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Tests of Pervious Concrete as Learning Tool: Comparative Study about Evolution of The Trait, Methods and Complementary Analysis

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Abstract

The execution of pervious concrete pavements has been used over the years as a pedagogical resource in the Civil Engineering course at Universidade do Estado de Mato Grosso (UNEMAT), campus of Tangará da Serra – MT, Brazil. With the purpose of aggregating scientific knowledge to the academics, providing advances in the technique used in the production of pervious concrete, as well to the development of the University's physical space. In this article, some of these studies will be presented in order to discuss the scientific observations made by academics in the development of practices and to evaluate the evolution in the methodologies of trait and execution. The characteristic that allow water infiltration has made porous concrete chosen to remedy problems due to the accumulation of water at several points on campus. In addition, another necessity was to promote the interconnection between classroom blocks. The works were evaluated taking into account the reports developed by the academics during the activities. In this analysis, the advancement of the techniques employed even when the students did not have the appropriate equipment. It was possible to observe modifications in the techniques of staining the concrete and the level of difficulty of the drainage process involved. The results were discussed in view of both the evolution of the technique of preparation of the pervious concrete pavement by the academics, as well as the practice as a didactic and social resource. Recently, besides the permeability, the thermal properties of porous concrete have also begun to be explored. Would the pervious concrete pavements has betters thermal performance than the conventional ones? In the state of Mato Grosso for presenting high annual average temperatures if, the pervious pavements contributes to a lower heat retention compared to the conventional one, this would show an excellent alternative for the substitution of the conventional pavements, prioritizing the thermal comfort of the academic community. Because of that, a comparative analysis was performed between the temperature values recorded in the porous pavements, in the conventional and green areas of the campus. The methodology of this research consisted in performance of temperature measurements with an infrared thermometer, the measurements was for 20 days distributed in four months, four times per day (8 a.m., 11 a.m., 5 p.m., and 7 p.m.). The rainy season in the region caused some variations in the results, since conventional concrete, when moist, takes longer to lose this moisture and absorb heat. The colors chosen in the painting also influenced results, because, in the pavements that the pervious concrete was not painted, showed lower temperatures than the conventional. The development of activities related to the analysis and production of pervious concrete contribute to the academic training of students of the Civil Engineering course on two fronts: obtaining technical knowledge and capacity for teamwork, exploring all the basic procedures of the routine of a real work.

Keywords: Pervious Concrete, Conventional Concrete, Pavement, Thermal Analysis, Learning Tool.

1. Introduction

The pervious concrete or porous concrete is the result of the mixture of Portland cement, aggregates, little water and additives. It is made without sand, unlike conventional concrete, thus limiting the content of fines. Due to the minimum amount of water involved in the mixture, it has a dry appearance. According to Höltz (2011) the index of emptiness of porous concrete can be from 15 % to 25 % and through these pores the water and the air can penetrate easily[1].

There are several ways to perform porous concrete, among them is molded in loco or molded in blocks. In addition, it can be presented in various colors, by adding dye during the preparation of the trait or by painting the final piece. The colors only influenced the appearance and thermal performance of the sidewalk, however other factors will influence the percolation of water.

In order to make good water percolation in the soil, it is necessary to pay attention to the soil type of the subbase. According to Araújo (2016) of clayey soils, which present little water percolation, are not good to serve as a basis for porous concrete, because they caused the accumulation of water[2]. Also, according to Araújo another factor is the depth of the groundwater that should be at least 1.20 m deep aiming to avoid contaminations. Still to ensure that there will be no accumulation of water according to Schueller (1987) the correct would be to perform a subbase with coarse aggregates, to function as a reservoir of stones[3].

At the Universidade do Estado de Mato Grosso (UNEMAT), tests were carried out proving the previous statements, producing pervious concrete within the campus. In the discipline of Experimental Physics, as pedagogical resource is propose to the academics of the Civil Engineering course that promote improvements on the University campus, some groups of students chose the porous concrete to accomplish this. Thus, during the academic semesters, we can observe the evolutions in the trait and the technique used in the production of the pervious sidewalk.

In this article will be approached some of the projects carried out, seeking to understand the advances made and point out the positive or negative points of the tests. Based on the pervious pavements of the campus, there is a comparison between them to observe the advances and improvements made by the students, showing how the practical projects are value for the academic life. Allied to this comparative study, it was made some thermal analysis of the pervious concrete, trying to prove that the pervious pavement absorbs less heat than the conventional pavement.

To make comparisons between the techniques employed and the advances, it was realized a literature review of the reports produced by the students during the execution of their concrete[4-6]. Therefore, we can compare the executive methods, equipment used and additives. Thus, obtaining the evolution of the technique with the advancement of semesters and the educational gain produced.

2. Pervious Concrete Sidewalks

At Universidade do Estado de Mato Grosso (UNEMAT), campus of Tangará da Serra – MT, Brazil, the academics of the Civil Engineering course, development of pervious concrete sidewalks[7]. To fulfill the activity proposed by the professors, they performed by improvised methods due to lack of resources, such as machinery and tools. Even without ideal situations, the results were promising and remedied problems with water accumulation. The tests produce improvements for the academic community and contributes for learning and research for students of the Civil Engineering course. To facilitate understanding the sidewalks performed by students on campus have been listed from 1 to 5 and are arranged according to the development of the first to the last one.

2.1. Sidewalk 1

For this project, the academics identified a problem of water accumulation in one of the drinking fountains of the University, the concrete in front of this drinking fountain was degraded and always moist. Seeking to solve the problem was proposed by the group to remove the concrete in the proximity and the saturated soil of water, to develop the previous sidewalk molded in loco, the Photograph 1 shows the old sidewalk.

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Photograph 1. How it was the sidewalk.

In two traits were develop, one used in the lower layer and the second for the finishing layer. The measurements were made on a precision scale provided by the UNEMAT laboratory. In order to obtain better esthetics results, the first trait used aggregates of a higher granulometry than in the second one.

The traits performed were the following:

- 1st trait: 140 kg of gravel 02 (19 mm to 25 mm); 20 kg of gravel sifted in the sieve of N°. 4 (4.76 mm); 35 kg of cement CP-V ARI; 11.3 kg of water; and
- 2nd trait: 80.16 kg of gravel sifted in the sieve of N°. 4 ; 15.84 kg of gravel sifted in sieve N°. 4; 4 kg of sand; 25 kg of cement CP-V ARI; 8.92 kg of water; 0.5 kg of blue dye.

During the execution the academics used a cylindrical weight made of metal to compress the two layers of permeable concrete develop, and it was shown in Photographs 2 and 3.

Photograph 2. 1st trait.

Photograph 3. 2^{nd} trait.

Yet as finishing the students used mold and spray paint to form the Civil Engineering logo on the sidewalk, the Photograph 4 shows the finished project.

Photograph 4. Finished project.

2.2. Sidewalk 2

This project was conceived by students of the 2017/1 class, as an initiative to create a passage between the blocks, in which classes of the Civil Engineering course are taught. The passage was planned to have 1.40 meters wide and the 2.98 m long, this being the total distance between the pavilions.

The trait in this project consisted of an equivalent proportion 1:4 (each kilogram of cement four kilos of aggregates) and the amount of water corresponded to 35% of the

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cement mass. As in previous projects, two layers of concrete were developed, the first being using aggregates of larger diameter and the second, aggregates of smaller diameter, as shown in the Photograph 5.

Photograph 5. Observation of the two layers.

At first the concrete was scattered in a square of wood. Soon after the first layer was compacted with the "soquete" made by the group, because it does not dispose of the appropriate equipment, which in this case is the roll. The tool made is shown in the Photograph 6.

Photograph 6. "Soquete".

Since the pervious concrete does not have a great quantity of water in its composition, it was necessary to hydrate it with the use of a sprayer, as shown in Photograph 7. And then the sidewalk was covered by canvas for the cure, as shown in Photograph 8.

Photograph 7. Hydration of concrete.

Photograph 8. Concrete hydration and compaction.

The Photograph 9 shows the finished sidewalk, after painting with black spray and side protection with sand and gravel.

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Photograph 9. Finished sidewalk.

2.3. Sidewalk 3

Similarly, to the project of sidewalk 1, this was intended to solve the accumulation of water on the floor in front of another drinking fountain at the campus, which frequently was often flooded. Due to the clayey soil of the region, a preparation was necessary, because the clayey soil hinders the percolation of water. To do this preparation, academics used pavement residues that existed until then, as a reservoir of stones.

This procedure was carried out in order to promote better water absorption by the soil, Photograph 10 shows the soil preparation.

Photograph 10. Soil preparation.

On this sidewalk the academics performed two traits. In both cases, a precision scale of the UNEMAT physics laboratory was used. Similar, to the sidewalk 1 and 2 projects the first trait development for the 1st part used coarse aggregates and in the trait for the finish was used aggregates of lower thickness. The traits performed were:

- 1st trait 1:4, 200 kg gravel 1, 50kg cement, water/cement: 0.35 = 17.5 L; and
- 2nd trait 2:1:4, 100kg of granilla, 25kg cement, water/cement: 0.35 = 8, 75L.

A Wooden board was used for laths the concrete and a adapted compactor, also made of wood, prepared by the students of the sidewalk project 2, served for the compaction of the pavement. After compaction, the concrete was hydrated and protected by canvas. Photographs 11 and 12 show the above in 1st and 2nd trait.

Photograph 11. Use of “soquete” to compact the concrete.

Photograph 12. Hydration of concrete hydrate it with a sprayer.

In this project there was no addition of dyes or paint, the final concrete has its natural color, as shown in Photograph 13.

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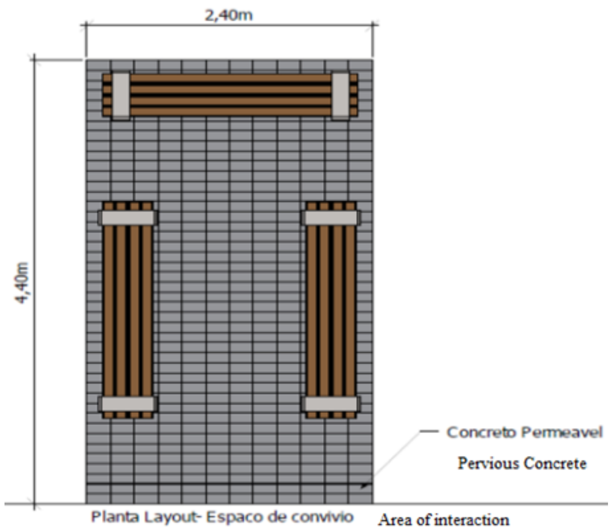
Photograph 13. Finished sidewalk.

2.4. Sidewalk 4

In this project, the students had the intention of expanding an area of interaction already existing on the campus that was also produced by academics. The students of sidewalk 4 aimed to increase the capacity of people who could be received, the pervious concrete was chosen so that the percolation of water in the locality was not reduced. Interesting to observe on this project is that the group had support from an academic of the architectural course to produce a sketch before the execution of the work. The Photograph 14 shows the sketch of the plan.



Photograph 14. Sketch.

To accomplish this work, the students were interested in knowing more about the granulometry of the aggregates. And for that, they accomplish a technical visit to a local quarry

(Pedremat Extração de Pedras Ltda. - PEDREMAT) to learn more about the process of obtaining the aggregate until it reaches the form that is used in concrete. The Photograph 15 shows the academics during the technical visit.

Photograph 15. Sketch.

The chosen trait was 1:4, that is, 1 kg of cement for each 4 kg of aggregate, with water 35 % cement proportion. The acquisition of one ton of aggregate was made and the cement available at the University were used. To develop the porous concrete they use 800 kg of aggregate, 200 kg of cement and 70 liters of water. The Photograph 16, is the trait and the square of wood.

Photograph 16. Trait.

Unlike the others, this group had access to a tool that facilitated the process of execution of the work a compressor roller, intending to distribute the whole dough evenly. The Photograph 17 shows the tool being use.

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Photograph 17. The compressor roller in use.

To finalize the area was covered by canvas to protect the concrete of the sun and the rains. The next day, it was necessary hydrated the concrete. The Photograph 18 shows the sidewalk finished.

Photograph 18. Finished sidewalk.

2.5. Sidewalk 5

The sidewalk was designed to pave a passage often used by students and professors of the University that until then was unpaved. This project was the most complex of those carried out until the present day. For its realization it was necessary a considerable amount of landfill and the installation of a small drainage system since the locality presented a large volume of water due the rains and the clayey soil.

This was the most dimensioned sidewalk develop until then by the students, due to the irregularity of the terrain it was necessary to use surveying equipment to measure the unevenness and calculate the landfill. The Photograph 19 shows the collection of the topographic data.

Photograph 19. Student using surveying equipment.

The students carried out a work of earthworks on the ground with specialized machinery, were used about 24 m^3. The Photographs 20 and 21 show the execution of the earthworks.

Photograph 20. Earthworks (view 1).

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Photograph 21. Earthworks (view 2).

Only after that the students demarcate the perimeter of the sidewalk and started the works of the drain. The Photograph 22 shows the students demarcating the locality and initiated the drain preparation. The work of the drain must the following measures and materials: 6 concrete tubes of 0.20 m per 1 m were used and a 1x1 m collector box , depth of 0.50 m was constructed for the capitation of water with a decay of 0.10 m. The Photograph 22 and 23 show the students building the drain.

Photograph 22. Drain (view 1).

Photograph 23. Drain (view 2).

In the report available of this work there is no data on the trait and development of the sidewalk after that. The Photograph 24 shows finished sidewalk.

Photograph 24. Finished sidewalk.

3. Thermal Analysis

The temperature analyses were developed by infrared thermometer, for 20 days distributed over four months and four measurements per day at the following hours 8 a.m., 11 a.m., 5 p.m., and 7 p.m. In some moments of the research, it was impossible to do measurements for consecutive days, because of the rainy season characteristic for this region. Data collection began at 28 February 2019 and finished at 14 May 2019, with an average of 5 days of collection per month on five pervious sidewalks in the campus and it was measurement in Celsius degrees.

For the disposition of the data will be made thermal amplitudes in three parts, morning, afternoon and night. For the amplitude of the morning will be made the difference between the measurement of 11 a.m. and 8 a.m., for the afternoon the difference will be between 5 p.m. and 11 a.m. The data collected at 7 p.m. is for observation of the thermal delay, comparing the measurement of 7 p.m. and 5 p.m. it was called as night. The data accompanied by the negative signal represent the temperature loss.

The collected data were arranged in tables, making the averages of the amplitudes to have monthly values. Subsequently, the averages of the months, so it can be evaluate the data obtained in a more simplified way. The averages for each month of the five study sites can be observed in the Tables 1 to 5. The abbreviations were used to indicate each material: PC-pervious concrete; CC-conventional concrete; and GA-green areas.

Table 1. Sidewalk 1 averages of the thermal amplitudes per month in Celsius degrees (°C).

Sidewalk 1			
February			
-	Morning	Evening	Night
PC	3.54	-1.90	-2.20
CC	3.34	-1.10	-1.70
GA	3.84	-0.20	-1.80
March			
-	Morning	Evening	Night
PC	3.54	-1.90	-2.20
CC	3.34	-1.10	-1.70
GA	3.84	-0.20	-1.80
April			
-	Morning	Evening	Night
PC	3.54	-1.90	-2.20
CC	3.34	-1.10	-1.70
GA	3.84	-0.20	-1.80
May			
-	Morning	Evening	Night
PC	3.54	-1.90	-2.20
CC	3.34	-1.10	-1.70
GA	3.84	-0.20	-1.80

Table 2. Sidewalk 2 averages of the thermal amplitudes per month in Celsius degrees (°C).

Sidewalk 1			
February			
-	Morning	Evening	Night
PC	11.14	-2.40	-3.40
CC	11.40	-8.00	-2.60
GA	7.34	-8.30	-3.00
March			
-	Morning	Evening	Night
PC	24.5	-18.55	-0.70
CC	10.57	-3.20	-0.40
GA	9.40	-6.65	-0.40
April			
-	Morning	Evening	Night
PC	17.05	-8.40	-2.00
CC	10.45	-2.57	-1.65
GA	8.25	-3.84	-1.45
May			
-	Morning	Evening	Night
PC	24.70	-25.90	-1.40
CC	12.84	-11.80	-3.40
GA	13.24	-15.10	-2.00

Table 3. Sidewalk 3 averages of the thermal amplitudes per month in Celsius degrees (°C).

Sidewalk 1			
February			
-	Morning	Evening	Night
PC	5.50	-0.50	-1.60
CC	10.87	-8.10	-2.40
GA	6.37	-2.00	-3.60
March			
-	Morning	Evening	Night
PC	6.70	-0.05	-1.50
CC	7.14	-0.75	-0.80
GA	6.34	-2.25	-1.60
April			
-	Morning	Evening	Night
PC	6.62	-0.27	-2.40
CC	9.50	-0.20	-3.40
GA	8.33	-5.67	-1.90
May			
-	Morning	Evening	Night
PC	5.14	-4.90	-0.40
CC	6.14	-3.00	-0.20
GA	6.27	-8.00	-3.80

Table 4. Sidewalk 4 averages of the thermal amplitudes per month in Celsius degrees (°C).

Sidewalk 1			
February			
-	Morning	Evening	Night
PC	9.50	-9.50	-3.10
CC	9.30	-8.45	-1.60
GA	8.20	-9.80	-1.40
March			
-	Morning	Evening	Night
PC	16.45	-16.70	-1.80
CC	13.50	-7.50	-1.60
GA	18.25	-17.00	-1.40
April			
-	Morning	Evening	Night
PC	9.35	-4.24	-1.20
CC	12.38	-5.70	-1.25
GA	8.78	-4.10	-1.10
May			
-	Morning	Evening	Night
PC	14.80	-12.60	-3.00
CC	18.24	-13.10	-1.30
GA	8.57	-8.10	-1.20

Table 5. Sidewalk 5 averages of the thermal amplitudes per month in Celsius degrees (°C).

Sidewalk 1			
February			
-	Morning	Evening	Night
PC	13.40	-4.80	-1.90
CC	9.60	-3.90	-0.80
GA	5.70	-0.30	-2.50
March			
-	Morning	Evening	Night
PC	28.24	-19.75	-1.90
CC	19.80	-16.50	-1.70
GA	12.80	-11.75	-1.30
April			
-	Morning	Evening	Night
PC	21.05	-9.57	-4.15
CC	12.40	-6.90	-2.10
GA	9.15	-5.10	-1.70
May			
-	Morning	Evening	Night
PC	27.24	-24.7	-2.00
CC	18.80	-18.50	-1.10
GA	13.97	-17.40	-1.80

In the Tables 1, 2, 3, 4 and 5, there is negative temperatures, because they represent temperature loss or cooling. Analyzing the tables, it is noted that the pervious concrete gains heat more quickly than conventional concrete but also loses the heat faster than the others.

4. Results and Comparisons

Through the above, the educational advancement and of the technology employed by academics is remarkable. An important point to be highlighted are the methods of homogenization of the concrete. The pervious concrete is more complicated to homogenize than the conventional, because most of the composition is aggregates and cement, as was seen in the students ' trait, making the mixture heavier than the mixture for conventional concrete. The students used creativity to solve the question when faced with this difficulty. The sidewalk 1 used a piece of heavy and cylindrical metal for this. On the sidewalk 2 there was the manufacture of a wooden tool, which was reused by other academics afterwards. In other groups, there were partnerships with entrepreneurs and the financial sector of the University and had access to appropriate equipment.

Related to drainage, the sidewalk group 3 did the soil preparation previously using construction residues to increase the permeability of the clayey soil. The group on the sidewalk 5 has built a drainage system, with concrete tubes and collector box. This shows that there was an evolution in the understanding that only the pervious concrete is not enough to avoid flooding, so this instigates the students to produce functional projects.

Another point to be highlighted was that students of sidewalk 4 had the support of one architecture student, who helps them with drawings and sketches. This shows the importance of the partnership between different areas from the academic environment. Emphasizing that Civil Engineers and Architects are largely connected in the professional environment, and practicing the partnership between the courses contributes to disseminate the idea of respect and collaboration in University.

Still on the sidewalk 4 another highlight is the technical visit that the group carried out adding knowledge to the group members about the extraction of the aggregates.

Academics are concerned about the finishes details of the projects to improve the campus environment and make it more enjoyable and for this they carried out paintings. The concretes that received painting or dye had the highest temperatures, because the colors chosen were dark, increasing the absorption of heat. The Tables 6, 7, 8, 9 and 10 show the averages for each study locality. In the tables, abbreviations were used to indicate each material: PC-pervious concrete; CC-conventional concrete; and GA-green areas. The data accompanied by the negative signal represent the temperature loss.

Table 6. Sidewalk 1 averages in Celsius degrees (°C).

Average			
Locality 1	Morning	Evening	Night
PC	5.46	-1.90	-1.60
CC	5.49	-2.15	-1.28
GA	6.16	-3.39	-1.29

Table 7. Sidewalk 2 averages in Celsius degrees (°C).

Average			
Locality 1	Morning	Evening	Night
PC	19.35	-13.81	-1.88
CC	11.32	-6.39	-2.01
GA	9.56	-8.47	-1.71

Table 8. Sidewalk 3 averages in Celsius degrees (°C).

Average			
Locality 1	Morning	Evening	Night
PC	5.99	-1.43	-1.48
CC	8.41	-3.01	-1.70
GA	6.83	-4.48	-2.73

Table 9. Sidewalk 4 averages in Celsius degrees (°C).

Average			
Locality 1	Morning	Evening	Night
PC	12.53	-10.76	-2.28
CC	13.36	-8.69	-1.44
GA	10.95	-9.75	-0.68

Table 10. Sidewalk 5 averages in Celsius degrees (°C).

Average			
Locality 1	Morning	Evening	Night
PC	22.48	-14.71	-2.49
CC	15.15	-11.45	-1.43
GA	10.41	-8.64	-1.83

During data collection it was observed that conventional concrete when it was wet after rains took much longer to gain temperature than pervious concrete. The pores in the porous concrete allow the air to enter and allow the passage of water easier than the conventional one, for this reason absorbs heat quickly. The same porous that makes it warmer faster also allows it to cool faster. The night data shows that the heat loss is higher in the pervious concrete than in the conventional one, however the green area presented the lowest temperatures.

5. Conclusions

Observing the evolution of the students we can notice advances in the technique of sidewalks production and learning about the trait and method of pervious concrete execution. In some sidewalks, the students did staining tests, with the addition of dye or paint of the concrete. The colors chosen were dark and so they had negative impacts on the temperature, as they absorb more heat than the light colors.

In addition to the practical activity, the students are requested to produce reports, describing not only the specifications of the traits, as well as the difficulties of development and the main scientific observations made during the project. In the projects undertaken, the academics observed the high temperature that the concrete reached during the chemical reactions and the dry aspect of the pervious concrete due to the amount of water used, which in this case is smaller than the conventional concrete.

One point to be highlighted is the importance of the reports produced by the students, as can be observed the group of the sidewalk 5 did not perform a full report even having done a complex work for the academic level.

It is remarkable the improvement of academics seen the improvised methods and conditions with the sidewalks were develop. Creativity, the ability to solve problems and cope with short deadlines and low costs have been widely developed and are of great importance to the professional of the construction sector. The educational gain is so significant that projects like this should be extended to other materials and innovations of construction, seeking to increase the field of practice knowledge acquired by the students. This works contributes to the academic well-being and to the training of professionals with knowledge of alternative technologies to conventional concrete.

This shows the importance of performing practical work during graduation, allied to this there was development of techniques that can be improved and disclosed to the public to be used. Then it could be developed a social work with the local population for knowledge of the material and how to perform it in the local residences.

As for the study of temperature, it can be noted that the pervious concrete absorbs heat faster than the conventional yet loses the heat faster as well. This is due to the existing pores in its composition, allowing the air to come in and out easier. Thus, in the morning the pervious concrete will heat faster than the conventional, already in the afternoon and night will cool easier. Another characteristic observed is that after rainfall the conventional concrete has more lower temperatures in relation to the pervious because it remains moist for longer, slowing the heat absorption.

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