Sustainable Urban Pavement for Cities Affected by El Niño using Porous Concrete

B Aguirre 1*, M Anchiraico 1, J Rodríguez 2, F García 3

1 Bachelor, Civil Engineering Program, Universidad Peruana de Ciencias Aplicadas, Lima, Perú
2 Full Professor, Civil Engineering Program, Universidad Peruana de Ciencias Aplicadas, Lima, Perú
3 Professor, Civil Engineering Program, Universidad Peruana de Ciencias Aplicadas, Lima, Perú

* u201517072@upc.edu.pe

Abstract. The El Niño phenomenon is caused by the change in atmospheric pressures, which produce the accumulation of hot surface waters on the eastern flank of the Pacific Ocean; causing intense rainfall that runs over the surface affecting the urban drainage of the city due to the lack of a permeable pavement; porous concrete allows infiltration of surface water runoff through its pores. The present investigation evaluates porous concrete in the range of w/c relationships of 0.30 and 0.32; the results indicate that the compressive strength, flexural strength and permeability coefficient increase; and that the surface runoff, cost, water footprint and carbon footprint are lower than conventional concrete.

1. Introduction

Many countries have witnessed different catastrophes over the years, which have caused economic, social and environmental damage to populations, due to anthropic and/or natural changes caused by cyclones, hurricanes, droughts, and floods; the latter two being related to the La Niña and El Niño phenomena. El Niño is the product of a shock of sea surface temperature and air pressure that occurs in the equatorial Pacific Ocean [1], its frequency and intensity is related to climate change and the greenhouse effect, it manifests itself in a non-periodic [2] and has a duration of 7 to 16 months [3]; chronologically, it begins in 1957 and ends in 1958, then continues in the periods of the years 1965-1966, 1972-1973, 1982-1983, 1986-1987, 1987-1988, 1991-1992, 1997-1998, 2002-2003, 2009-2010 and 2016-2017 [4]. Historically, the 1997-1998 event was the one that caused major economic damage, ranging from US $ 32 billion to US $ 96 billion in the countries of the Pacific Basin and the Tropics [5], and produced the greatest impacts negative effects on the sanitation of cities, causing damage to their water supply systems, sewage and rainwater [5], [6], [7].

These damages were produced by surface runoff, product of excessive rains, present in the impervious carriageways of the roads which were conceived without an integral technical conception of the engineering professionals between urban planning and drainage systems, and lack of resources [8]; generating damage to drinking water supply and sewerage systems, and an increase in surface temperature and floods [6]; given this situation, the possibility arises of using sustainable urban drainage systems (SUDS) to control floods and pollution generated in an integrated and sustainable way [9], being able to design a porous concrete (PC) permeable pavement to reduce and drain surface runoff.
from urban areas, as well as the effect of urban heat [10], [11]. This concrete that is placed in the wearing course, contains little or no amount of fine aggregate [12], presents a significantly greater amount of pores than conventional concrete (CC), whose void content is from 11% to 35% [13], its w/c ratio varies between 0.28 and 0.40 [14], it has a resistance to compression between 28.5 to 285.5 Kg/cm² [15], and its permeability coefficient is between 0.4 to 1.7 cm/s [12]. As drawbacks of the PC, we can mention that it is not applied to heavy traffic because its high content of voids does not allow it to reach the resistance required to meet the load requirements of high traffic [16]; it also presents the risk that, applied to permeable pavement, the infrastructure will fill up and degrade when an adequate maintenance program has not been followed [17].

One way to visualize the efficiency of this permeable pavement is by using computer programs developed for rain and runoff, which allow knowing the dynamic responses of the elements that make up an urban drainage system for a rain event [18]; among the tools used for SUDS we have: Model for Urban Stormwater Improvement Conceptualization (MUSIC) [19], Benefits of SUDS Tool (BEST) [20], System for Urban Stormwater Treatment & Analysis Integration (SUSTAIN) [21] and Stormwater Management Model (SWMM 5.1) [22], this being used in research because it incorporates a simulation module for sustainable drainage techniques [10].

Some investigations carried out on the mechanical behavior of PC for the w/c relation with respect to compressive strength, flexure and permeability coefficient at 28 days indicate that the compressive strength increases [16], being able to reach up to 12% for w/c of 0.30-0.34 [23], [24]; that the flexural strength increases [25], reaching a value of 12% for w/c between 0.30-0.34 [26], [25]; and that the permeability coefficient should not have an w/c less than 0.30 [24], the w/c of 0.32 being optimal to obtain a permeability coefficient greater than 2 mm/s [27]; [28] indicates that the w/c influences the permeability coefficient. In the economic field, we can indicate that PC can reduce the general costs of a project [29], when its manufacture is largely manual and can be done without heavy equipment, the cost is lower [30], and it is advisable to analyze the material costs [26].

In the environmental aspect, there are some studies on the sustainability of urban pavements, [31] indicating that the water footprint increases, due to the runoff of rainwater that flows through the paved surfaces; the excess of this water generates a lower value of the water resource, which causes water losses due to lack of control [32], recommending good management [33]. Regarding the carbon footprint, we can indicate what was expressed in [34], [35] who argue that the use of a permeable pavement is a good alternative to reduce greenhouse gas emissions, because by mitigating the heat island urban carbon dioxide (CO2) is reduced.

The city of Tumbes located to the East with respect to the Pacific Ocean and at 6 m.a.s.l presents a recurrence of hydrometeorological dangers, marked by the occurrence of floods due to the occasional presence of torrential rains [36]. The last rainfall was in 2017, whose intensity was 16 times more than the annual average of precipitations, it caused intense rains and floods that left considerable damage to: public institutions, health, education and homes [37]. A large number of homes were affected because they were located in the channels of streams and rivers, they were located in areas with a deficient storm drainage system, and because they were built without a drainage system for rain, generating destruction in the water pipes and drain [36]. To date, the city does not have an appropriate storm drainage system for the volume of precipitation of an event such as the El Niño phenomenon [38].

This research addresses the problem of the lack of a sustainable permeable urban pavement in cities affected by the El Niño phenomenon. For this, the compressive strength, flexural strength and permeability coefficient of PC were studied; and the unit cost, water footprint, carbon footprint, and storm runoff comparison between a CC pavement and a PC pavement using SWMM 5.1 software.

2. Materials and methods

2.1. Materials
Type V Portland Cement was used [39]; the aggregates were natural with a maximum size of Ø 3/4" [40]; ZRR PLAST-971 [41] Superplasticizer was used; the water was drinkable [42]. Surface runoff was simulated with an HP OMEN laptop with Intel (R) Core (TM) processor it-8750H CPU @ 2.20GHZ and SWMM 5.1 software [43]; it was also used for footprints [44].
2.2. Methods

2.2.1 Tests performed. The PC of $f'c = 210 \text{ Kg/cm}^2$ was designed [39, 40, 41, 42], with w/c ratios of 0.30 and 0.32, coarse aggregate (95%) and fine aggregate (5%). Table 1 shows the mixes, preparation and curing for 28 days [45]; 4 specimens were used per test: compression (6 "x12") [46], permeability coefficient (4 "x8") [47], and flexion (6 "x6" x15") [48].

2.2.2. Unit prices. The data referenced in [49], [50] and [51] were used in the elaboration of the analysis of unit prices of the CC and PC.

Water footprint: The Declaration of Environmental Product type “Cradle to Gate” [52], the procedure of [53] was followed. The consumption of blue water in the life cycle of construction products was considered, it was done in 2 stages: Product, with 3 mandatory modules (A1, A2 and A3) and Construction, with 2 optional modules (A4 and A5), which are indicated:

- **Module A1 (Raw materials):** extraction and processing of materials and production.
- **Module A2 (Transport):** round trip distance from materials to concrete plant, fuel and efficiency.
- **Module A3 (Fabrication):** manufacture of concrete and washing of mixing equipment.
- **Module A4 (Transport):** round trip distance from the plant to the construction site, fuel and its efficiency.
- **Module A5 (Transport):** cleaning work area, washing machines, curing concrete.

2.2.3. Carbon footprint. The type “Business-to-consumer” [54] was considered, with the principles of [55], [56] and the procedure of [57]. The equivalent carbon emissions in the life cycle of a product were considered, developing in 5 stages that are indicated:

- **Raw Material:** production of aggregates, cement and superplasticizer additive.
- **Transport:** transportation of materials to the concrete plant according to round trip distances.
- **Production:** concrete manufacturing process in the plant.
- **Distribution:** transport of the prepared concrete to the project according to the round trip distance.
- **Construction:** machines used in placing concrete.

3. Results and analysis

3.1. Compressive strength

Figure 1 shows the effect of w/c on the compressive strength at 28 days, it is seen that when changing from PC-0.30 to PC-0.32 the resistance rises from 252.00 kg/cm$^2$ to 266.5 kg/cm$^2$, which indicates a 5.75% increase over PC-0.30. [58], [59] studied mixtures with PC for w/c of 0.30, 0.35 and 0.27, 0.30, finding an increase in resistance of 12.31% and 1.16% when going from a lower to a higher w/c. [60] indicates that this is because the mixture is more fluid and better wraps the aggregate.

![Table 1: Mix design for 1 m$^3$ of PC.](image)

**Figure 1.** Effect of w/c on compressive strength.
3.2. Flexural strength
Figure 2 shows the effect of w/c on flexural strength at 28 days, it is seen that when changing from PC-0.30 to PC-0.32 the resistance increases from 34.10 kg/cm² to 37.40 kg/cm², which indicates an increase of 9.68% compared to PC-0.30. [58], [61] studied mixtures with PC for w/c 0.30, 0.35 and 0.34, 0.38 finding an increase in resistance of 4.20% and 20.01% when going from a lower to a higher w/c. [61] indicates that this is due to the greater hydration of the cement.

3.3. Permeability coefficient
Figure 3 shows the effect of w/c on the permeability coefficient at 28 days, it is seen that when changing from PC-0.30 to PC-0.32 the coefficient rises from 0.88 cm/s to 0.92 cm/s, which indicates a 4.55% increase compared to PC-0.30. [62], [63] studied mixtures with PC for w/c 0.28, 0.31 and 0.30, 0.35 finding an increase in resistance in 212.50% and 2.85% when going from a lower to a higher w/c. [61] indicates that this is due to decreased adhesion between set and aggregate cement.

3.4. Surface runoff
Table 2 shows the surface runoff of a CC and a PC, it is seen that the runoff in the PC decreases by 42.43% after 30 minutes. [64], [65] evaluated the runoff of a permeable and a porous pavement using SWMM 5.0 software, and also compared several conventional development systems with a low impact development, finding a runoff reduction of 54.79 % and 98.3% in permeable pavement and in low-impact development. [66] indicates that this is because the precipitation falling on the permeable pavement surface infiltrates into a deposit that stores it.

| Runoff | Hours    | CC (l/s) | PC (l/s) | Reduction (%) |
|--------|----------|----------|----------|---------------|
|        | 00:30:00 | 2074.30  | 1194.17  | 42.43         |
|        | 01:00:00 | 2642.78  | 1194.17  | 54.81         |
|        | 01:30:00 | 1805.78  | 161.25   | 91.07         |
|        | 02:00:00 | 1703.55  | 161.25   | 90.53         |
|        | 02:30:00 | 1429.34  | 0.00     | 100.00        |
|        | 03:00:00 | 1386.33  | 0.00     | 100.00        |

3.5 CC and PC unit prices
Table 3 and Table 4 show the analysis of unit prices per m³ of CC and PC, it is seen that the unit price of S/357.43 ($ 99.87 USD) for PC is 1.15% less than S/361.57 ($ 101.03 USD) of CC. [67] compares the costs of the pavements of 2 parking lots 0.15m thick built with CC and PC, finding that the cost of the PC pavement is 6.19% less. [68] compares the cost of a conventional development technique with
that of permeable pavement in a project, finding that the cost of permeable pavement is 19.64% lower. [69] indicates that the cost of the PC is lower because it minimizes the need to use runoff retainers.

Table 3. Analysis of unit prices of 1m$^3$ of CC.

| Description            | Unit | Crew | Quantity | Price S/ | Partial S/ | Total S/ |
|------------------------|------|------|----------|----------|------------|----------|
| **Materials**          |      |      |          |          |            |          |
| Water                  | m$^3$|      | 0.2300   | 5.68     | 1.31       | 361.57   |
| Fine sand              | m$^3$|      | 0.5775   | 42.29    | 24.42      |          |
| Portland cement        | bag  |      | 10.8000  | 21.60    | 233.28     |          |
| Crushed stone 1/2”     | m$^3$|      | 0.3853   | 51.61    | 19.89      | 278.89   |
| **Workforce**          |      |      |          |          |            |          |
| Foreman                | hh   |      | 0.2000   | 0.0727   | 23.08      | 1.68     |
| Operator               | hh   |      | 2.0000   | 0.7273   | 19.23      | 13.99    |
| Official               | hh   |      | 2.0000   | 0.7273   | 15.94      | 11.59    |
| Pawn                   | hh   |      | 8.0000   | 2.9091   | 14.33      | 41.69    |
| **Teams**              |      |      |          |          |            |          |
| Manual tools           | %WF  |      | 3.0000   | 68.94    | 2.07       |          |
| Concrete mixer         | hm   |      | 1.0000   | 0.3636   | 26.60      | 9.67     |
| Concrete vibrator      | hm   |      | 1.0000   | 0.3636   | 5.48       | 13.73    |

Table 4. Analysis of unit prices of 1m$^3$ of PC.

| Description            | Unit | Crew | Quantity | Price S/ | Partial S/ | Total S/ |
|------------------------|------|------|----------|----------|------------|----------|
| **Materials**          |      |      |          |          |            |          |
| Water                  | m$^3$|      | 0.1343   | 5.68     | 0.76       | 357.43   |
| Fine sand              | m$^3$|      | 0.0300   | 42.29    | 1.27       |          |
| Coarse aggregate ¾”    | m$^3$|      | 0.5600   | 28.90    |            |          |
| Portland cement        | bag  |      | 9.8739   | 121.28   |            |          |
| Superplasticizer 971   | lt   |      | 4.5700   | 32.54    |            |          |
| **Workforce**          |      |      |          |          |            |          |
| Foreman                | hh   |      | 0.2000   | 0.0727   | 23.08      | 1.68     |
| Operator               | hh   |      | 2.0000   | 0.7273   | 19.23      | 13.99    |
| Official               | hh   |      | 2.0000   | 0.7273   | 15.94      | 11.59    |
| Pawn                   | hh   |      | 8.0000   | 2.9091   | 14.33      | 41.69    |
| **Teams**              |      |      |          |          |            |          |
| Manual tools           | %MO  |      | 3.0000   | 68.94    | 2.07       |          |
| Concrete mixer         | hm   |      | 1.0000   | 0.3636   | 26.60      | 9.67     |

3.6. Water Footprint of CC and PC

For the calculation of the Water Footprint (in l) of Conventional Concrete (WF$_{CC}$) and of the Water Footprint (in l) of Porous Concrete (WF$_{PC}$), equation (1) was applied:

$$WF_{CC} = WF_{PC} = WF_{A1} + WF_{A2} + WF_{A3} + WF_{A4} + WF_{A5}$$

(1)

where, WF$_{A1}$: Water footprint of module A1 (l), WF$_{A2}$: Water footprint of module A2 (l), WF$_{A3}$: Water footprint of module A3 (l), WF$_{A4}$: Water footprint of module A4 (l), WF$_{A5}$: Water footprint of module A5 (l). We find WF$_{A1}$ with (2):

$$WF_{A1} = WF_{FA,CA} + WF_{CE} + WF_{SA}$$

(2)
where; \(WF_{FA}, WF_{CA}, WF_{CE}, WF_{SA}\): Water footprint of fine and coarse aggregates (0.73 l) [70], cement (0.73 l) [70], superplasticizer additive (0.73 l) [70]. Replacing in (2): \(WF_{A1} = 159.93\) l (a) and \(WF_{A1} = 162.37\) l (b). We find \(WF_{A2}\) with (3):

\[
WF_{A2} = 2 \times [DC \times DW \times WF_{D} (D_{FA} + D_{CA} + D_{CE} + D_{SA})]
\]

(3)

where; 2: number of round trips, DC: Diesel consumption (0.71 l/m³) [70], DW: Diesel weight (0.85 Kg/l) [70], \(WF_{D}\): Diesel water footprint (0.05 l/Kg) [70], \(D_{FA}, D_{CA}, D_{CE}, D_{SA}\): Transport distances of the supplier of fine and coarse aggregates (35.80 Km) [44], cement (9.20 Km) [44], superplasticizer additive (7.4 Km) [44], to the ready mix concrete plant. Replacing in (3): \(WF_{A2} = 1.79\) l (c) and \(WF_{A2} = 1.99\) l (ch). We find \(WF_{A3}\) with (4):

\[
WF_{A3} = WM + WC/AC
\]

(4)

where; WM: Amount of water for mixing (230 l), (134.28 l) [51], [71], WC: Amount of water for cleaning mixing equipment (5000 l) [70], AC: Amount of concrete for a concrete mixer with a discharge capacity of 3m3 (6.80 tn = 6800 Kg) [70], (6.33 ton = 6330 Kg) [71]. For the PC, the WC value was obtained considering that this concrete uses a lower w/c ratio to guarantee a good adhesion of the cement paste with the aggregates [72], therefore the amount of water in the mix will be less than the CC. Having considered the amount of 4650 l, obtained by discounting 7% which is the difference between materials per m³ of a CC and a PC. Replacing in (4): \(WF_{A3} = 964.86\) l (d), \(WF_{A3} = 968.88\) l (e). We find \(WF_{A4}\) with (5):

\[
WF_{A4} = 2 \times [DC \times DW \times WF_{D} x D_{PO}]
\]

(5)

where, 2: Constant that represents the number of round trips, DC, DW, \(WF_{D}\): indicated when calculating \(WF_{A2}\), \(D_{PO}\): Distance from the ready-mix concrete plant to the work (23.30 km) [44]. Replacing in (5): \(WF_{A4} = 1.58\) l (f). We find \(WF_{A5}\) with (6):

\[
WF_{A5} = K \times (WM/AC)
\]

(6)

where; WM, AC: indicated when calculating \(WF_{A3}\), K: Variable that depends on the type of concrete (K = 0.06 conventional and K = 0.02 porous). The K values were defined based on the greater loss of moisture from an air curing compared to a curing with a protective blanket, being approximately 3 times more [73], having considered a K value = 0.06 for the case of CC. Replacing in (6): \(WF_{A5} = 344.12\) l (g), \(WF_{A5} = 107.21\) l (h). Replacing (a), (c), (d), (f), (h) and (b), (ch), (e), (f), (h) in (1): WFCC= 1472.28 l, WFP= 1142.03 l.

**Figure 4.** Water footprint of CC (a) and PC (b) referenced by percentages of their modules.
Figure 4 presents the WFCC and WFPC, appreciating that the A3 module has a greater incidence in both specimens, reaching a higher value for the PC of 76.08%, which represents 16.08% more compared to 65.54% of the CC. Likewise, we must indicate that the water footprint for the CC is 1472.28 l and 1142.03 l for the PC, which represents 22.43% less; This difference is associated with Module A5 (Construction), which is obtained 344.12 l for the CC and 107.21 l for the PC, which is equivalent to 31.13% and represents 68.85% less, which is related to the lower amount of water Required for curing by using wet blankets versus CC pressure water jet curing. Additionally, we can mention that the difference is also related to Module A3 (Manufacturing) where it reaches 964.86 l for CC and 868.88 l for PC, which is equivalent to 90.05% and represents 9.95% less; being related to the least amount of water in the mixture and the washing of the plant. In this regard, some authors indicate that the greater water footprint of the CC is associated with the volume of concrete [74] and the waste of water [75].

3.7. Carbon footprint of CC and PC

The calculation of the Carbon Footprint (in KgCO$_2$e) of Conventional Concrete (CF$_{CC}$) and of the Carbon Footprint (in KgCO$_2$e) of Porous Concrete (CF$_{PC}$) was done with equation (16):

$$CF_{CC}=CF_{RM}+CF_{TR}+CF_{PD}+CF_{DI}+CF_{CO}$$

(7)

where, $CF_{RM}$: Carbon Footprint of the Raw Material for the materials (KgCO$_2$e), $CF_{TR}$: Carbon Footprint of the Transport from the supplier to the concrete plant (KgCO$_2$e), $CF_{CD}$: Carbon Footprint of the Production in the concrete plant (KgCO$_2$e), $CF_{Di}$: Carbon footprint of the Distribution using the transport from the concrete plant to the work (KgCO$_2$e), $CF_{CO}$: Carbon footprint of the Construction using different machines for placing the concrete (KgCO$_2$e). We find $CF_{RM}$ with (8):

$$CF_{RM}=CF_{FA}+CF_{CA}+CF_{CE}+CF_{SA}$$

(8)

where, $CF_{FA}$, $CF_{CA}$: Carbon footprint of fine and coarse aggregates, $CF_{CE}$: Carbon footprint of cement, $CF_{SA}$: Carbon footprint of superplasticizer additive. The variables $CF_{FA}$ and $CF_{CA}$ are found with (9) and (10):

$$CF_{FA}=4.7 \times FA/1000$$

(9)

$$CF_{CA}=4.7 \times CA/1000$$

(10)

where, 4.7: Constant for fine and coarse aggregates (KgCO$_2$e/ton) [76], 1000: Conversion factor (Kg/ton), FA, CA: Quantities of fine aggregate (924 Kg) [51], (78.64 Kg) [71] and coarse aggregate (655 Kg) [51], (1472.02 Kg) [71]. Replacing in (9) and (10): $CF_{FA}=4.34$ KgCO$_2$e (i), $CF_{CA}=3.08$ KgCO$_2$e (j); $CF_{FA}=0.37$ KgCO$_2$e (k), $CF_{CA}=6.92$ KgCO$_2$e (l). The variable $CF_{CE}$ is obtained with (11):

$$CF_{CE}=800 \times N/1000$$

(11)

where, 800: Constant for the cement (KgCO$_2$e/ton) [57], 1000: Conversion factor (Kg/ton), N: Quantity of cement (459 Kg) [51], (419.64 Kg) [71]. Replacing in (11): $CF_{CE}=367.20$ KgCO$_2$e/ton (m), $CF_{CE}=335.71$ KgCO$_2$e/ton (n). The variable $CF_{SA}$ is obtained with (12):

$$CF_{SA}=1.17 \times AS$$

(12)

where, 1.17: Constant for the superplasticizer additive (KgCO$_2$e/Kg) [77], SA: Amount of the superplasticizer additive (4.57 Kg) [71]. Replacing in (12): $CF_{SA}=5.35$ KgCO$_2$e (ñ). Replacing (i), (j), (ñ) and (k), (l), (n), (ñ) in (8): $CF_{RM}=374.62$ KgCO$_2$e (o), $CF_{RM}=348.35$ KgCO$_2$e (p). We find $HC_{TR}$ with (13):

$$CF_{TR}=2 \times F \times (DF_{FA}+CF_{FA}+CF_{CE}+CF_{SA})$$

(13)
where, 2: number of round trips, F: CO$_2$e emission factor per km traveled (2 kgCO$_2$e/km) [78], $D_{FA}$, $D_{CA}$, $D_{CE}$, $D_{SA}$: transport distances of the supplier of fine aggregates (35.80 Km) [44], coarse (35.80 Km) [44], cement (9.20 Km) and superplasticizer additive (7.40 Km) [44] to the ready mix concrete plant (Km). Replacing in (13): $C_{FTR} = 323.20$ kgCO$_2$e (q), $C_{FTR} = 352.80$ kgCO$_2$e (r). We find, $C_{FPD} = 271.00$ kgCO$_2$e considering 271.00 kgCO$_2$e (emission in concrete plant) [79] (s). We find $HC_{DI}$ with (14):

$$C_{FDI} = 2 \times F \times D_{RC}$$

(14)

where, 2: number of round trips, F: considered in $C_{FDI}$, $D_{RC}$: Transport distance from the ready mix concrete plant to the work (26.30 km) [44]. Replacing in (14): $C_{FDI} = 105.20$ kgCO$_2$e (t). We find $CF_{CO}$ with (15), (16), (17). We find $CF_{CO}$ with (15), (16), (17):

$$CF_{CO} = CH_{MC,CC,VC} x HT_{MC,CC,VC} x EF_{MC,CC,VC}$$

(15)

$$E_{MC} = E_{CC} = E_{VC} = WH_{MC,CC,VC,CO}$$

(16)

$$E_{MC} = E_{CO} = HC_{MC,CO} x WH_{MC,CO}$$

(17)

where, $CF_{CO}$: Carbon footprint of the machinery used in placing the concrete (kgCO$_2$e), $CF_{MC,CC,VC,CO}$: Hourly fuel consumption of mixer (40 l/h) [57], cutter (51 l/h) [57], vibrator (11 l/h) [57], and compactor (16 l/h) [57], $WH_{MC,CC,VC,CO}$: Concrete mixer working hours (4.62 h) [57], cutter (0.37 h) [57], vibrator (289.74 h) [57], and compactor (h), $EF_{MC,CC,VC,CO}$: Emission factor (2.47 Kg CO$_2$e / l) [57] for concrete mixer, cutter, vibrator and compactor. Replacing in (16) for CC: $E_{MC} = 456.46$ kgCO$_2$e (u), $E_{CC} = 46.61$ kgCO$_2$e (v), $E_{VC} = 7872.24$ kgCO$_2$e (w) and with these in (15): $CF_{CO} = 8375.31$ Kg CO$_2$e (x). Replacing in (17) for PC: $E_{MC} = 456.46$ kgCO$_2$e (u), $E_{CO} = 7345.98$ kgCO$_2$e (y) and with these in (15): $CF_{CO} = 7802.44$ Kg CO$_2$e (z). Replacing (o), (q), (s), (t), (x) and (p), (r), (s), (t), (z), in (7): $CF_{CC} = 9449.33$ Kg CO$_2$e, $CF_{PC} = 8879.79$ KgCO$_2$e.

Figure 5 presents the $CF_{CC}$ and $CF_{PC}$ referenced by stages, where it is seen that stage 5 Construction has a greater incidence in both concrete, reaching a higher value for the CC of 88.63%, which represents a 0.86% more compared to 87.87% of the PC. Likewise, we can indicate that the carbon footprint for the CC is 9449.33 kgCO$_2$e and 8879.79 kgCO$_2$e for the PC, which represents 6.03% less, which is related to the use of the vibrator and concrete cutter. Additionally, we can mention that the difference is also related to stage 1 Raw Material, where it reaches 374.62 kgCO$_2$e for CC and 348.35 kgCO$_2$e for PC, which is equivalent to 92.99% and represents 7.01% more; being related to the greater amount of cement required for the preparation of concrete. On the other hand, it is worth mentioning
that in stage 2 Transport, the PC is 352.80 kgCO₂e and the CC 323.20 kgCO₂e, being higher by 9.16%, due to the use of the superplasticizer additive. In this regard, some authors indicate that PC has greater reflectivity in pavements [80], produces an increase in pavement albedo that reduces CO₂ emissions [81] and acts as a sustainable strategy to reduce CO₂ emissions [82].

4. Conclusions
The lack of a drainage system in cities affected by El Niño causes flooding and the collapse of the sewerage system, altering the quality of life in regions and countries.

The higher w/c ratio allows sufficient hydration of the cement paste and leads to increased compressive strength of the concrete.

The increase in flexural strength is due to a better bond between the cement and the aggregates.

The increasing permeability coefficient contributes to a greater collection of rainwater due to the non-clogging of the concrete pores.

The reduction in surface runoff is due to the amount of its voids, which guarantees the effective circulation of water and the adequate management of rainwater.

The lower cost of porous concrete is due to its lower quantity of component materials compared to those used in conventional concrete.

The lower water footprint in a porous concrete is related to the infiltration of surface runoff waters.

The lower carbon footprint of porous concrete reduces carbon emissions and lowers the heat island effect.

5. References
[1] Yan J 2020. Temporal Convolutional Networks for Prediction of ENSO. Sc Rep, 10, p. 1-15.
[2] Cornejo M 2017. Gestión de riesgos: El caso de El Niño / Oscilación sur p.1-72.
[3] Trenberth K 1997. The Definition of El Niño. Nat Center for Atl Res, 78, p. 2771-2777.
[4] Aziz O. El Niño: Predicted hydrologic response in the US. Env & Water Res 2010, 9 p.
[5] Glantz M. Once Burned: Lessons Learned from 1997-98 El Niño, Un Press, 2001, p. 1-313.
[6] Rocha A 2017. El meganiño 1997-98. Lima, p. 1-53.
[7] CEPAL 1998. Ecuador: Evaluación efectos socio-económicos El Niño 1997-1998, p. 1-78.
[8] Tucci C 2007. Gestión de Inundaciones Urbanas. World Met Org, 315, p. 1-317.
[9] Karabegović I 2019. New Technologies, Development and Application II. p. 790-797.
[10] Bai Y. Evaluation System for Optimal Allocation of LID Facilities. Water 2019, 11, p. 341.
[11] Shrivastava A 2018. Global Warming for Sustainable Drainage System, Co Tech, p. 15-28.
[12] Singh R. Investigación experimental sobre hormigón permeable, Civ. In. 2020, p. 229-240.
[13] Barišić I 2017. Pervious concrete mix for sustainable pavement solution. Earth Env, p. 1-7.
[14] Yahña A 2014. New approach to proportion pervious concrete. Con Mat, p. 38-46.
[15] ACI. Report on pervious concrete. ACI-522, 2010, p. 1–38.
[16] Hesami S 2014. Effects of rice husk ash, fiber of pervious concrete. Con Ma, p. 680-691.
[17] García E 2011. Control de escorrentías urbanas mediante pavimentos permeables, p 1-10.
[18] Mayz C 2018. Diseño alternativo para implementar SUDS con software, Jo In, p. 285-299.
[19] Wong T 2002. Model for Urban Stormwater Improvement Conceptualization. Urb Dr, 4 p.
[20] Ashley R 2016. Using the multiple benefits of SuDS tool to deliver long-term benefits, 4p.
[21] Lai Fu 2010. Current Capabilities and Planned Enhancements of Sustain, p. 3271-3280.
[22] Gironás J 2010). A new applications manual for the Storm Management. Env Mo So, 2 p.
[23] Zhuhan Y 2018. Experimental Research on Recycled Concrete Road Base. Co En Ge, p. 8.
[24] Lian C 2010. Optimum mix design of enhanced permeable concrete. Co Bu Ma, 8 p.
[25] Liu W 2019. Performance of New Permeable Concrete Materials, Nat Env Pol Tec, 7 p.
[26] Borhan T 2020. Experimental investigations on polymer pervious concrete. Con Mat, 12.
[27] Tabatabaeian M 2019. An innovative performance pervious concrete with epoxy. Bu Ma, 2.
[28] Šešlija M. Possibilities of pervious concrete in road construction. Teh Vjes, 2018, 13 p.
[29] Tennis P. Pervious concrete pavements. EB302.02. PCA & RMCA, 2004, p. 1-32.
[30] Obla K 2010. Pervious concrete-An overview. Indian Concrete Journal, 84, p. 9–18.
[31] Zhou L. Ecological impacts of green roofs and permeable pavements. J En Ma.2018, 21p.
[32] Sotelo J, et al. Huella hídrica, desarrollo y sostenibilidad en España. 5, 2011.
[33] Cámara Valencia. Cuaderno de Comercio y Sostenibilidad: Huella Hídrica. 2017, p. 1-30.
[34] Larsen L 2015. Urban climate & adaptation strategies. Ecol & Env, 13, p. 486-492.
[35] Espíndola C 2012. Huella del Carbono. Conceptos, Métodos de Estimación. Inf Tec, 14 p.
[36] Goméz D 2017. Evaluación geológica de las zonas afectadas El Niño 2017-Tumbes, 71 p.
[37] Bayer A 2014. An unforgettable event: Study 1997-98 El Niño in northern Peru. Dis, 21 p.
[38] Torres V 2015. A 10 años de privatización EMFATUMBES ¿Éxito o fracaso? pp. 1-32.
[39] ASTM. ASTM C1157, Performance Specification for Hydraulic Cement.
[40] ASTM. ASTM C33, Specification of Aggregates for Concrete.
[41] ASTM ASTM C494, Specification for Chemical Admixtures for Concrete.
[42] ASTM. ASTM C1602, Specification for Mixing Water Used in the Production of concrete.
[43] USEPA 2015. Storm Water Management Model - User's Manual Version 5.1, pp.1–353.
[44] Google Maps. Recuperado 2020 de: https://www.google.com.co/maps/place/Lima.
[45] ASTM, ASTM C192. Practice for Making and Curing Concrete Test Specimens.
[46] ASTM, ASTM C39, Method for Compressive Strength of Cylindrical Concrete Specimens.
[47] ASTM, ASTM C78, Method for Determination of Flexural Strength of Concrete.
[48] ICONTEC. NTC 4483. Método para determinar la permeabilidad del hormigón al agua.
[49] Ureta L. Revista Costos, Edición de Aniversario. Abril, 2017, Lima, p. 1-108.
[50] Cámara Peruana Construcción. (2014). Costos y Presupuestos en Edificaciones, pp 1-375.
[51] Castillo, R. (2013). Tabla de dosificaciones y equivalencias. UNACEM, pp. 1-9.
[52] SIS. SS-EN 15804, Sustainability of construction works, environmental product, 11 p.
[53] Netz J, Sundin J 2015. Water Footprint of Concrete, pp. 1-72.
[54] BSI, PAS 2050 Specification for life cycle greenhouse gas emission of goods, services, 46 p.
[55] ISO. ISO-14067. Greenhouse gases, Carbon footprint products, Requirements, guidelines
[56] ISO. ISO-14064. Part 1: Specification with guidance at the organization level.
[57] Encinarro L, Díaz T 2014. Estudio y desarrollo de huella de carbono: vía ferroviaria, 59 p.
[58] Liu H 2018. Strength, permeability of pervious concrete with others porosities, Ap Sc, 17 p.
[59] Mulyono T 2019. Pervious Concrete for Permeable Pavement. Con Ear & Env Sci, 16 p.
[60] Zhu H 2020. Study Permeability, Recycled Aggregate Pervious Concrete, Fibers, Ma, 19 p.
[61] Guo P, et al. (2011). Pavement Performance of Steel Pervious Concrete. ICTE, p. 1-6.
[62] Yang, H. 2018. Experimental Study on Permeability of Concrete. Con Ear & Eng Sci, 8 p.
[63] Ibrahim, 2020. Hydraulic & strength characteristics of pervious concrete, Co Bu Ma, 13 p.
[64] Zhu H 2019. Simulation study of permeable pavement on reducin flood risk. Tr Sc Te, 10 p.
[65] Wilson C 2015. Comparison of Runoff Quality and Quantity, J En En, 11 p.
[66] Fassman E 2010. Urban Runoff Mitigation by Permeable Pavement System, J Hy En, 11 p.
[67] Rehan T 2018. Life Cycle Cost Analysis for Traditional, Permeable Pavement. Co Re, 11 p.
[68] Weitman D 2008. Reducing Stormwater Costs through LID Strategies and Practices, p. 11.
[69] Parasivamurthy P 2010. Improving Ground Water Recharge Using Pervious Concrete, 9 p.
[70] Netz J 2015. Water Footprint Concrete. School of Architecture and Built Env, 73 p.
[71] Aguirre B 2020. Diseño óptimo de pavimento drenante de concreto con SWMM 5.1, 25 p.
[72] Md. Sufiuddin 2007. Effect of different curing methods on properties concrete. Au J, 9 p.
[73] Neville A., Brooks J., Concrete Technology, Longman Group, UK, 1997, p. 1-460
[74] Rajaei M 2014. Case of Wind Plant Life Cycle Energy, Emissions, Water Footprint, 16 p.
[75] Hoekstra A 2011. The water footprint assessment manual, Earthscan, p. 1-228.
[76] García M 2016. Análisis de huella de carbono de industria de concreto y agregados, p. 145
[77] Albornoiz J 2015. Cálculo de huella de Carbono, hormigones geopoliméricos, Chile, 106 p.
[78] BSI. 2008. Guide to PAS 2050: How to assess the carbon footprint of good, services, 59 p.
[79] HOLCIM. 2014. EPD of Ready-Mix Concrete, p.1-13.
[80] Lee K 2010. Cool Pavements as Sustainable Approach to Green Streets & Highways, 9 p.
[81] Akbari 2007. Global cooling: Effect of urban albedo on global temperature. Conf, Bu 17 p.
[82] Debnath B 2018. Pervious concrete as alternative pavement strategy, J Pav Eng, 17 p.