**ISSN 1840-4855**
**e-ISSN 2233-0046**

**Original scientific article**
**http://dx.doi.org/10.70102/afts.2025.1732.001**

# SUSTAINABLE CONSTRUCTION AND THE USE OF PREFABRICATED CONCRETE

Svjetlana Banjac[1], Saša Papuga[2], Gordana Broćeta[3]

*[1]University of Banja Luka, Bosnia and Herzegovina. e-mail: svjetlanavlaski@gmail.com,*
*orcid: https://orcid.org/0009-0004-3622-2913*
*[2]Faculty of Technology, University of Banja Luka, Bosnia and Herzegovina.*
*e-mail: sasa.papuga@tf.unibl.org, orcid: https://orcid.org/0000-0001-7400-1186*
*[3]Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka,*
*Bosnia and Herzegovina, e-mail: gordana.broceta@aggf.unibl.org,*
*orcid: https://orcid.org/0000-0001-5555-6610*

***Received: December 04, 2024; Revised: January 15, 2025; Accepted: February 03, 2025; Published: March 28, 2025***

## SUMMARY

Given that the construction industry has a significant impact on the environment and consumes large amounts of natural and energy resources, it represents a very important segment in sustainable construction. This paper provides an overview of sustainable building and the application of prefabricated concrete, specifically prefabricated concrete slabs, within the sustainable construction system. Additionally, the aim of this research was to analyze the life cycle (LCA) of prefabricated slabs, with a system boundary from the cradle to the grave, where conclusions were drawn and values of environmental impact were obtained. The analysis was conducted on a specific case, leading to results indicating that the cement production phase dominates the overall warming potential when it comes to the production of prefabricated concrete slabs.

Key words: *sustainable construction, prefabricated concrete, cement industry, LCA.*

## INTRODUCTION

Construction is an activity that consumes a lot of natural and energy resources; therefore, it represents an important segment of sustainable development [1]. Concrete is regarded as the most widely used building material, with estimates suggesting that around 25 billion tons of concrete are produced globally yearly, translating to over 3.8 tons per person annually. In construction worldwide, twice as much concrete is used compared to all other building materials combined. [26]. In pursuit of a more sustainable economy and response to the fight against negative climate change (global warming) and the reduction of the greenhouse effect, the construction sector is increasingly focusing on more rational resource use and reducing environmental burdens. This is why sustainable development is often associated with sustainable construction. [3, 4]. The impact of construction on the environment occurs throughout the entire life cycle of a building, which includes execution (production of building materials and their installation), building usage (operation and maintenance), and the completion of the life cycle (demolition). During the design phase, attention should be paid to the future building's impact on the environment and the environment's impact on the building itself, due to the interplay of the sociocultural and economic dimensions of sustainable development. Designing should prioritize solutions that rationally use natural resources and energy during construction and use, while ensuring the quality and durability of the future building, as well as the possibility of its removal and the reuse or recycling of its components. Sustainability in the execution phase means using as few natural resources as possible, specifically utilizing building materials with reduced $CO_2$ emissions and less energy consumed in the production, transport, and installation of these materials. The ideal material life cycle represents a circular flow, where waste from one process serves as raw material for another. Materials that utilize recycled raw materials are favored, as they save energy, reduce pollution in the production of new products, and lead to lower $CO_2$ emissions. [27] Given that buildings are significant energy consumers, they are recognized as having the greatest potential for reducing total energy consumption at the national level [23]. To achieve sustainability in the construction sector, energy efficiency is being introduced to reduce energy consumption and $CO_2$ emissions, in line with EU legal frameworks. Since this area is strictly defined by regulations, it represents good potential for developing sustainability in construction, providing new activities for the construction industry [2]. The final phase of the building's life cycle, according to sustainability principles, should focus on the reuse and recycling of components from demolished buildings. This paper demonstrates the possibility of using prefabricated concrete in a sustainable construction system.

## SUSTAINABILITY AND SUSTAINABLE CONSTRUCTION

### The Concept of Sustainability

Sustainability is defined as the ability to maintain a relatively long-term existence across various domains of life. It is also described as a process in which people maintain changes in the environment through balanced homeostasis, where resource exploitation, investment direction, technological development, and institutional changes are in harmony, enhancing current and future potential to meet human needs and aspirations. For many, sustainability is examined through ecological, economic, and social domen. It can be said that sustainable development meets the needs of the present without compromising the needs of future generations [6] [29] [8].

The first beginnings about sustainability appeared in Hans Carl von Carlowitz's book, published in 1713. Over time, this idea developed through numerous conferences and summits, some of the most significant being: the United Nations Conference on the Human Environment (Stockholm 1972), the UN Conference on Environment and Development (Rio de Janeiro 1992), World Summit on Sustainable Development (Johannesburg 2002), UN Conference on Sustainable development (Rio de Janeiro, Brazil, 2012) and Agenda 2030 (New York, 2015) [9] [10].

The general rule is that sustainable development can only be achieved if all three dimensions (economy, environment and society) are integrated and viewed equally. The social dimension of sustainable development implies fairness and takes into account the needs of the majority of the inhabitants of the Earth. Sustainable social development is an integrated process of building all human capabilities. Environmental protection - the ecological dimension - implies awareness of the importance of environmental pollution. The mentioned dimensions (economic, social and ecological) show the basic starting points of the concept of sustainable development.

This understanding is illustrated in Figure 1 with three overlapping ellipses that denote the three pillars of sustainability which are not mutually exclusive and can be mutually reinforcing. [8] [9] [10]

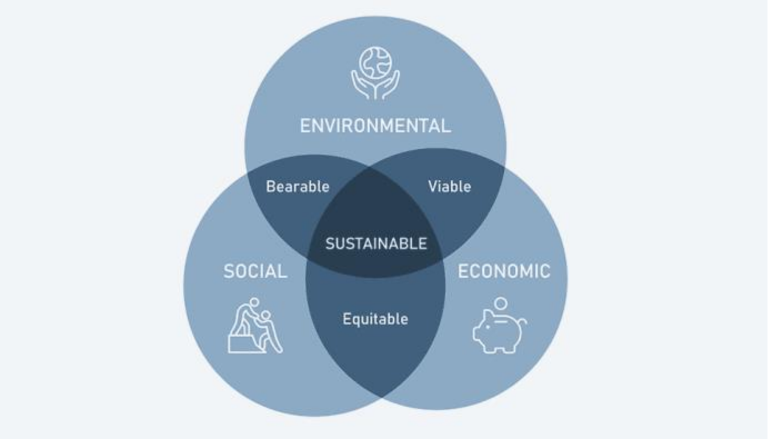

Figure 1. The "three pillars" of Sustainability [10]

**Sustainability in Construction**

As the construction industry consumes natural and energy resources, it is necessary to reduce the negative impacts of construction on the environment and meet other sustainability criteria. Various rating systems have been developed to measure the level of construction sustainability and ensure the best quality at the highest level of certification.

Sustainable construction is viewed in the context of sustainable development, aiming for a balance between ecological, economic, and sociocultural perspectives [18]. Recognizing construction as a significant resource consumer, sustainable practices have become a priority in modern construction and energy sectors, closely linked to sustainable development principles. Achieving a balance among the three interdependent components of sustainable development is essential to counter negative trends.

Engineering disciplines advocate for the evolution of new technologies to ensure efficient resource and energy use, minimize waste, reduce environmental impact, and contribute to economic development, positively influencing sustainable development [5]. That is why it is important to raise awareness about the development of sustainable construction.

Returning to the field of construction, it is important to note that construction materials, both in their production and exploitation, have a great impact on the environment.

Therefore, it is very important to use the benefits provided by sustainable building materials.

Due to their environmental benefits and contribution to the creation of environmentally friendly structures, sustainable building materials have become popular. [11]

Many studies have shown that sustainable building materials have significant benefit to the environment. Life cycle assessment (LCA) studies have shown that these materials had lower carbon emissions, energy consumption, and resource depletion. This emphasizes their potential to contribute to global sustainability goals and to address the construction sector's ecological footprint.

Economic research has revealed a complicated interaction between initial and long-term cost advantages. While some sustainable materials have shown significant cost advantages over their lifetime, others require significant inputs. This emphasizes the importance of a holistic strategy that takes both short-term and long-term expenditure returns, emphasizing the importance of new financing mechanisms and regulatory incentives. Also, some of the conclusions are the importance of technology and innovation in promoting sustainable materials. Outcomes studies [11] imply that emerging technologies can improve design, production and application sustainable materials.

Some of the important sustainable materials are wood, recycled metal (steel and aluminum, for example), bamboo, recycled glass, green concrete, prefabricated concrete etc.

Due to the volume, these materials will not be treated further in this paper. The emphasis is on the use of prefabricated concrete, and this paper analyzes the use of prefabricated slabs.

This necessity for measuring and reporting on sustainable construction leads to two types of assessment tools [10]:

- Criteria Based Tools (CBT)
- Life Cycle Assessment (LCA)

In the LCA methodology, environmental impact is evaluated throughout the entire lifecycle. However, due to misconceptions about its complexity, CBT is often preferred as a more widely accepted method, based on scoring specific criteria regarding environmental impact. Numerous certification systems for sustainable buildings have been developed globally, including:

- LEED (USA)
- BREEAM (UK)
- DGNB (Germany)
- SBTool (Canada)
- CASBEE (Japan)
- Green Star (Australia)
- Minergie (Switzerland)

The evaluation of these systems is based on specific criteria, and the assessment area, in addition to energy efficiency, includes other ecological, social, and economic parameters that impact sustainable development. These parameters consider factors such as human and environmental health, water savings, material selection, and indoor quality [7]. Each of these parameters is assigned points, which are ultimately summed up. [13]

## Sustainable Construction and the Use of Prefabricated Concrete

### *Advantages of Prefabricated Concrete Components*

The three traditional objectives of construction are time, cost, and quality. Because the production of precast elements is easier to control, precast concrete generally offers higher quality and durability compared to cast concrete. Precast concrete has excellent economic value, which can be beneficial for large commercial projects or small businesses. In traditional concrete construction, steel rebar tying, support formwork, and concrete pouring are done on site. When using prefabricated elements, the construction process is simpler, construction sites are concentrated and the construction process is easier to follow, ensuring high construction quality. The concrete strength of prefab components is generally one degree higher than the design strength. Once precast components are manufactured, they can meet the requirements of pure concrete. There are several advantages that prefabricated constructions have, in comparison with the use of classic concrete.

In summary, the advantages of using prefabricated concrete components in the construction industry can be presented as follows [12]:

- Predictability and Reliability
- Productivity
- Safety, Health, and Environment: (reduction of waste, less noise, less dust, etc.; less air pollution; lower energy consumption in transport and on-site work; easier recycling of materials).
- Interfaces and Coordination

However, prefabricated concrete may have some drawbacks due to its characteristics. For example, since precast concrete products are produced on a standard basis, the use of precast concrete can affect the design possibilities of a building. In addition, any change to the specification of the elements presents a challenge. Any change in order quantity or type of precast concrete products can significantly affect project delivery. [12]

From a sustainability perspective, carbon emissions in the construction industry can be divided into two groups: efficient and inefficient emissions. The principles of sustainable production focus on inefficient emissions generated by activities in three construction phases: production, delivery, and assembly. [12].

## APPLICATION OF LIGHTWEIGHT PREFABRICATED SLABS

Reinforced concrete structures can be built in two ways:

- Traditional Method: Casting on-site in prepared formwork with reinforcement and scaffolding.
- Prefabricated Method: Using prefabricated reinforced concrete (RC) elements that are produced industrially or artisanally (in a factory or workshop) and are installed and assembled after achieving the designed concrete strength, then connected into a cohesive unit – the structure (figure 2).

Reasons for Using Lightweight Prefabricated Slabs:

- Material Savings: By using lightweight prefabricated slabs, up to 50% savings in concrete and 50% savings in reinforcement can be achieved compared to traditional slabs. For example, when constructing 1,000 square meters, this results in savings of 35 tons of concrete and 7.5 tons of reinforcement.
- Green Construction: Using the same amounts of materials, labor, and energy, 1 square meter of traditional slabs produces only 0.4 square meters compared to 2.5 square meters of lightweight prefabricated slabs.

Figure 2. Appearance of Prefabricated Reinforced Concrete Slab (Source: From the Prefabricated Elements Manufacturer)

- Low Weight: The hollow slab is a prefabricated prestressed element with a lightweight cross-section, using only prestressing cables as reinforcement. The weight of lightweight slabs is 28-46% less than that of solid concrete sections of the same height.
- Large Spans: With prestressing, larger spans can be achieved compared to traditional construction methods. Lightweight slabs can span up to 14 meters without supports, corresponding to beam spacings of 15 meters. This building system requires fewer load-bearing elements placed at greater distances apart, allowing for faster and more economical construction.
- Versatility: These slabs are applicable in masonry and steel constructions, too. Their primary use is in intermediate floor construction, but they can also serve as façade panels, beam elements, or bridge slabs.
- Fast and High-Quality Production: They feature high production quality and material savings. The manufacturing process is fully automated, with high-quality concrete and prestressing cables that meet necessary material certifications. The advantage of hollow slabs over traditional floor construction is seen in the rapid production of elements with minimal labor. Their assembly is also straightforward and quick, covering large areas in a short time.

- Software Support: Hollow slabs are designed and sized using licensed software like Floor CAD, in accordance with EC2 and BS 8110 standards. This program tracks the entire process from design to production and transportation for assembly.
- Aesthetic Finish: After production and installation, hollow slabs require no additional treatment or aesthetic corrections. Their manufacturing occurs on specially designed tracks, resulting in an exceptionally smooth underside. Automated production ensures precise manufacturing of uniformly sized elements, facilitating neat stacking in the structure.
- By analyzing all these parameters, along with the aforementioned benefits of prefabricated elements, it can be concluded that, in addition to faster execution and material savings, $CO_2$ emissions are reduced at every step of production, making prefabricated slabs an exceptional construction product for sustainable building practices.

## LCA (LIFE CYCLE ASSESSMENT) OF PREFABRICATED SLABS

Life cycle assessment (LCA) is presented as a mechanism for analyzing and calculating the total impact of a product on the environment, taking into account every phase of the life cycle (preparation of raw materials, production process, sale and transport, until disposal of the product). LCA has a key role in maintaining the balance between product, processes, or service development, and environmental protection. [10] This paper presents the results of the life cycle assessment of prefabricated concrete elements, specifically prefabricated slabs. A significant number of researchers have addressed this issue, resulting in a wealth of literature on prefabricated concrete, concrete, and constructions made from these materials. One notable study is the LCA of prefabricated elements by a group of authors [12]. Additionally, some researchers have compared LCA results of prefabricated concrete with monolithic concrete [15]. The findings in [15] indicate that cement production has the greatest environmental impact on concrete production. Several strategies to mitigate the environmental impact of cement production have been proposed, including reducing energy consumption in kilns, improving the quality and durability of cement (and consequently concrete), and selecting alternative materials for cement production [14]. Furthermore, the study in [16] concluded that cement production has the largest environmental impact, with significant contributions to air pollution from trucks and pumps used in the production and installation processes. A significant study in this field is the LCA analysis of buildings made from prefabricated concrete conducted by Canadian researchers in 2012 [17], in collaboration with the CPCI Technical Institute for Concrete and Prefabricated Concrete. This study thoroughly analyzed buildings across several cities and examined all construction elements and their environmental impacts. Another group of authors [30] provided a life cycle assessment of commercial buildings made from prefabricated concrete, with a cradle-to-grave perspective. The results indicated that, throughout the entire lifespan of the building, walls made of prefabricated concrete have a lower environmental impact compared to buildings with masonry walls. In [19], the authors analyzed floors made from prefabricated elements, investigating energy consumption and CO2 emissions during production, transportation of construction materials, transport of prefabricated components, demolition, and reuse. This study also included a Life Cycle Cost (LCC) analysis, demonstrating that prefabricated floors consume less energy and emit less CO2 than traditional floors [25]. The following section provides a brief overview of LCA in general, focusing on specific issues, with descriptions of input parameters, calculation methods, etc.

### LCA According to International Standards

Four main choices for defining system boundaries in LCA study are shown below. (based on the ISO 14044:2006 standard) [20]:

1. Cradle-to-Grave
2. Cradle-to-Gate
3. Cradle-to-Cradle
4. Gate-to-Gate

These frameworks provide a comprehensive structure for conducting LCA and assessing the environmental implications of prefabricated concrete products.

## Method

Life cycle assessment (LCA) is used for a comprehensive analysis of the movement of energy and materials into and out of the environment throughout the entire life cycle of a product, process or service. The LCA method is based on the ISO 14040 (2006) and ISO 14044 (2006) standards.

This study focuses on the life cycle analysis of prefabricated slabs. The research aims to enhance the understanding of the life cycle performance of prefabricated concrete in the context of prefabricated slabs, which are widely used in the construction industry in Bosnia and Herzegovina.

For this analysis, the functional unit chosen is 1 square meter of prefabricated slab. The results are presented in Table 7. The ecological flows shown include emissions into the air, soil, and water, as well as the consumption of energy and material resources.

Figure 3 illustrates the four iterative phases of LCA. These four phases, which are essential for effectively conducting an LCA study, are detailed in a series of ISO standards (ISO 14040:2006; ISO 14041:1998; ISO 14042:2000) [21][22].

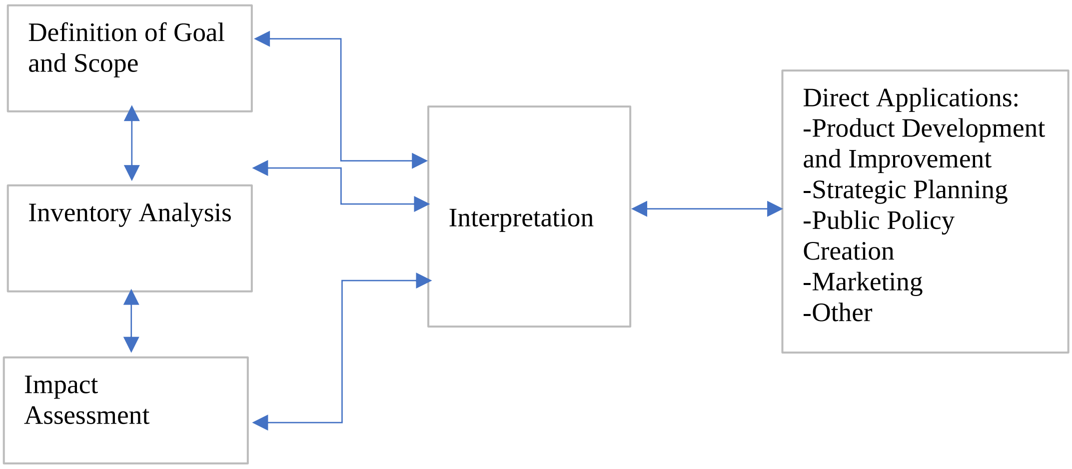

Figure 3. The four phases of life cycle assessment are an iterative process

LCA analysis is carried out by iterating four phases, as shown in Figure 4.: goal and scope definition of the study, life cycle inventory, life cycle impact assessment and interpretation.

Different evaluation methods used in LCA analyzes and different commercial codes for implementation are known, some of them are the IPCC method, which expresses the impact of $CO_2$ equivalent emissions, the CED method, which evaluates the energy used during the entire life cycle of a product or service, etc. [20][21][22].

The data used in this study includes the quantity of materials involved in the production of concrete slabs, a list of material suppliers in construction, and the transportation methods used for delivering materials.

For this study, the LCI (Life Cycle Inventory) analysis, which is the first step in the environmental impact assessment, involved collecting data on precast concrete products within the boundaries of the factory process, as shown in Figure 4. LCI data on precast concrete products were obtained from two precast concrete factories in Bosnia and Herzegovina.

Additional LCI process data on materials and construction were obtained from the proprietary LCI database on building materials and construction maintained by the Baune Institute [28].

The production of prefabricated elements consists of several steps: mixing concrete, transporting it to molds in trucks or specially designed transporters, or in concrete containers lifted by bridge cranes, pouring the concrete into the molds, consolidating through vibration, leveling, and finishing the surface, curing and stripping the forms.

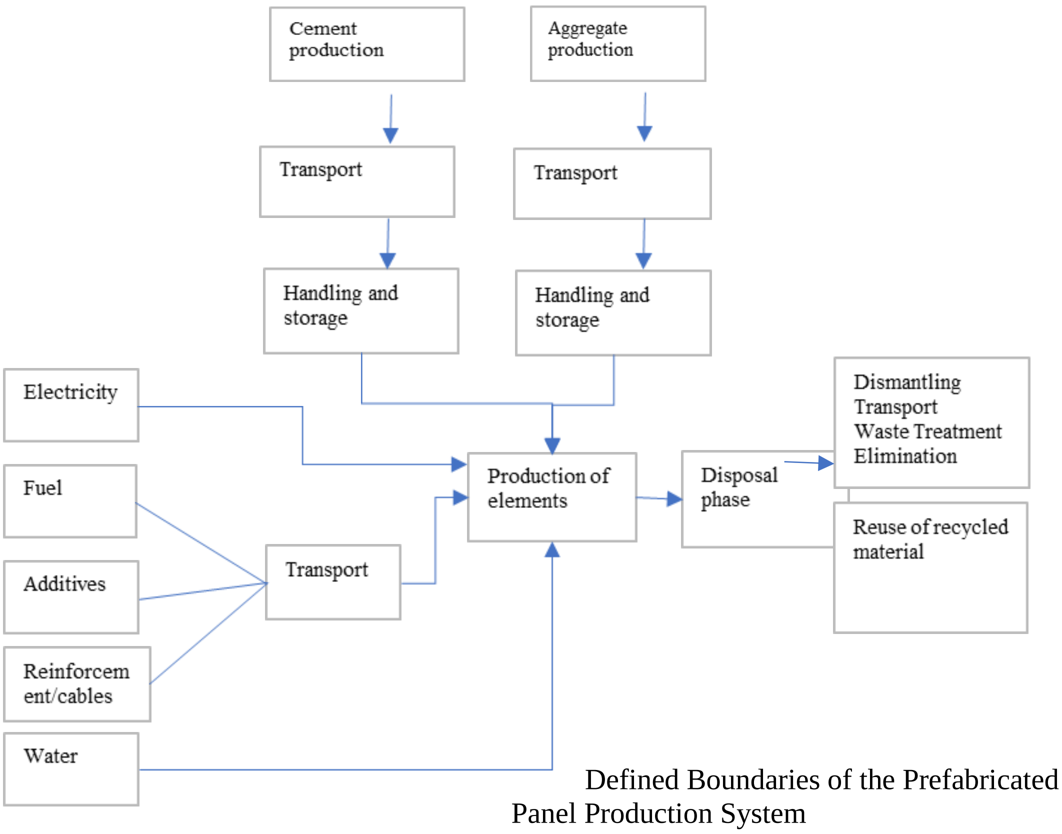

Figure 4. Life Cycle Analysis

This time, the location of the construction site will not be considered.

Raw Material Data for Prefabricated Slab Production:

For a 5m long PPB-200 slab with a width of 1.2meters, approximately 1.25 cubic meters of concrete is required, resulting in 6 square meters of finished slab, or 0.208 m³/m².

Table 1 presents the quantities of individual components used for the production of a single prefabricated slab with a thickness of 0.2 meter, a width of 1.20 meter, and a length of 5meters.

Table 1. Consumption of Individual Components for a Prefabricated Concrete Slab Measuring 5 m in Length and 1.2 m in Width

| Consumption of Individual Components | Cement | Water | Aggregate |
|---|---|---|---|
| Quantity (kg) | 540kg | 160kg | 2400kg |
| Total: | 3100kg materials / approx. 520kg/ square meters slab | | |

Pre-Stressing Steel: No additional reinforcement is required aside from pre-stressing steel. Cold-drawn steel wires and pre-stressing wires are high – strength steels used for manufacturing prefabricated pre – stressed concrete panels.

CEMENT: CEM I 25.5N - Portland cement contains 95-100% Portland cement clinker, with the addition of natural gypsum as a setting regulator in amounts up to 5%, which is ground together in a ball mill. A certificate of conformity has been obtained according to the applicable standards BAS EN 197-1, BAS EN 197-2. The distance from the cement factory to the prefabricated elements factory is approximately 4 kilometers, and delivery is made via tanker up to 27 tons. This cement is particularly used for the production of prefabricated concrete elements and products, which allow for quick removal of formwork, and for the production of prestressed concrete structures, as well as in the most demanding construction projects where high mechanical resistance, early strength and early mechanical loading are required. CEM I 52.5 N is also used in the factory production of special mortars, plasters and construction chemicals.

AGGREGATE: Natural aggregate from the Bosna River, fractions 0/4, 4/8, 8/16 millimeters. Procurement is carried out by truck from a location approximately 90 kilometers away from the prefabricated elements factory. The purpose of the aggregate for concrete follows the EN 12620:2008 standard.

Here are Tables 2, 3, and 4 of the manufacturer regarding the characteristics of aggregates, provided by fractions:

Table 2. Characteristics of 0/4 mm Aggregate (Data from the Prefabricated Elements Manufacturer)

| EN 12620:2002+A1:2008<br>Concrete aggregate<br>Aggregate fraction 0/4 mm | |
|---|---|
| Fraction | 0/4mm |
| Granulometric composition | $G_f85$ |
| Coarseness | MP |
| Content of fine particles | $f_3$ |
| Quality of fine particles | 0,7 |
| Shape index | - |
| Resistance to crushing | - |
| Content of acid-soluble sulfates | $AS_{0,2}$ |
| Total sulfur content | 0,048 |
| Chloride content | <0,003 |
| Bulk density | 2,65 |
| Dry particle density with pores | 2,52 |
| Saturated particle density, surface dry | 2,57 |
| Water absorption | 1,92 |
| Humus content | None |
| Light organic pollutants | 0,00 |
| Testing with magnesium sulfate | - |
| Mineralogical-petrographic composition | quartz sand |

Table 3. Characteristics of 4/8 mm aggregate (Data from the Prefabricated Elements Manufacturer

| EN 12620:2002+A1:2008<br>**Concrete aggregate**<br>**Aggregate fraction 4/8 mm** | |
|---|---|
| Fraction | 4/8mm |
| Granulometric composition | $G_f85/20$ |
| Coarseness | - |
| Content of fine particles | F1,5 |
| Quality of fine particles | - |
| Shape index | SI15 |
| Resistance to crushing | - |
| Content of acid-soluble sulfates | $AS_{0,2}$ |
| Total sulfur content | 0,048 |
| Chloride content | <0,003 |
| Bulk density | 2,7 |
| Dry particle density with pores | 2,58 |
| Saturated particle density, surface dry | 2,63 |
| Water absorption | 1,71 |
| Humus content | None |
| Light organic pollutants | - |
| Testing with magnesium sulfate | - |
| Mineralogical-petrographic composition | heterogeneous diabase gravel |

Table 4. Characteristics of 8/16 mm aggregate (Data from the Prefabricated Elements Manufacturer

| EN 12620:2002+A1:2008<br>**Concrete aggregate**<br>**Aggregate fraction 8/16 mm** | |
|---|---|
| Fraction | 8/16mm |
| Granulometric composition | $G_c85/20$ |
| Coarseness | - |
| Content of fine particles | F1,5 |
| Quality of fine particles | - |
| Shape index | $SI_{20}$ |
| Resistance to crushing | $LA_{20}$ |
| Content of acid-soluble sulfates | $AS_{0,2}$ |
| Total sulfur content | 0,048 |
| Chloride content | <0,003 |
| Bulk density | 2,73 |
| Dry particle density with pores | 2,63 |
| Saturated particle density, surface dry | 2,66 |
| Water absorption | 1,41 |
| Humus content | None |
| Light organic pollutants | - |
| Testing with magnesium sulfate | $MS_{18}$ |
| Mineralogical-petrographic composition | heterogeneous diabase hornstone gravel |

In the following, Table 5 presents the classes of concrete used in the precast slab.

Table 5. Classes of concrete used in the precast slab; (Table obtained from the manufacturer of precast elements)

| Serial no. | Product label | Strenghth Class | Exposure Class | Consistency Class | Chloride Content Class | Maximum Aggregate Size Dmax | Other Declared Properties |
|---|---|---|---|---|---|---|---|
| 1. | BAUBET-6MB/2 | C 50/60 | XC1 - XC4,<br>XS1 - XS3,<br>XD1 - XD3,<br>XA1 | S1 zemljovlažni | Cl 0,10 | Dmax 16 | - |

Prestressing Strands 1860/1670.

Figure 5. Precast Slabs [22].

Table 6. Declared Unit

| LABEL | Value | Unit |
|---|---|---|
| Conversion Factor to 1 kg | 520 | kg/square meter |
| Weight per Unit Area | 520 | kg/square meter |
| Declared Unit | 1 | square meter |
| Layer Thickness | 0.20 | meter |

## System Boundaries

System Type: From cradle to grave. The selected system boundaries include the production of precast slabs, encompassing the extraction of raw materials and auxiliary materials, as well as the disposal phase (figure 5 & table 6). The following processes are detailed:

A1-A3 Production Phase.

Module A1: Extraction and processing of concrete raw materials and prestressing steel.

Module A2: Transport of basic and auxiliary materials to the production facility.

Module A3: Production of precast concrete in the factory (energy consumption, including dosing and mixing, filling concrete, compaction, and curing), emissions, and waste management processes up to landfill.

C1: Dismantling and demolition.

C2: Transport – transport of precast concrete slabs to the waste processing facility. The transport distance to the waste processing facility is taken as 50 kilometers.

C3: Waste treatment – The assumed recycling rate for prestressed precast slabs is 95%, with a recycling loss of 5%.

C4: 5% of the recycling loss is landfilled during the waste processing of the slabs.

D: Reuse and potential for regeneration.

## LCA Results

Indicator values are obtained by multiplying factors with the corresponding material/energy flows.

Table 7. Presentation of Results ENVIRONMENTAL IMPACT according to EN 15804+A1: 1 square meter of Prestressed Precast Concrete Slab. The factors used for these calculations are from CML (characterization factor - version 4.1 October 2012) [28]

**X -** included in LCA; **MND -** Module Not Declared; **MNR -** Module Not Relevant.

| Production Phases | | | Construction Phase of Buildings | | Usage Phase | | | | | | | Disposal Phase | | | | Liabilities Outside System Boundaries |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raw Material Supply | Transport | Production | Transport from Manufacturer to Place of Use | Assembly | Usage/Application | Maintenance | Repair | Replacement | Renovation | Energy Consumption for Building Management | Water Use for Building Management | Dismantling/Demolition | Transport | Waste Treatmen | Elimination | Reuse of Recycled Material |
| **A1** | **A2** | **A3** | **A4** | **A5** | **B1** | **B2** | **B3** | **B4** | **B5** | **B6** | **B7** | **C1** | **C2** | **C3** | **C4** | **D** |
| X | X | X | MND | MND | MND | MND | MNR | MNR | MNR | MND | MND | X | X | X | X | X |

| Parameter | Unit | A1-A3 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|
| Global Warming Potential | [kg $CO_2$ - Äq] | 6,41E+1 | 0,00E+0 | 1,20E+0 | 1,15E+0 | 2,55E-1 | 4,84E+0 |
| Stratospheric Ozone Depletion Potential | [kg CFC11 - Äq] | 2,90E-13 | 0,00E+0 | 3,97E-16 | 5,69E-15 | 1,42E-15 | 3,78E-14 |
| Soil and Water Acidification Potential | [kg $SO_2$ - Äq] | 7,76E-2 | 0,00E+0 | 8,12E-4 | 6,50E-3 | 1,63E-3 | 8,95E-3 |
| Eutrophication Potential | [kg $(PO_4)_3$ - Äq] | 9,70E-3 | 0,00E+0 | 1,74E-4 | 1,59E-3 | 1,85E-4 | 3,34E-4 |
| Tropospheric Ozone Formation Potential | [kg $E_{then}$ - Äq] | 8,86E-3 | 0,00E+0 | 2,08E-5 | 7,10E-4 | 1,23E-4 | 2,94E-3 |
| Abiotic Resource Depletion Potential | [kg Sb - Äq] | 4,73E-5 | 0,00E+0 | 1,11E-7 | 1,11E-6 | 9,83E-8 | 9,87E-5 |
| Fossil Fuel Depletion Potential | [MJ] | 4,08E+2 | 0,00E+0 | 1,61E+1 | 1,85E+1 | 3,62E+0 | 4,24E+1 |

Table 8. LCA Results - Environmental Impact for 1 square meter of Precast Slab, Thickness d = 0.20 metre and Weight 520 kg/square meter

| Parameter | Unit | A1-A3 | C1 | C2 | C3 | C4 | D |
|---|---|---|---|---|---|---|---|
| Global Warming Potential | [kg $CO_2$ - Äq] | 33332.00 | 0 | 624 | 598 | 132.6 | 2516.8 |
| Stratospheric Ozone Depletion Potential | [kg CFC11 - Äq] | 0.00 | 0 | 2.0644E-13 | 2.9588E-12 | 7.384E-13 | 1.9656E-11 |
| Soil and Water Acidification Potential | [kg $SO_2$ - Äq] | 40.352 | 0 | 0.42224 | 3.38 | 0.8476 | 4.654 |
| Eutrophication Potential | [kg $(PO_4)_3$ - Äq] | 5.044 | 0 | 0.09048 | 0.8268 | 0.0962 | 0.17368 |
| Tropospheric Ozone Formation Potential | [kg Ethen - Äq] | 4.6072 | 0 | 0.010816 | 0.3692 | 0.07626 | 1.5288 |
| Abiotic Resource Depletion Potential | [kg Sb - Äq] | 0.024596 | 0 | 0.00005772 | 0.0005772 | 0.000051116 | 0.051324 |
| Fossil Fuel Depletion Potential | [MJ] | 212160 | 0 | 8372 | 9620 | 1882.4 | 22048 |

## LCA INTERPRETATION

Analyzing the results presented in Table 8, it can be concluded that the cement production phase dominates the overall global warming potential when it comes to the production of precast concrete slabs. Specifically, the global warming potential, expressed as $CO_2$ equivalent emissions for cement production alone, amounts to 33,332.0 $CO_2$-eq, while for all other phases, this emission has a total value of 3,871.4 $CO_2$-eq. A similar conclusion, but with slightly different system boundaries and product type/functional unit, is reached in the study presented in reference [15], as well as in [31]. Additionally, a group of authors in [28] demonstrated that the composition of cement could be significantly improved and concluded that concrete might be produced without performance loss while decidedly reducing the negative environmental impacts associated with its production. The authors in [24] addressed similar issues, specifically finding long-term solutions for reducing $CO_2$ in the cement and concrete sector, given that commonly used supplementary cementitious materials are not globally available in sufficient quantities.

## CONCLUSION

The task of the construction industry should be to reduce negative impacts on the environment and other sustainability criteria. As buildings certified for sustainable construction represent a good example of construction and investment, they are becoming more sought after in the market, promoting sustainable building practices. This also encourages builders and investors to plan their future projects sustainably and apply for sustainable construction certification, as such projects will yield greater benefits.t can be concluded that the profession should explore sustainable construction and educate participants in the construction sector through organized professional seminars and workshops.

From the presented LCA study, the following conclusions can be drawn: The cement production phase dominates the global warming potential. The acidification potential is almost exclusively dominated by cement production and the prestressing steel used. The ozone depletion potential for precast concrete slabs is determined by the costs of cement production and the manufacturing process. The eutrophication potential for precast concrete slabs is mainly determined by the prestressing steel and cement production. Other impact factors include production and transport. The photochemical ozone formation potential is also primarily related to cement and prestressing steel production, with the production process playing a subordinate role. The potential for abiotic depletion of fossil and non-fossil fuels arises from the processes of cement, sand, and steel production, as well as during manufacturing and transport. Primary energy (non-renewable and renewable) during the production of precast concrete slabs is predominantly driven by the expenses for cement production, while secondary contributions come from the prestressing steel used, production, transport, and used sand, which dominate the non-renewable primary energy consumption. The consumption of primary energy from renewable sources is primarily determined by the cement, production, and prestressing steel used.

## REFERENCES

[1] Bjegović D, Štirmer N, Serdar M. Sustainable construction and material selection. InThird international scientific and professional conference 2010 (pp. 1289-1294).

[2] Jain A, Babu KA. An examination of cutting-edge design and construction methods concerning green architecture and renewable energy efficiency for Tier-II cities of India. Arch Technol Sci. 2024;2(31):57-69. https://doi.org/10.70102/afts.2024.1631.057

[3] Marjaba GE, Chidiac SE. Sustainability and resiliency metrics for buildings–Critical review. Building and environment. 2016 May 15;101:116-25. https://doi.org/10.1016/j.buildenv.2016.03.002

[4] Nahmens I, Ikuma LH. Effects of lean construction on sustainability of modular homebuilding. Journal of architectural engineering. 2012 Jun 1;18(2):155-63. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000054

[5] Dewangan H, Dewangan T. Sophisticated Design and Integrative Modeling of Sustainable Environmental Practices in Contemporary Pharmacy and Pharmaceutical Industries. Natural and Engineering Sciences. 2024 Sep 1;9(2):395-406. https://doi.org/10.28978/nesciences.1575486

[6] James P. Urban sustainability in theory and practice: circles of sustainability. Routledge; 2014 Sep 19. https://doi.org/10.4324/9781315765747

[7] Rahman F, Lalnunthari. Development of an image processing system for monitoring water quality parameters. Int J Aquat Res Environ Stud. 2024;4(S1):27-32. https://doi.org/10.70102/IJARES/V4S1/5

[8] Adams WM. The future of sustainability: Re-thinking environment and development in the twenty-first century.

[9] Papuga S. Malozagađujuće tehnologije i čistija proizvodnja. Banja Luka: Univerzitet u Banjoj Luci; 2022.

[10] Redclift M. Sustainable development (1987–2005): an oxymoron comes of age. Sustainable development. 2005 Oct;13(4):212-27. https://doi.org/10.1002/sd.281

[11] Abera YA. Sustainable building materials: A comprehensive study on eco-friendly alternatives for construction. Composites and Advanced Materials. 2024 May 16;33:26349833241255957. https://doi.org/10.1177/26349833241255957

[12] Wu P, Low SP. Lean and cleaner production: Applications in Prefabrication to reduce carbon emissions. Springer; 2013.

[13] Bernik A, Cetina L. Comparison of 3D Scanning and Photogrammetry. Polytechnic and design. 2018 Mar 26;6(1):29-46. https://doi.org/10.19279/TVZ.PD.2018-6-1-04

[14] Xiang P, Afsari F, Dong L. Cement industrial impacts on greenhouse emission and evaluating the reduction strategies. Int Acad J Innov Res. 2017;4(2):80-88.

[15] Ramsey D, Ghosh A, Abbaszadegan A, Choi J. Life cycle assessment of Pre-cast concrete vs. Cast-in-place concrete.

[16] Rakhmawati AN, Devia YP, Wijatmiko I. Life cycle assessment (LCA) analysis of concrete slab construction for estimating the environmental impact. Rekayasa Sipil. 2020 Oct 30;14(3):232-7.

[17] Canadian Precast/Prestressed Concrete Institute. Life cycle assessment of precast concrete commercial buildings. CPCI Technical Research Bulletin.

[18] Chaname-Chira R, Santisteban-Chevez D, Tafur KMR, Villalobos PG, Campos-Ugaz W, Alcaide-Aranda LIDC, Villegas DRA. Critical thinking and the impact on university education for sustainable development. Indian J Inf Sources Serv. 2024;14(3):93-101. https://doi.org/10.51983/ijiss-2024.14.3.13

[19] Ahmed IM, Tsavdaridis KD. Life cycle assessment (LCA) and cost (LCC) studies of lightweight composite flooring systems. Journal of Building Engineering. 2018 Nov 1;20:624-33. https://doi.org/10.1016/j.jobe.2018.09.013

[20] Standard I. Environmental management-Life cycle assessment-Requirements and guidelines. ISO; 2006.

[21] Organización Internacional de Normalización. Environmental Management: Life Cycle Assessment: Goal and Scope Definition and Inventory Analysis: ISO 14041. International Organization for Standardization; 1998.

[22] International Organisation for Standardisation (ISO). ISO International Standard 14042:2000, Environmental management – Life cycle assessment. Life cycle impact assessment. 2006.

[23] Rahman MS, Basu A, Nakamura T, Takasaki H, Kiyomoto S. PPM: Privacy Policy Manager for Home Energy Management System. J. Wirel. Mob. Networks Ubiquitous Comput. Dependable Appl.. 2018 Jun;9(2):42-56.

[24] Tait MW, Cheung WM. A comparative cradle-to-gate life cycle assessment of three concrete mix designs. The International Journal of Life Cycle Assessment. 2016 Jun;21:847-60. https://doi.org/10.1007/s11367-016-1045-5

[25] Marinković M, Radović A, Carević V. Carbonation of limestone powder concrete: state-of-the-art overview. Building Materials and Structures. 2023;66:127-37.

[26] Marinković SB, Malešev M, Ignjatović I. Life cycle assessment (LCA) of concrete made using recycled concrete or natural aggregates. InEco-Efficient construction and building materials 2014 Jan 1 (pp. 239-266). Woodhead Publishing. https://doi.org/10.1533/9780857097729.2.239

[27] Štirmer N. Utjecaj građevnog materijala na okoliš. Radovi Zavoda za znanstveni i umjetnički rad u Požegi. 2012 Nov 15;1(1):293-311.

[28] https://ibu-epd.com/

[29] Kuhlman T, Farrington J. What is sustainability?. Sustainability. 2010 Nov 1;2(11):3436-48. https://doi.org/10.3390/su2113436

[30] Marceau ML, Bushi L, Meil JK, Bowick M. Life cycle assessment for sustainable design of precast concrete commercial buildings in Canada. Green Building Library. 2012 Jun 6;1.

[31] Dong YH, Wong CT, Ng ST, Wong JM. Life cycle assessment of precast concrete units. InInternational Conference on Civil, Environmental and Architectural Engineering Madrid, Spain 2013 Mar 28.