CESARE'17
COORDINATING ENGINEERING FOR SUSTAINABILITY AND RESILIENCE
Dead Sea, Amman, Jordan
3-8 May 2017
JORDAN UNIVERSITY OF SCIENCE & TECHNOLOGY
IRBID - JORDAN

# DESIGN FOR SUSTAINABILITY AND RESILIENCE – NEW TERMS FOR TRADITIONAL TASKS OR AN ENLARGEMENT OF THE PERSPECTIVES FOR ENGINEERS

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**Keywords:** Construction works, Life cycle analysis, Sustainability assessment, Resilience

**Abstract.** *The fulfilment of requirements for the technical and functional quality of building components and construction works, as well as their optimization in terms of construction costs or construction time form part of the traditional design tasks performed by engineers. However, nowadays, they are also confronted with issues concerning the contribution of constructions to sustainable development and a new theme: resilience. But are these tasks really new? The paper discusses the traditional engineering tasks and approaches that already provide a starting point for assessing the sustainability of building components and structures. For example, structural stability, fire-, sound- and heat-protection, as well as flexibility and adaptability, can be considered as significant starting points in this regard. New tasks arise in the area of sustainable use of resources.*

*This paper presents approaches to life cycle analysis and the state of international standardization. It shows that life cycle assessment and a full life cycle analysis can support the work of engineers. Finally, the relationship between sustainability and resilience is discussed. Robust, durable structures can support sustainable development. However, the environmental, economic and possibly social consequences (here in terms of benefits and costs) of more resilient structures are to be taken into account.*

## 1 INTRODUCTION

Design and construction requirements for construction works with regard to stability, functional quality, and design quality, as well as the efficient use of material (and financial) resources, have already been present for thousands of years- cf. [1]. Also the change/adaptation of the use of existing structures (for example in the case of church buildings) or the reuse and repurposing of building components (for example, ancient columns, natural stones, etc.) were a matter of course. Although design tools and construction products have been rapidly developed in the meantime, the basic requirements for buildings have remained almost unchanged. One example is the basic requirements for buildings as laid down in the EU Construction Products Regulation [2]:

1) Mechanical resistance and stability
2) Safety in case of fire
3) Hygiene, health and the environment
4) Safety and accessibility in use
5) Protection against noise
6) Energy economy and heat retention
7) Sustainable use of natural resources

Comparatively new is the requirement No. 7 *Sustainable use of natural resources*. This is explained as follows: "*The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following: (a) reuse or recyclability of the construction works, their materials and parts after demolition; (b) durability of the construction works; (c) use of environmentally compatible raw and secondary materials in the construction works*." [3, p. 34].

This requirement is also linked to traditional design tasks and strategies, such as "design for environment" (DfE) and "design for deconstruction" (DfD). Dealing with the durability, the ease of deconstruction and recycling, as well as the flexibility and adaptability of building structures, is a common design task. However, a new and, therefore, additional aspect is the consideration of sustainable use of natural resources. This expands the scope of activities of architects and engineers and requires the additional use of data and tools.

The inclusion of a requirement for sustainable use of natural resources in the EU Construction Products Regulation was made in the context of an overall increased interest in the implementation of sustainable development principles. It thus becomes all the more necessary to assess the sustainability of buildings and civil engineering works, as well as for the public sector to set an example through requiring information on the use of natural resources in the context of green public procurement [4].

## 2 FROM LIFE CYCLE ASSESSMENT (LCA) TO LIFE CYCLE ANALYSIS

An environmental performance assessment is a method used to determine and assess the use of resources and the undesirable effects on the global and local environment. It is based on the method of environmental Life Cycle Assessment (LCA). In the past, LCA was mostly used in academia, since there was often a lack of concrete LCA data on construction products and construction processes. This situation has begun to change. For example, in Germany, a database with information on life cycle assessment for construction products [5] is freely available, the assessment of both the resource consumption and impacts on the environment is part of the national sustainability assessment system for the public sector (BNB [6]), as well as the one available for the free real estate market (DGNB [7]). However, the use of sustainability assessment systems is limited to a few individual projects, which means that LCA is only integrated into the building design and decision-making processes in exceptional cases. Rather, it is often carried out, if at all, only by specialists in isolation from the design process.

An integrated approach is pursued by the authors. It is proposed to integrate LCA into the analysis of the life cycle of buildings and structures already during the early design process. This also makes it possible to deal with all questions relating to sustainability assessment already in the planning/design phase and to analyze the respective interactions and trade-offs. An investigation of the type and extent of a) the fulfilment of functional and technical requirements, b) the consumption of resources and the effects on the environment as part of the environmental performance, c) the lifecycle costs and the consequences for value stability and value development as part of the economic performance, as well as d) the social performance with its partial aspects of safety, health and satisfaction of the users, as well as the design and urban quality, must therefore be included. This is illustrated in Fig. 1.

The technical quality also includes durability, resistance, ease of maintenance as well as ease of dismantling and recycling. Risks, marked with an "R" in the figure, are also determined and evaluated.

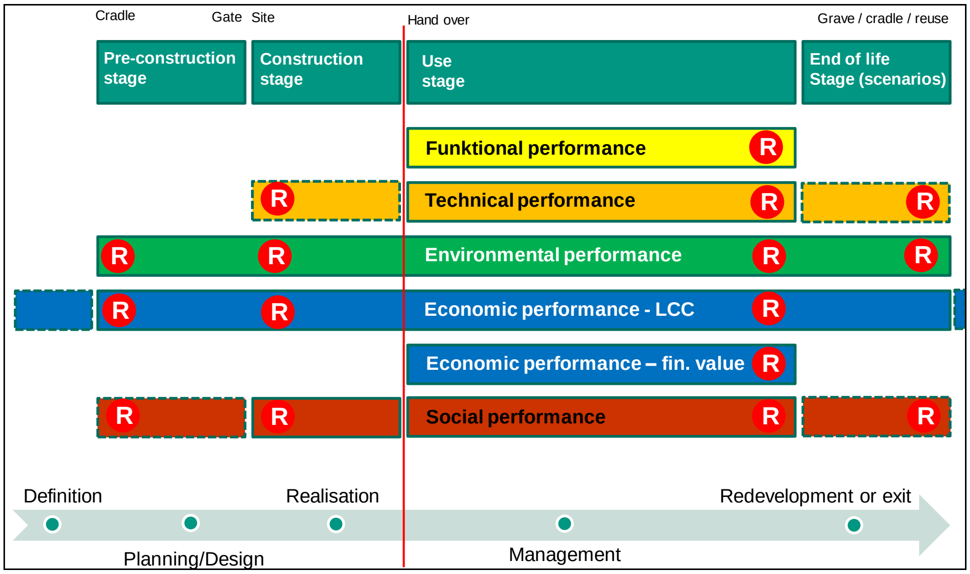


Figure 1: Overview of the Sub-topics of a Life Cycle Analysis (Lützkendorf)

It becomes clear that the different stages of the building life cycle have to be recorded and taken into account for each sub-topic of a cycle analysis.

## 3 CURRENT STATE OF STANDARDIZATION

The description and assessment of the contribution of buildings and civil engineering works to sustainable development has been the subject of international standardization activities for several years now. Within the framework of ISO TC 59 SC 17 *Sustainability in Buildings and Civil Engineering Works* several standards and reports have already been developed for application to buildings, including

- ISO/TR 21932:2013: *Sustainability in buildings and civil engineering works -- A review of terminology*
- ISO 15392:2008: *Sustainability in building construction -- General principles*
- ISO 21929-1:2011: *Sustainability in building construction -- Sustainability indicators -- Part 1: Framework for the development of indicators and a core set of indicators for buildings*
- ISO 21931-1:2010: *Sustainability in building construction -- Framework for methods of assessment of the environmental performance of construction works -- Part 1: Buildings*

ISO 15392 provides the basis for a uniform understanding of sustainability in the construction and real estate industry. A sustainability assessment always requires determining and assessing the environmental, economic and social performance of buildings in their design and operation simultaneously and with equal status. The fulfillment of functional and technical requirements is a prerequisite. The basis for the development of assessment criteria and indicators are protected goods and protection goals. For the area of environmental performance, these are explained here [8]. The standard is under revision. Work has already begun on ISO/WD 20887: *Design for Disassembly and Adaptability of Buildings*.

In order to support an application of ISO 15392, the standard ISO/TS 12720: 2014: *Sustainability in buildings and civil engineering works - Guidelines on the application of the general principles in ISO 15392* exists. The special features of civil engineering structures are discussed in:

- ISO/TS 21929-2:2015: *Sustainability in building construction -- Sustainability indicators -- Part 2: Framework for the development of indicators for civil engineering work*
- ISO/CD 21931-2: *Sustainability in building construction -- Framework for methods of assessment of the environmental performance of construction works -- Part 2: Civil engineering works*.

ISO 21929-1 provides the basis for the development and application of assessment criteria and indicators. For buildings, a core list of indicators is provided that should form the basis of sustainability assessment systems of all kinds. For the first time ever, through this standard approaches are provided for an analysis of side- and follow-up-effects. For example, it shows that climate change affects not only the ecosystem, but also society and the economy. This approach should and will be expanded in the coming years. In 2017, the work on an additional standard dealing with the creation of the basis required to develop and interpret benchmarks will start.

ISO 21931-1 provides the basis for a description and assessment of the environmental performance of buildings. In particular, the assessment criteria are here named. They are mainly based on the impact categories of a life cycle assessment (LCA), but also include the quality of design and management processes. The standard is under revision. It is now planned to include the bases for the description and assessment of economic and social performance. In this regard, the international standardization process will take the lead from already existing European standards developed within CEN TC 350 *Sustainability of Construction Works*. These are:

- EN 15643-3:2012: *Sustainability of construction works - Assessment of buildings - Part 3: Framework for the assessment of social performance*
- EN 16309:2014+A1:2014**:** *Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology*
- EN 15643-4:2012**:** *Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance*
- EN 16627:2015: *Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods*

Additionally, standards relevant to the life cycle of buildings and civil engineering works have already been developed within ISO TC 59 SC 14 *Design Life*. These include, among others:

- ISO 15686-2:2012: *Buildings and constructed assets -- Service life planning -- Part 2: Service life prediction procedures*
- ISO 15686-4:2014: *Building Construction -- Service Life Planning -- Part 4: Service Life Planning using Building Information Modelling*
- ISO 15686-5:2008: *Buildings and constructed assets -- Service-life planning -- Part 5: Life-cycle costing*
- ISO 15686-10:2010: *Buildings and constructed assets -- Service life planning -- Part 10: When to assess functional performance*

It becomes clear that the analysis of the lifecycle of buildings and the assessment of their contribution to sustainable development has been marked by a transition from a predominantly qualitative to a predominantly quantitative approach. Nowadays, the assessment of the economic performance is mainly based on the results of an analysis of the life cycle costs in the narrower (Life Cycle Costing – LCC) and broader (Whole Life Costing – WLC) sense. It is currently discussed whether and to what extent effects on the stability and development of the economic value, as well as financial risks, can be taken into account. For example, high energy consumption, high levels of greenhouse gas emissions and air pollutants, risks to the environment and health, or a low degree of flexibility and adaptability of buildings, are already acknowledged as sources of financial risks.

The assessment of the environmental performance is based mainly on the results of a life cycle assessment. The essential standard for this is

- ISO 14040:2006*: Environmental management - Life cycle assessment -- Principles and framework*

However, in everyday design work, it is not necessary to carry out an LCA for a complete building in the strict sense. In fact, it is sufficient to determine the type and quantity of each product installed into the building and link this information with data on the use of resources and the undesirable effects on the global and local environment caused by the product's production, installation, maintenance, removal and disposal. Environmental product declarations (EPD) – which are declarations for describing environmentally relevant characteristics and properties of products – provide such data. EPD's must meet the requirements of the international standard,

- ISO 21930:2007: *Sustainability in building construction -- Environmental declaration of building products* (currently under revision)

To assess the social performance of buildings, the satisfaction of individual users plays a decisive role. During the design phase, one can refer to

- ISO 7730:2005: *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*

The trend here goes in the direction of adaptive comfort models. It has proven useful to consult building users using structured questionnaires during building's operation considering both the heating and cooling period and to combine the information obtained from such surveys with the measurement and analysis of indoor climatic parameters.

The development of international standards on the topic of sustainable construction is now being achieved with the active participation of only a few countries. It is recommended to involve the national standardization bodies of different countries even more than has hitherto been the case. At the same time, it is suggested to follow closely the status and development of standardization activities in this field. The consideration of sustainable development aspects generally has consequences for the process of standardization and the development of standards. Almost every construction related standard has direct or indirect links to the topic of sustainability. ISO Guide 82:2014 *Guidelines for addressing sustainability in standards* formulates recommendations on how sustainability aspects are to be taken into account in standardization.

Standards that have hitherto reacted in a backward-looking way to the events in the past should now also contain elements of a forecast of future burdens. For example, standards that cover design loads related to wind, rain, snow, flood, etc., it is important to take into account the consequences of climate change, which are already evident.

## 4 RELATIONSHIP BETWEEN SUSTAINABILITY AND RESILIENCE

The term "sustainable" refers to buildings and civil engineering works that, on the one hand, fulfill the technical and functional requirements and, on the other hand, have an above-average environmental, economic and social performance. This means to achieve at the same time: a) low resource use, low negative impact on the global and local environment, low environmental risks and a positive contribution to the protection of biodiversity, b) low life cycle costs, high value stability and low financial risks, c) a high level of user satisfaction together with above-average security and comfort, including effective health and safety procedures of those involved in the construction process. In addition, requirements for the architectural design quality and the integration into the urban environment, as well as the quality of the design, execution and management processes, have to be fulfilled. In order to demonstrate the consideration of all these features and characteristics, various systems exist around the world for the certification of buildings' contribution to sustainable development (including BRREAM, LEED, CASBEE, DGNB/BNB - cf. also [9]).

Resilience is a current topic in the scientific discussion. In part, attempts are being made to establish it as an independent research item or to consider it as a topic that will soon replace the discussion on sustainability. There are numerous activities on this topic [10], [11], [12]. From the authors' point of view, resilient solutions aim to develop robust and highly durable buildings and structures. Resilient buildings and structures should have the capability to not (completely) fail in the event of a partial failure of components, and return to their initial state after a disturbance or to maintain their central functions in any case. The concept of "resilience" can thus be applied to the materials and engineering sciences as well as the city planning. It becomes clear that maintaining the technical and functional quality, protecting the life and health of users, as well as protecting physical and economic values, can be considered aspects of this concept. In this regard, parallels can be drawn to the protected goods / areas of protection and protection goals, from which also the requirements for sustainable buildings are derived.

From the authors' point of view, the topic of resilience initially focuses on the characteristics and properties of buildings and civil engineering works, which can be interpreted as (additional) benefits or the fulfilment of technical or functional requirements. In any case, the effort to realize these features and properties must also be assessed. For example, are load-bearing reserves, back-up solutions, emergency units or parallel systems necessary? Therefore, for resilient solutions it is first necessary to investigate whether and to what extent their design and realisation lead to an increase in the consumption of material resources, additional negative effects on the local and global environment and additional costs for the sake of countering possible risks arising in the future only with a certain degree of probability. However, at occurrence of disastrous events and disruptions of normal life, the resilient building solutions are more robust and resistant. This leads to lower risks for life and health, reduces the material and economic damages and ensures the functional capability.

It becomes clear that even resilient structures should be subject to a sustainability assessment. The energy and material flows in the lifecycle, the effects on the global and local environment as well as the life cycle costs must be always determined and assessed. Life cycle approaches followed up to now and in particular the systems for the certification of the buildings' contribution to sustainable development are based on a deterministic life cycle model on the basis of a clear scenario. In this case, the requirements for resilience should be included in the task brief (client's brief) and must be taken into account in the functional equivalent. A more extensive examination of the costs/efforts and benefits associated with resilient structures requires the transition to stochastic models [13] taking into account the probability of occurrence and extent of losses/damage or other failure consequences.

Thus, the consideration of circumstances requiring robust and resistant structures leads to a logical further development of the life-cycle analysis.

## 5 CONSEQUENCES FOR THE DESIGN

The increased emphasis on aspects of sustainability and resilience has consequences for the design and design process. It is recommended by the authors to act in a two-stage process; to first carry out a site analysis, and then perform a life cycle analysis accompanying the design process (at different work stages of the design process).

Site analysis is an essential starting point for project development both for planners and decision-makers in the real estate sector. Besides the traditionally collected information on the macro and micro location, it is now also important to describe the situation at the site and on the land plot in such a way that important technical requirements for the construction works can be derived from this description, e.g. specific requirements for structural stability in response to the specific subsoil conditions. This includes the analysis of identifiable natural and man-made hazards in the present and future or the estimation of current and future consequences of climate change. Risk maps are increasingly available [14], [15] as sources of information. This development is driven, among others, by firms in the insurance industry.

On the basis of this information, from the results of the location analysis, risks or concrete requirements in the present and future can be identified in the lifecycle of the property to be planned and transferred to the task formulation (client's brief).

The building design, taking into account sustainability aspects in connection with the application of systems for certification of sustainability, has so far mostly followed a deterministic life-cycle model, usually with a consideration period of approx. 50 years. Individual systems – including the German sustainability assessment systems – already assess the functionality and adaptability, the ease of deconstruction and recycling as well as the durability; the inclusion of criteria for assessing resilience to the adverse impacts of climate change is underway. However, in lifecycle stages of a building taking place in the far future, the conditions of market, environment or use may change drastically. Therefore, where necessary and useful, several scenarios can be developed for the future life cycle of the property, including the specific demands or requirements. The respective probability of the occurrence of specific burdens or other special situations or changes is to be discussed. It can be assessed whether and to what extent the building can still cope with such changes or can be adapted to them and, on the other hand, how much is the (additional) effort for the production of robustness, resistance or adaptability. A weighing process needs to be carried out between an effort to be carried out today and events that are only highly likely to occur in the future.

It is recommended by the authors to take into account the technical and functional aspects of resilience already in the client's brief when it comes to the definition and formulation of the requirements. The question to ask is in relation to which current or possibly future requirements or special situations, the structure should prove to be robust and resistant? At the same time, requirements for the economic, environmental and social performance have to be formulated. This is already the subject of the European standard EN 15643-1:2010: *Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework*. This concept is illustrated in Fig. 2.

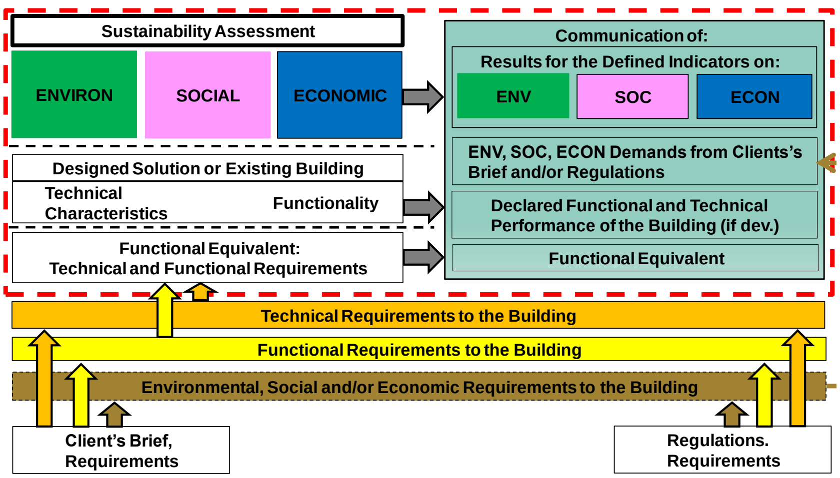


Figure 2: Example for the Integration of Environmental, Social and Economic Requirements into the Client's Brief and Building Regulation Requirements

In the economic domain, this concerns the already known approaches, such as “design to cost” (DTC) or “design to life cycle cost” (DTLCC), or the creation of a framework for the construction costs. In the environmental domain, first examples show a budget for embodied impacts on [16], while in the social domain a minimum level of user satisfaction can be specified as the goal. Performing a life cycle analysis at different stages of the process offers the advantage of being able to examine and influence the interactions between cost and benefit, as well as between technical, economic, environmental and social parameters on the basis of the available information at each design stage - see also Fig. 3.

For example, in the UK, there is already the Green Overlay to the RIBA Outline Plan of Work [17] that offers an appropriate and accessible vehicle for mapping the ways in which sustainable design activities can be integrated into the design and construction process of buildings, as a simple set of adjustments to each of the traditional RIBA work stage activities.

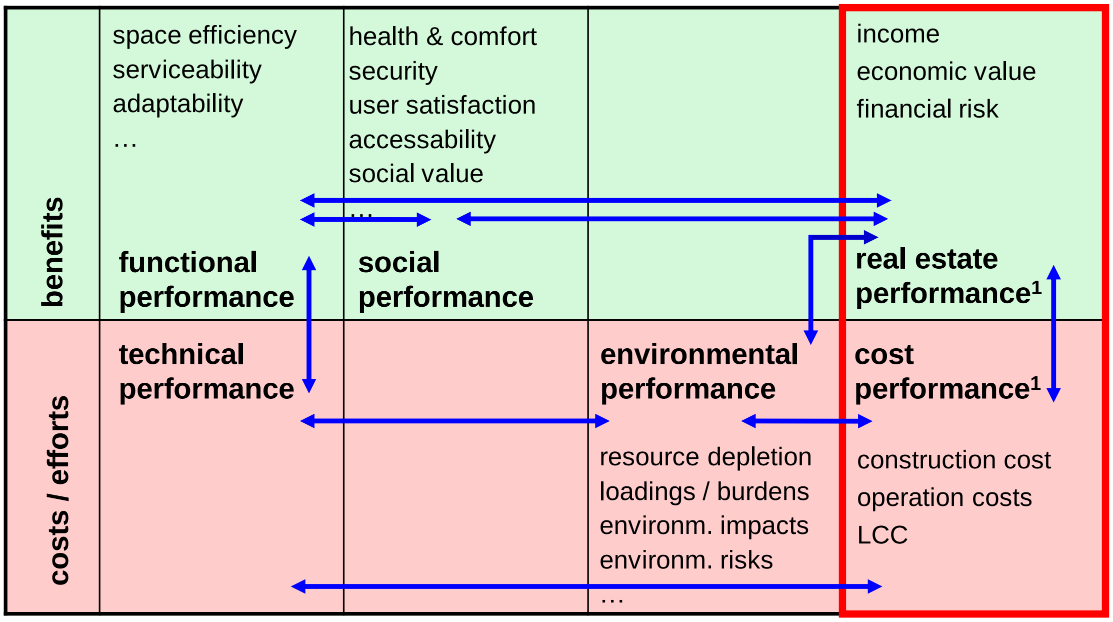


Figure 3: Interactions between the Different Sub-topics of a Life Cycle Analysis (Lützkendorf)

Finally, it is important to document the essential characteristics and properties of the building in a complete and transparent way. This includes information on the life cycle resource consumption and environmental pollution, on the environmental and health-related soundness, the robustness and resilience under normal and extreme conditions, as well as on ease on deconstruction and recycling. This is an additional service for the client/owner who needs such information for the rental and marketing of his property, as well as for the valuation and insurance or for a sustainability certification.

## 6 CONCLUSION AND OUTLOOK

It becomes clear that topics such as sustainability or resilience hardly entail new requirements for the work of designers and engineers. Many sub-tasks are already treated as part of their traditional activities. It does not make sense to distinguish between traditional design and a sustainability- and resilience-focused design. It is also not useful to consider sustainability and resilience as two completely separate approaches. Rather, it is necessary to combine design and assessment tasks in a life cycle analysis accompanying the design process and to deal with the overall performance of buildings.

An additional task, however, is required. It becomes increasingly necessary to integrate an environmental performance assessment into the design process and to provide specific information on the environmental and health compatibility or friendliness of construction products to the client, to public authorities and to third parties (banks, insurance companies, appraisal specialists). It can be assumed that in the future more and better data, tools and benchmarks will be available for an environmental performance assessment and solutions; for example, BIM is expected to support integrated approaches for an overall performance assessment more in future. It is also important to document in a complete and transparent way the overall performance of a building achieved in its design and construction in the form of a building file that should be updated during the life cycle of the project when, for example, a maintenance or modernization work is taking place.

Finally, it can be said that the increasing attention to the sustainability and resilience of construction works does not only create new tasks for engineers, but it also provides opportunities for additional earnings and an improved competitiveness.

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