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OPTIMIZATION PARAMETER SETS FOR SUSTAINABLE CONCRETE IN TUNNELS

LARISSA STRÖMBERG[1], MALIN LÖFSJÖGÅRD[2], ANDERS ANSELL[2], and STAFFAN HINTZE[1]

[1]*NCC Nordic Construction Company, Infrastructure Business Area, Solna, Sweden*
[2]*KTH Royal Institute of Technology, Division of Concrete Structure, Stockholm, Sweden*

Public and private clients are beginning to set complex optimization requirements, taking into consideration environmental and cost-efficiency parameters over the built construction's lifetime. The early design process is currently irreversible, and this makes it difficult to change a concrete structure in the later detailed design stage, when more accurate information is available regarding environmental impact and life-cycle costs. There is a dilemma in complying with existing standards to achieve technical requirements while optimizing a concrete structure in order to reduce the climate impact. The long-term goal of the project is to develop a new theoretical concept for dynamic optimization strategies which can be applicable to the early design, the client-requirement preparation, the detailed design, the production and the follow-up stages. This paper presents the results of the up-start phase of the project. The work has focused on the identification of current practice regarding clients' requirements for technical, environmental and cost-efficiency parameters. An analysis of these requirements with sprayed concrete (shotcrete) in a number of ongoing projects has led to the identification of optimization parameter sets. The project has also shown how the physical values of those parameters can be collected from existing statistics, experience recovery databases and previous project requirements, or calculated according to standardized methods and tools. The concept developed will be used in a demonstrative modeling in the next project step.

Keywords: Multiple client requirements, Markov chain analysis, Life cycle assessment, Life cycle cost, Concrete structures.

1 INTRODUCTION

The European Commission has developed guidelines on climate change (EU commission 2011) and challenges the Member States to redesign their industries and community-building process to be more climate-neutral by 2050. Sweden has taken initiatives aiming to achieve a fossil-free transport sector by 2030 and a climate-neutral nation by 2045 (The Swedish Parliament 2017). The European directive (EU directive 2014/24/EU) on public procurement in the Member States proposes a supplement to the traditional tender evaluation model in which competitive bidding proposals are no longer evaluated on the basis of price. Sweden adopted the directive as the new Public Procurement Act, PPA (The Swedish Parliament 2016), which proposes that alternative tenders are evaluated on the basis of the total life-cycle costs, LCC. PPA allows a contracting authority to refer to an eco-labeling as proof that the procurement object meets certain requirements, e.g. an Environmental Product Declaration, EPD.

Flexibility in dimensioning concrete structures based not only on traditional technical parameters but also on "new" parameters such as LCC and Life Cycle Assessment, LCA is becoming increasingly important. The main obstacle to the development of sustainable structures and the creation of business models with these is the fact that environmental engineering is not integrated with current technical design practice.

Several Swedish public clients such as the Swedish Transport Administration, STA (2015), Stockholm County Council, SCC (Stockholm County Council 2016) and Swedish municipalities (Common Environmental Requirements for Construction Work 2018) have begun to require that infrastructural projects be evaluated with respect to climate impact based on the total life-cycle perspective as well as price. When the STA tightens its demands by 2020, with a 30% reduction in climate impact in each infrastructural project, it will be very difficult to meet them without altering the current technical design. The early design process is irreversible, and this makes it difficult to change a concrete structure in the later detailed design stage to take into consideration not only a contract price but also environmental parameters.

There is a growing interest in developing digital optimization tools based on inter-disciplinary aspects that can be used to support the evaluation of design options for the creation of more sustainable concrete structures. Almeida *et al.* (2016) have developed an optimization method for bridges based on technical performance and LCC with numerical modeling based on Markov chains theory and it is used to calculate a compound performance index for each design option based on a five-level scale. In another North American project, an attempt has been made to create an optimization strategy to identify the most sustainable blend of Portland cement, PCC for road pavements. The aim was to find the option with the best performance based on three aspects: LCC, technical performance and LCA, and a matrix of 10 different strategies including different mixes of Portland cement, road designs and maintenance actions has been developed (Alauddin Ahammed 2017). In a Norwegian project, the LCA modeling tool has been used in the Scandinavian ETSI model (Bridge Life Cycle Optimization) to optimize multiple sustainability aspects for bridges. The tool enables the most sustainable bridge structure to be designed based on LCA, LCC and technical functions (Brattebø 2012). Sen and Roesler (2017) have developed a digital modeling concept for the entire life cycle of concrete road pavements.

The present research project aims to further develop existing models for optimizing individual concrete structures into a more flexible and interactive modeling concept for all concrete structures. The focus of the project is on creating ways of making changes in technical design based on LCA and LCC aspects, regardless of the stage of the project. An earlier KTH study of the parameters reflecting the technical performance of concrete structures and a numerical modeling matrix based on Markov chains theory (Ansell *et al.* 2002) will be further developed in the present project. A previously developed digital LCA calculation interface (Strömberg 2017) will also be used.

2 DESCRIPTION OF THE FRAMEWORK

The purpose of this research project is to develop a dynamic optimization concept to complement traditional structural design and construction practice, public procurement routines, product development processes and client follow-up control in order to create more sustainable concrete structures. The aim is to build a mathematical model that indicates which optimization parameters determine that one concrete structure is more climate-neutral than another for the same technical performance and price. The model can then be used to identify the most effective and direct actions, from the early planning phase to the final demolition of the structure.

The developed concept is based on international Standards and building practice, and it complies with current research in this area. The international Standard, ISO 15686-5 (2008), has been used to define in-depth aspects of the sustainability of a construction project. Environmental, economic and technical performance are the sustainability aspects described in the Standard, which gives a basic outline of how the different sustainability aspects can be integrated into the entire design process taking into consideration the whole life-cycle of the building or engineering work, see Figure 1. The Standard describes the general framework for the application of LCA and LCC, along with technical parameters to different types of construction and to different process stages: early planning, preparation of bidding requirements, design, construction, maintenance and end of life.

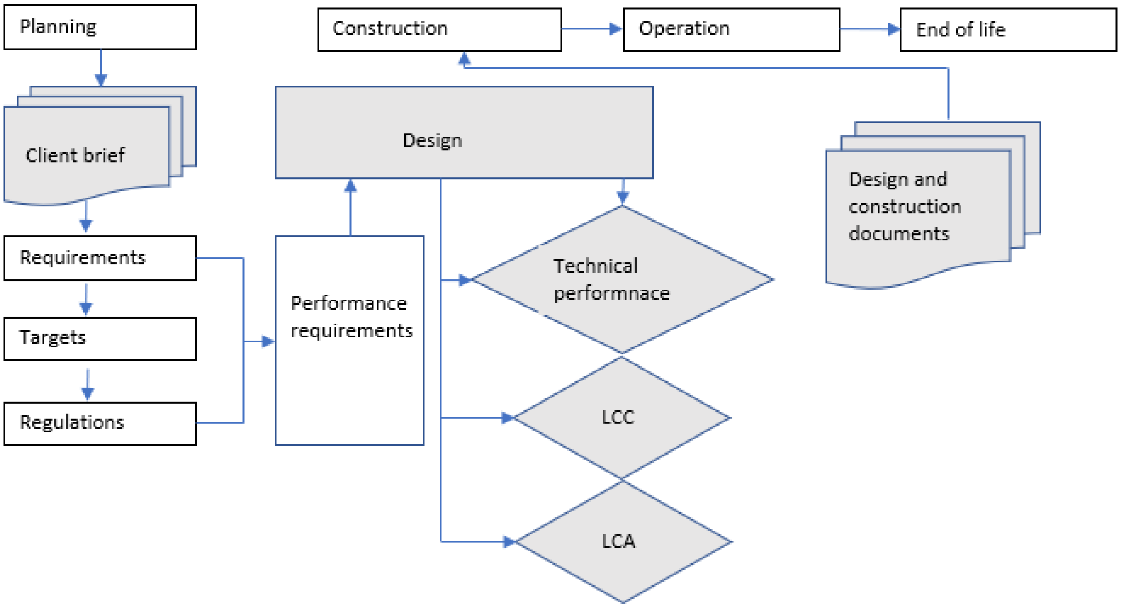

Figure 1. Performance requirements according to ISO 15686-5 (2008) (with some modifications).

The next step will include an overall demonstration of the optimization matrix and the modeling concept. To be able to use the Markov chains theory, a matrix with optimization parameters for each aspect and the physical values of all possible random parameters is required. These values can be generated by measurement or taken from literature sources or feedback from previous infrastructural projects. The probability vector with different life-cycle scenarios for the design of a concrete structure can then be modeled, making it possible to optimize the most sustainable option based on multiple aspects such as technical or functional performance, LCA and LCC. Optimization according to Markov chains theory makes it possible to include the times when different parameters which are a part of the optimization matrix may affect the optimization results.

The developed concept will be demonstrated on shotcrete used as rock reinforcement in traffic tunnels with optimization parameters based on typical requirement specifications in Swedish infrastructural projects. In the future, it will be possible to generalize the concept and apply it internationally to different types of concrete structures. The climate impact of the spray concrete reinforcements in STA's tunnel projects accounts for nearly 33% of the overall climate impact of the whole project calculated on a single tunnel section (Gröndal 2018). Shotcrete is interesting because the Norwegian Public Roads Administration has banned the use of plastic fiber reinforcement in sprayed concrete for environmental reasons (Myren *et al.* 2018). Plastic fiber reinforcement is nevertheless still considered in some countries to be an environment-friendly alternative to steel reinforcement due to its lower weight.

3 IDENTIFICATION OF PARAMETERS AND CONSTRAINTS

The large number of project documents describing the requirements of Swedish clients with regard to technical performance, LCA and LCC have been analyzed, and project requirements from STA, SCC and several Swedish municipalities have been evaluated. The project has developed a matrix with optimization parameters covering most of current clients' requirements regarding climate impact reporting, the calculation of life-cycle costs and functional requirements for the shotcrete reinforcements. The need for information and the sources for this information, e.g. some physical values for the optimization parameters in order to perform a mathematical modeling with the concept in the next step of the project, was also mapped.

3.1 Parameters for Technical Performance

The current practice of using technical parameters makes it possible to compare alternative designs independently of the client or the performer. The industry-wide acceptance of the same standardized requirements in accordance with the European standards and Swedish building regulations have led to a uniform working method. Many parameters are in use to define the technical performance of shotcrete reinforcement according to Standard EN 1992-1-1, STA's requirements (STA 2016) and project-specific requirements, but three parameters of crucial importance for this type of concrete structure: overlay, stock thickness and material consumption (Dalmalm 2018) have been chosen. According to Dalmalm (2018), optimizing these parameters leads to the greatest economic and environmental savings.

3.2 Parameters for LCA

The analysis has shown that there are different variants in the requirements for calculation, reporting, optimization and follow-up of the LCA in the client's project specifications. A full LCA contains several environmental categories, but the primary requirement in the evaluated inquiries from the STA, SCC and Swedish municipalities is the climate impact. This may lead to sub-optimization when a design is optimized to be climate neutral but may cause other adverse environmental impacts, such as waste generation, eutrophication, acidification, utilization of non-renewable resources etc. In the long term, more extensive LCA client requirements must be developed.

ISO 15686-5 (2008) sets out the system perspective for the definition of sustainability for a building or a civil engineering work, but in order to elaborate some explicit parameters for LCA in this study we use the EN 15804 (2012). Standard which specifies an industry-approved method for the development of an EPD for a construction product. An EPD should always be reviewed and approved by an official EPD-program operator so that it can be used to compare the environmental performances of similar products in, for example, public procurement. An EPD contains seven mandatory environmental impact categories, including climate impact, acidification, eutrophication, etc. The information in an EPD can be used as a reliable measure of environmental performance and can be accepted for use in reporting, marketing, procurement and product development.

This present project plans to use only climate impact as an optimization parameter for LCA, since this is judged to be sufficient to meet the current reporting requirements in the Swedish construction industry. In order to be able to perform an LCA for a shotcrete structure, the LCA-software Gabi (2018) will be used with an associated database of emission factors.

3.3 Parameters for LCC

The analysis has shown that claiming an LCC is not as widespread among Swedish public clients although both the European directive 2014/24/EU and the PPA (The Swedish Parliament 2016) recommend applying life-cycle costs for the evaluation of tender proposals instead of the traditional procurement based on price.

The project proposes that the ISO 15686-5 (2008) standard be used to calculate the LCCs. Both the STA (2017) and the recommendation of the Swedish authorities regarding the implementation of the PPA (The Swedish Parliament 2016) refer to this Standard for the conduct of an LCC. The Standard defines life-cycle costs for a built structure as the sum of the investment, operation, maintenance and final settlement costs. An LCC can be calculated on the basis of present values and as annual costs. With the present values, investment costs can be weighed against the future costs and benefits. The annual costs are mainly useful when different maintenance costs are weighed against each other or against the benefits gained.

The STA has developed and implemented an Excel-based calculation tool for the LCC for road structures, the ambition being to conduct LCC for the evaluation of all infrastructural projects within a few years. For the LCC calculations in the next stage of this project, the STA's LCC tool (STA 2017) and the STA’ Bridge and Tunnels Management System, BaTMan (STA 2018) will be used.

4 CONCLUSIONS

Firstly, theoretical grounds for a modeling concept have been developed based on a review of international standards, previous research, current design practice, and European Unit’s and Sweden's goals in a sustainable construction sector. Secondly, optimization parameters and input data requirements for such modeling have been identified based on mapping of a large number of client specifications in Swedish infrastructural projects.

The next step will include an overall demonstration of the optimization matrix and the modeling concept. The developed concept will be demonstrated on shotcrete used as rock reinforcement in traffic tunnels with optimization parameters based on typical requirement specifications in Swedish infrastructural projects.

It is a major socio-economic challenge to convert the current construction process into a more climate-neutral and cost-effective process taking into consideration the whole life-cycle perspective and achieving the high-level climate policy goals at the European Unit level. The concept developed in the present project will hopefully create more flexibility in the inter-disciplinary optimization of concrete structures and allows changes to be made during the detailed design and construction. The overall result of this project is to increase knowledge accumulation about sustainability aspects at least in 20% of the Swedish construction sector and to adopt the developed modeling concept at least for 20% of all public infrastructural projects with budget over EUR 500,000 by 2021.

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