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POROUS PAVEMENTS IN THE CONTEXT OF SUSTAINABLE URBAN DESIGN CONCERNS

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ABSTRACT

Hydrology explores a cycle that entails the transport and storage of water. However, this system of transport and, or storage can be significantly impacted by urbanization. Typically, urban drainage design is intended to create habitable spaces that are typically extensively paved surfaces that have the potential to generate significant run-off. One solution that has been extensively explored is the use of porous pavements to mitigate sustainability concerns posed by urban hydrology. The current paper provides a literature review of sustainable development initiatives, including Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), Water Sensitive Urban Design (WSUD). Specifically, the review explores how these approaches have interrogated the use of porous pavements in their strategies. The review found that the three concepts, SUDS, LIDS, and WSUD, have a significant convergence, especially regarding porous pavements. The review noted that SUDS employs strategies to promote groundwater recharge and reduce flooding, LID advocates for mimicking the natural environment by attempting to preserve the pre-development hydrograph. WSUDS encompasses a range of strategies, including LID, and sometimes SUDS, that are intended to restore water balance in urbanized spaces. All these strategies were partly based on the need to reconsider improving the infiltration of urban surfaces. The case meant considering various forms of porous pavements.

Keywords: porous pavement, sustainable urban drainage systems (SUDS), low impact development (LID), water sensitive urban design (WSUS).

1. INTRODUCTION

Contemporary design and development activities tend to increasingly emphasis sustainability. The case has attracted growing attention to developing technologies with a smaller environmental footprint. Accordingly, considerable studies have advanced the concepts of sustainable urban drainage systems (SUDS), low impact development (LID), and water sensitive urban design (WSUD) (Kale, Halwele, Rathod, & Jirapure, 2017; Cahill, Godwin, & Tilt, 2018; Monrose & Tota-Maharaj, 2016). The listed concepts have been prompted, for the most part, by the effects of urbanization that range from the need for floodwater management, pollution management, and erosion and sediment control. Sustainable hydrological systems in the urban spaces have been presented as a way to solve urban developmental problems such as excessive run-off and the reliance on centralized potable water supply systems by providing means for retaining water in the urban environment (Broadbent, Coutts, Tapper, Demuzere, & Beringer, 2018).

Regarding urban developments, several scholars have mentioned the importance of sustainability in hydrological systems. Goldenfum *et al.* (2007), for instance, emphasized the need for effective management of urban drainage (As cited in Monrose & Tota-Maharaj, 2016). Also, integrated urban water management (IUWM) interventions have advocated for WSUD as a sustainable way to manage water needs for urban areas. (Broadbent, Coutts, Tapper, Demuzere, & Beringer, 2018). Part of the hydrological problem in urban development has been the conversation around the conversion of otherwise permeable natural surfaces into impervious surfaces that contribute significantly to increased surface run-off and flooding (Monrose & Tota-Maharaj, 2016; Wong, 2006). Accordingly, the concept of porous pavements has been widely explored as a possible mitigation measure. Porous pavements have been advanced as having a significant impact on the efforts towards sustainable urban hydrology (e.g., Cahill, Godwin, & Tilt, 2018; Kale, Halwele, Rathod, & Jirapure, 2017; Selbig & Buer, 2018).

Porous pavements have been variably described as permeable pavements or pervious pavements (e.g., Cahill, Godwin, & Tilt, 2018; Imran, Akib, & Karim, 2013). Various designs of porous pavements have also been advanced over time. Imran, Akib, and Karim, (2013), for instance, defined porous pavements as pavements designed by omitting the fine aggregate from concrete mix. Consequently, the resultant pavement has permeable spaces that allow it to drain fluids. However, different designs or pavement layouts have also been demonstrated to provide permeability. Accordingly, different types of pavements have been developed and tested for various applications. Some of the types include porous pavers, pavers with apertures, pavers with wide joints, porous asphalt, and reinforced grass (Beecham & Myers, 2010; Novo, Bayon, Castro-Fresno, & Rodriguez-Hernandez, 2013).

The application of porous pavements is important in the context of SUDS, LID, and WSUD. Conventional urban drainage design is intended to facilitate efficient drainage of excess run-off as fast as possible. Typically, stormwater exceeding the drainage capacity can cause urban flooding (Qin, Li, & Fu, 2013). Also, uncontrolled stormwater, primarily occurring in significantly paved surfaces in urban spaces, has been demonstrated to not only create drainage problems but also threaten water quality and the environmental sustainability. (Imran, Akib,

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& Karim, 2013). These concerns have prompted the need for more sustainable options and interventions which are advanced using SUDS, LID, and WSUD approaches. Notably, conventional urban hydrological design, as described in this paper, is less concerned with sustainability (e.g., Wong, 2006; Novo, Bayon, Castro-Fresno, & Rodriguez-Hernandez, 2013). Chocat *et al.* (2007) (As cited in Monrose & Tota-Maharaj, 2016) mentions that conventional drainage systems do not focus on environmental concerns relating to water quality, visual amenity, biodiversity, and ecological protection. Recognizing the need for advancing the sustainable hydrological design, the current paper reviews literature on the use of porous pavements as a tool for advancing SUDS, LID, and WSUD.

2. LITERATURE REVIEW

The introduction of this paper has presented an overview of SUDS, LID, and WSUD. Based on the overview, it was possible to make a few deductions. Firstly, it can be observed that urban development, almost always, presents hydrological challenges. The case is arguably valid for both conventional urban design that has little regard for the surrounding ecology as well as more progressive design approaches that regard the need for sustainability. Some of the problems, as described by Imran, Akib, and Karim (2013), include drainage problems, flash floods, and water pollution. Secondly, it appeared that considerable effort had been made to address the problem. For example, Kale *et al*. (2017) trace studies on permeable pavements back from the 1970s. Supposedly, the need for scholarship on the porous pavement was prompted by the understanding of the effects of paved surface on constructed surfaced. Such studies were associated with SUDS. Primarily, the objective of improving infiltration in the urban surfaces was to reduce run-off volume and promote hydrograph attenuation. Given the common goal that has been highlighted, it is possible to interrogate SUDS, LID, and WSUD while focusing the discourse on the application of porous pavements as a method to advance these hydrological and sustainable urban design approaches.

2.1 Porous/Permeable Pavements

Porous pavements have been described in this paper as achieved through design interventions that deliberately intend to create pores in pavements. Inherently, permeable pavements have been defined as those having open spaces in their structure to allow water and air to pass through. These pavements can be used in place of conventional pavements, including roads, parking lots, courtyards, among others (Kale, Halwele, Rathod, & Jirapure, 2017; Imran, Akib, & Karim, 2013). As demonstrated by Imran, Akib, and Karim (2013), studies have shown that the permeability of pavements is significantly influenced by the level of fine aggregates in a concrete mixture.

The primary objective of porous pavement design is to allow infiltration through the pavements. Accordingly, porous pavements have a role in the urban hydrological design that considers the need to not only evacuate stormwater but also allow it to infiltrate into the ground (Figure-1). Porous pavements are, therefore, intended to reduce run-off volume (Kale, Halwele, Rathod, & Jirapure, 2017). Several studies have demonstrated the potential impacts of run-off in urban environments. Uncontrolled stormwater run-off has been considered a drainage problem. That is why hydrograph attenuation becomes essential in urban design (Kale, Halwele, Rathod, & Jirapure, 2017; Imran, Akib, & Karim, 2013; Wong, 2006).

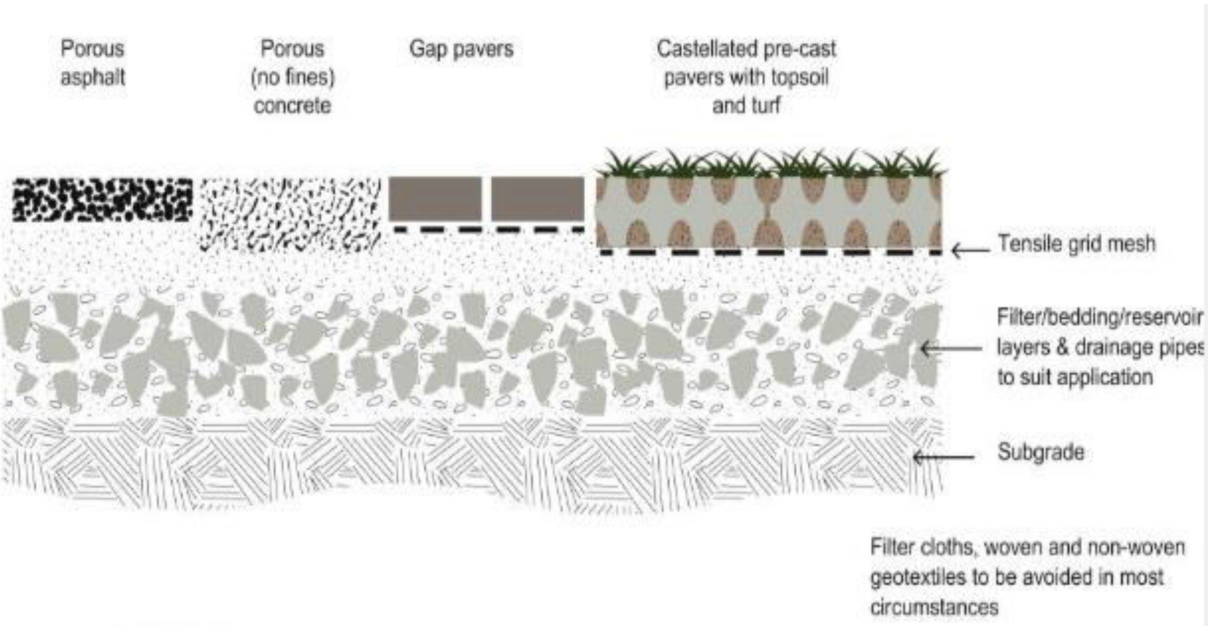

Figure-1. Permeable paving technologies. Source: Adapted from Hoban (2019).

Consequently, water sensitive urban design considers the need to reduce available stormwater run-off. Consistently, Cahill, Godwin, and Tilt (2018) mentioned that porous pavements are a form of stormwater management system. The property of pavements being porous, which can be termed as unconventional, allows water to move through void spaces within the pavement and eventually infiltrate into underlying soils (see Figure-1).

The essence of increasing scholarship on porous pavements can be attributed to two interconnected ideas as advanced in this literature review. Firstly, sustainable development has increasingly gained importance in contemporary debate. According to Goldenfum *et al.* (2007), for example, it is mentioned that sustainability has been recognized as a critical concept for the effective management of urban drainage (As cited in Monrose & Tota-Maharaj, 2016). While design is always anchored on data and statistics, sustainability mostly means looking beyond artificial avenues to modify the environment. The effects of uncontrolled or excessive run-off have been extensively demonstrated. For instance, (Imran, Akib, & Karim, 2013) observed that uncontrolled stormwater run-off not only creates drainage problems and flash floods but also presents a considerable threat to water quality and the environment. Similar studies have also demonstrated that controlling stormwater in urban spaces is increasingly a challenge (e.g., Palhegyi, 2010; Selbig & Buer, 2018). Ideally, the hydrological design considers both transport and storage of water. In this case, mostly transport of excess stormwater away from urban spaces. However, several practical scenarios can make transport and, or storage a problem. Permeable pavement systems in urban areas have been demonstrated to provide a solution, especially in cases of intensive undrained stormwater (Wong, 2006; Qin, Li, & Fu, 2013; Palhegyi, 2010).

A study by Selbig & Buer (2018) attempted to demonstrate the importance of porous pavements by focusing more on the storage, rather than the transport aspect, of water as a way to manage stormwater in urban areas. Stormwater management plans typically specify peak flow control for one or more discrete events. Accordingly, design guidelines provide a range of parameters to consider beyond the estimated volume of water. The concept of porous pavement becomes essential as it significantly influences surface characteristics and consequent effective run-off. The alteration in surface characteristics of the environments through urban design has been extensively mentioned (e.g., Monrose & Tota-Maharaj, 2016; Palhegyi, 2010; Selbig & Buer, 2018). For example, it is stated that urbanization significantly modifies watershed and stream hydrologic and geomorphic processes. Palhegyi, (2010) observes that by altering terrain, modifying vegetation and soils, and introducing impervious surfaces, the process of urbanization significantly influences the natural hydrology. Also, a study, according to Chocat *et al.* (2007) (as cited in Monrose & Tota-Maharaj, 2016), mentions that conventional hydrology does little to mimic natural hydrology. The study observed that conventional drainage systems do not focus on environmental concerns relating to water quality, visual amenity, biodiversity, and ecological protection (Monrose & Tota-Maharaj, 2016).

There is a longstanding scholarship on porous pavements for various applications, as demonstrated in the previous paragraphs (e.g., Monrose & Tota-Maharaj, 2016; Kale, Halwele, Rathod, & Jirapure, 2017). However, the focus of this study was on the hydrological impact of porous pavements in the context of SUDS, LID, and WSUD. As these are efforts towards a more sustainable development, it was possible to posit that porous pavements are an attempt to mimic the natural environment. For example, Imran, Akib, & Karim (2013) notes that permeable pavement systems (PPS) could be an efficient solution for sustainable drainage systems and control water. Consistently, a study by Selbig and Buer (2018) established that permeable pavements could help to re-establish a more natural hydrologic balance and reduce run-off volume. The design of porous pavements allows for the surface to trap and slowly release precipitation through infiltration instead of allowing it to run off. The following section delves into how porous pavement technology is consistent with SUDS, LID, and WSUD guidelines.

2.2 Sustainable Urban Drainage Systems (SUDS)

This paper has highlighted the potential impacts of urbanization on the environment and sustainability. The studies reviewed have highlighted the hydrological challenges posed and the need for sustainability. A considerable number of studies and researchers have acknowledged the shifting attention towards more sustainable drainage systems. Some have even affirmed that conventional drainage systems can no longer manage increasing run-off due to a changing climate (Monberg, Howe, Ravn, & Jensen, 2018; Monrose & Tota-Maharaj, 2016; Arahuetes & Cantos, 2019). Accordingly, Sustainable Urban Drainage Systems (SUDS) have been promoted as an adaption to the hydrological challenges. SUDS has been defined as encompassing strategies aimed at reducing floods due to urban stormwater run-off, and mitigating pollution. These strategies are described as natural and effective, and they intend to influence infiltration, transportation, and retention of stormwater (Monberg, Howe, Ravn, & Jensen, 2018; Arahuetes & Cantos, 2019).

Notably, the definition of SUDS mentions the need to allow for infiltration and retention of stormwater. In the context of pavement design, these definitions could be explored with consideration of reported trends in climate change and increasing urbanisation. On the one hand, concerns have been raised regarding climate change which has a direct effect of design data. Monberg, Howe, Ravn, and Jensen (2018), for example, mentioned that conventional drainage systems could not manage the new flows of run-off. Consequently, most urban centres have experienced aggravated floods and associated impacts. Several theories can explain the phenomena. Basic principles of hydrological design, for instance, assign run-off coefficient to different surfaces. Typically, studies have shown the different surfaces have different values of run-off coefficient (C) to reflect their capacity to either generate run-off, or retain and infiltrate stormwater (e.g., Befani, 2009; Buda, Kleinman, Srinivasan, & Bryant, 2009). Accordingly, changing the surface characteristics translates to a change in the hydrological processes. It is then possible to note that the definition of SUDS addresses the run-off coefficient. In part, SUDS seeks to alter the value of C in order to improve the rate of infiltration and reduce the net run-off volume.

Secondly, while not expressly appear in the provided definition of SUDS in this paper, retention of stormwater translates to what a significant number of studies have referred to as groundwater storage (e.g., Befani, 2009; Amos *et al.,* 2014). As a result, even when aggravated floods are not the problem, assuming no significant flooding effects in urban areas, studies have shown that transportation of stormwater from the large paved surface without allowing for infiltration could have a significant effect on groundwater storage. While addressing the topic, undesirable effects on the environment and the physical processes are demonstrated by Amos *et al*. (2014). In their study, the researchers inferred that an observed contemporary uplift of the southern Sierra Nevada previously attributed to tectonic or mantle-derived forces is partly a consequence of human-caused groundwater depletion. Groundwater depletion, which could be prompted by lack of groundwater recharge, has been therefore linked to earth tremors. Other impacts include effects on soil health, including the levels of various salts in the underlying and immediate soils.

Accordingly, the implementation of SUDS strategies part of the transition of urban areas towards sustainable development (Monberg, Howe, Ravn, & Jensen, 2018). That is the SUDS strategies mentioned in this paper influence development by placing a measure to ensure different habitat conditions. The case is achieved by a variety of inherent characteristics such as water dynamics, water quality, recreational use of water, management procedures, size, and structural heterogeneity of build environments. These initiatives are intended to achieve what Palhegyi (2010) described as mimicking natural hydrology. Consequently, some of the technologies used, as outlined by Monberg, Howe, Ravn, & Jensen (2018), include the use of Green roofs, Permeable surface, Infiltration trenches, filter drains and filter strips, Swales and shallow drainage channels, Detention basins, ponds and wetlands, Flooding parks. Notably, permeable surfaces have been mentioned as a strategy proposed by SUDS (Monberg, Howe, Ravn, & Jensen, 2018; Arahuetes & Cantos, 2019). Permeable pavements have been demonstrated to significantly reduce the effects of flooding as observed by Arahuetes & Cantos (2019).

2.3 Low Impact Development (LID)

The hydrological challenges of urbanization have also been interrogated within the low impact development (LID) guidelines. This review has mentioned the potential for urban development to alter natural hydrology and influence water transport, infiltration, and storage within urban spaces. For example, in describing conventional stormwater management in the urban space, Christensen and Schmidt (2008) mention that traditional urban stormwater management approaches exhibit a disconnection from natural systems. Accordingly, LID has been widely explored as a solution to the sustainability issues associated with Urban development (e.g., Qin, Li, & Fu, 2013; Marchioni & Becciu, 2014; Palhegyi, 2010; Dietz, 2007). Also, the foregoing discussion has highlighted increasing attention to the need for sustainable development. Fundamentally, and perhaps conventionally, urban drainage systems have been described as intended to drain surface run-off from urban areas such as paved streets, parking lots, sidewalks, and roofs (Qin, Li, & Fu, 2013). However, this approach has been regarded as mostly unsustainable. For instance, it has been mentioned that conventional drainage systems do not focus on environmental concerns relating to water quality, visual amenity, biodiversity and ecological protection. This is a problem (Chocat *et al*., 2007; Monrose & Tota-Maharaj, 2016; Dietz, 2007).

Consequently, LID has been presented as an attempt to advance a more sustainable urban development approach that minimizes the disturbance of the natural environment. A definition of LID according to Qin, Li, & Fu (2013) regards it as a more sustainable solution for urban stormwater management than conventional urban drainage systems. An article by Monrose & Tota-Maharaj (2016) even likened it to mimicking natural hydrology. Primarily, it has been demonstrated that the process of urbanization modifies watersheds and stream hydrologic and geomorphic processes. Such alterations tend to have a significant impact on the terrain, vegetation, and soils (Palhegyi, 2010). However, it is becoming evident, as can be deduced from the LID philosophy, that there is need to minimise disturbance of the natural hydrological characteristics. Consistently, Dietz (2007) dates back LID approaches back in the year 1999 and presents it as a mitigation to increased impervious surfaces. Further, Dietz, (2007) describes LID as an effort to preserve the pre-development hydrology. Notice the porous pavers and the amended soils in Figure-2.

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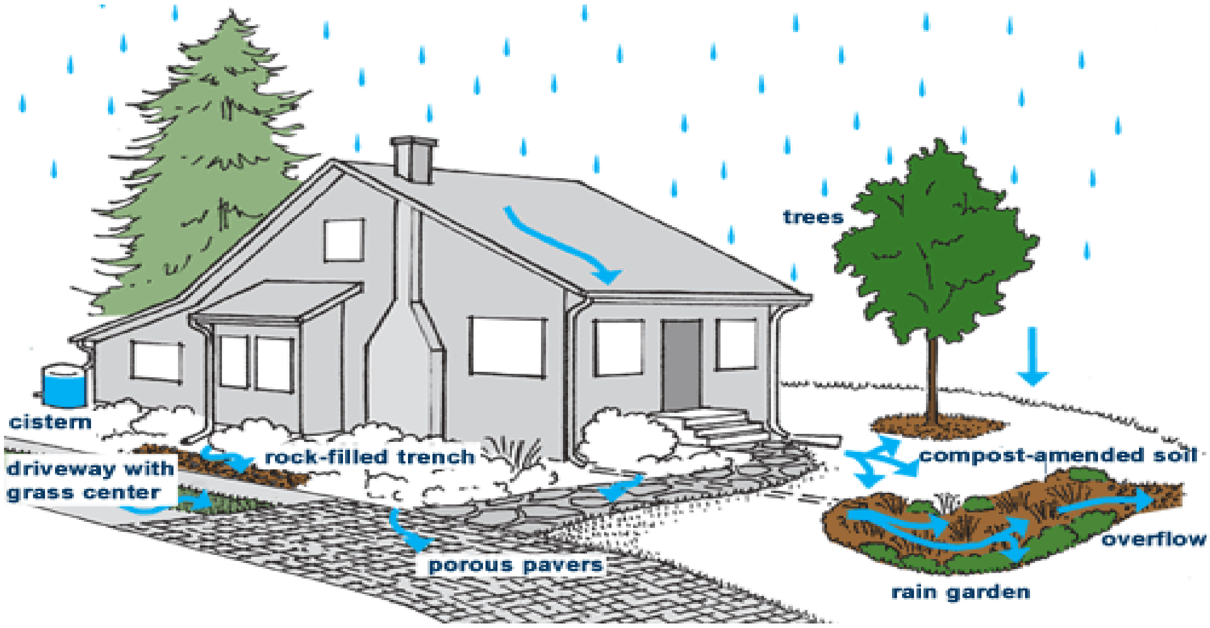

Figure-2. An Illustration of LID strategies. Source: Seatle.gov (2020).

Several strategies have been adopted to advance LID. Essentially, these strategies are intended to address groundwater recharge, streamflow, and water supply impacts. That is, studies have demonstrated that regardless of where land development occurs, the increases in imperviousness, the changes in vegetation, and the soil compaction associated with that development result in significant increases in run-off volume. As a result, the hydrological balance is disturbed following reduced groundwater recharge, reduced stream base flow, and possible alteration of stream channel morphology. Overall, the water supply is negatively impacted. As a solution, urban drainage systems are generally designed to drain surface run-off from urban areas as fast as possible. Stormwater has been viewed as a problem in urban hydrological design (Goldenfum *et al*., 2007; Monrose & Tota-Maharaj, 2016; Palhegyi, 2010).

Permeable paving has been adversely mentioned as one of the tools adopted in LID. Porous pavements have been proposed as a substitute for conventional impervious surfaces (such as low-traffic roadways, path walks, and car parks). According to a study by (Marchioni & Becciu, 2014), it was observed that previous pavements could retain up to two- thirds of rainfall in an urban watershed. As such, LID is becoming a popular approach to mitigate the effects of urban development by providing stormwater treatment and volume reduction (Palhegyi, 2010).

2.4 Water Sensitive Urban Design (WSUD)

The discussion of SUDS and LID appeared to converge significantly. The two approaches tend to address the sustainability of urban hydrological systems. Notably, the tools used in the two approaches seem to have similar goals. For instance, facilitating groundwater recharge (Imran, Akib, & Karim, 2013). An article by Donofrio, Kuhn, McWalter, & Winsor, (2009) defines water-sensitive urban design (WSUD) is an integrated water management system that encompasses low-impact design (LID), water conservation and recycling, water quality management, and urban ecology. Consistently, Wong (2006) mentions that WSUD is a framework that provides a common and unified method for integrating the interactions between the built environment and the water cycle. Notably, the definitions of WSUD present it as an integrated strategy that can have different components. The basis of the approach is systems and interventions that collectively meet the overall objective of the framework. The definition even mentioned LID (see Figure-3), which has been discussed independently, as one of the strategies in WSUD. However, some commentators have viewed SUDS, LID, and WSUD as possible substitutes. For instance, Morison *et al.* (2010) observed that WSUD had been referred to as LID in the USA, and SUDS in the United Kingdom (as cited in Nassar, Waseef, & Elsamaty, 2017).

Notably, WSUD cannot be strictly defined. Rather, perhaps it is prudent to view it as a framework or a guideline with set objectives. Accordingly, the approach is mostly addressed in terms of systems and based on a range of principles. For instance, Donofrio, Kuhn, McWalter, & Winsor, (2009) outlines the following as some of the key principles of WSUD; Protect water quality, restore urban water balance, protect natural systems, and protect and enhance natural water systems within urban developments.These principles appear to address, among other sustainability issues, urban water management. For instance, (Nassar, Waseef, & Elsamaty, 2017) mentions that strategies convey water, detain, and infiltrate water are elements of WSUD. This goal is consistent with the interventions outlined in SUDS. That is, SUDS was intended to influence infiltration, transportation, and retention of stormwater (Monberg, Howe, Ravn, & Jensen, 2018; Arahuetes & Cantos, 2019).

Overall, the goals of WSUD is to advance a sustainable urban design by focusing on water balance. Accordingly, as mentioned in this review, applicable strategies attempt to mitigate the effects of urban development on the pre-development hydrology. Ideally, the approach is concerned with mitigating design factors to minimize flooding and similar impacts beyond the subject of this review. For instance, Selbig & Buer (2018) notes that the approach attempts to reduce the peak rates of discharge by preventing large, fast pulses of precipitation through the stormwater system. For the most part, such an objective can be achieved using the porous pavement. Consistently, as part of WSUD strategies, Hoban (2019) addresses the adoption of such technologies as porous asphalt, pervious concrete, permeable interlocking concrete pavement, and grid pavement systems. Further, since WSUD is also concerned with groundwater recharge and supply to cities, it is mentioned that permeable pavements can be designed in such a way that undrained systems can collect water for reuse and recycle.

2.5 Porous Pavements in the Context of SUDS, LID, and WSUD

The literature review has explored SUDS, LID, and WSUD. These three approaches can be generally described as forms of adaption measures that are intended to advance sustainable urban design. Accordingly, it was possible to note a significant convergence in these strategies. In some cases, it was possible to discuss one approach as a subset of the other. For instance, in the definition of SUDS, Monberg, Howe, Ravn, & Jensen (2018) describes the approach entailing decentralized elements such as LID and WSUD, among other drainage solutions. Infiltration trenches are mentioned as one of the strategies. Similarly, (Arahuetes & Cantos, 2019) defined SUDS as structural elements aimed at reducing flooding of urban rainwater run-off. Such elements are described to employ infiltration mechanisms. Alternatively, Donofrio, Kuhn, McWalter, & Winsor (2009) defined WSUD as an integrated water management system that encompasses low-impact design (LID), among other strategies in urban ecology. Notably, the three approaches tend to converge.

Further, the three approaches appear to be concerned with stormwater management. Even more specifically, they all touch on strategies to allow for infiltration of rainwater in urban spaces as a way to reduce surface run-off and prevent flooding, or as a way to improve groundwater recharge. Essentially, the aim is to make urban hydrological design sustainable (e.g., Arahuetes & Cantos, 2019; Cahill, Godwin, & Tilt, 2018; Hoban, 2019). Accordingly, the three approaches appear to advocate for an effort to reduce the hydrological impact of pervious surfaces. That is; SUDS employ strategies to promote groundwater recharge and reduce flooding, LID advocates for mimicking the natural environment by attempting to preserve the pre-development hydrograph, and WSUDS encompasses a range of strategies, including LID, and sometimes SUDS, that is intended to preserve the natural systems, restore water balance, and reduce hydromodification among other interventions. These cases highlight the need for substituting previous urban surfaces with porous surfaces.

Water environments, such as waterways and coastal waters, and water supply catchments are vital areas where urban development can have significant impacts. Pervious pavements are used in various environmental applications, and their efficiency has been proved in removing pollutants such as hydrocarbons (Pratt 1999; Newman *et al.* 2002; Novo, Bayon, Castro-Fresno, & Rodriguez-Hernandez, 2013). Typically, urban drainage design systems are intended to create habitable spaces in extensively paved surfaces that generate significant run-off. According to Wong (2006), therefore, stormwater has no value. Stormwater is the core engineering problem that needs addressing. As such, drainage systems are designed to artificially, drain excess run-off as fast as possible. The case is despite the fact that water environments are potential sites for urban development. Accordingly, this paper has mentioned that strategies to maintain the pre-development hydrology or effect a hydrological balance after development is essential.

The adoption and application of pervious surfaces have been found to have a long history. Their development is reported as early as the 1970s (e.g., Thelen *et al*., 1972). Fundamentally, the porous pavements have been required to be able to provide structural requirements of pavements, while allowing run-off to infiltrate freely through the pavement surfaces and into a base/sub-base reservoir (Tota-Maharaj, 2010; Tota-Maharaj, 2011) (Monrose & Tota-Maharaj, 2016). The case highlights the need to consider the underlying soils. Consequently, the adoption of the various forms of porous pavements is a factor of the characteristics of the underlying soil. For example, Cahill, Godwin, and Tilt (2018) note that the infiltration rate of the native subgrade soils and the capacity of the base rock are important when considering porous pavements. That is, they should be balanced to infiltrate direct rain and run-off.

For the most part, the review literature has fronted the adoption of porous pavement as a substitute for conventional impermeable urban pavements. The underlying problem, therefore, can be narrowed to the need to improve the infiltration of stormwater in the urban areas. This strategy has been explored and expensively mentioned in the three approaches discussed in this paper. As a consequence, most studies concerned with the effectiveness of the proposed sustainable solutions have mostly evaluated the efficiency of pavements on reducing run-off volume (Kale, Halwele, Rathod, & Jirapure, 2017). Accordingly, a range of porous pavement technologies has been explored. For instance, Hoban (2019) described permeable paving as a broad range of paving technologies that can allow water to permeate through a trafficable surface. While the review has extensively adopted the use of the term “Porous pavements,” the description by Hoban (2019) appears to present “porous pavements” and “permeable pavements” (see Figure-1).

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3. SUMMARY

Summarily, the review of literature has attempted to explore the use of porous pavements in the context of Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), and Water Sensitive Urban Design (WSUS), see Figure-3. Porous pavements, also referred to as pervious pavements, have been established as an attempt to influence the run-off coefficient in the built environment. The literature review has established that increasing urbanization compounded with the effects of climate change has had a considerable impact on hydrology. Paving surfaces, which is typical of urban development, has been observed to directly impacts the run-off coefficient and exacerbate incidents of excessive stormwater and flooding. As a result, conventional hydrological design systems have been described as being inconsistent with natural systems and as having many paradoxical shortcomings (e.g., Christensen & Schmidt, 2008).

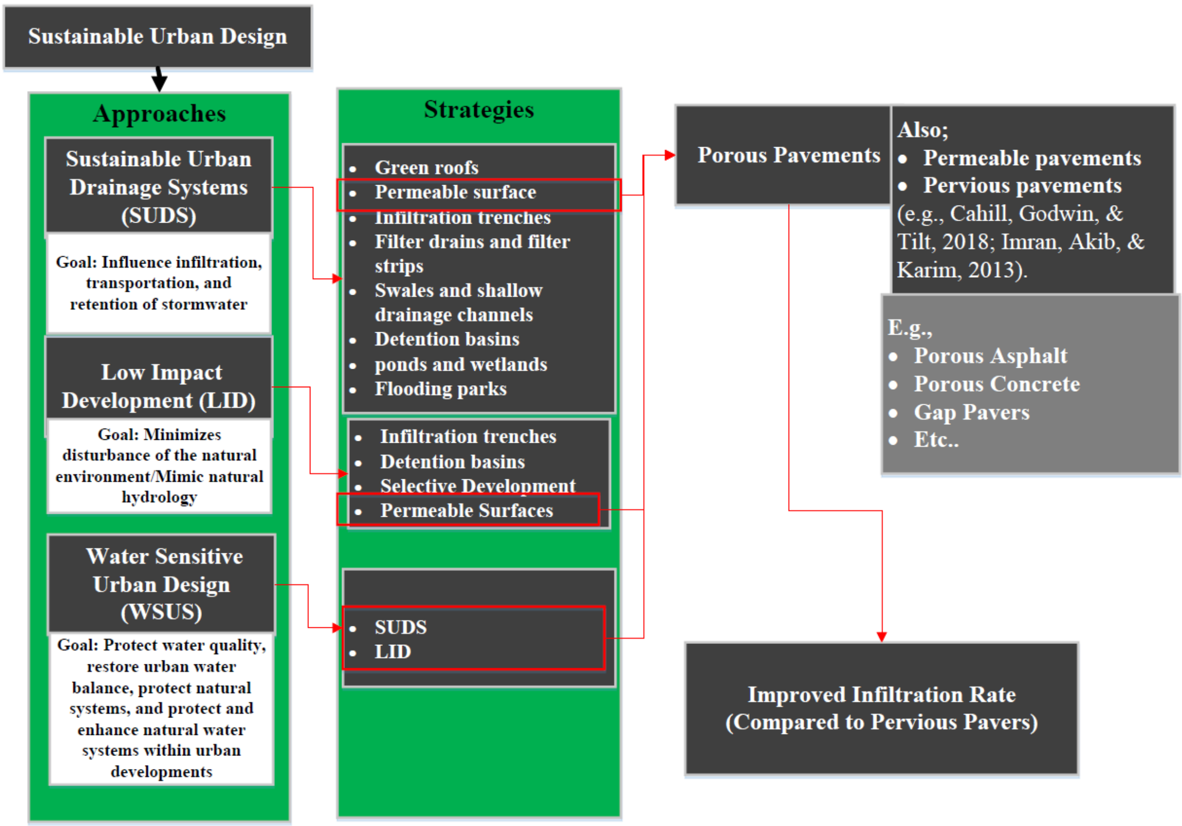

Figure-3. Conceptual framework.

While hydrological design efforts have evolved to address the challenges or urban stormwater management, there has been considerable records of the inadequacy of conventional drainage systems. While the case could be partly attributed to increased levels of paving, some studies have considered the potential effect of climate change. For instance, it has been mentioned that conventional urban drainage systems are not sustainable. (Goldenfum et al., 2007; Monrose & Tota-Maharaj, 2016). Accordingly, several strategies have been proposed under the framework of SUDS, LID, and WSUD to address the sustainability problem of urban hydrology. Also, the review of the approaches, and with regards to porous pavements, observed significant similarity. In fact, the study established that the terms SUDS, LID, and WSUD could be used interchangeably with little strategic consequences (see Figure-3).

Notably, while concepts discussed in this review (Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), and Water Sensitive Urban Design (WSUS)), present possible solutions to sustainability, the literature review noted a range of challenges. Typically, the design is based on guidelines that factor in the availability, cost, and engineering characteristics of materials and effectiveness of the technology, among other factors. Also, somewhat standard design manuals leave little room for modifications in design. Accordingly, new strategies tend to present considerable challenges. The industry tends to consider several factors, including their technical capacity, cost against the benefit to the various stakeholders, and material availability. For instance, a review by Beecham & Myers (2010) mentioned that because of structural considerations, interlocking permeable pavers have become popular, particularly in the U.K.

Nonetheless, while the reviewed approaches seem to touch on porous pavements, studies have placed a range of caveats. According to Hoban (2019), for example, it was observed that permeable pavements could be most practical for low traffic loads, and surfaces that are mainly subject to predominantly direct rainfall. That is, the nature of porous pavement makes them vulnerable to the forces of surface run-off and sediment load. Also, underlying soils must be considered. For instance, porous pavements could only be adequate where infiltrated water can be readily absorbed into the underlying layers. As a consequence, it may be challenging to apply them where the underlying base is predominantly clay soil or impervious rock.

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