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Cost-Benefit Analysis between Conventional Concrete and High Performance Concrete: Case Study of a Residential Building

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***Abstract*— The present study makes a comparative analysis of the cost-benefit ratio between Conventional Concrete (CC) and High Performance Concrete (HPC). To obtain the consumption rates of concrete, steel and shape of each case, two studies of the same structure out changing only one variable were carried: the characteristic strength of concrete to compression (fck). In the first case, the fck 25 Megapascal (MPa) representing the CC was applied, and in the second case, fck 50 MPa corresponding to the HPC. To analyze the structural elements, it was used the software Cypecad. It was confirmed one of the initial hypotheses (the consumption of concrete, steel and form would decrease with the use of High Performance Concrete). The second hypothesis was not confirmed (the HPC would be more financially advantageous than the CC), but factors that may have led to this non-confirmation were pointed out.*

I. INTRODUCTION

The cost-benefit discussion is widely used in our lives and in several areas and it would be no different in the area of civil engineering, where the evolution is always towards a better quality and behavior of the structures, coupled with the reduction of expenses.

[7]. Botelho et.al. (2006) Conventional Concrete (CC) is currently one of the most widely used and widespread construction materials in Brazil. [11]. Accordingly to Metha and Monteiro et.al. (1994) it is a composite material that essentially consists of a continuous agglomerating medium (hydraulic cement + water) within which particles or fragments of aggregates are immersed (granular material such as sand, gravel, crushed stone), forming a block monolithic. When used with reinforcement it's called reinforced concrete.

[9]. For Geyer and Sá et.al. (2005) High Performance Concrete (HPC) is a special concrete in order to improve existing results. [1]. As for Aitcin et.al. (2000) it differs from Conventional Concrete in terms of the addition of active silica and superplasticizers, materials capable of significantly improving the performance of concretes, changing their chemical and mechanical properties.

Each work has particular characteristics, and the choice of the most appropriate concrete in the execution of the project according to the existing need is decisive. Be your interest the lowest cost, the lowest consumption of reinforcement, more slender structures, a decrease in the structure's own weight or even an increase in the execution speed and greater durability. It is up to the structural engineer together with the architect and the builder engineer to make the most appropriate option for a given type of work.

This work presents a comparison between Conventional Concrete and High Performance Concrete in a case study of a Residential Building through computer simulations using the software Cypecad version 2014, based on the Brazilian standard [12]. NBR 6118 et.al.

(2014) from the Brazilian Association of Technical Standards (ABNT). The calculations of the efforts and dimensioning were obtained by means of lists issued by the program, which after being verified and analyzed, allowed the obtaining of the quantities related to the volume of concrete, the weight of steel and the area of forms.

II. LITERATURE REVIEW

1. ARMED CONCRETE

1.1. Conventional Concrete

[16]. Pinheiro et.al. (2007) say that Conventional Concrete is a building material from the mixture, in an appropriate proportion of binders, aggregates and water. [11]. While for Metha and Monteiro et.al. (1994) it is a composite material that essentially consists of a continuous agglomerating medium (hydraulic cement + water) within which particles or fragments of aggregates are immersed (granular material such as sand, gravel, crushed stone) forming a monolithic block. When armed with ironware it gets the name of reinforced concrete.

1.1.1. Benefits

[18]. Accordingly to Süssekind et.al. (1980) the main advantages responsible for the true growth of concrete and absolute dominance of the world market are: economy, freedom in project design, safety, obtaining a monolithic structure, infrequent maintenance, and not least, resistance to effects thermal, atmospheric and mechanical wear.

[6]. Barata et.al. (1998) add "[...] the economic repercussion related to the high incidence of pathological manifestations in the constructions with this material implies in huge amounts of resources in the recovery".

1.1.2. Disadvantages

[18]. Süssekind et.al. (1980) affirm that the great disadvantage of conventional reinforced concrete is its own weight, in the order of 2.5 t/m³, demolition difficulties (renovation), low degree of thermal protection (this requires mainly in roofing, application of products to avoid this problem) and last but not least, the inevitable cracking of the concrete in the parts in tensioned areas.

1.2. High Performance Concrete

[1]. Aitcin et.al. (2000) understand that the high performance concrete differs from Conventional Concrete in terms of the addition of active silica and superplasticizers, changing their mechanical and other properties. [16]. Where as for Pinheiro et.al (2007) the HPC can be obtained by mixing cement and conventional aggregates with active silica, metakaolin and plasticizer additives. Instead of active silica, it can be used fly ash or blast furnace residue.

[6]. Barata et.al (1998) affirm that active silica is a by-product of metallurgical industries that produce metallic silicon and silicon iron. The metakaolin is an aluminosilicose material from calcination of kaolinitic clays at temperatures between 600ºC and 900ºC. As for superplasticizer additives, they are chemical additives that allow the complete dispersion of the cement grains, thus allowing obtaining fluid mixtures with a low water/cement ratio, ensuring substantial increases in strength and durability.

1.2.1. Benefits

[16]. Pinheiro et.al (2007) argue that its characteristics are better than Conventional Concrete, such as: high initial and final mechanical resistance, low permeability, high durability, low segregation, good workability, high adhesion, reduced exudation, lower deformability due to shrinkage and creep, among others.

Another factor worth mentioning as an advantage of HPC and quite valid is its application. [10]. Mendes et.al (2002, p. 1) mention: "The main applications of HPC in civil construction have been in tall buildings, underwater platforms, bridges, viaducts, road pavements and industrial floors, both Conventional Concrete and High Performance Concrete are indicated. However, HPC stands out in the slimmer and bolder structures, with greater spans, located in densely urban or industrial atmospheres loaded with aggressive agents. Where the interest is to reduce the structure's own weight, load the foundations, increase the floor area and/or significantly reduce the columns."

[8]. Gamino et.al (2003) report that the increasingly frequent use of High Performance Concrete (HPC) is fundamentally centered on the following aspects:

- High resistance to compression that allows the reduction of cross sections, obtaining more slender structures and with less own weight providing savings in formwork and lower costs with the foundation.

- Less instantaneous deformations due to its high modulus of elasticity.

- Reduction of the fluency phenomenon.

- Lower permeability of hardened concrete contributing to a slower carbonation process that causes corrosion in the reinforcements.

- Greater durability.

- Good compressive strength achieved at low ages that can provide shorter stripping times and shorter execution times for reinforced concrete works.

[6]. For Barata et.al. (1998), the use of mineral additions in HPC concrete, in addition to improving its technological characteristics, reduces considerably the consumption of cement for the same resistance or permeability level.

1.2.2. Disadvantages

[1]. While for Aitcin et.al. (2000), what can be considered as disadvantages and some reasons for not using this material is that high performance concrete requires greater technical and scientific rigor in its preparation and greater care in its preparation, requiring a hand of more specialized work, increasing the cost of producing the final product. [16]. Pinheiro et.al (2007) confirm by mentioning that Conventional Concrete has low labor cost, in general, it does not require a highly qualified professional, as well as low cost of materials (water and coarse and fine aggregates).

[1]. Aitcin et.al. (2000) bring another disadvantage, it would be regarding the economic value of production, since the selection of materials for the production of HPC is more complicated. It must be done carefully, since the cements and aggregates available present great variations in their compositions and properties, and there is no clear system that facilitates the choice of the most appropriate type and aggregate yet.

However, accordingly to [8]. Gamino et.al (2003, p 4) the fragile behavior of this material can be an inconvenience, for example, in regions of high seismic risk or places where differential repression occurs.

1.3. Mechanical and Rheological Properties of CC and HPC

[11]. Metha and Monteiro et.al (1994) say that the performance and durability are linked factors that determine whether a material has quality or not. The performance of the material means its behavior in use, and the durability of a material refers to the conservation of its performance throughout its useful life.

[8]. Gamino et.al (2003) add that the ductility is: "The measure of the ability of a material, section, structural element or structural system to undergo inelastic deformations in the vicinity of a possible rupture, without substantially losing its resistant capacity. It is an important property given to elements, it introduces with respect to the capacity to redistribute efforts when acting, for example, of differential settlements or earthquakes on the structure.".

After analysis through the stress-strain curve, it is noticed that concretes with higher strengths have stress-strain curves that are more accentuated and linear when compared to concretes with lower strengths. It is also added that Conventional Concretes tend to have higher ductility compared to High Performance Concretes, noting that this observation is fully valid only for the concrete material, and cannot necessarily be extended to individual parts, such as, conventional and reinforced concrete beams and high performance. It is also added that, however, ductility is directly affected by quantities of a physical order in relation to the dimensions of the structural element and by quantities of a mechanical order with regard to the materials that comprise the structure.

[15]. Neville et.al (1982) mention that durability means that a given concrete structure will have satisfactory continuous performance for the purposes of which it was designed, this is to say that it will maintain its resistance and normal service conditions during the specified or expected useful life.

Strength and durability depend on the proportion between the materials that make it up. To obtain a good concrete, whether conventional or high-performance, the basic operations of material production must be carried out with perfection: cement, water, fine aggregates (sand), coarse aggregates (stone) and the basic operations of concrete production, which are: dosage or mixing, mixing, densifying and curing, as it is the sum of all these factors that differentiate the CC and HPC [16]. Pinheiro et.al (2007).

Basic operations for the production of concrete are also essential for assessing the strength of the concrete. The dosage or trace is the indication of the proportions and quantification of the materials that make up the mixture in order to obtain a concrete with certain previously established characteristics. A highlight in the preparation of the concrete is the care that must be taken with the quality and quantity of the water used. Both excess and lack are harmful to concrete, as water is responsible for activating the chemical reaction that transforms the cement into a binding paste. Lack of water leaves the concrete full of holes, if its quantity is very small, the reaction will not occur completely. If it is higher than ideal, the resistance will decrease depending on the pores that will occur when this excess evaporates.

The ratio between the weight of water and cement used in the dosage is called the water/cement factor (w/c). [15]. Neville et.al (1982) inform that the relationship between water and aggregate is essential for the evaluation of resistance, because the larger the aggregate particle, the smaller the area to be wetted per unit of mass, that is, the larger the aggregate size, the smaller the water demand. With the reduction of the water/cement ratio, there is an increase in strength, as they are inversely proportional.

[3]. Alves et.al (2005) add that in addition to the care that must be taken with the choice of aggregate, HPC differs from CC, since in the dosage the active silica is added between 5% and 10% of the cement mass and superplasticizer additives with a dosage between 0.5% and 3% of the binder. Active silica is an ash collected in the electrostatic filters of silicon iron production kilns, whose grains are 100 times larger than cement, exerting influence on the properties of fresh concrete and on the hydration of cement compounds. It is a use of industrial waste, thus presenting a high ecological potential for the incorporation of this material, since the use of concrete that has a socioenvironmental character is extremely important nowadays. Superplasticizers make it possible to reduce the factor (w/c) from 0.40 to 0.24 with perfectly viable mixtures for applying the techniques available in the current construction sites.

The resistance rises with active silica due to the greater formation of C-S-H and the addition of superplasticizers, making it possible to reduce the factor (w/c). Durability improves with a reduction in permeability and factor (w/c). The active silica does not contribute to the elevation of the heat of hydration. It reduces to factor (w/c) less than 0.40. Concluding that the active silica increases the resistance, without increasing the heat release [4]. Alves et.al (2006).

Due to these additions, it is possible to obtain better characteristics in HPC than in traditional concrete, such as: high initial and final mechanical strength, low permeability, high durability, low segregation, good workability, high adhesion, reduced exudation, less deformability due to shrinkage and creep, among others [16]. Pinheiro et.al (2007).

[15]. For Neville et.al (1982), resistance depends on only two factors: water / cement ratio as already mentioned above and the degree of density. Densification is the compacting of the concrete mass, seeking to remove from it the largest possible volume of voids - gain of resistance. The usual means of densification is vibration. Vibration has the effect of fluidizing the mortar component of the mixture, reducing internal friction and accommodating the coarse aggregate. Concrete must have a good particle size distribution in order to fill all voids, as porosity in turn influences the permeability and strength of concrete structures. The low quality in the concrete densification process results in a decrease in mechanical strength, increased permeability and porosity, and lack of homogeneity in the structure.

Curing is the name given to the procedures used to promote the hydration of the cement and consists of controlling the temperature and the outlet and entry of moisture into the concrete [15]. Neville et.al (1982). Water curing should be continuous and last at least seven days, although it is preferable to reach twenty-eight days. If the curing with water is done properly, problems that will affect the volumetric stability and the mechanical strength of the concrete can be avoided. Failure to comply with the cure leads to a decrease in the final strength of the concrete and the possibility of cracking in the structure [5]. Azevedo et.al (2005).

Care must be taken when selecting the material and when preparing concrete, whether conventional or high-performance, as all these steps affect the result, changing its properties: strength, durability and performance. As for the economic value of production, HPC is more expensive than Conventional Concrete. Because the selection of materials for the production of HPC is more laborious, it must be done carefully, since the available cements and aggregates vary widely in their compositions and properties and there is still no clear system that facilitates the choice of the type of cement and the most appropriate aggregate for HPC [1]. Aitcin et.al. (2000).

Additives, although not always cheap, do not necessarily represent an additional cost because it can result in savings, such as, for example, in the cost of labor required for densification, the possibility of reducing the cement content or improving durability [17]. Silva et.al (2014).

Therefore, it is possible to note that HPC requires greater technical and scientific rigor in its elaboration and greater care in its preparation when compared to Conventional Concrete [1]. Aitcin et.al. (2000).

The application of concrete is quite wide, ranging from the construction of buildings, warehouses, industrial floors, highways, hydraulic and sanitation works, to various structures. Most of the time it is the need for the project that determines the choice of concrete to be used [16]. Pinheiro et.al (2007).

2. Cost-benefit of Conventional Concrete and High Performance Concrete

[1]. Aitcin et.al. (2000) say that there are many advantages that justify the increasing use of HPC in the construction sector. In Brazil, it is possible to highlight three fundamental factors: the high durability, the possibility of building slimmer structures and the strength of the material in particularly aggressive regions. The use of active silica in concrete in marine atmosphere environments guarantees environmentally compatible porosity levels to minimize the hydraulic retraction of the concrete, thus ensuring greater durability in the structure.

Planning is inherent in construction. It is necessary to compare technical alternatives, and the cost, nowadays, it is an essential factor for verifying the feasibility of the project and for carrying it out. The cost-benefit ratio or CBR is an indicator that lists the benefits of a project or proposal and their costs. In the first instance, the use of Conventional Concrete would be more interesting, but when analyzing all the factors together, it is not only a determining factor, but also the sum of all of them, in choosing the most appropriate concrete.

[6]. Accordingly to Barata et.al. (1998) concrete is undoubtedly one of the most commonly used construction materials in engineering, as it has a low acquisition cost, flexibility of execution and is water resistant.

Some of the advantages of using Conventional Concrete (CC), [16]. as brought by Pinheiro et.al (2007) would be: low cost of materials (water, cement, coarse and small aggregates), low labor cost, as in general it does not require professionals with high level of qualification, reduced maintenance costs, as long as the structure is well designed and properly built, and finally, ease and speed of execution, because time is money.

[6]. Barata et.al. (1998) also mention the production of HPC is usually linked to the use of mineral additions, which in general are tailings, residues or by-products from other industries. There are numerous mining and metallurgy industries across the country that release significant amounts of waste into the environment that cause serious pollution and deforestation problems. Based on this, we can affirm that the HPC in addition to the aforementioned has the benefit of the facility of obtaining the material that composes it, with the use of industrial waste, associated with the sustainability of the environment.

As for HPC, even though it has a higher cost in the production of materials and labor, as it requires greater technical rigor and selection of materials, the so-called direct costs, the higher strengths brought significant changes in the use of the concrete material. The possibility of slender shapes, a decrease in the volume of concrete, a smaller shape area, a reduction in the steel rate, savings in maintenance, a reduction in the structure's own weight or even an increase in the speed of execution, the so-called indirect costs, is possible thanks to the adoption of higher resistance resulting in economic viability [14]. Neto et.al (2002). [10]. Mendes et.al (2002) come up with the affirmation that although the cost of HPC is slightly higher than the conventional one, it can be properly used when the benefit becomes greater than the cost.

This work was supported by the use and importance of concrete, be it conventional or high performance, in search of improving the mechanism of the structures in the face of the interest of lower expenses. The cost-benefit ratio is important to actually cooperate with the applicability and feasibility of the technological alternative proposed by this research. Technological advances would be useless if it is not possible to use these resources in favor of a compensating cost associated with consumption on a large scale.

III. METHODOLOGY

For the development of this research, an analysis of a structural model by comparative method was carried out. The structural model is a residential building and for the purpose of comparison, only one parameter was changed in order to differentiate them, as there are countless factors that influence the properties of this material, such as: water/binder ratio, type and consumption of cement, mix composition, type and quantity of mineral additions as well as additives, particle size, shape and maximum characteristic of coarse and fine aggregate, degree of cement hydration, type of cure, among others.

The research does not address aspects consistent with dimensional stability, such as the modulus of deformation, a property that is strongly influenced by the characteristics of the coarse aggregate.

The evaluated and modified variable was a mechanical property, the fck (characteristic compressive strength of concrete), starting from the need to set parameters as factors to limit this research, and as a consequence of the higher strengths, there were changes in the sections of the columns.

At first, the fck used was 25 MPa, the same used in the building already constructed, corresponding to Conventional Concrete. And in the second moment, for High Performance Concrete (HPC), the fck adopted was 50 MPa, in order to continue to use the Brazilian Standard (NBR 6118) [12] which limits the concrete class to C50.

Where the fixed parameters, that is, those that were not modified in the two analyzes were: overload (SCU), permanent load (CP), coverings (column, beam and slab), beam and slab dimensions and wind action, based on NBR 6123 de 1988. [13].

The experimental research was divided into three stages. The first consisted of defining the entire structure of the case study in the software, after running, all security checks and analyzes were performed in the Ultimate (ELU) and Service (ELS) Limit States. The second consisted of obtaining quantitative data, extracted from the program, in order to be able to assemble graphs in order to be able to make analyzes of the indices of inputs, such as concrete in m^3, steel in kg and shape in m^2, contemplating for the main objective of this research. Finally, the third stage consisted of the evaluation and judgment of the technical and economic possibility of using concrete with a performance far superior to that normally employed.

After calculations were performed in Cypecad, and their consumption indexes were obtained, graphs of the structures were made, analyzing the costs of each one. For the cost calculations of the structures, the following values were adopted (in reais R$ - Brazilian currency) based in the metropolitan region of the city of Salvador, Bahia, Brazil:

- Conventional Concrete: R$ 300.00/m³
- High Performance Concrete: R$ 500.00/m³
- Folded steel: R$5.00/kg
- Form for solid slab: R$40.00/m²

IV. CASE STUDY

4.1. Presentation of the Structural Model

To carry out these analyses, a real structure project was used, provided by the Francisco Peixoto Engenheiros Associados structural project office. The residential building analyzed comprises 18 floors, being: basement, ground floor, 1st floor, type - 2nd to 10th floor, lower roof, upper roof, engine room, barrel and elevated reservoir. Next, for a visualization and presentation of the Structural Model analyzed and worked on, it follows the types of floors for each case, structure, which was launched in the program.

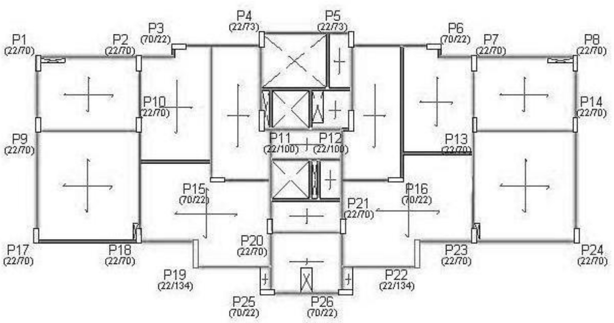

Fig. 1: Structural model - Conventional Concrete.

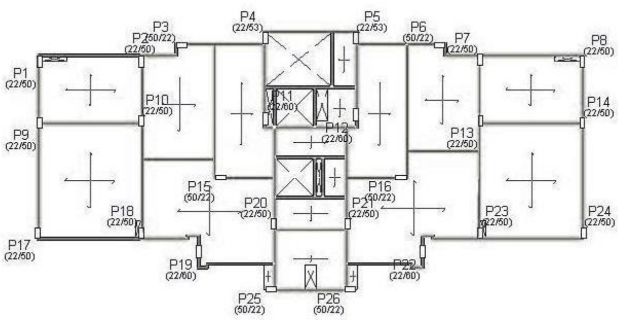

Fig. 2: Structural model - High Performance Concrete.

4.1.1. Coverings

- Pillars: 3.0 cm
- Beams: 3.0 cm
- Slabs: 2.5 cm

4.2. Actions Considered

4.2.1. Vertical

Table.1: Vertical actions.

Group's name	S.C.U	C. Permanents
Coverage, Barrel and Reservoir	0.15	0.10
Type Floors	0.25	0.10
Garages and Play Ground	0.30	0.10

4.2.2. Wind

2nd order effects analysis - value: 1.43, applied as a factor for increasing displacements.

Load Coefficients:

+ X: 1.00 -X: 1.00

+ Y: 1.00 -Y: 1.00

Basic Speed: 30.00 m/s

Roughness: Category: III; Class: B

Probabilistic factor: 1.10

Topographic Factor: +X: 1.00 -X:1.00 +Y:1.00 -Y:1.00

4.3. Resulting Global Stability (Gamma z)

According to NBR6118: 2014, the Gamma z coefficient has the main objective, for calculation purposes, to classify the structure as to the displacement of the nodes; with this, it is possible to assess the importance of global 2nd order efforts. It is determined from the results of a 1st order linear analysis, for each loading case considered in the structure.

Its value is calculated and compared with the limit values from which the structure must be considered as a mobile node. The Gamma z value is defined by:

$$\text{(1)} \quad \text{Gamma z} = \frac{1}{1 - \frac{\Delta M_{tot,d}}{M_{1,tot,d}}}$$

$\Delta M_{tot,d}$ - It is the sum of the products of all vertical forces acting on the structure, with their calculation values, by the horizontal displacements of their respective points of application, obtained from the 1st order analysis

M1,tot,d - It is a tipping point, that is, the sum of the moments of all horizontal forces, with their design values, in relation to the base of the structure.

The structure is considered to be of fixed nodes if the condition Gamma z ≤ 1.1 is established.

4.3.1. Conventional Concrete C25

Table.2: Gamma z (CC)

Wind + X	1.064
Wind – X	1.064
Wind + Y	1.046
Wind – Y	1.046

Analysis and Verification:

Wind + X and –X: Gamma z = 1.064 ≤ 1.1 Ok

Wind +Y and –Y: Gamma z = 1.046 ≤ 1.1 Ok

4.3.2. High Performance Concrete C50

Table.3: Gamma z (HPC)

Wind + X	1.070
Wind – X	1.070
Wind + Y	1.048
Wind – Y	1.048

Analysis and Verification:

Wind + X and –X: Gamma z = 1.007 ≤ 1.1 Ok

Wind +Y and –Y: Gamma z = 1.048 ≤ 1.1 Ok

V. RESULTS OF STRUCTURES

5.1. Input Collections

After analyzing the structures in the software, Cypecad, it was possible to extract from it the results of the following values of the total consumption of steel (kg), shape (m²) and concrete (m³) of each case, Conventional Concrete and High Performance Concrete, explained in the tables below, for a better quantitative analysis of the inputs.

Table.4: Total consumption of inputs (CC)

Conventional Concrete	
Steel (kg)	65815
Form (m²)	6843
Volume (m³)	618

Table.5: Total consumption of inputs (HPC)

High Performance Concrete	
Steel (kg)	58204
Form (m²)	6660
Volume (m³)	519

5.2. Input Cost Percentages

With the figures shown in tables 4 and 5, it was possible to make percentage graphs, of the cost of the inputs of each of the structures separately and respectively, Conventional Concrete and High Performance Concrete, using the values in reais (R$), indicated in the methodology.

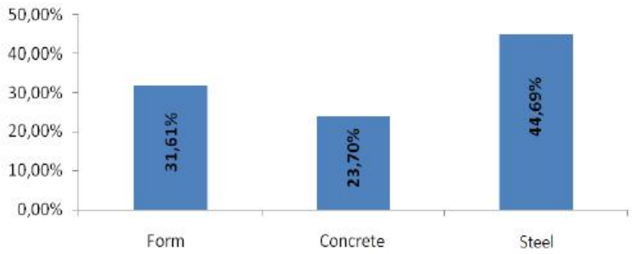

Fig. 3: Percentage graph of CC inputs.

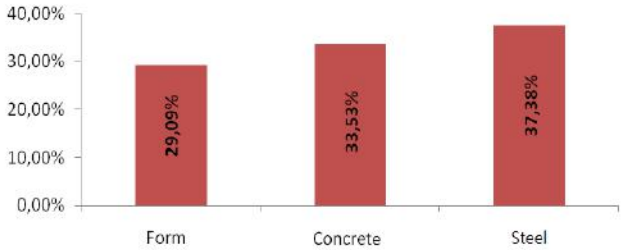

Fig. 4: Percentage graph of HPC inputs.

After analyzing each of the structures in isolation, for a better comparative analysis and visualization, a graph of the two cases was made together of the input costs of each concrete, as it can be seen below.

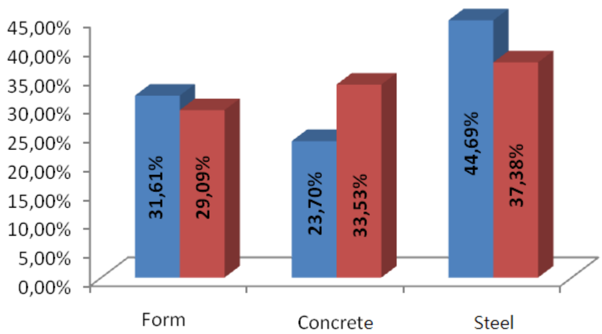

Fig. 5: Comparative graph of the percentage cost of inputs between CC and HPC.

5.3. Cost of Inputs in Reais (R$) per Square Meter

In terms of variable costs, costs that change according to production or quantity, materials (form, concrete and steel) fall into this category, hence the need to set monetary values, see Item III (Methodology) , to be able to evaluate and compare, from the financial point of view, the real financial difference between the concrete analyzed here. The comparative graph of the cost of inputs in reais (R$) per square meter is shown on the following page.

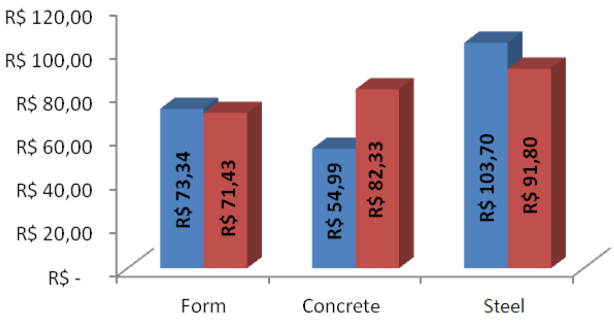

Fig. 6: Comparative graph of the cost in R$/m² of inputs between CC and HPC.

With these data it is possible to make a global analysis of the inputs (form, concrete and steel) that are the most important in the financial expenses of a work and are the conditioning parameters of this research. When making the sum of these inputs, we quantify the expense for each case (work) analyzed. Which results in the comparative graph of the total cost of the works that is explained below (Fig.7).

It is worth noting that the projected real structure was only the target for motivating the study analysis carried out here. The total financial cost of the work presented here does not correspond to the total cost of the work actually built, as the cost of each material used in the work discussed here was not taken into account, but rather the values addressed and portrayed in Item III (Methodology).

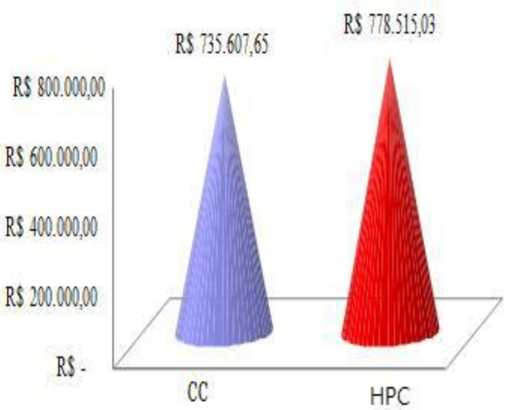

Fig. 7: Comparative graph of the total cost of works.

VI. ANALYSIS OF RESULTS

Based on the results provided by the Cypecad software and observing the resulting graphs generated above, it was possible to arrive at the following analyzes.

6.1. Differences in Input Costs

6.1.1. Form

Conventional Concrete (CC) was 2.67% more expensive than High Performance Concrete (HPC), corresponding to a cost difference of R$ 1.90/m² and totaling a difference in final expenditure on the work of R$ 6.036,33.

The importance of obtaining a smaller quantity, in m², necessary to be used in a work is indisputable, as they are temporary structures and cannot always be reused. Currently, with the high cost of wood, the need for higher quality (technological control of materials), reduction of losses (materials and labor productivity), reduction of delivery times (competitiveness) etc., it is imperative that the engineer gives due importance to the dimensioning of the temporary formwork and shoring, considering the assembly and disassembly plans and their reuse in the same work.

6.1.2. Steel

When analyzing the steel, the Conventional Concrete (CC) was 12.96% more expensive than the High Performance Concrete (HPC), thus corresponding to a cost difference of R$ 11.90/m². Totaling a difference in final expenditure on the work of R$ 37.727,05.

The decrease in the amount of steel, in kg, in the work ends up leading to other factors here that are not possible to be considered quantitatively, but it will have as consequence: lower labor costs and faster construction.

6.1.3. Concrete

When analyzing the concrete, the high performance (HPC) was 49.71% more expensive than the conventional (CC). Corresponding to a difference in cost of R$ 27.34/m², totaling a difference in final expenditure on the work of R$ 86.670,75.

However, when analyzing the volume of concrete, the High Performance Concrete (HPC) was 19.08% lower than that used in the structure made with Conventional Concrete (CC). Therefore, we know that there will be, consequently, other cost reductions in the work, such as: reduction in execution time, reduction of costs with employees (labor), with rent and/or purchase of forms, equipment and several other productivity gains.

6.2. Difference in Total Cost of Work

With that it was possible to account for the sum of these three inputs analyzed here, form, steel and concrete and we arrived at the following quantitative result: the structure in which the High Performance Concrete (HPC) was used was 5.83% more expensive than the structure where Conventional Concrete (CC) was used. Thus, corresponding to a difference in the total cost between the two works of R$ 42,907.38. This value can be easily deducted in other activities existing in a work such as those already mentioned here in this research in Item 6.1. But we will leave to delve deeper and list these concepts later.

6.3. Analysis of the Type Floor Pillars

Through the visualization of the floor plan of the type floor of each structure, where the dimensions of the columns used are shown, it is possible to perceive that there is a great reduction in the dimension of this structural element in the building in which the High Performance Concrete was used, as can be seen in Fig.8 and Fig.9.

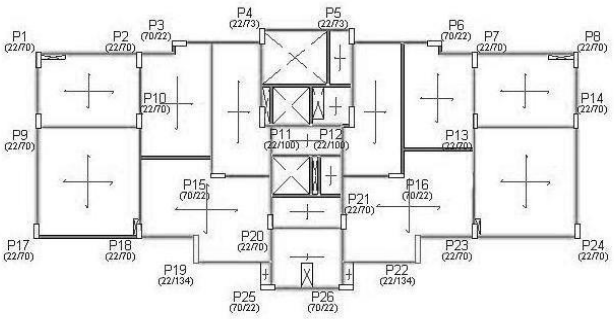

Fig. 8: Dimension of the pillars (CC)

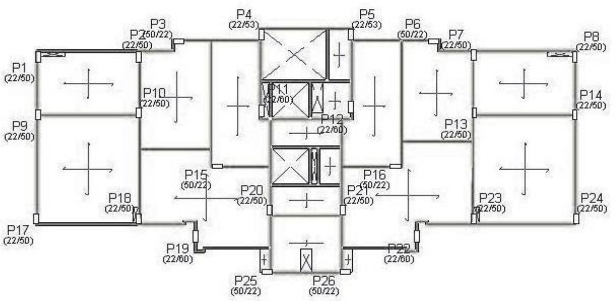

Fig. 9: Dimension of the pillars (HPC)

There was a reduction in cross-section in all pillars in the structure in which High Performance Concrete was used. The vast majority of this reduction was 28.6%, with the exception of the P11 and P12 pillars, where this reduction reached 40%, the section of which was (22x100) passing to (22x60). And two other pillars, which are worth mentioning, were the P19 and P20 pillars, which reduced by 55.22%, more than half, reducing the section from (22x134) to (22x60).

The reduction in the dimensions of the columns is one of the great advantages of using High Performance Concrete, because with the reduction of the section of the columns, in addition to reducing the volume of concrete, the amount of steel and shape, as mentioned earlier, is totally interesting to increase the useful area, a factor of indisputable importance, since the entrepreneur always aims at a larger useful area aiming at the sale of the property. This factor also stands out in the parking areas, because most of the time there is always a concern of the design engineer to adapt its structure to meet the architect and / or entrepreneur's will, which is the gain of vacancies in the parking area.

VII. CONCLUSION

It is not an easy task to determine which of the concretes is the most advantageous and the most economically viable in the execution of the design of a residential building in the face of so many variables involved. However, for this case study, by restricting the variation only to the fck and keeping the other variables constant, it was possible to determine, through the analysis of quantitative-financial results, which of the solutions is more economical.

In the study, it considered a conventional building using the fck of 25 MPa and in a second moment the same building with the fck 50 MPa. At the end of it, a comparative graph was elaborated containing the value of the total cost of each work of the analyzed structures, in this, it was clear the difference in cost of each analyzed case.

With the analysis of comparatives through the refinement of data obtained by the Cypecad program, it was possible to see the confirmation of one of the hypotheses. There was a decrease of the gross values of form, concrete and steel in High Performance Concrete. However, it was not determinant for this to be more financially advantageous, as HPC has a higher cost per cubic meter compared to Conventional Concrete.

It was assumed that with the use of High Performance Concrete, the costs with materials and labor would be more advantageous than Conventional Concrete, since the high cost of HPC would be easily eliminated when compared to the good results achieved with the decrease of concrete volume, smaller form area, reduction of steel rate and economy with maintenance. However, the results showed that in the total cost of the works, the use of Conventional Concrete was more economically viable. Thus, the hypothesis that the structure made with the HPC would be more economical has not been confirmed, even with a decrease in the consumption inputs of the HPC compared with the CC.

Through this study, it was possible to reach the conclusion that the percentage cost with the shape of the CC was 2.67% higher than the HPC. In the analysis of steel, the percentage cost was that the CC is 12.96% higher than the HPC. In the concrete analysis, the percentage cost of HPC was 49.71% higher than the CC. Lastly, in the structure in which the HPC was used, the total value of the percentage cost was 5.83% higher than the structure in which the CC was used, corresponding to a difference in the total cost of the works of R$ 42,907.38. [2]. Accordingly to Albuquerque et.al (1998) a 10% reduction in the cost of the structure can represent a decrease of 2% in the total cost of the building. In other words, for the case study analyzed, with the use of HPC there may be an increase of approximately 1.2% in the total cost of this building.

On the other hand, there was a significant reduction in the sections of the pillars. In some cases, reaching more than half. What weighed heavily in this analysis, because it is not just the cost that is in focus, but also cost-benefit. As currently the usable area as the quantities vacancies is a constant concern of engineers, it has become a crucial factor in the decision. An additional cost of 1.2% becomes small when compared to the gain in the usable area added to the gain in construction speed, as time is money.

The benefit involves major technical and economic responsibilities, so the execution of works must take advantage of all the possibilities available. Therefore, incorporating the preparation of a preliminary project, careful laboratory studies, monitoring of the executive phases, control of materials, and training of qualified labor for the works is a way of implementing quality assurance procedures and achieving benefits in favor of its interests.

It must be thought that currently there are impositions of more modern structures, in the sense that larger spans and little interference of the structure itself in their use are desired, for this reason, they already need a higher strength concrete.

Therefore, it is essential to carry out studies and quantify the real behavior of these parameters for the conditions available at the first moment before the work begins. These studies would be in form of analyzes: of the appropriate materials, correct proportions and monitoring of results, the costs of implementing the methodologies for the desired work, remuneration of specialized professionals involved in technical and economic studies in the design and execution, resulting in the viability of the choice adopted.

Thus, it is worth noting that the choice of concrete to be used depends on a large number of variables, some of which are not included in this work, such as execution time, foundation costs, among others. Therefore, this study did not intend to present valid results for all types of structures, but it serves as a parameter to assist professionals in the area during the preparation of a preliminary project.

VIII. FUTURE SCOPE

Suggested as subjects of studies for future works some subjects related to the adopted approach:

- Make a parametric study varying the lengths of the spans and the number of floors.
- Add cost of foundations.
- Quantify the production time of the execution of the structure.
- Include other structural systems, such as ribbed slabs.

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