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# Achieving multifunctionality in green infrastructure projects: a fuzzy evaluation and Gini index of Key drivers in developing countries

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**Abstract**
While many developed countries are well advanced in green infrastructure (GI), more efforts are needed to bring less developed regions to speed. Existing evidence shows that GI understanding differs significantly among stakeholders due to the multifunctionality concept. As key technical stakeholders in GI implementation, there is little empirical knowledge of the multifunctional attributes of GI systems among built environment professionals in developing regions. This study provides an in-depth analysis to fill this knowledge gap through a combination of the Gini coefficient and fuzzy synthetic evaluation toward understanding the multifunctionality concept of GI among built environment professionals in developing regions. As a measure of dispersion, the stationary driver points to a constant factor that underpins the implementation of GI across several geographic regions. The need to mitigate urban heat islands and enhance ecosystem services were revealed as the anchors among built environment professionals in supporting GI development; hence, specific attention needs to be accorded to these dimensions in GI policies. Ecosystem services, water resources management, and thermal regulation were identified as the three broad multifunctional drivers of GI in developing nations. For effective water management in GI projects, integrated green-grey infrastructure systems are recommended. To achieve thermal objectives, insulation materials are pivotal. The ecosystem properties are more passive as compared to thermal and water management; hence, specific considerations must be accorded to ensure GI success. The key contribution of the study was the delineation of the key multifunctional factors that support GI adoption and implementation success in developing regions.

**Keywords** Green infrastructure · Multifunctionality · Climate change · Environmental sustainability · Built environment

Extended author information available on the last page of the article

## 1 Introduction

Scientists contend that greenhouse gas (GHG) emissions are rising despite worldwide attempts to limit them under the Kyoto Protocol, a UN programme (Koh, 2018). In the same vein, pressing global environmental issues include climate change. Recent studies have shown that green infrastructure (GI) systems can be a useful policy tool for tackling these complex issues (Owusu-Manu et al., 2023; Seidu et al., 2024). In several scholarly works, the concept of GI has gained momentum over the past decades. GI is generally considered an alternative engineering approach for stormwater management that also includes temperature control and air quality management. The terms Nature-Based Solutions, green-grey infrastructure, sustainable urban drainage systems, ecological infrastructure and sponge cities have been widely used in GI debates across the years based on specific objectives (Alves et al., 2024; Seidu et al., 2024; Yuan et al., 2024). These new directions are integrated systems that are designed to perform multitudes of functionality in a manner analogous to that of natural processes. Consequentially, GI systems have the potential to become an essential tool in the management of excessive rainfall in urban regions.

Proponents of GI have perused the concept from diverse applications, disciplines and multifunctional dimensions (Alves et al., 2024). The question of what drives GI adoption and implementation success is therefore based on the region, stakeholders' perceptions and knowledge levels. Engineers and built environment professionals may convey and recommend GI to clients based on their own understanding of what GI is due to the multifunctional nature of these systems. Some key attributional drivers include community well-being enhancement, urban heat island mitigation, environmental sustainability, ecosystem services provision and biodiversity enhancement. The exposition of Wang and Banzhaf (2018) noted that the multifunctionality concept is a core driver in the GI agenda and will play a critical role in the future research landscape. This is due to the evolving nature of the concept based on the different dimensions and needs of society. Similarly, Korah et al. (2024) revealed that GI in Ghana (Kumasi) has increasingly become fragmented despite the encouraging volume of green space development in the region. This may partly be attributed to a lack of effective planning for GI systems. Interestingly, Hansen et al. (2019) directed that each of the multifunctional dimensions of GI requires a systematic assessment as well as the inherent interactions that exist towards driving GI efforts. A comprehensive knowledge of GI is therefore key to enticing investors and communicating effectively with stakeholders.

While many developed countries are well advanced in GI (Fu et al., 2021), due to knowledge development and technological advancement, more efforts are needed to bring less developed regions to speed in GI awareness (Essuman-Quainoo & Jim, 2023), implementation (Owusu-Manu et al., 2023), multifunctional benefits and critical limitations. In a typical developing country, such as Ghana, where several flooding incidents (Mensah & Ahadzie, 2020) and dilapidated drainage infrastructure (Ibrahim et al., 2023) have been recorded, the prospect of GI offers promising results if properly adopted and implemented. Some efforts have been made in this region towards GI adoption and implementation, including green drainage infrastructure, green stormwater infrastructure (Ibrahim et al., 2023); green roofs and green wall drivers (Essuman-Quainoo & Jim, 2023). Although the study by Essuman-Quainoo and Jim (2023) perused GI drivers in the Global South using Ghana as a case study, the findings were generalized to cover a broad group of stakeholders including opinion leaders, end users, horticulturists and park management whose opinions and GI understanding varies significantly. Hence, findings do not reflect the perspective of the built environment on the knowledge of the multifunctional attributes of GI.

A typical setback in GI debates is the complexity of performance assessment under different climatic conditions (Fu et al., 2021; Mantillaet al., 2023). This means that GI must be specifically designed and tailored while considering specific local conditions and needs (Mantilla et al., 2023). As a result, the same GI (e.g., green roofs, green walls) implemented in different locations within a geographical catchment may have a broad range of differing performance and cost-effective features (Webber & Kuller, 2021). Literature also show that intensive green roofs perform better than extensive green roofs in thermal insulation, stormwater management and the provision of recreation (Aleksejeva et al., 2024). The current study by Cook et al. (2024) sheds light on the multifunctionality concept in GI projects, clearly depicting that GI design requires intentional considerations, thereby refuting the passive design notion. From the forgoing, it is clear that knowledge of the multifunctionality concept is crucial to ensure that GI achieve the intended objectives and functionality. Given that built environment professionals provide technical knowledge and expertise towards the execution of GI projects, it is expedient to investigate the knowledge levels of GI from the perspective of these technical experts to provide relevant knowledge toward effective communication, design, implementation and monitoring. In this study, we argue that GI adoption and implementation success hinge on effectively conveying the multifunctional prospects and a keen consideration of client objectives. These gaps were examined in the context of a developing nation through a combination of stationary attribute analysis and fuzzy evaluations. Researchers have adopted fuzzy synthetic evaluation method to draw inference in subjective constructs (Zafar et al., 2022). Further, FSE method was also adopted in the built environment to examine the drivers of circular economy in modular integrated construction (Wuni et al., 2022). However, FSE applications in GI knowledge assessment have not been explored, particularly in the developing nation context. To ensure a holistic conveyance of GI benefits and attributes, the Gini mean analysis was adopted as a complementary analysis to FSE to peruse the pivots among built environment professionals in GI projects. Gini index as a stationary measure of dispersion, provides an arbitrary factor that is central to pioneering a concept (GI).

A combination of geometric mean analysis, Gini coefficient, principal factor analysis and fuzzy synthetic evaluations was adopted in this study to provide an in-depth understanding of the multifunctional drivers of GI among built environment professionals in developing regions. As a dimension reduction technique, the principal component analysis was used to measure the variance, while FSE was utilised to prioritise professionals' understanding of GI functionality. The novelty in this study aside the robust methods include several key insights. Firstly, while some functionalities of GI are passive, other benefits such as flood resistance and drainage infrastructure resilience require a more intentional design and planning considerations. The results provide novel insights to urban planners, landscape architects and engineers towards designing, implementing and monitoring GI projects in the future. The Gini index provided additional insights to architects and project managers on the passive dimensions of GI that are mostly communicated and conveyed to stakeholders. The FSE provided further insights into the criticality of each group of GI functionality. The results contribute to the global debates on increasing the awareness and knowledge of GI, particularly in less developed regions.

## 2 Conceptualising GI

The significant role of GI has been stressed in achieving several global objectives, including low-carbon cities, carbon neutrality and sponge cities (Dong et al., 2023a). Consequently, the subject of what constitutes GI is multifaceted. In the opinion of Zuniga-Teran et al. (2020) towards understanding the multidimensions of GI in urban resilience, the concept covered vegetated sites in urban areas that perform three broad categories of functionality: stormwater management, environmental benefits and recreational purposes. Concomitantly, in line with the work of Zheng and Barker (2021), GI is an ecosystem support approach through the application of natural (vegetated areas) and semi-natural systems. In this perspective, GI was viewed as a response strategy to climate complications posed by 'grey infrastructure' system and the built environment in urban centres. Prior, Wang and Banzhaf (2018)'s definition encompasses an integration of ecosystem services into human interactions. Pauleit et al. (2019) comprehensive review of the Green Surge project broadens the coverage of GI to both green and blue spaces in urban centres that improve social cohesion, enhances biodiversity improve social cohesion, enhance biodiversity and other societal benefits. As an end result, Kamjou et al. (2024) opined that GI is a response to the aftermath of climate change, unsustainable production and nature depletion. GI may be classified into private (green roofs, green walls) and public components (parks, neighbourhood gardens) (Kamjou et al., 2024). Prior, Pauleit et al. (2019) classified GI into building greens (green walls, extensive and intensive roofs), parks, agriculture, private, industrial and commercial components. While GI advocacy and adoption have seen a wider uptake globally, several hindrances still hamper the transition, including path dependency on grey infrastructure, lack of professional expertise in green projects and regulatory and financial hurdles (Pauleit et al., 2019; Seidu et al., 2024). In the current scholarly debates, several terminologies have emerged in GI literature, which may be attributed to the multifunctionality concept. Concepts such as sponge cities (Y. Chen et al., 2019); nature-based solutions (Remme et al., 2024); low impact development (Kansal & Bisht, 2024) and sustainable urban drainage systems (Muwafu et al., 2024) have all garnered attention among researchers in promoting GI technologies. However, it is evident that these terminologies tackle specific multifunctional dimensions (functions) of GI in the climate change narrative. For instance, the sponge city concept mainly focuses on the sustainable water resources management dimension of GI (Qiao et al., 2020), whereas nature-based solutions are more tailored toward ecosystem services provision and biodiversity preservation (Adu Boateng et al., 2023). Consequently, these terminologies are used depending on the regions, specific contexts and needs. In this study, GI comprises of climate adaptation technologies integrated into buildings (green roofs, green walls) and other infrastructure components; holistically designed to deliver multiple benefits, including effective flood management, enhanced energy efficiency and increased carbon capture, contributing to a more sustainable and resilient built environment (Fig. 1).

### 2.1 GI and the multifunctionality concept

As environmental friendliness has become an important component of urban development, the conventional grey infrastructure system has been criticized for its poor ability for multifunctional water management and flexibility in adjusting to future climatic and hydrological changes (Tansar et al., 2023). The rapid spread of urbanisation has resulted in an increase in impermeable surfaces, which has, in turn, altered the natural hydrological

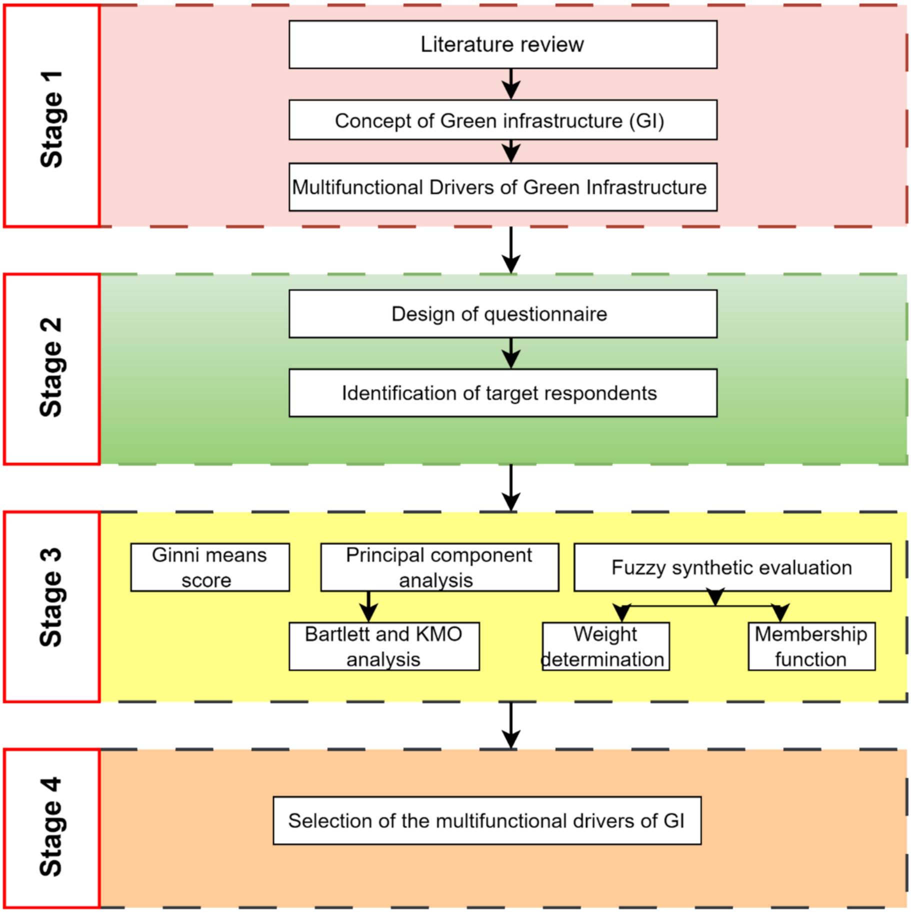


**Fig. 1** Research framework of the study

processes (Wang et al., 2023a, 2023b). Novel solutions such as GI refer to decentralized practices built on catchment surfaces comprising porous and vegetated areas meant to increase infiltration, improve air quality and retention of urban stormwater runoff. In this light, several GI components have received scholarly attention in recent years. Green roofs emerged as a predominant GI component widely studied across regions (Essuman-Quainoo & Jim, 2023; Tam et al., 2016). Categorized into extensive and intensive typologies, green roofs can provide several environmental benefits due to the nature-based systems (plants) employed and rainwater quality enhancement. Simultaneously, green roofs can mitigate urban heat islands while reducing stormwater runoff volume. Permeable pavements are popular GI technologies implemented to decrease runoff, recharge groundwater, mitigate the urban heat island effect and eliminate pollutants (Xie et al., 2019).

Similarly, bio-retention areas have been discussed as key GI components. The unique abilities of these systems to restore the water cycle using natural features have been noted. In recent decades, many bio-retention facilities have been set up in metropolitan areas for the dual aims of preventing flooding and enhancing the area's green amenities (de Macedo et al., 2017). These have shown higher promise against standalone grey infrastructure in dealing with urban flooding and rainwater pollution. Conversely, though bio-retention areas have been studied and used in many places, design novation remains a challenge (Sagrelius et al., 2023).

GI adoption globally differs and this is significantly influenced by specific site conditions and needs. Generally, GI systems can effectively function in both present and future scenarios in multifunctional areas when appropriately designed (Bertilsson et al., 2019). Under extreme conditions and uncertainties, GI systems, when combined with grey (traditional piped infrastructure) and blue infrastructure (water management systems) are known to provide reliability and resilience while limiting failure (Bertilsson et al., 2019). Concomitantly, GI contributes to the refilling of subsurface aquifers and improvements in water quality. As a result, natural hydrologic cycle restoration has been identified as a key driver of GI (Song et al., 2020). Other key drivers of GI, such as water management, flood mitigation and ecology services, have been expounded in several works (Carpio-Vallejo et al., 2024). Runoff volume control and pollution reduction have been investigated. GI is able to reduce runoff amounts and peaks via infiltration and retention. Runoff, in this regard, is seen as an advantage rather than a liability. Consequently, GI systems could enhance the landscape, promote the interconnection of ecosystems and reduce the risk of flooding, thereby assisting urbanized areas in their transition toward sponge cities (Fletcher et al., 2015).

## 3 Research methods

This study assessed the key multifunctional drivers of GI in urban development and climate change adaptation. Quantitative strategists universally agree that phenomena and constructs can be quantified numerically and empirically to solve social issues (Jayasena et al., 2024). Through deduction, numerical quantification approaches were adopted to achieve the study objective. Using Scopus and Web of Science databases, “green infrastructure” OR “sponge city” OR “sponge cities” OR “green stormwater infrastructure” AND “multifunctionality” OR “multifunctional” OR “drivers” OR “determinants” OR “drives” OR “attributes” OR “benefits” OR “Functions” were utilised as keywords. The inclusion of concepts such as sponge cities and green stormwater infrastructure was to ensure relevant works were not excluded. These concepts have been utilized in green infrastructure literature based on regions and specific need (Yuan et al., 2024). A total of 500 research papers were revealed, limiting the search to final papers and journal articles published in English revealed 388 research works. Based on the title and abstract screening, 97 research articles relevant to the research objective were selected. A deep perusal of content led to the exclusion of an additional 32 articles. The remaining 65 articles were included in this review. After extracting relevant drivers and multifunctional dimensions of green infrastructure from the works, similar drivers were merged, which consolidated a total of sixteen drivers included in the questionnaire survey.

### 3.1 Questionnaire development

These drivers were developed into a close-ended questionnaire. Questionnaires have been leveraged in several studies to draw insights from a broad range of professionals in various fields to provide empirical results for decision-making (Seidu et al., 2023). In this study, questionnaires enabled the gathering of representative data from built environment professionals to understand their perspective on GI drivers in developing nations. To ensure the adequacy and consistency of the survey tool, a pilot study was conducted. Ten built environment professionals were invited to provide a preliminary assessment to ensure the validity of the instrument. The constructs were deemed appropriate and representative of the multifunctionality concept in GI projects. Adopting a 5-point Likert scale, where a rating of 1 was deemed insignificant and 5 was deemed very significant and following the sample distribution and response rate adopted (Wuni et al., 2022). Following similar sampling techniques in the region (Oduro et al., 2024), the Cochran formulation was adopted to determine the sample requirements in this study using Eq. 1 (Cochran, 1977).

$$n = \frac{z^2 * p(1-p)}{e^2} \tag{1}$$

In this design, 10% margin of error and 1.96 were selected as $e$ and $z$ values, respectively (Cochran, 1977). Based on this approach, a total sample of 96 was chosen in this study. Approximately, 100 questionnaires were administered to built environment professionals. Architects, Quantity Surveyors, Engineers, Planners, Procurement and Environmental Officers formed the sample frame due to their expertise and requirement to ensure a sustainable built environment (Owusu-Manu et al., 2023). A response rate of 62% was recorded, which was adequate following several sustainability studies in the region (Adabre et al., 2021; Oduro et al., 2024; Seidu et al., 2023; Wuni et al., 2022). To ascertain the reliability and validity of measuring instrument, a reliability test was conducted. Given that the Cronbach's Alpha coefficient of 0.700 or higher is considered reliable, the coefficient of the measuring instrument in this study (0.9) was considered excellent. Further, a preliminary background analysis of the respondents was assessed. The built environment is made of various technical professionals who perform distinct roles in project execution. While Architects and Landscape Designers are predominantly engaged in green and eco-design, engineers are primarily concerned with project planning and execution. Among the respondents, Quantity Surveyors made up the largest group, consisting of 27 (or 43.5%) of the total respondents; 11 (or 17.7%) of the respondents worked as Project Managers; 12 (or 19.3%) were Engineers; 6 (or 9.7%) were Academic Researchers; 3 (or 4.8%) represented Architects; 2 (or 3.2%) were Planning Officers; and 1 (or 0.6%) was an Environmental Expert. The results were, therefore, representative of the built environment professionals involved in GI.

### 3.2 Gini mean score analysis

The complexity of the multifunctionality concept in GI projects generates different opinions among different stakeholders. The implication is that stakeholders may prioritize different GI functions within the same project, which may lead to unmet objectives. It is, therefore, expedient to identify a common factor within each stakeholder group to serve as a reference point in planning, designing, and implementing GI projects. As a stationary measure of dispersion, the Gini mean was adopted to generate an absolute driver of GI projects in developing countries (Ali et al., 2024). Relying on the relative importance index (RII),

$$\left(\frac{\sum w}{AXN}\right) \tag{2}$$

where $w$ represents the importance attributed by respondents to a driver (this was given on a Likert Scale of 1 to 5, where 1 indicated that a driver was Insignificant and 5 indicated very significant), $A$ represents the maximum importance attainable (given as 5 on the Likert Scale), and $N$ represents the total number of respondents; the Gini mean through weighted geometric mean can make lucid the key stationary drivers of GI (Ali et al., 2024). This was determined using the equation below;

$$\text{G.M. (w)} = \text{Antilog}\frac{\sum w \log \text{RII}}{\sum \text{w}} \tag{3}$$

where, G.M ($w$) = weighted geometric mean, $\sum w$ = total sum of weights assigned to RII.

The stationary driver was identified as the variable whose RII is closest to the weighted geometric mean. The analysis in this study revealed two main drivers closest to the weighted mean, hence, both drivers were positioned as key drivers of the multifunctionality concept in GI projects development in developing countries.

### 3.3 Principal component analysis

Having identified the stationary drivers of GI in developing nations, further inferential analysis was conducted to draw more insights into the multifunctional drivers of GI. Due to the large number of drivers identified in empirical studies worldwide, there is a possibility of several drivers having related outcomes. Using a reduction technique, it can be determined how many possible variables are measuring different facets of the same underlying phenomenon. For this reason, principal component analysis was adopted as an inferential analytical method. This is necessary given the regional disparity in GI projects globally (Seidu et al., 2024). As preliminary and adequacy check criteria, Bartlett and Kaiser–Meyer–Olkin tests were conducted, where the acceptable thresholds are ($p < 0.05$) and 0.6 for Bartlett and Kaiser–Meyer–Olkin tests, respectively. A KMO of 0.884 and Bartlett's coefficient ($p < 0.05$) were interpreted as *superb and satisfactory*, respectively. The Guttmann-Kaiser rule states that only factors with the Eigen value > 1 should be maintained, while the Cattel screen test states that not all additional components should be included after the start of the elbow (Goretzko, 2022). In accordance with this criterion, three components were extracted and discussed.

### 3.4 Fuzzy synthetic evaluation

Fuzzy set theories are able to draw objective inferential insights from subjective statements using mathematical logic (Zafar et al., 2022). To understand the interactions between the 16 multifunctional drivers of GI in developing regions, fuzzy logic was applied. FSE has been applied in the built environment to assess the interactions between risk factors (Zafar et al., 2022); drivers of modular integrated construction (MiC) (Hassan Ali et al., 2023); drivers of circular economy in MiC (Wuni & Shen, 2022) and success factors in public–private partnerships sustainability. In this design, FSE was adopted as a complementary inferential tool to prioritize the multifunctional drivers of GI as well as the criticality of each component revealed in the factor analysis. The basic steps in this FSE included a) defining and eliciting what the multifunctional drivers of GI, these are presented in Table 1 above; b) establishing a linguistic scale for experts opinion, the scale adopted in this study was a 5-point Likert scale ranging from 1 to 5, where 1 was deemed insignificant and 5 deemed very significant; c) assigning and calculation of weights for drivers of GI and the respective group or component weights based on mean scores; d) the final step was the

**Table 1** Multifunctional drivers of GI

| Code | Multifunctionality dimension | Driver description | References |
|---|---|---|---|
| MD1 | Environmental sustainability | Promoting environmental sustainability | Korkou et al. (2023) |
| MD2 | Community health and well-being improvement | Enhancing community health and wellbeing | Säumel et al. (2016) |
| MD3 | Stormwater quality management | Managing the quality of runoff | Cristiano et al. (2023), Seyedashraf et al. (2023) |
| MD4 | Flood Resilience | Functioning as a flood mitigation strategy | Fletcher et al. (2015), Zhang et al. (2023) |
| MD5 | Air quality enhancement | Improving air quality | Ghazalli et al. (2018) |
| MD6 | Biodiversity enhancement | Increasing and preserving biodiversity | Hoyle and Cottrill (2023) |
| MD7 | Hydrology resilience | Ensuring a balance in the provision of hydrological services | Wang et al. (2023a, 2023b) |
| MD8 | Runoff volume control | Controlling excessive stormwater runoff | Dong et al. (2017) |
| MD9 | Ecology and Ecosystem services | Supporting the vitality of urban ecosystems | Fletcher et al. (2015) |
| MD10 | Urban heat island mitigation | Mitigating the urban heat island effect | Chen et al. (2023), Shao and Kim (2022) |
| MD11 | Pollution control | Controlling pollution through infiltration and sedimentation | Raimondi et al. (2023) |
| MD12 | Nature-based solution | Embracing nature-based solutions | Kooijman et al. (2021) |
| MD13 | Urban resilience | Fostering the creation of adaptable urban environments | Banzhaf et al. (2022) |
| MD14 | Hydrological cycle restoration | Restoring the natural water flow system | Hong et al. (2021) |
| MD15 | Key driver for sponge cities | Driving the Sponge Cities initiative towards transforming cities into water sensitive urban areas | Dong et al. (2023a, 2023b) |
| MD16 | Grey infrastructure resilience | Reinforcing the durability of traditional (conventional) infrastructure | Bertilsson et al. (2019) |

(Authors Construct, 2024)

determination of membership functions. Applying FSE revealed key interactions between the drivers and the group relationships. The following equations were used to calculate the weight for each driver and component of GI (Oluleye et al., 2023).

$$Wi = \frac{\mu i}{\sum_{i=1}^{5} \mu i}, \ 0 < wi < 1, \ \text{where} \sum_{i=1}^{5} wi = 1 \tag{4}$$

where W$i$ *is obtained* by dividing the mean score ($\mu i$) for each driver or component, and $\sum \mu i$ represent the sum of the mean scores of all drivers.

To determine the membership function of each component, the total weightings for all drivers under a component (group) were multiplied by the membership function matrix for the component (Oluleye et al., 2023). This is expressed as:

$$Gi = Ki\ (Ri) \tag{5}$$

where $Ki$ is the total weightings for all drivers under a component and $Ri$ is the membership function matrix for the component.

The final fuzzy matrix for each component is determined by obtaining a product of $Gi$ and the grades assigned using the Likert scale. Thus, *Gi * (1,2,3,4,5).*

## 4 Analytical results

### 4.1 Stationary and major drivers of GI

Tables 2 and 3 illustrate the mean scores, relative importance index (RII), and pairwise comparisons toward determining the stationary driver (s) and major drivers of GI.

Using Eq. 3,

Several steps were taken to determine the geometric mean in accordance with (Ali et al., 2024).

Firstly, the RII was calculated using Eq. 2.

For MDI, ($\sum w$) total participants weightings of a driver (265), A (maximum weight–5) and N = 62 respondents.

$$\text{RII} = \frac{265}{5 \times 62} = 0.855$$

Next, we determine $Wi$ (weight of each RII), this is expressed as: G.M x $\frac{RIIi}{RII1}$, where G.M represents Gini's mean, $RIIi$ = any driver relative importance index. $RII1$ = The highest RII value.

As an inequality and dispersion quotient, a stationary driver is defined as a constant factor that underpins the adoption, implementation, and sustainability of a project across several geographic regions. As elicited in (Ali et al., 2024), the stationary driver is most likely the factor that has the closest RII value to the weighted geometric mean G.M (w), which is equivalent to 0.795 as illustrated in Table 3. Two drivers, *ecology and ecosystem services* and *urban heat island mitigation,* exhibited the closest RII values to the *G.M (w)* and, hence, were determined as the two stationary drivers of GI in developing countries. This is consistent with the findings of Gwedla et al. (2024), who revealed that ecosystem services are a major objective that drives investment in GI in South Africa. This implied that efforts to foster GI planning, design and implementation often consider the ecological and

**Table 2** Stationary and main drivers of GI

| Criterion | RII | W$i$ | Log (RII) | W$i$. Log RII |
|---|---|---|---|---|
| MD1 | 0.855 | 0.0393 | −0.068 | −0.003 |
| MD2 | 0.832 | 0.0383 | −0.080 | −0.003 |
| MD3 | 0.823 | 0.0378 | −0.085 | −0.003 |
| MD4 | 0.823 | 0.0378 | −0.085 | −0.003 |
| MD5 | 0.810 | 0.0372 | −0.092 | −0.003 |
| MD6 | 0.806 | 0.0371 | −0.094 | −0.003 |
| MD7 | 0.806 | 0.0371 | −0.094 | −0.003 |
| MD8 | 0.803 | 0.0369 | −0.095 | −0.004 |
| MD9 | 0.797 | 0.0366 | −0.099 | −0.004 |
| MD10 | 0.790 | 0.0363 | −0.102 | −0.004 |
| MD11 | 0.787 | 0.0362 | −0.104 | −0.004 |
| MD12 | 0.777 | 0.0357 | −0.110 | −0.004 |
| MD13 | 0.752 | 0.0346 | −0.124 | −0.004 |
| MD14 | 0.748 | 0.0344 | −0.126 | −0.004 |
| MD15 | 0.748 | 0.0344 | −0.126 | −0.004 |
| MD16 | 0.745 | 0.0343 | −0.128 | −0.004 |
| SUM | | 0.5841 | | −0.058 |
| GM (w) 0.795 | | | | |

urban heat island mitigation dimensions. Designers (Architects) and other built environment professionals need to effectively communicate these drivers to clients, investors, and policymakers toward GI adoption and implementation. Having ascertained the stationary drivers of GI, the main drivers, ranked by the RII values in Table 3, include 'environmental sustainability,' 'community health and well-being improvement,' stormwater quality management,' 'Flood Resilience', and 'Air quality enhancement.'

## 4.2 Principal component analysis

The Guttmann-Kaiser rule states that only factors with the Eigen value > 1 should be maintained, while the Cattel screen test states that not all additional components should be included after the start of the elbow (Goretzko, 2022). In accordance with this criterion, three components were extracted: climate and ecology adaptability, thermal control and urban resilience, and water resources management, obtaining a variance of 28.161%, 22.017%, and 18.277%, respectively, cumulatively accounting for 68.54% of the variance. Table 4 presents the factor loading of each variable studied.

## 4.3 Fuzzy synthetic evaluation

Tables 5, 6, and 7 illustrate the weights for all drivers as well as the component and membership functions. These were calculated as established in Sect. 3.4. After determining and extracting three components through the principal component analysis, the criticality of each component was ascertained in accordance with (Oluleye et al., 2023) and presented in Table 7.

From Eq. 4, $Wi = \frac{\mu i}{\sum_{i=1}^{5} \mu i}$, the weight of each driver was computed.

**Table 3** RII pairwise comparison

| Rank | Code | μ | RII | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MD1 | 4.27 | 0.855 | 0.110 | | | | | | | | | | | | | | | |
| 2 | MD2 | 4.16 | 0.832 | 0.107 | 0.087 | | | | | | | | | | | | | | |
| 3 | MD3 | 4.11 | 0.823 | 0.107 | 0.084 | 0.078 | | | | | | | | | | | | | |
| 4 | MD4 | 4.11 | 0.823 | 0.103 | 0.084 | 0.075 | 0.078 | | | | | | | | | | | | |
| 5 | MD5 | 4.05 | 0.810 | 0.078 | 0.080 | 0.075 | 0.075 | 0.065 | | | | | | | | | | | |
| 6 | MD6 | 4.03 | 0.806 | 0.068 | 0.055 | 0.071 | 0.075 | 0.062 | 0.061 | | | | | | | | | | |
| 7 | MD7 | 4.03 | 0.806 | 0.065 | 0.045 | 0.046 | 0.071 | 0.062 | 0.058 | 0.061 | | | | | | | | | |
| 8 | MD8 | 4.02 | 0.803 | 0.058 | 0.042 | 0.036 | 0.046 | 0.058 | 0.058 | 0.058 | 0.058 | | | | | | | | |
| 9 | MD9 | 3.98 | 0.797 | 0.052 | 0.035 | 0.033 | 0.036 | 0.033 | 0.054 | 0.058 | 0.055 | 0.052 | | | | | | | |
| 10 | MD10 | 3.95 | 0.790 | 0.049 | 0.029 | 0.026 | 0.033 | 0.023 | 0.029 | 0.054 | 0.055 | 0.049 | 0.045 | | | | | | |
| 11 | MD11 | 3.94 | 0.787 | 0.049 | 0.026 | 0.020 | 0.026 | 0.020 | 0.019 | 0.029 | 0.051 | 0.049 | 0.045 | 0.042 | | | | | |
| 12 | MD12 | 3.89 | 0.777 | 0.045 | 0.026 | 0.017 | 0.020 | 0.013 | 0.016 | 0.019 | 0.026 | 0.045 | 0.045 | 0.039 | 0.032 | | | | |
| 13 | MD13 | 3.76 | 0.752 | 0.032 | 0.022 | 0.017 | 0.017 | 0.007 | 0.009 | 0.016 | 0.016 | 0.020 | 0.045 | 0.039 | 0.029 | 0.007 | | | |
| 14 | MD14 | 3.74 | 0.748 | 0.032 | 0.009 | 0.013 | 0.017 | 0.004 | 0.003 | 0.009 | 0.013 | 0.010 | 0.045 | 0.035 | 0.029 | 0.004 | 0.003 | | |
| 15 | MD15 | 3.74 | 0.748 | 0.023 | 0.009 | 0.000 | 0.013 | 0.004 | 0.000 | 0.003 | 0.006 | 0.007 | 0.045 | 0.010 | 0.025 | 0.004 | 0.000 | 0.003 | |
| 16 | MD16 | 3.73 | 0.745 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.045 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Sum | | | 0.978 | 0.633 | 0.507 | 0.507 | 0.351 | 0.307 | 0.307 | 0.280 | 0.232 | 0.315 | 0.165 | 0.115 | 0.015 | 0.003 | 0.003 | 0.000 |

**Table 4** Principal Component Analysis results and factor loadings

| | GI Drivers | Factor loading | % of variance explained |
|---|---|---|---|
| *Code* | *Climate and Eco adaptability* | | |
| MD1 | Environmental sustainability | 0.712 | 28.161% |
| MD3 | Stormwater quality management | 0.621 | |
| MD8 | Runoff volume control | 0.783 | |
| MD11 | Pollution control (infiltration & sedimentation) | 0.823 | |
| MD12 | Nature-based solution | 0.698 | |
| MD6 | Biodiversity enhancement | 0.621 | |
| MD9 | Ecology and Ecosystem services | 0.701 | |
| MD4 | Flood Resilience | 0.527 | |
| *Thermal control and urban resilience* | | | |
| MD15 | Key driver for sponge cities | 0.582 | 22.017% |
| MD5 | Air quality enhancement | 0.766 | |
| MD10 | Urban heat island mitigation | 0.753 | |
| MD13 | Urban resilience | 0.798 | |
| *Sustainable water resources management* | | | |
| MD7 | Hydrology resilience | 0.660 | 18.277% |
| MD16 | Grey infrastructure resilience | 0.706 | |
| MD14 | Hydrological cycle restoration | 0.620 | |
| MD2 | Community health and well-being improvement | 0.779 | |

For MD 1,

$\mathrm{W}_i = \frac{4.27}{4.27+4.11+4.02+3.89+4.03+3.98+4.11} = 0.132$. This process was repeated for all the remaining GI functionalities.

To determine the weight of each group, the same approach was followed, thus, group weight is obtained by dividing the sum of mean scores for each group by the total sum of mean scores for all groups.

To calculate the group weight (Climate and Eco adaptability),

$w_i = \frac{32.43}{32.43+15.5+15.37} = 0.512$. The process was repeated for all groups.

The membership function for each multifunctional dimension of green infrastructure is calculated from the responses using the 5-point Likert Scale in percentage terms. The percentage score for each point on the Likert scale (Insignificant, less significant, moderate, significant, and very significant) was determined based on the responses from built environment professionals (Oluleye et al., 2023). For MD1, 3.2% of the respondents deemed it less significant (2), 19.4% deemed it moderately significant (3), 24.2% deemed it significant (4) and 53.2% deemed it very significant (5).

The membership function for MD1 is, thus, expressed as (0.00, 0.03, 0.19, 0.24, 0.53). This process is repeated for all drivers, as shown in Table 6.

The membership functions for each component group were computed using Eq. 5,

$$Gi = Ki\,(Ri)$$

where $Ki$ the total weightings for all drivers under a component and $Ri$ is the membership function matrix for the component.

**Table 5** Weights determination of key drivers

| Components | Drivers | Mean | Driver weight | Component weight |
|---|---|---|---|---|
| Climate and Eco adaptability | | | | 0.512 |
| | MD1 | 4.27 | 0.132 | |
| | MD3 | 4.11 | 0.127 | |
| | MD8 | 4.02 | 0.124 | |
| | MD11 | 4.02 | 0.124 | |
| | MD12 | 3.89 | 0.120 | |
| | MD6 | 4.03 | 0.124 | |
| | MD9 | 3.98 | 0.123 | |
| | MD4 | 4.11 | 0.127 | |
| Thermal control and urban resilience | | | | 0.244 |
| | MD15 | 3.74 | 0.241 | |
| | MD5 | 4.05 | 0.261 | |
| | MD10 | 3.95 | 0.255 | |
| | MD13 | 3.76 | 0.243 | |
| Sustainable water resources management | | | | 0.242 |
| | MD7 | 3.74 | 0.243 | |
| | MD16 | 3.73 | 0.243 | |
| | MD14 | 3.74 | 0.243 | |
| | MD2 | 4.16 | 0.271 | |

**Table 6** Membership functions of key drivers

| Drivers | Membership function of key drivers | | | | |
|---|---|---|---|---|---|
| MD1 | 0.000 | 0.032 | 0.194 | 0.242 | 0.532 |
| MD3 | 0.000 | 0.048 | 0.177 | 0.387 | 0.387 |
| MD8 | 0.016 | 0.048 | 0.161 | 0.452 | 0.323 |
| MD11 | 0.000 | 0.048 | 0.242 | 0.435 | 0.274 |
| MD12 | 0.000 | 0.097 | 0.210 | 0.403 | 0.290 |
| MD6 | 0.000 | 0.065 | 0.177 | 0.419 | 0.339 |
| MD9 | 0.000 | 0.081 | 0.129 | 0.516 | 0.274 |
| MD4 | 0.000 | 0.032 | 0.161 | 0.468 | 0.339 |
| MD15 | 0.000 | 0.097 | 0.323 | 0.323 | 0.258 |
| MD5 | 0.000 | 0.048 | 0.194 | 0.419 | 0.339 |
| MD10 | 0.032 | 0.032 | 0.161 | 0.500 | 0.274 |
| MD13 | 0.032 | 0.081 | 0.210 | 0.452 | 0.226 |
| MD7 | 0.000 | 0.032 | 0.226 | 0.419 | 0.323 |
| MD16 | 0.016 | 0.048 | 0.306 | 0.452 | 0.177 |
| MD14 | 0.000 | 0.065 | 0.339 | 0.387 | 0.210 |
| MD2 | 0.000 | 0.032 | 0.129 | 0.484 | 0.355 |

**Table 7** Membership functions of components of key drivers

| Components | Membership functions | Group weights | Criticality score |
|---|---|---|---|
| Climate and Eco adaptability | (0.002 0.056 0.182 0.413 0.347) | 0.512 | 4.051 |
| Thermal control and urban resilience | (0.016 0.064 0.220 0.424 0.275) | 0.244 | 3.879 |
| Sustainable water resources management | (0.004 0.044 0.247 0.437 0.269) | 0.242 | 3.922 |

For component 1 (climate and ecosystem adaptation functionalities) matrix determination, the membership functions of the components in the group are expressed first in a matrix form as,

$$Ki = \begin{pmatrix} 0.00 & 0.03 & 0.19 & 0.24 & 0.53 \\ 0.00 & 0.05 & 0.18 & 0.39 & 0.39 \\ 0.02 & 0.05 & 0.16 & 0.45 & 0.32 \\ 0.00 & 0.05 & 0.24 & 0.44 & 0.27 \\ 0.00 & 0.10 & 0.21 & 0.40 & 0.29 \\ 0.00 & 0.07 & 0.18 & 0.42 & 0.34 \\ 0.00 & 0.08 & 0.13 & 0.52 & 0.27 \\ 0.00 & 0.03 & 0.16 & 0.47 & 0.34 \end{pmatrix}$$

$$Ri = (0.132, 0.127, 0.124, 0.124, 0.120, 0.124, 0.123, 0.127)$$

The final fuzzy evaluation matrix for component 1 is given as;

$$Gi = (0.132, 0.127, 0.124, 0.124, 0.120, 0.124, 0.123, 0.127)$$

$$\mathrm{X} \begin{pmatrix} 0.00 & 0.03 & 0.19 & 0.24 & 0.53 \\ 0.00 & 0.05 & 0.18 & 0.39 & 0.39 \\ 0.02 & 0.05 & 0.16 & 0.45 & 0.32 \\ 0.00 & 0.05 & 0.24 & 0.44 & 0.27 \\ 0.00 & 0.10 & 0.21 & 0.40 & 0.29 \\ 0.00 & 0.07 & 0.18 & 0.42 & 0.34 \\ 0.00 & 0.08 & 0.13 & 0.52 & 0.27 \\ 0.00 & 0.03 & 0.16 & 0.47 & 0.34 \end{pmatrix} = (0.0020.0560.1820.4130.347)$$

The process was repeated for all the groups.

The final process of the FSE was the determination of criticality score for each group.

This is expressed simply as *Gi* as determined above multiplied by the weighting scale (1 to 5) (Oluleye et al., 2023), as indicated in the linguistic scale used in Sect. 3.4.

Criticality score of component 1 is determined as,

(0.002 0.056 0.182 0.413 0.347) * (1, 2, 3, 4, 5) = 4.051.

The process is repeated for the other components.

From Table 6, the membership functions show a high degree of association and interaction among the multifunctional objectives of GI. The analysis prioritized climate and ecological objectives, with a critical score of 4.051 over water management and thermal needs. This is consistent with the findings of (Zhang et al., 2022), which revealed GI as key strategy for ecology conservation. The general implication is that GI is mostly perceived as a climate adaptation and ecological conservation strategy in these regions. This was followed by sustainable water resources management attributes with a criticality score of

3.922. Thermal control and urban resilience drivers obtained a critical score of 3.879. The analysis shows that built environment professionals are more aware of some functionality (ecology and urban heat mitigation) than others (stormwater and sponge cities applications). Efforts are needed to holistically convey all these benefits to professionals to foster adoption. Again, while GI may passively perform ecological functions, intentional design considerations are needed to achieve multifunctional benefits such as thermal comfort and stormwater management.

## 5 Discussion of survey findings

### 5.1 Climate change adaptation and ecological drivers

Climate change has emerged as a global phenomenon widely investigated in several domains due to its effects on urban health, stormwater crises and extreme temperatures. GI has proven effective in managing these complications through carbon offsetting and the provision of ecosystem services. Component one was, therefore, rated the most widely known GI functionality among built environment professionals. Existing hard built-up spaces have been criticized for their single functionality and less flexibility in adjusting to future climatic and hydrological changes. On the contrary, GI has some specific attributes that transcend this single functionality conundrum. Component one comprising eight (8) key functionalities of GI systems; 'environmental sustainability', 'stormwater quality management', 'runoff volume control', 'pollution control (infiltration & sedimentation)', 'nature-based solution', 'biodiversity enhancement', 'ecology and ecosystem services' and 'flood resilience'. The statistics depict that the most understood GI functionality was environmental sustainability. As a key consequence of climate change in the observed region, flood resilience has also become a key driver of GI in Ghana (Mensah & Ahadzie, 2020) and other parts of the world (Zhang et al., 2023). Consequently, GI can enhance infiltration, reduce stormwater run-off and eventually offer biodiversity enhancement to urban regions. In this component, the stationary driver (ecology and ecosystem services) plays a key role globally in enhancing GI efforts as the knowledge dimension is common among built environment professionals globally. This component, therefore, play serve as a key starting point when communicating GI to investors and policymakers in the region. As the most well-understood GI functionality, it is necessary to investigate, through case studies whether specific design considerations are required to achieve these group of functionalities. For instance, regarding carbon sequestration (green roofs, green walls etc.), which GI typologies perform better? These are questions that need case studies answer in these regions, considering climatic conditions.

### 5.2 Thermal control and urban resilience

The thermal functionalities of GI have garnered some attention in scholarly works. The temperature control abilities of GI have been documented across different regions (Wang & Banzhaf, 2018). Green roofs decreased ambient temperatures up to 3 K, while green walls significantly reduced building surface temperature up to 15 °C (Bartesaghi Koc et al., 2018). This prospect of GI has therefore inspired attention from professionals. Extreme heat does not only induce stress in urban areas but contributes to health complications. In Ghana for instance. Evidence indicated that extreme heat significantly affected health and resulted in heat gain (Codjoe et al., 2020). More recently, extreme heat led to high electricity consumption and cost implications in these regions (Kayaga et al., 2021). With GI demonstrating a high promise in urban heat island mitigation in several regions, it is plausible that built environment professionals considered this component a critical dimension. Component two, explaining 22.017% of the total variance, included: 'key driver for sponge cities (cooling of cities),' 'air quality enhancement,' 'urban heat island mitigation' and 'urban resilience.' While sponge cities are mostly associated with stormwater management, these systems are equally effective in temperature control through cooling. This showed in the low factor loading (0.58), indicating a low level of correlation within the group. The implication is that the concept is not fully understood among professionals in developing countries. Mitigation of urban heat islands and urban resilience have become key drivers in GI. More recently, GI was observed as a critical tool against urban heat islands (Chen et al., 2023) and contribute to the fight against climate change impact. To varying degrees, urban planning has implemented the paradigms of restoration, conservation, adaptation and sustainable development to strengthen resilience. The statistical analysis revealed that '*improving air quality*' is a major driver of GI adoption. Interestingly, Bartesaghi Koc et al. (2018) revealed that little is known about the prospect of GI in thermal comfort control in tropical countries and developing countries. Further analysis revealed a lack of standardized and performance data on temperature regulation in green areas. To ensure effective thermal performance, some key design factors must be considered including insulation materials in buildings (Tam et al., 2016). Finally, for continuous performance improvement, machine learning, remote sensing and thermal imaging present valuable opportunities for GI optimisation.

### 5.3 Sustainable water resources management

Although component three explained 18.277% of the total variance, some critical GI drivers were found in this group, as indicated in the FSE criticality score. While PCA simply measured variance explained, FSE prioritised factors based on criticality. The significant role of GI in sustainable water management has been stressed and honed in serval literal works (Fletcher et al., 2015; Seidu et al., 2024). Generally, knowledge on drivers in this group is fairly low. The key drivers under this category include 'hydrology resilience,' 'drainage infrastructure resilience,' 'hydrological cycle restoration' and 'community health and well-being improvement.' Particularly, this lag may be attributed to the dilapidated nature of water infrastructure in these regions. The hydrological cycle performance is often disrupted through several unsustainable activities; concreting and impervious pavements that prevent infiltration. Due to their natural functionalities, including infiltration and sedimentation, GI can restore the natural hydro cycle. GI systems allow easy infiltration and proper functioning of the hydrological cycle and further provide easy flow of water (Freeborn et al., 2012). GI improve the efficiency of grey systems in several ways, hence limiting urban runoff at its source and having the ability to reduce system inputs in terms of total volume and peak flow (Dong et al., 2017). Accumulating data suggests that integrating GI into urban planning might also reduce flood hazards and the consequential loss of and damage caused by such disasters (Thorne et al., 2018). In tandem, the application of GI in water management has seen several evolutions in terminology and functions, including sponge cities, water-sensitive urban design, sustainable urban drainage systems, low impact development and nature-based solutions (Dong et al., 2023a, 2023b; Jones et al., 2022). Key objectives of these systems are pollution control in urban waterways and stormwater control. In these debates, GI systems have been used to collect, filter and reuse stormwater in Singapore, while surface water quality improvement was the goal in Philadelphia (Liu & Jensen, 2018). More efforts are however, still needed to convey these benefits to stakeholders and policymakers. The design and planning of GI to effectively manage water in urban areas is not passive. For instance, evidence in some case studies show that an integration of both green and grey infrastructure performs better than each individually in flood management and drainage resilience (Tansar et al., 2023). This dimension of GI functionality requires expertise and skill in life cycle cost analysis, feasibility analysis, technological applications, financing and other project management considerations. Towards stormwater management in urban centres, green (permeable) pavements have been discussed as a key strategy to tackle the impermeability conundrum posed by building and construction (Wang et al., 2019). Permeable pavement design, construction and maintenance require competence from architects, landscape designers, engineers and other construction professionals to ensure that objectives are met. However, green pavement design guidelines are still emerging and more efforts are still needed to ensure wide adoption and implementation. In some regions (China), green pavements showed significant abilities in stormwater quality improvement when applied to 26% of the study area (Zhu et al., 2021). Thus, by understanding the multifunctional abilities of GI, green pavements can be effectively designed to control pollution, manage stormwater quantity and provide cooling in cities (Liu et al., 2020).

## 6 Conclusions, implications and recommendations

GI adoption and implementation differ globally, and different factors account for this variability. Through a combination of Gini mean analysis, principal component analysis and FSE, the results indicated that ecological and ecosystem services and urban heat island mitigation drive GI implementation among built environment professionals in Ghana, as these factors are well known and understood. Three broad classifications were realized and prioritized as climate and ecological adaptation drivers, sustainable water resources management drivers and thermal and urban resilience drivers in order of criticality, respectively. The results of this study provide pivotal areas for built environment professionals to drive GI. Firstly, the findings point to ecological and ecosystem services and urban heat island mitigation as the stationary drivers of GI in Ghana. GI systems are generally understood as ecosystem provision and heat mitigation strategies. This provides ample data for policymakers, designers, engineers and other stakeholders in advocating GI projects. The increasingly unfavourable weather conditions in these regions stressed the need to implement GI in hot tropical regions. Secondly, the results are relevant to sustainability advocates and friends of the environment towards developing compelling arguments in raising environmental awareness and education. Global climatic change impacts the entire world and does not respect geopolitical barriers so at some stage, the public must demand and implement change. The findings also point that sustainable water management abilities of GI needs more education and training. The study provides several novel contributions to both theory and practice.

Knowledge of ecological functions and urban heat island mitigation in GI is appreciable in developing countries, while stormwater and drainage resilience application are less understood. Again, there is a need to lead GI development efforts with the multifunctional properties to offset the perceived enormous initial construction costs. More importantly, there is a critical need to develop GI knowledge through project-based learning, workshops, formal education and media campaigns to communicate the full benefits to stakeholders. As a practical implication, for architects and other built environment professionals, there is need to consider specific project objectives in GI planning and design. For instance, in flood prone areas, a combination of pervious pavements, green roofs and traditional grey infrastructure may be more suitable against standalone components. Finally, in extreme heat regions such as Ghana, considerations need to be accorded GI design parameters such as insulation materials thickness in green roofs. In green walls, orientation is crucial to ensure optimal performance.

Some insights and recommendations of the study include: future research endeavours may consider targeting other stakeholders to provide a more holistic perspective towards GI adoption. This is because knowledge of GI differs among stakeholders. By understanding different stakeholders understanding of GI, strategic policies can be formulated to consider a broad range of societal needs. This can further improve stakeholder engagement and collaboration efforts. This will eventually lead to acceptance of GI in less developed regions. Further, more case studies are needed to provide more empirical data for further analysis to effectively convey the full scope of GI functionality. Case studies on GI functionality are sparse in developing regions. This lag presents a challenge when communicating GI functionality to multiple stakeholders due to a lack of practical evidential data. Through case study analysis, effective GI strategies can be developed to support planning and risk management. Additionally, to encourage more professionals to become involved in GI development, the multifunctional ability of GI needs to be incorporated into academic training institutions, as single-use debates (heat mitigation) are not enough to spur GI adoption due to perceived high initial costs. Past studies in developing regions showed that a critical barrier to GI adoption is the perceived initial costs. Thus, there is a need for practitioners to effectively convey both the financial and non-financial value of GI technologies to improve willingness to pay among stakeholders. Regarding the limitations, the study is based on the built environment professionals' perspective only; other stakeholders' opinions may vary due to differences in GI awareness and knowledge. Further, the work is focused on Ghana only—similar studies in a broader geographical context may yield similar or dissimilar results. Finally, other analytical methods, such as machine learning techniques and artificial neural networks, may be adopted in further studies to overcome the limitations of factor analysis and fuzzy evaluations to draw additional reliable insights.

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