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High performance concrete applied in structural columns overlooking sustainability.

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ABSTRACT

In the last decades, the concept of sustainable construction has been addressed in several engineering projects in the world. The search of materials that provide more durable projects and with long service life is a worldwide consensus. Many researchers do not consider the concrete an attractive material from the standpoint of sustainable construction. This article aims to demystify this scenario and apply high performance concrete in structural columns aiming to sustainability issues. It is a case study of a building located in the municipality of São Paulo. It was noted that the concept of sustainable construction is absolutely in line with the use of high performance concrete in structural columns.
Keywords: Sustainable construction, service life, concrete, high performance concrete.

RESUMEN

En las últimas décadas, el concepto de construcción sostenible se ha abordado en varios proyectos de ingeniería en el mundo. La búsqueda de materiales que proporcionen proyectos con alta vida útil es un consenso en todo el mundo. Dicho esto, muchos investigadores no consideran al hormigón un material atractivo desde el punto de vista de la construcción sostenible. Este artículo intenta desvelar este panorama y presentar una aplicación de hormigón de altas prestaciones en columnas estructurales con vistas a los aspectos de sostenibilidad. Es un estudio de caso de un edificio situado en el municipio de São Paulo. Se observó que el concepto de construcción sostenible está absolutamente de acuerdo con el uso de hormigón de altas prestaciones en columnas estructurales.
Palabras claves: Construcción sostenible, vida útil, hormigón, hormigón de altas prestaciones.

RESUMO

Nas últimas décadas, o conceito de construção sustentável e de sustentabilidade tem sido abordado em diversos projetos de engenharia espalhados pelo mundo. A busca por materiais que proporcionem projetos com elevada vida útil é um consenso mundial. Isto posto, muitos pesquisadores consideram que o concreto não é um material atrativo do ponto de vista de uma construção sustentável. Através de um estudo de caso de uma edificação localizada no município de São Paulo, este artigo busca desmistificar este panorama e, concomitantemente, apresentar uma aplicação do concreto de alta resistência em pilares estruturais com vistas aos aspectos de sustentabilidade. Observou-se que o conceito de construção sustentável está em concordância com o uso de concreto de alta resistência em pilares estruturais.
Palavras-chave: A construção sustentável, vida util, concreto, concreto de alto desempenho.

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1. INTRODUCTION

Since the beginning of humanity, instinctively, the man seeks to satisfy at least three basic needs: food, shelter and comfort. However, with the discovery of agriculture[1], about 10,000 years ago, the man realized he could produce his own food, making a link with the land, no longer nomadic and become the "owner" of these fertile territories.

According to Salvadori (2006), since the discovery of agriculture, shelters or temporary tents were replaced by stronger habitation and a fixed fireplace began to occupy the central place of the environment. A large number of huts are set in fertile regions, the contact between families became more frequent and intimate, and arose the first village, which would bind by a network of trails. This fact introduced the concept of society as we know it today.

The need for stronger housing led, indirectly, the human being to seek natural resources that would allow viable buildings that supported weather, high winds, rain and even the fire action. In other words, instinctively, the man search would be for a building with a higher "service life" than the temporary constructions. For this purpose, of course, the human being realized the need to use more resistant and durable materials.

Consecutive generations were observing, adapting and creating new forms of durable construction and this fact, coupled with the growth of the Earth's population[2], was requiring more and more natural resources of the planet for use in their habitations.

The unrestrained use of natural resources combined with the degradation of the environment for extracting, handling of these raw materials and their processing and later disposal, caused a major global concern about aspects related to the concept of sustainability

It is understood that sustainability is a systemic concept that can be defined as a development that meets the needs of the present without compromising the needs of the future generations. In general, for a human enterprise to be sustainable, it must meet four basic requirements: it must be ecologically correct, economically viable, socially just and culturally accepted. Therefore, sustainability is a principle in agreement with three vital fields: social, economic and environmental, as shown in Fig. 1 (*Concrete Centre*, 2007).

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[1] This information was extracted from the book "Why the buildings stand up" written by Mario Salvadori, which was translated into Portuguese in 2006. Mario Salvadori (1907-1997) was professor emeritus of civil engineering and architecture at Columbia University, honorary member of the American Institute of Architects and author of eighteen books, including "Why Buildings Fall Down" in conjunction with Matthys Levy (Salvadori, 2006).

[2] The ONU published a document in 1999 called "The World at Six Billion", in which it is posible to see that only in the last two hundred years, the world population has grown dramatically: in 1800 the world population reached 1 billion people and date of preparation of the document (1999) reached the mark of 6,000,000,000.

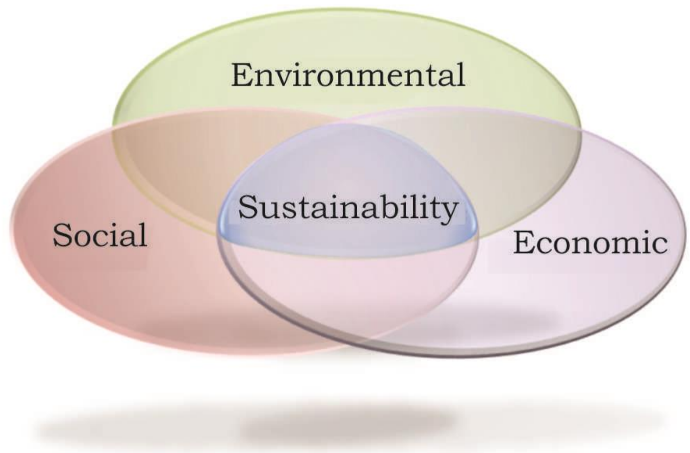

Figure 1. Macro configuration of sustainability linked to three vital areas: social, economic and ambiental (adapted from *Concrete Centre*, 2007)

In general, it is noticeable that the finite natural resources of the world are being used and discarded at a rate that the world can not afford. In addition, the emissions caused by the consumption of these resources are causing environmental pollution and degradation is leading to global climate change. The environmental impact caused by the human being has been strongly urged by organizations[3] all over the planet. Great movements on the disclosure of environmental degradation are being promoted in Brazil[4] and in the world, even so, the concept of sustainability is still resistance in some sectors of society, including the construction industry.

The construction industry consumes most of the extracted natural resources of the planet and in this panorama, concrete is largely responsible for this consumption It is noteworthy that the concrete is the material most consumed by humanity, after wáter (Mehta, 2008). Therefore, investment in alternatives that promote sustainable building is currently seen as the great challenge of global engineering. In Brazil, the Instituto para o Desenvolvimento da Habitação Ecológica – IDHEA is a pioneer in the direction of the certification works with sustainable features.

According to IDHEA, the concept of sustainable construction is based on developing a model that allows the civil construction face and propose solutions to major environmental problems of our time, without giving up modern technology and the creation of buildings that meet the needs of their users. According to this perspective, sustainable construction behaves as a system that promotes conscious changes in the environment in order to meet the needs of construction and use of modern man, preserving the environment and natural resources, ensuring quality of life for current and future generations.

[3] One of the most active organizations in the defense of the environment is Greenpeace, which has an interesting theme, which is reproduced below publication of IBRACON's book, **Concreto: ensino, pesquisa e realizações,** chapter 50, authored by Prof. Dr. Salomon Levy: "When the last tree has fallen, when the last river has dried, when the last fish is caught, humanity will understand that money does not come" (Levy, 2007).

[4] In Brazil, it is important to emphasize that happened in Rio de Janeiro - first Brazilian city to join the event - "**A Hora do Planeta**", a worldwide movement to combat global warming. The initiative, known internationally as Earth Hour includes the symbolic gesture of turning off the lights of the houses at 20:30h and keep them off for 60 minutes.

In this respect, the focus of this paper is to approach the concrete use for sustainable construction model, noting that the presented case study is just a sophisticated alternative that allows the concrete volume reduction in a structure and not of change its characteristics related to the incorporation of recycled aggregates and use of ecologically correct cement in the mixture.
The objectives of this paper are: (a) draw a panorama and analyze the use of concrete in sustainable construction; (b) disclose the use of high strength concrete with a view to the aspects of sustainability; and (c) promote discussion of the topic for researchers and construction companies.

2. APPROACH OF CONCRETE USE IN SUSTAINABLE BUILDINGS AND THE SERVICE LIFE CONCEPT

It is estimated that the concrete current consumption in the world is of the order of 11 billion tons per year. If we consider that at least one-seventh[5] of this mass is the amount of cement produced annually around the globe, we obtain an approximate value of 1.6 billion tons.
Regarding the cement, Isaia and Gastaldini (2004) report that in their production its consumes 5.5GJ of energy and releases approximately 1ton of CO_2 per ton of clinker. These numbers translated, means that all of the cement produced in the world is matched between 5% and 8% of the CO_2 global total emitted annually into the atmosphere. Considering that 1ton of cement has about 70% of clinker, it is observed that a year are issued by the cement industry, about 1 billion tons of CO_2 into the atmosphere. Despite the numbers are not representative face global CO_2 emissions (representing on average 6% of the total issued, but of course can not be overlooked), cement production for use in concrete has been reformulating to monitor global sustainable development. Basically, there are two ways to reduce the amount of CO_2 in the atmosphere, caused by the production of cement: reducing production quantity (limit production), and replacement of the "pure cement" one or more mineral admixtures, most industrial by products typical case of blast furnace slag and fly ash, turning the product "ecologically correct cements".
In practice, a worldwide initiative adopted by several researchers, including in the Brazil, is the replacement of the cement by blast-furnace slag and fly ash from power plants. According to Levy (2005), this substitution has shown technical advantages, particularly environmental and economic, since it can significantly reduce both the emissions of CO_2 in the atmosphere, and the power consumption. Thus, it has been possible to reduce the clinker production, with a smaller amount of limestone and consequently reducing the amount of CO_2 emitted to the atmosphere, making these more environmentally correct cement.
In global terms, it is possible to quantitatively measure how sustainable initiatives reflect in the environment. In 2009, was produced by the Concrete Centre the document "The concrete industry - Sustainability report performance" indicators with a direct 27% reduction in CO_2 emissions since 1990, the total production of cement in the UK región. Another document produced by the Concrete Centre in 2005, named "Civil Engineering - Sustainable solutions using concrete" provides indicators of the world's cement companies where, for example, Lafarge Cement reduced in 20% and the Heidelberg Castle Cement in 15% the emission of CO_2 in its global production.
However, the environmental impact of the concrete is not only caused by cement. For the production of concrete, other materials are also consumed as sand and gravel. According Klein

[5] This corresponds to a concrete with approximately 350 kg of cement per cubic meter.

(2008) and Isaia and Gastaldini (2004), is estimated that 12 billion tons of aggregates are consumed each year. Considering also the impact of the operation, all the processing and transport of this raw material, it is observed that the actual manufacturing process affects significantly the environment. In addition, records up to this amount the consumption of more than 1 trillion gallons of water per year.

Therefore, it is emphasized that only the control of CO_2 emissions in cement production does not contribute to the "salvation" of the planet, as the pertinent aspects of sustainable construction using the concrete as the main material. It is necessary to analyze the material applied globally in the structure and not the individual components.

It is noted an interesting paradox about this: as the consumption of cement and concrete that are used as a nation development indices can, at the same time, be used as environmental degradation index?

One of the answers is to think about the structure, construction, the end product, not the materials separately. It allows to clarify that analyzing the structure, the end product, not the materials separately; means applying one of the most important concepts of engineering: the concept of service life[6].

Sustainable construction is directly related to life concept because, as noted by Klein (2008), the increase in service life in general, has been a good long-term solution for the preservation of natural resources, reduction of impacts and energy savings. It is meant that service life is the period of time during which the structures remain within the minimum performance requirements, provided that attended the use and maintenance instructions prescribed by the structural designer and the builder and executed the necessary repairs arising any accidental damage.

Helene (1997) points out that concrete structures must be designed, constructed and used so that, under the environmental conditions and compliance with the preventive maintenance conditions specified in the structural design, retain their security, stability, ability to service and acceptable appearance during a preset period of time, without requiring extra steps to maintain and repair.

At least five alternatives can be adopted so that the concrete is increasingly used in sustainable buildings: acting on the materials, use recycled aggregates, use self-compacting concrete, employ high service life concrete and employ high strength concrete. Is not part of scope of this document the study of all these alternatives, however, will discuss the use of high strength concrete in structural columns through a case study. The main objective is to demonstrate that it is possible to use a high strength concrete (with higher consumption of cement per cubic meter) meeting the sustainability requirements, because reducing the total concrete volume in the construction and increased life project.

3. CASE STUDY

The structural elements (columns), object of this case study, belong to the e-Tower, an office building with 162m tall and 42 floors (including 04 underground), located at Rua Funchal, 418, Vila Olimpia, Sao Paulo, Brazil. In this building were casting 5 columns over the four basements,

[6] In Brazil, the periods of service life are defined in the standard ABNT NBR 15575. It is also recommended for this topic consult the standard BS 8500: 2006 "*Concrete – Complementary British Standard to BS EN 206-1*".

through the ground floor and 4 more floors with a concrete f_{ck} = 80MPa[7] at 28 days of age. In Fig. 2 is posible to see the architectural building prospecting of the e-Tower (Concrete International, 2003).

Figure 2**.** Architectural Prospecting of e-Tower, in São Paulo, Brazil (*Concrete International*, 2003)

The high strength concrete was the technical and economic solution presented to building e-Tower, due to the need to reduce the dimensions of the pillars of the north facade that had increased load in basements. The initial study provided a tough section of the order of 0.90m^2, approximately 90cm x 100cm. These dimensions were adopted because of the concrete compressive strength adopted for the whole structure (f_{ck} = 40MPa). However, the architecture requested that the maximum dimensions of these structural elements did not exceed 60cm x 70cm. For this purpose, has increased the concrete f_{ck} to 80MPa and the whole structural design was redone.
According to Helene (2005), the use of high strength concrete was necessary because the distance between columns to allow the fitting of two means vague: at least 4.20 m, the most recommended 4.40m - in São Paulo, the Building Code provides that average vacancy shall be at least 2.10m wide. Moreover, according to the approved project, the columns should facemills the aligned corridor and most limited size to 70cm. The situation of the change in project design can be seen in Fig. 3.

[7] In 2002 Brazil received recognition from the international community when brokes the high strength concrete record in the world at that time. Details about the world record are described in the article: "*HPCC in Brazilian Office Tower: High-performance colored concrete offers strength, thinner columns, more usable space, and aesthetics*" (Hartmann & Helene, 2003). It is emphasized that the concrete has reached an average strength level of 125MPa at 28days of age.

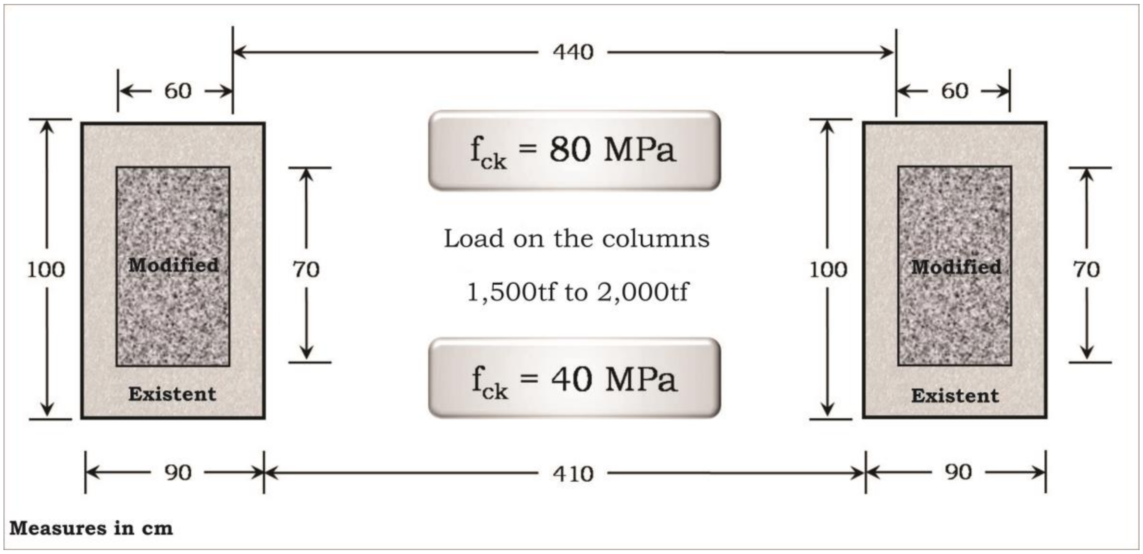

Figure 3**.** Project design of the e-Tower: existing columns in the original design with f_{ck} = 40MPa (60cm x 70cm) and modified columns with f_{ck} = 80MPa (90cm x 100cm)

This change in design (size reduction of the columns) enabled the relevant study about the aspects of sustainable construction. In terms of service life and sustainability, one of the main mechanisms of a deleterious concrete structure is corrosion of the reinforcement. All carbon steel is eternally protected by a high alkalinity environment with a pH greater than 12. This fact is known to be observed in the case of Portland cement concrete structures without chlorides, as the hydration products of the curing reaction between the cement grains anhydrous and water, releasing large amounts of $Ca(OH)_2$, NaOH and KOH are strong bases (Helene, 1986). This passivation protection capacity can be lost over time due to various actions of which the main ones are the chloride penetration and the reaction of carbon dioxide CO_2 with alkalis of hydration products, resulting low alkaline salts, a phenomenon known by carbonation of concrete.

When the concrete strength is increased, lower is the risk associated with equipment corrosion, given the high difficulty of penetration of aggressive agents. According to Levy (2005), with smaller pores and disconnected from each other, the high-strength concrete is less subject to the action of aggressive agents dissociated in water, which increases its durability and hence useful life of the structure design. According Kaefer apud Levy (2005), the strength of high-strength concrete dosed with silica fume or other additions could reach between 60MPa and 120MPa, while the brazilian average in the earlies twenty-first century, it was 20-25MPa. Thus, the author points out that a building may be have columns with dimensions up to 30% lower, with the same load capacity. That said, the conducted case study was identified that the modified columns have suffered significant area reduction, as shown in Table 1. It is emphasized that the high strength concrete was studied used an amount of about 35% of admixtures to replace the total amount of cement.

Table 1. Data collected in the case study on the high strength concrete columns of the building e-Tower, relating to design changes.

	Original Project	**Modified Project**	**Reduction / increase**
Compressive strength of the structural columns f_{ck} (MPa)	40	80	100% (increase)
Cross section of the structural element (cm)	90 x 100	60 x 70	**53% (reduction)**
Area (projection) of the structural element (m²)	0.90	0.42	

From the point of view of sustainable construction, some important parameters were achieved with this design change: increase the useful life, reducing the use of natural resources, environmental impacts, energy and the total volume of concrete work (even with a consumption of cement per cubic meter of concrete exceeding the original design of concrete - with f_{ck} = 40MPa). Specifically on the elevation of service life, have been adopted some standardized values of established bibliographies[8] to illustrate the magnitude of the growth, as shown in Table 2, which is possible to observe an increase of ten times the design service life.

Table 2. Data obtained in the practical case study on high performance concrete columns of e-Tower building in relation to the growth of the service life.

	Characteristic[(1)] cover of project (cm)	**Carbonation constant adopted [(2)]: k_{CO2} (cm/year$^{1/2}$)**	**Estimated service life of project (years)**
Structural column (90cm x 100cm) with f_{ck} = 40MPa	3.0	0.245	150
Structural column (60cm x 70cm) with f_{ck} = 80MPa	3.0	0.077	1500

(1) *It was considered as characteristic design cover within tolerance of ABNT NBR 6118:2014.*
(2) *This value was adopted according to the Recommended Practice Ibracon only for the purpose of demonstrating that the life of the structure increases ten times when the specific resistance change, in this particular case. It is noteworthy, however, that these coefficients were estimated.*

[8] The carbonation coefficient was estimated based on literature: ***Prática recomendada IBRACON – Comentários Técnicos NB-1***, published in 2003. The adopted model is based on the simplified mechanism of deterioration of the structure by carbonation, by the formula: $e = k_{co2} \bullet \sqrt{t}$, being *e* the concrete covering in cm, ***k_{co2}*** the carbonation constant in cm/year$^{1/2}$ and ***t*** in **years** (Medeiros; Andrade; Helene, 2011).

As for the economy of natural resources, it was found that there was a considerable reduction of all materials used in the concrete composition with f_{ck} = 80MPa, compared to 40MPa concrete. The volume of aggregates was reduced by 70%, while 20% of the cement according to Table 3.

Table 3. Data collected on a study of the high strenght concrete columns of the e-Tower building, related reductions in isolated material and the global concrete.

Material	**Reduction**
Sand	70%
Crushed stone	70%
Cement	20%
Water	53%
Concrete	**53%**

4. FINAL CONSIDERATIONS

In relation to the objectives of the study, the literature review and the case study allowed to obtain an overview of how the concrete - seen as a material - can be considered attractive of the design point of view of sustainable construction.

It is emphasized, however, that frequently is confused cement with the concrete material. Cement is a component of concrete and can not be considered in isolation, as appropriate to the unique aspects of sustainability. In Fig. 1 of this work is revealing that the concept of sustainability is grounded in three vital areas: social, economic and environmental. Therefore, when the concrete is used, parameters such as noises, human efforts, durability and service life should be priorities.

Abroad, especially in the UK, has been extensive the program involving the sustainability of the concrete, from the analysis of the constituent components alone (cement and aggregates) to the equipment seen as a whole. Several literatures indicate initiatives to minimize the environmental impact, and as determined, there are enough indicators that show significant positive results in the last 20 years. Some of these indicators have been cited throughout this work.

Finally, it is considered that the use of high-strength concrete columns is a sustainable alternative because it preserves natural resources, reduces environmental impact, saves energy and increases the potential for extraction of natural resources for other purposes. Reducing the volume of concrete and the considerable increase of service life - as demonstrated in this work - justify the principles of sustainable construction, even with a consumption of cement per cubic meter of concrete upper concrete considered "conventional". So it is not correct to say that the higher the consumption of cement per cubic meter of concrete, the lower the potential of sustainable construction, when considering the high strength or high performance concrete.

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