea levels and increases in the frequency or intensity of some extreme weather events (Hajek 2016a). Floods, tropical storms, hurricanes, tornados, wildfires, heat and cold waves, longer periods of drought etc. are more and more frequent and with higher intensity. These impacts threaten human health by affecting the quality of food, water, air, and the entire quality of environment in which we live. The frequency of climate-related natural disaster is now nearly five times higher as it was in the 1970s (WMO 2015) – see Figure 1.

As a consequence, socio-economic problems graduated in recent years, including human migration. These aspects are in mutual interaction. Depletion of natural sources influences climate and causes economic and social stresses. Quality of the environment directly influences biodiversity, social life of humans and existence of animals on the Earth.

IOP Conf. Series: Materials Science and Engineering **442** (2018) 012013 doi:10.1088/1757-899X/442/1/012013

The natural and socio-economic effects and changes are different (in qualities and quantities) in different regions. It is thus essential to consider regional specifics.

New situation in natural and socio-economic environment requires new technical concepts and solutions for construction of new and reconstruction and modernization of existing structures – buildings and infrastructure, like roads, bridges, dams etc. Structures and all built environment should be better prepared for new conditions – they should be sustainable and resilient. Advanced codes for structural design based on a holistic approach and considering a wide range of sustainability issues are thus essential, and urgently needed.

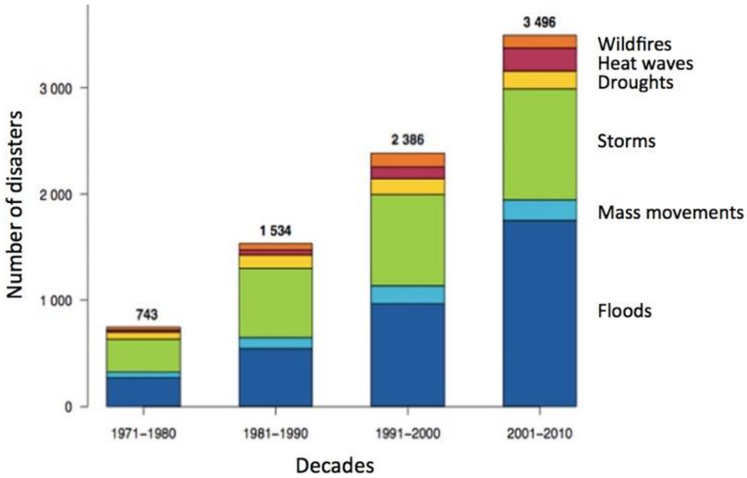

Figure 1. Increasing number of disasters by hazard type since 1970 (based on WMO data)

2. Sustainability perspective

Sustainability represents in general savings of biodiversity including survival of humans on the Earth. In International Standard ISO 15392 (ISO 2008) are presented general principles of sustainability related to buildings and other construction works. There are three primary aspects (pillars) of sustainability: social, environmental and economic. These pillars are formed by groups of aspects with associated performance levels and goals:

- Social aspects: social performance – social responsibility
- Environmental aspects: environmental performance – environmental impact
- Economic aspects: economic performance – economic efficiency

The performance level of structures could be optimized and assessed by wide range of criteria (described by indicators and benchmarks) in the framework of these three pillars of sustainability. Figure 2 presents the framework of sustainability perspective covering three pillars of sustainability. Basic criteria of structural performance – safety, serviceability, durability – are social aspects, they are part of social responsibility. Environmental impact could/should be assessed using LCA standard methodology. Economic efficiency could/should be assessed using LCC standard methodology. Resilience is going across all three pillars of sustainability.

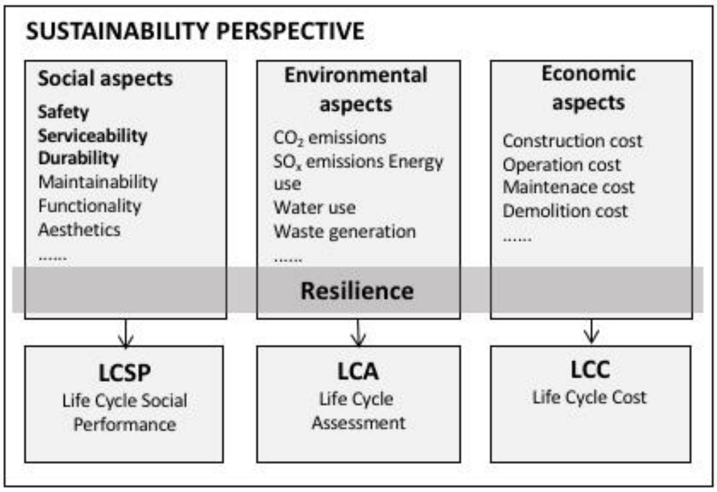

Figure 2. Framework of Sustainability perspective and assessment

It is essential to consider changes and development of performance within the entire life of a structure. Life Cycle approach is thus important part of any criteria assessment. This could be performed using standard assessment methods:

- Social criteria: LCSP – Life Cycle Social Performance – standard technical requirements and assessment (e.g. safety, serviceability, durability, … etc.). These requirements and methodologies for their assurance are specified in wide range of technical standards.

- Environmental criteria: LCA – Life Cycle Assessment – defined in standards ISO, CEN, ACI ... (e.g. ISO 14040 and associated standards).

- Economic criteria: LCC – Life Cycle Cost – standard LCC procedure defined in standards ISO, CEN, ACI, … (e.g. ISO 15686-5 and associated standards).

3. Role of concrete and concrete structures

3.1 Environmental impact of concrete and concrete structures

During the last century, concrete evolved into the most important building material in the world. At present concrete is the second most used material on the planet, after water. Annual production of concrete in the industrialized world amounts to 1.5–3.0 tonnes per capita (fib 2013). World cement production increased 12-fold in the second half of the last century (Hajek et al. 2011). Nevertheless, compared with other building materials, the specific magnitude of harmful impact embodied in a concrete unit is relatively small, see Figure 3.

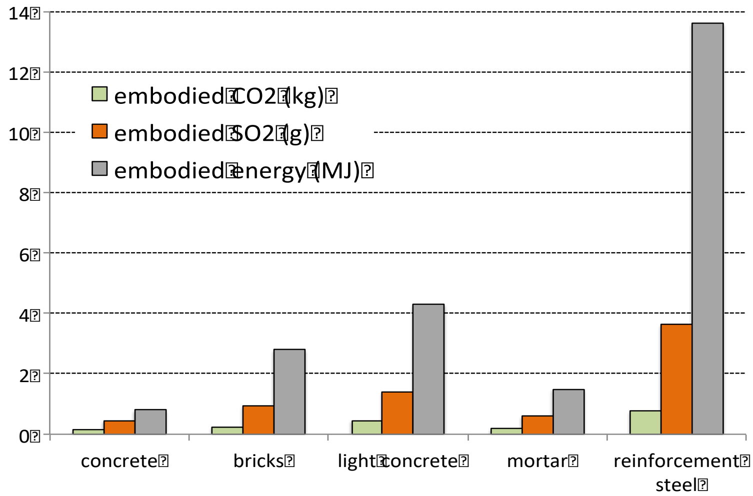

Figure 3. Environmental impacts of basic building materials based of generic data (data source: GEMIS 2010)

However, due to the high production of cement and concrete structures (the cement industry now accounts for approximately 8% of global man-made CO_2 emissions), the final negative cradle-to-gate global warming potential of all concrete structures is high (fib 2004). Due to recent development of concrete technology, concrete gradually becomes building material with high potential for new technical solutions, resulting in needed environmental impact reduction and consequent social and economic improvement.

With respect to specifics of concrete presented as a strong and durable material it is possible to design and construct robust structures with high level of resilience when faced to the exceptional natural or man-made disasters. High structural safety and reliability, and higher fire resistance of concrete (compared to other materials) results in a better resistance to extreme conditions during natural disasters (floods, storms, winds, hurricanes, tornados, fires, earthquakes, etc.) and terrorist attacks.

To gain from these advantages of concrete, it requires a better knowledge about technological processes and their impacts from wide variety of sustainability aspects within entire life cycle – from acquisition of materials, through production of concrete and concrete components, construction, use, up to demolition of concrete structure and recycling.

3.2 Advantages of concrete structures

Concrete is from many aspects structural material convenient for design of sustainable and resilient buildings and other engineering structures. Concrete structures are, in comparison to other materials, usually robust and strong to resist to exceptional loads during storms, hurricanes, tornados, floods, earthquakes and man-made explosions. Concrete is incombustible material with high fire resistance. High thermal mass of concrete could help to keep internal environment during heat and cold waves and can save energy needed for cooling of buildings. Concrete floors or walls can also significantly contribute to acoustic solutions in buildings.

Principal advantages of concrete structures from sustainability and resiliency viewpoints could be summarized into following points (Hajek 2016b):

- structural safety, including high resistance to exceptional effects like natural disasters (floods, storms, winds, hurricanes, tornados, fires, earthquakes, etc.) or man-made effects;
- thermal mass - concrete can contribute to energy savings associated with cooling and heating;
- acoustic properties – due to high specific weight of concrete, air-born sound protection of concrete floors or walls is good;
- high fire resistance – important especially for division of building into different fire compartments;
- long term durability enabling longer service life of buildings;
- flexibility – concrete technology enables high level of design flexibility;

- maintainability reducing operational cost and increasing overall building quality;
- use of recycled materials substituting natural materials in concrete mix.

These advantages could be significant in designing new constructions as well as in renovation of existing concrete structures. With respect to specifics of concrete presented as a strong and durable material it is possible to design and construct on this material bases robust structures with high level of resilience when faced to the exceptional natural or man-made disasters.

4. Contribution of concrete to sustainable Development Goals

United Nations (UN) summit Rio+20 held in 2012 in Brazil initiated a process of defining of a unified set of sustainable development goals. In October 2015 UN adopted Resolution 70/1: *Transforming our world: the 2030 Agenda for Sustainable Development* (UN 2015). This Agenda is a plan of action for people, planet and prosperity and should stimulate action up to 2030 in areas of critical importance for humanity and the planet. The principal goal is to end poverty, protect the planet and ensure prosperity for all.

There are specified 17 Sustainable Development Goals (SDGs) with 169 associated targets which are integrated and indivisible and balance three dimensions of sustainable development: economic, social and environmental. These new goals and targets came into effect on 1 January 2016 and guide the actions up to 2030. It is expected, that all stakeholders, all of us, will work to implement the SDGs Agenda within own countries and at the regional and global levels, taking into account national specifics and priorities.

One of the priority is sustainable urban development as a crucial aspect influencing the quality of life of people. Construction industry as a main stakeholder responsible for the use of material and energy resources has a key role in the implementation of SDG actions in the process of design, development and operation of buildings, roads, bridges and other infrastructure creating urban built environment. Concrete and concrete structures play in this process significant role.

In the following subchapters of this paper there are presented selected targets, where concrete industry and concrete structures can contribute to solution of SDG goals. Nevertheless, this selection is not enclosed and can serve as an inspiration and motivation for other stakeholders involved in concrete industry and in development of built environment. For further rethinking you can use whole SDG system presented at UN web pages (www.un.org).

4.1 Contribution of concrete industry to SDG 1: End poverty in all its forms everywhere

One of the target of SDG 1 is to build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

In case of extreme events and disasters concrete structures provide:

- high level of resistance;
- high level of resilience;
- concrete structures can serve as shelters for people in case of extreme events.

4.2 Contribution of concrete industry to SDG 3: Ensure healthy lives and promote well-being for all at all ages

Concrete structures can contribute to following targets of SDG 3: (a) substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination and (b) halve the number of global deaths and injuries from road traffic accidents by following aspects:

- standard concrete is non-toxic, there are not used any hazardous chemicals;
- concrete can positively contribute to acoustic quality in buildings;
- high performance quality of buildings and infrastructure can improve people‘s health and wellbeing.

4.3 Contribution of concrete industry to SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all

One of the principal target of SDG 7 is to double the global rate of improvement in energy efficiency by 2030. Concrete structures can contribute to this target by:

- optimization of concrete mix, shape optimization and effective structural and technological concepts of concrete structure; this can result in a reduction of embodied energy in the concrete structure;
- concrete structures in buildings can due to high thermal mass reduce heating/cooling energy demands – especially reduce cooling energy demand in hot areas.

4.4 Contribution of concrete industry to SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Important target of SDG 8 is to improve progressively, through 2030, global resource efficiency in consumption and production.

- Recent development of concrete and new types of silicate composites including use of recycled components represents a great potential for resource efficiency in consumption and production.

4.5 Contribution of concrete industry to SDG 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation

Concrete industry can contribute to several SDG 9 targets: (a) develop quality, reliable, sustainable and resilient infrastructure, to support economic development and human well-being, (b) promote inclusive and sustainable industrialization, significantly raise industry's share of employment and gross domestic product, (c) upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes and (d) enhance scientific research, upgrade the technological capabilities of industrial sector, encouraging innovation and substantially increasing number of research and development workers.

Contribution to solution of these targets by concrete industry is essential and could be supported by

- the use of concrete structures for development of high quality, reliable, resource efficient and resilient built environment – housings and infrastructure;
- development and adoption of clean and environmentally sound technologies and industrial processes in production of concrete, concrete elements and structures and operation of concrete structures;
- continuing scientific research of concrete structures and associated technologies for design, construction and operation;
- support of dissemination of advanced technologies, research and innovation into developing countries.

4.6 Contribution of concrete industry to SDG 11: Make cities inclusive, safe, resilient and sustainable

SDG 11 covers, besides others, following targets (a) to ensure access to adequate, safe and affordable housing and basic services for all, (b) to provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, (c) to enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning.

- Concrete structures play/and will play in the development of sustainable and resilient cities and their infrastructure crucial role.
- Concrete structures provide high level of safety, reliability and resilience of buildings and infrastructure in cities.

IOP Conf. Series: Materials Science and Engineering **442** (2018) 012013 doi:10.1088/1757-899X/442/1/012013

4.7 Contribution of concrete industry to SDG 12: Ensure sustainable consumption and production patterns

SDG 12 is focused to implementation of the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns. Targets relevant to concrete industry are (a) to achieve by 2030 the sustainable management and efficient use of natural resources, (b) substantially reduce waste generation through prevention, reduction, recycling and reuse and (c) encourage companies to adopt sustainable practices and to integrate sustainability information into their reporting cycle. This could be achieved through:

- optimization of concrete mix, resulting in a more efficient use of natural resources;
- increasing use of different kinds of recycled materials incl. recycled concrete aggregate in a concrete mix – and thus saving natural resources and reducing negative environmental impact (reduction of GHG emissions etc.).

4.8 Contribution of concrete industry to SDG 13: Take urgent action to combat climate change and its impacts

Main goal of SDG 12 is to support actions to reduce impacts of climate change by strengthening of resilience and adaptive capacity to climate-related hazards and natural disasters.

- Concrete structures have in case of climate-related hazards and natural disasters high level of resilience and adaptive capacity.

4.9 Contribution of concrete industry to SDG 17: Revitalize the global partnership for sustainable development

Targets of the last SDG 17 are focused to different actions in five areas: Finance, Technology, Capacity-building, Trade and Systemic issues. The leading principle is to promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries.

Implementation of advanced concrete technologies with reduced environmental impacts and increased performance quality could significantly contribute to solution of global problems. This requires international cooperation, access to science, technology and innovation, dissemination of knowledge, support in education and cooperation in science.

It is evident from the above overview that optimized concrete structures using new types of concrete in advanced technologies can significantly contribute to fulfilment of some specific targets of Sustainable Development Goals, and especially can contribute to reduction of global environmental impacts and can support increase of sustainability and resilience of built environment and entire society. The role of concrete industry in the process of sustainable development is thus essential.

5. Implementation of sustainability approach into Model code

5.1 General – fib attitude and process

The need for consideration of sustainability in the design and assessment of concrete structures has been already specified in previous *fib* Model Code 2010 (fib 2012). This was initiated by *fib* SAG8 Sustainability initiative and *fib* Commission 3 both chaired by Koji Sakai.

Preparation of the new *fib* Model Code 2020 (MC2020) started in 2016 From the very beginning sustainability was considered as one of the leading principles. Convener of Task Group 10.1 “Model Code 2020” Stuart Matthews expressed in Editorial for journal Structural Concrete (Matthews 2017) following:

- MC2020 will take sustainability as a fundamental requirement, based upon a holistic treatment of societal needs and impacts, life-cycle cost and environmental impacts.
- MC2020 provides an important opportunity to further advance our approach to the sustainable design, construction and through-life care of concrete structures.

This clearly shows fib attitude to implementation of sustainability approach into design, construction and operation of any concrete structure.

fib Commission 7 Sustainability is responsible for taking care about specific chapters implementing sustainability approach into Model Code 2020. The goal of *fib* is to publish new Model Code MC2020 in the year 2020.

5.2 Concept of sustainability approach in MC2020

Sustainability should become a basic concept of any design, construction process, operation, maintenance and repair of concrete structure. Sustainability should be presented in MC2020 as a conceptual approach – as an "umbrella" for efficient/high quality design and operation of concrete structures through entire life cycle – considering all three pillars – social, environmental and economic.

Sustainability approach should be implemented into MC2020 in accordance with international standardization – ISO 15392 General principles. Environmental assessment should be solved using existing standard methodologies of LCA and economic pillar using standard methodologies of LCC (see Chapter 2). There are already standardized methodologies in ISO, CEN or other standard systems. The MC2020 should to specify the need for these assessments (LCA, LCC) and provide references to existing standards.

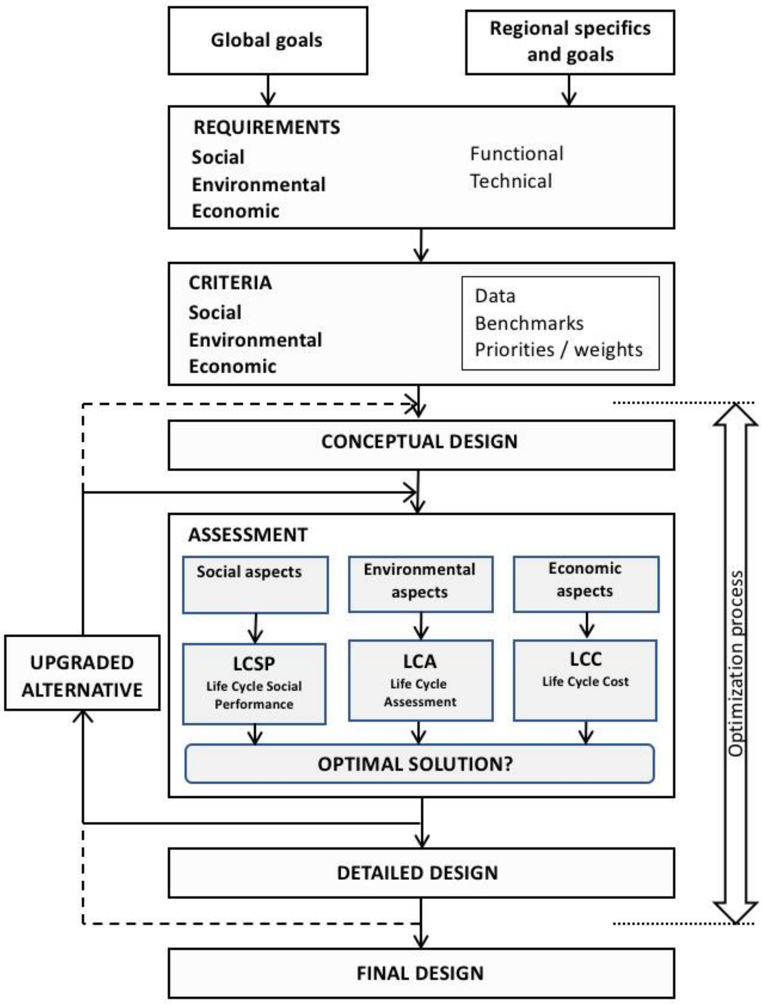

Figure 4. General Framework of sustainable design and assessment of concrete structures

Basic framework of sustainable design and assessment of concrete structures is shown in Figure 4. Based on global goals (given in SDGs) and regional specifics and goals are specified requirements and corresponding criteria associated with three sets of sustainability aspects. Optimization process is cyclic iterative prosecco starting with conceptual design, searching optimal solution based on assessment and resulting with detailed design and final design.

Safety, serviceability and durability of concrete structure is a part of social pillar of sustainability (see Figure 2). Specific needs for increase of reliability in specific regional conditions (climatic, geomorphological etc.) should be respected and solved within the framework of reliability concept of design of concrete structures. In this sense reliability concept should be extended also for the environmental consequences and needs for resilience.

Mixing of three pillars of sustainability into “simple” decision: what is the “most sustainable” solution could result in wrong decision and could be misused by different parties in order to support some preferred solution. E.g. increase of structural reliability could be in general in contradiction with optimum solution in environmental and economic pillar of sustainability. Mathematically expressed: solution of sustainable optimal result is typical multicriterial problem and could be searched in the form of Pareto optimum set of solutions – however, this is not practical and manageable for design code to be used by professional engineers. The code should be independent and should leave decision about weights between economy, environment and social pillars to decision makers or politics.

5.3 Regional specifics

There is a different ability of various societal and environmental systems in individual regions to mitigate or adapt to specific changes, including the extent of global change effects and potential natural or man-made disasters.

Considering resiliency, especially of buildings, the climate conditions and potential impacts and loses are essential for the design of sustainable structures/buildings. In different regions there are different major risks of natural disasters.

In general, the process of design and construction of structures varies in different countries and regions. They are more or less determined by regional specifics due to different material basis, energy mix, different climate conditions, different technology (based on the local labor cost, tradition in organization of work and different climate conditions) and differences in cultural traditions. Regional specifics should be considered when collecting the embodied environmental data of different materials. The type of material sources, mining technologies, transport means, transport distance and technology of production have a significant influence on the final unit embodied values.

As noted in chapter 3.2, concrete is from many aspects convenient structural material from viewpoints of sustainability and resiliency. The basic components of concrete are available in the most regions of the world. However, the level of technology and quality of construction is based on long-term tradition in construction and on economy aspects in the specific region. The implementation of standards for design and construction of concrete structures is especially in developing countries essential. Only thus could be ensured high performance quality and long-term functionality of concrete structures – from the perspective of sustainability and resiliency of buildings and other infrastructure in the built environment.

6. Conclusion

Sustainability should become a basic concept - an “umbrella” for efficient/high quality design and operation of concrete structures through entire life cycle – considering all three pillars – social, environmental and economic. Environmental assessment should be solved using existing standard methodologies of LCA and economic pillar using standard methodologies of LCC. There are already standardized methodologies in ISO, CEN or other standard systems. The goal of *fib* is to publish new Model Code MC2020 in the year 2020.

Acknowledgements

This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I (NPU I), project No. LO1605 - University Centre for Energy Efficient Buildings – Sustainability Phase.

References

[1] fib 2004. *fib* Bulletin 28. Environmental design – State-of-the-art, ISBN 2-88394-068-1
[2] fib 2012. *fib* Bulletins 65 and 66. Model Code 2010 - Final draft, Volume 1, Volume 2, ISBN 978-2-88394-105-2, ISBN 978-2-88394-106-9
[3] fib 2013. *fib* Bulletin 71. Integrated Life Cycle Assessment of Concrete Structures, Hajek, P. et al. State-of-the art report, ISBN 978-2-88394-111-3
[4] GEMIS 2010. *Global Emission Model for Integrated Systems* - version 4.6, database, www.oeko.de/service/gemis/, Öko Institut.
[5] Hajek, P., Fiala, C. & Kynclova, M. 2011. Life Cycle Assessment of Concrete Structures - Step towards Environmental Savings, *Structural Concrete*, Journal of the fib, Volume 12, Number 1, ISSN 1464-4177.
[6] Hajek, P. 2016a. Sustainability of concrete structures in changing World, In proc. *International Conference on Concrete Sustainability ICCS16*, Madrid
[7] Hajek, P. 2016b. Sustainable Concrete and Concrete Structures – Challenge for Sustainable Future, In proc. *fib Symposium 2016, Performance-based approaches for concrete structures*, Cape Town
[8] ISO 15392 - Sustainability in building construction — General principles
[9] Matthews, S. 2017. fib Model Code 2020 - A new development in structural codes. *Structural Concrete*, Journal of the fib, Volume 18, Issue 5, Pages 651–652
[10] UN 2015. Resolution adopted by the General Assembly on 25 September 2015. RES 70/1 Transforming our world: the 2030 Agenda for Sustainable Development
[11] WMO 2015. World Meteorological Organisation 2015. *www.wmo.int* and *www.theguardian.com*