EVALUATION OF INTERLOCKING STONE: ITS ROLE IN FLOOD CONTROL AND BUILDING SUSTAINABILITY

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Abstract

This study evaluated interlocking stone, investigating its role in flood control and building sustainability. The study mentioned that the application of interlocking stones in urban infrastructure has emerged as a promising solution for addressing two critical challenges facing modern cities: flood management and sustainable construction. In the context of carrying out this research, essential components formed some of the subheads of this work, and some included the concept of interlocking stones, the concept of flood control, the concept of flood, and the concept of building sustainability. It mentioned the types of interlocking stones to include: concrete interlocking pavers, clay interlocking pavers, natural stone interlocking pavers, and permeable interlocking concrete pavers (PICP), among many others. The study also mentioned the types of floods to include: riverine (fluvial) floods, coastal floods, urban floods, and pluvial (surface water) floods, among others. Interlocking stones were noted to have some of the following effects on flood control, some of which included reduction of surface runoff, enhanced groundwater recharge, and prevention of waterlogging in urban areas. Based on this, the study concluded that the evaluation of interlocking stone technology highlights its significant contributions to flood control and building sustainability, making it an essential component of modern urban infrastructure. One of the recommendations made was that municipalities should integrate interlocking stone pavements in high-risk flood areas and public spaces to enhance water infiltration, reduce surface runoff, and improve urban resilience against flooding.

Keywords: Interlocking Stones, Flood Control and Building Sustainability.

Introduction

The application of interlocking stones in urban infrastructure has emerged as a promising solution for addressing two critical challenges facing modern cities: flood management and sustainable construction. Moreover, the depletion of natural resources, the escalation of environmental issues such as floods, and the rise in energy use push architects and designers towards the creation of sustainable and eco-friendly structures (Isaac &Usanga, 2024). In addition to their flood control benefits, interlocking stones align with sustainable building objectives by offering long-lasting, resilient surfaces that require minimal maintenance and adapt well to diverse climatic conditions.

As climate patterns shift and urban areas expand, the frequency and intensity of flooding have escalated, placing immense strain on existing drainage systems and endangering infrastructure, economies, and communities (Chen, Jiang, & Wu, 2022). Traditional impervious pavements—such as asphalt and concrete—amplify these risks by preventing natural water infiltration, thus increasing surface runoff and exacerbating flood conditions in urban landscapes. Interlocking stones, conversely, are designed to support permeability, enabling rainwater to percolate through the surface and recharge groundwater systems, which is essential for flood mitigation and ecological health.

Constructed from durable materials and installed without the use of binding agents, interlocking stone systems allow for both flexibility and load distribution, reducing the likelihood of cracks and structural failures over time. This adaptability to shifting loads and environmental stressors is not only financially beneficial—through reduced maintenance costs and extended life cycles—but also aligns with the goals of sustainable urban development, including resource efficiency and reduced ecological impact. Moreover, the role of interlocking stones in urban resilience aligns with global initiatives such as the United Nations' Sustainable Development Goals (SDG 11) that emphasise sustainable cities and resilient infrastructure (United Nations, 2019). As cities increasingly seek ways to integrate flood control into the urban fabric without compromising structural integrity or environmental quality, interlocking stones present a viable, multifunctional solution. Consequently, evaluating their effectiveness in flood control and sustainable construction not only reveals their immediate utility but also underscores their value as a cornerstone of resilient urban development.

Concept of interlocking stones

Precast concrete components known as interlocking stones, interlocking pavers, or interlocking blocks are made to fit together without the need for mortar. Because of their strength, beauty, and ease of upkeep, these stones are frequently utilised in paving applications for outdoor spaces like patios, driveways, and pathways. Interlocking stones are a popular option in both urban and rural settings because of their emphasis on sustainability, modularity, and practicality. Precast concrete modules in a variety of forms, colours, sizes, and thicknesses are known as interlocking concrete pavers, or more popularly, pavers, paver stones, or interlocking paver stones. The purpose of pavers is to provide an easy-to-build and attractive concrete pavement surface for applications such as. Patios, Driveways, Pathways, Parking Lots, and many more. Imuetinyan, Omoregie, & Abraham (2016) asserted that interlocking concrete pavement consists of solid concrete paving units with joints that create openings in the pavement surface when assembled into a pattern.

Fig 1: Picture of Interlocking stones
Source: https://www.growgreen.ca

The concept of interlocking stones is the idea of connecting stones together to create a pattern, or surface interlocking means to connect parts so that the motion of one part is restricted by another. Interlocking stones come in different patterns and are produced in different shapes and sizes, and the edges of each paving stone are shaped to accommodate the next one for proper bonding. Interlocking concrete paving ensures the vitality and stability of the construction of a pavement. The weight and traction of a heavy load that passes over the pavement can be given ample support by having the load distributed over the individual units of interlocking paver stop. Interlocking stones are environmentally friendly, as they allow for permeable paving, which supports water infiltration and reduces surface runoff (Adeyemi&Akinpelu, 2021). Interlocking paver blocks can transfer loads and stresses laterally through an arching of bridging between units, spreading the load over a large area and reducing the stress, allowing heavier loads and traffic over sub-bases, which normally would require heavily reinforced concrete. This feature increases groundwater recharge and helps control flooding in urban areas, which is in line with sustainable urban planning practices.

Concept of flood control

The deliberate actions and infrastructural advancements utilised to regulate water levels and lessen flood damage are referred to as flood control. Effective flood control methods are essential for safeguarding ecosystems, infrastructure, and populations when flood frequency and severity increase due to climate change. Both structural and non-structural methods are used in flood control measures, which are increasingly combined with sustainable and natural solutions. The application of techniques to lessen or stop the destructive impact of flood waters is known as flood control. Flood control, sometimes referred to as flood mitigation or flood management, includes a broad range of tactics and actions meant to lessen the likelihood and effects of floods on the environment and populations. Understanding the causes of floods, forecasting their occurrence, and putting in place a variety of structural and non-structural solutions to lessen their damaging impacts are all part of this multifaceted approach.

Flood control refers to the methods and techniques used to stop or lessen the effects of flooding, which can be brought on by excessive rainfall, storm surges, or river overflow. This idea includes a range of methods, such as managing wetlands and natural waterways to absorb excess water, as well as building levees, floodwalls, and reservoirs. Communities, infrastructure, and ecosystems must all be protected from the destructive consequences of floods by effective flood control. Engineered solutions including dams, levees, floodwalls, and retention basins are examples of flood control techniques. These methods aim to contain or divert water away from flood-prone areas, protecting urban and rural communities from rising water levels. Dams, for instance, provide water storage and control release, which helps manage river flow and reduce flood risks downstream (Sholichin& Nasir, 2020). Recent studies emphasisehybrid structures, combining concrete barriers with vegetated buffers, to absorb wave energy and protect coastal regions more effectively (Lian et al., 2021).

Concept of flood

An excess of water that submerges normally dry ground is called a flood. When used to describe "flowing water," the term can also refer to the tide's inflow. Public health, civil engineering, and agriculture are all very concerned about floods. The frequency and severity of flooding are frequently increased by human-induced environmental changes. Examples of human changes are land use changes such as deforestation and removal of wetlands, changes in waterway courses, or flood controls such as levees. Global environmental issues also influence causes of floods, namely climate change, which causes an intensification of the water cycle and sea level rise. For example, climate change makes extreme weather events more frequent and stronger. Natural types of floods include river flooding, groundwater flooding, coastal flooding, and urban flooding, sometimes known as flash flooding. Tidal flooding may include elements of both river and coastal flooding processes in estuary areas. There is also the intentional flooding of land that would otherwise remain dry.

Fig 2: Picture of a Flood
Source:https://guardian.ng/news

This may take place for agricultural, military, or river-management purposes. For example, agricultural flooding may occur in preparing paddy fields for the growing of semi-aquatic rice in many countries (Hjalmarson, 2017). Flooding may occur as an overflow of water from water bodies, such as a river, lake, sea, or ocean. In these cases, the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries. Flooding may also occur due to an accumulation of rainwater on saturated ground (Morrison, Westbrook & Noble 2018). The size of a lake or other body of water naturally varies with seasonal changes in precipitation and snowmelt. Those changes in size are, however, not considered a flood unless they flood property or drown domestic animals. Flooding can damage property and also lead to secondary impacts. These include, in the short term, an increased spread of waterborne diseases and vector-borne diseases, for example, those diseases transmitted by mosquitoes. Flooding can also lead to long-term displacement of residents.

Concept of Building Sustainability

The concept of building sustainability encompasses the design, construction, and operational practices that enhance environmental, social, and economic sustainability within the built environment. Building sustainability, according to Ruggerio (2021), intends to lessen the impact of buildings on the environment by integrating resilience and resource efficiency concepts into every stage of building and upkeep. In the end, this strategy minimises ecological footprints and creates better living environments for residents by cutting waste, increasing energy efficiency, and utilising materials that support long-term environmental goals. A study by Zhang (2020), cited in Edem (2024), outlined how the use of recycled materials and eco-friendly composites in building construction lowers the environmental impact of new buildings and also fits with the global push for more environmentally responsible construction methods, making sustainability a crucial factor in building construction and reflecting broader trends in green building practices.

Scholars have articulated various definitions and metrics for building sustainability, often shaped by frameworks like the Circular Economy (CE) and Life Cycle Assessment (LCA). Corona et al. (2019) emphasise that building sustainability aligns with circularity principles, where buildings are designed for adaptability, reuse, and eventual recyclability. The CE framework allows for sustainable development by extending the lifespan of resources through adaptive use, reducing waste, and optimising energy consumption in the built environment. Similarly, Korhonen et al. (2018) highlight that this approach provides scientific criteria that aid in shaping sustainable construction, thus allowing buildings to contribute effectively to ecological sustainability. Although research by David & Isaac (2019) mentioned that the durability or sustainability of a building relies upon attention to detail, an understanding of the limitations of the materials of construction, and an appreciation of their qualities.

In the context of social sustainability, Hall (2021) describes sustainable building practices as inclusive, addressing the needs of communities through equitable access to resources and promoting occupant well-being. He suggests that buildings should enhance social cohesion and meet the needs of diverse populations while providing safe, functional, and comfortable spaces. This perspective ties into the broader narrative that sustainable buildings not only benefit the environment but also serve as catalysts for social advancement and cohesion.

Long-term financial viability, cost savings through energy efficiency, and lower operating expenses are the main goals of economic sustainability in buildings. In construction, economic sustainability entails striking a balance between initial costs and lifecycle benefits that build up over time, creating long-lasting value for stakeholders. Sustainable buildings result in lower lifecycle costs and higher asset values, which benefit both property owners and occupants. Green building certification

The multifaceted nature of building sustainability, which includes environmental, social, and economic dimensions, illustrates the concept's broad applicability and relevance. As summarised by Olawumi& Chan (2018), building sustainability is not a one-size-fits-all model but rather a versatile framework that adapts to the context of each project (Olawumi& Chan, 2018). The evolution of sustainable practices in construction reflects a commitment to developing built environments that coexist harmoniously with natural ecosystems and contribute to the well-being of societies globally.

Types of Interlocking Stones

Interlocking stones are a popular choice in construction and landscaping due to their durability, aesthetic appeal, and ease of installation. They come in various types, each designed for specific applications and offering distinct benefits. This article explores the various types of interlocking stones:

- **Concrete Interlocking Pavers**

Concrete interlocking pavers are among the most common types of interlocking stones. They are made from a mixture of cement, sand, and aggregate, which are molded into various shapes and sizes. These pavers offer a high degree of versatility and can be used for driveways, walkways, patios, and commercial applications. One of their main advantages is the ability to withstand heavy loads, making them suitable for vehicular traffic. According to Alhassan et al. (2020), concrete interlocking pavers exhibit excellent durability and can last for several decades with minimal maintenance.

- **Clay Interlocking Pavers**

Clay interlocking pavers are made from natural clay that is molded and fired in kilns, giving them a unique appearance and color variations. These pavers are known for their aesthetic appeal, as they can enhance the visual aspects of any outdoor space. They are often used in residential patios, walkways, and garden paths. Clay pavers have a high resistance to weathering and UV radiation, which helps maintain their color over time. Clay interlocking pavers are also environmentally friendly, as they are made from natural materials and can be recycled.

- **Natural Stone Interlocking Pavers**

Natural stone interlocking pavers, such as granite, limestone, and slate, are quarried from the earth and cut into specific shapes for use in construction. These pavers are prized for their beauty and uniqueness, as no two stones are alike. They are often used in high-end residential projects, public spaces, and historical renovations. The durability of natural stone makes it an excellent choice for patios, walkways, and driveways. According to Tarek et al. (2021), natural stone pavers offer excellent thermal performance, making them suitable for hot climates.

- **Permeable Interlocking Concrete Pavers (PICP)**

Permeable interlocking concrete pavers (PICP) are designed to allow water to infiltrate through their joints and into the underlying soil. This feature makes them an environmentally friendly option for managing stormwater runoff and reducing the risk of flooding. They are ideal for driveways, parking lots, and walkways where drainage is a concern. PICP not only help mitigate flooding but also enhance groundwater recharge, promoting sustainable water management practices.

- **Rubber Interlocking Pavers**

Rubber interlocking pavers are made from recycled rubber, often sourced from used tires. They are lightweight, durable, and provide excellent shock absorption, making them ideal for playgrounds, sports facilities, and outdoor fitness areas. Rubber pavers are also slip-resistant and can withstand harsh weather conditions. As highlighted by Sahu et al. (2021), these pavers contribute to sustainability by recycling materials that would otherwise end up in landfills.

- **Grass Interlocking Pavers**

Grass interlocking pavers are designed to provide a green, natural appearance while still supporting vehicular and pedestrian traffic. These pavers have a grid structure that allows grass or other vegetation to grow through the openings, which enhances aesthetics and promotes ecological benefits such as biodiversity and cooling effects. Grass interlocking pavers can help manage stormwater runoff and improve the overall environmental quality of urban areas.

Types of Flood

Flooding is one of the most prevalent and devastating natural hazards, with diverse types depending on the source, geography, and climate conditions. Understanding the different types of floods is essential for implementing effective control measures and for devising disaster preparedness strategies tailored to specific flood risks (Jonkman& Dawson, 2019). Below are some of the most common types of floods, along with their characteristics and underlying causes

- **Riverine (fluvial) Floods**

Riverine or fluvial floods occur when rivers overflow their banks, inundating surrounding areas. This type of flooding can result from excessive rainfall, snowmelt, or the sudden release of water from upstream, such as a dam failure (Zhang, Li, & Han, 2021). Riverine floods are categorised into flash floods and slower-onset floods based on their speed and severity. Flash floods are intense and develop quickly, often within a few hours, making them particularly dangerous and difficult to forecast. Slower-onset floods, however, develop over days or even weeks, allowing for better forecasting and preparedness.

Fig 1: picture of Riverine (Fluvial) Flood
Source:https://www.arc.int/river-flood

Fig 2: Picture of Riverine (Fluvial) Flood
Source: https://www.istockphoto.com

- **Coastal Floods**

Coastal floods occur in low-lying coastal regions and are primarily caused by storm surges, high tides, and tsunamis, often exacerbated by rising sea levels due to climate change. Storm surges, caused by intense weather systems like hurricanes and typhoons, can push seawater inland, leading to significant flooding along coastlines. Coastal flooding is particularly devastating in areas with high population densities and critical infrastructure near shorelines, as it can result in extensive property damage and loss of life. The increasing frequency of extreme weather events and sea level rise has heightened the risk of coastal flooding, making it a central concern for climate adaptation strategies.

- **Urban Floods**

Urban floods are unique to built environments, often occurring in cities where impervious surfaces such as roads, parking lots, and buildings prevent natural water absorption. Urban flooding typically results from heavy rainfall exceeding drainage system capacity, causing streets, basements, and low-lying areas to flood. This type of flooding can occur quickly, particularly in areas with inadequate or ageing drainage infrastructure (Chen, Hill & Du, 2021). Urban floods disrupt daily life, cause property damage, and create public health hazards due to contaminated water mixing with sewage systems. As urbanisation continues, many cities are adopting "sponge city" concepts with permeable pavements and green roofs to reduce urban flood risks.

Fig 3: Picture of Urban Floods
Source: https://www.rmsi.com

Fig 4: Picture of Urban Floods
Source: https://www.dreamstime.com

- **Pluvial (surface water) Floods**

Pluvial flooding occurs when heavy rainfall overwhelms the capacity of the ground or drainage systems to absorb water. Unlike riverine flooding, pluvial floods can occur in any geographic location without a nearby body of water, including rural and urban areas. Pluvial floods typically occur after intense rainfall over a short period, often resulting in localised flooding on roads, fields, and basements. The impact of pluvial floods is increasingly evident in urban areas where impervious surfaces prevent natural water infiltration. Recent studies suggest that pluvial flooding is becoming more common due to climate change and intensified rainfall patterns.

- **Flash Floods**

Flash floods are sudden, short-duration floods characterised by rapid water flow and a high water level rise, often resulting from extreme rainfall, dam breaks, or glacial lake outbursts. Due to their sudden onset and intensity, flash floods are particularly dangerous, causing significant loss of life and property. These floods are most common in mountainous areas where steep slopes accelerate water flow and arid regions where dry soils are less absorbent. Flash floods pose unique challenges for disaster response due to their rapid onset, highlighting the need for early warning systems and preparedness in high-risk areas (Ramos, Roux &Hannart, 2021).

Fig 4: Picture of a Flash Flood
Source: https://www.youtube.com

- **Groundwater Flooding**

Groundwater flooding occurs when the water table rises to the surface, often due to prolonged periods of rainfall saturating the ground. This type of flood is slow to develop but can persist for weeks or months, especially in areas with underlying aquifers. Groundwater flooding is commonly observed in low-lying areas with poor drainage, where soil saturation contributes to waterlogging. While less dramatic than other flood types, groundwater flooding poses significant challenges for agriculture and infrastructure, causing damage to buildings, roads, and crops in affected regions.

Fig 5: Picture of Groundwater Flooding
Source: https://www.gsi.ie/en-ie/programmes-and-projects

Effects of Interlocking Stones on Flood Control

Interlocking stones, an increasingly popular material in urban development, provide unique benefits for flood control, particularly in mitigating urban waterlogging and managing stormwater effectively. As urban areas continue to grow, traditional impervious surfaces—such as concrete and asphalt—contribute to higher levels of surface runoff, leading to increased flood risk, particularly during heavy rainfall events (Ahmed, Goyal, & Choudhury, 2019). Unlike these conventional pavements, interlocking stones are designed to support permeability, enabling water to pass through gaps in the stones and seep into the underlying ground. This permeability is crucial for managing excess water in urban areas and protecting against flood hazards. However, they include:

- **Reduction of Surface Runoff**

One of the most significant effects of interlocking stones on flood control is their ability to reduce surface runoff. This type of pavement allows rainwater to penetrate the ground rather than flow across surfaces, reducing the volume and speed of runoff entering storm drains. Surface runoff reduction is vital in urban flood management, as heavy runoff can quickly exceed the capacity of city drainage systems, leading to localised flooding and infrastructure damage (Zhang & Li, 2021). Interlocking stones, particularly when paired with a permeable sub-base, facilitate the infiltration of water, thereby controlling the flow and volume of water during intense rain events and reducing the burden on stormwater infrastructure (Hoang &Fenner, 2018).

- **Enhanced Groundwater Recharge**

In addition to reducing runoff, interlocking stones contribute to groundwater recharge by enabling water to percolate through the soil. Traditional pavement blocks rainwater from reaching the subsurface, leading to a depletion of groundwater resources. Interlocking stones help address this issue by supporting natural hydrological processes, allowing rainwater to filter through the soil layers and recharge aquifers. This recharge is essential for sustaining groundwater levels, which are increasingly threatened by urban expansion and climate change-induced droughts. Groundwater recharge not only supports local water supplies but also mitigates the severity of future floods by improving soil water absorption capacity.

- **Prevention of Waterlogging in Urban Areas**

Waterlogging is a common urban problem resulting from excessive surface runoff, which can inundate streets, homes, and businesses during heavy rain. Interlocking stones, due to their permeable nature, effectively reduce the occurrence of waterlogging by directing rainwater into the ground. Research shows that permeable pavements can significantly decrease water pooling on surfaces, thus alleviating waterlogging. This reduction in surface water pooling is crucial for improving urban resilience, as it minimises disruptions to daily activities, prevents property damage, and reduces public health risks associated with stagnant water.

- **Alleviation of Pressure on Drainage Systems**

By absorbing and infiltrating rainwater, interlocking stones help alleviate the pressure on urban drainage systems, which are often overburdened during periods of intense rainfall. Many cities face challenges with ageing or inadequate drainage infrastructure that is incapable of handling sudden influxes of stormwater, which can lead to flash flooding and significant damage. The adoption of interlocking stones in high-risk flood zones can reduce the strain on drainage systems by allowing water to percolate naturally instead of overwhelming stormwater pipes and channels. This is particularly beneficial in areas prone to frequent rainfall and flooding, where a hybrid system of natural infiltration and engineered drainage can improve overall flood resilience.

- **Contribution to Urban Heat Island Mitigation and Reduced Flooding**

Interlocking stones also contribute indirectly to flood control through urban heat island (UHI) mitigation. As permeable surfaces, they reduce surface temperatures by allowing water infiltration, which has a cooling effect on surrounding areas. Lower surface temperatures reduce the likelihood of flash floods associated with high-intensity heat-driven rainfall events common in urban heat islands (Nguyen, Hang, & Pham, 2022). By providing a cooler surface, interlocking stones help maintain a balanced urban microclimate, which in turn influences rainfall patterns and minimises the potential for sudden, localised floods associated with UHI phenomena.

Conclusion

The evaluation of interlocking stone technology highlights its significant contributions to flood control and building sustainability, making it an essential component of modern urban infrastructure. By facilitating water infiltration, interlocking stones reduce surface runoff, alleviate strain on drainage systems, and enhance groundwater recharge, offering a natural solution to the challenges of urban flooding. Their durability, adaptability, and minimal maintenance requirements further align with sustainable building goals, ensuring long-lasting benefits with reduced environmental impact. As cities confront climate change and rapid urbanisation, interlocking stones present a practical, resilient, and ecologically sound approach to creating sustainable, flood-resilient urban environments. Embracing this technology is not only a step towards resilient infrastructure but also a commitment to future-proofing cities against the dual pressures of climate extremes and urban growth.

Recommendations

1. Municipalities should integrate interlocking stone pavements in high-risk flood areas and public spaces to enhance water infiltration, reduce surface runoff, and improve urban resilience against flooding.
2. It is recommended to invest in materials and designs of interlocking stones that can optimise their permeability, durability, and cost-effectiveness, ensuring they meet evolving flood control and sustainability requirements in diverse climates.
3. Establishing guidelines for the installation and upkeep of interlocking stone pavements can maximise their longevity and performance, making them a dependable element in sustainable infrastructure.
4. Government agencies should encourage property owners to use interlocking stones through awareness campaigns and financial incentives, emphasising their benefits for flood mitigation and sustainable construction.

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