Environmental Technology & Science Journal
Vol. 12 Number 2 December 2021

Evaluating the Physical Properties of Potential Green Roof Growth-Media Compositions for Use in the Nigerian Built Environment

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Received: 29/01/2022 **Revised: 12/02/2022** **Accepted: 19/02/2022**

The primary objective of this paper is to examine the physical properties of potential green roof growth-media compositions practicable for use in the Nigerian built environment. The study carried out an essential selection of material constituents of growth media blends mixed in a 3:1:1 ratio of natural stone-based gravels, soil and compost. Six substrate blends based on laterite stones, sandstone, granite, river gravel, pumice and recycled masonry debris were studied using relevant laboratory and empirical field evaluation methods. The granite-based blend is the heaviest sample with 1,713.30 Kg/m^3 in its saturated state, while the lightest in weight is the pumice blend with 869.30Kg/m^3 which is 50.7% less than the granite blend. The result revealed that up to 50-150mm green roof thicknesses can be obtained using the pumice blend on a light-weight construction, while 50-100mm thicknesses can be attained using the debris-based blend. In the case of other alternative blends, however, only the 50mm-thick extensive green roofs can be obtained without special structural considerations. After a one-year physical observation of all the sampled models, the plants remained in good condition with no form of deformation, clogging and leaching of the substrate. Therefore, the study submits that all the selected stone-based growth media blends are suitable for use locally. It also established that the pumice and debris-based substrates are the lightest in weight, and are hence more suitable for retrofitting and other remodelling exercises. The study creates an avenue for further research on ways to optimise the studied blends in a bid to enhance their performance and improve on the benefits the green roof system stands to offer locally.

Keywords: Green Roof, Growth-Media, Substrate, Water-Holding-Capacity, Gravel
DOI: https://dx.doi.org/10.4314/etsj.v12i2.14

INTRODUCTION

Typically, cities are becoming increasingly warmer due to human activities that temper with the physiologic character of the natural landscape. This phenomenon is grossly synonymous with the building and construction industry where surfaces of roofs and hard pavements alone cover a large portion of urban surfaces and absorb a large part of the sunlight that contacts them which results to hotter and more polluted environments with higher energy costs required to satisfy thermal comfort for the living spaces (Tiwari, Karmakar & Sharma, 2021; Choi, Lee, & Moon, 2018). Nigeria has rapidly developing cities with rising environmental challenges accelerated by negative attributes of the building industry such as pollution, blockage of floodplains, loss of natural landscape and biodiversity (Emechebe, 2020; Ojo-Fajuru, Adebayo & Adebayo, 2018). These environmental problems coupled with the inherent high-temperature distribution of the region makes it difficult to achieve indoor thermal comfort in buildings (Eludoyin & Oluwatumise, 2021; Akinwolemiwa, 2016). According to numerous studies within the tenet of environmental sustainability; however, one of the most recommended strategies to counter these environmental vices and improve the comfort condition of the built environment is the use of green roof to recover the lost natural greenery displaced by buildings roofs (Suszanowicz & Wiecek 2019).

A green roof is an engineered roof fabric where a building's roof is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane (Cascone, 2019). The green roof offers numerous passive benefits of environmental, economic and social significance, it is nevertheless linked with the cost of installation and maintenance, as well as challenges in an application for areas that are extremely hot and dry (Schweizer & Erell, 2014; Berardi & Hoseini, 2014). It is also predisposed to design and technical failures that involve slumping, clogging of drainage channels and failure of the growth media that leads to difficulty in plant growth and survival (Kazemi & Mohorko, 2017; Dvorak, 2011). However, the most critical and challenging aspects of green roof design involve ultimate failure of the supporting roof due to excessive loading from the characteristic weight of the green roof system (Schweizer & Erell, 2014; Dvorak, 2011). Although such a weight is grossly due to the build-up of the vegetation and several green roof components; the major element that primarily determines its weight is the growth medium, which is a blend of soil and the hardcore material that ensures stability and plant development capacity of the system (Vijayaraghavan, 2016).

As reiterated by Kazemi and Mohorko (2017); growing media compositions have direct effects on plant performance and is hence, considered to be the most important component of the green roof system. However, according to the American Society for Testing and Materials (ASTM), 2014; the growing media must primarily be lightweight in nature in its saturated form in order to avoid failure of the main roof system of the building. In light of this problem, this research is primarily focused on investigating the weight attributes and implication of some locally obtained growth media materials with the bid to obtain the categorical implication of using them as local substrate blends practicable for both new and retrofitted projects in the Nigerian building industry.

Studies have shown that the use of green roofs in Nigeria has remained unpopular despite the prospects it holds from the outlined potential benefits for the different climatic regions of the country. This has been attributed to lack of technical knowledge and the characteristic cost of the system (Salihu, 2018); however, it has also been observed that there is limited access to green roof studies, design frameworks and construction guidelines that are categorically entrenched in the local building code (Salihu, 2021). Therefore, although there are other horticultural, core engineering and economic dimensions to green roof research, this study is primarily pitched towards uncovering the appropriate lightweight growth media materials that can practically be sustained by both light and heavyweight roof systems predominantly found in the local building industry. The study hence is prompted by the dictates of Vitruviuos's principles; that a structure must first of all stand before any form of utility or economy is obtained thereof.

To achieve the primary goal of the study, the foremost objective put forward is to perform a critical selection of potential growing media blends feasible for adoption in the Nigerian built environment industry. The second objective of the study is to carry out a relevant evaluation on the efficacy of using the selected growing media samples with regards to its physical impact on the supporting roof, rate of water holding capacity, substrate stability and level of plant sustenance. The final objective of the study is to assess the level of compliance each of the prospective growth media bears in respect to established green roof codes and guidelines purported from locations with advanced knowledge of the system.

THE GREEN ROOF SYSTEM AND ITS BENEFITS

The performance and efficiency of green roofs depend on the climatic conditions inherent at the site of its installation. Its design and construction models are usually made up of either a built-up system, where layers are arranged across the entire area earmarked for coverage, or the modular system, where the modules are transportable in a pre-laid arrangement around the roof like a floor covering in a grid pattern (Blackhurst, Hendrickson & Matthews, 2010; Breuning, 2015). As shown in Figure 1, the major components of a green roof system include; the plants, an engineered growing medium, filter layer to contain roots and growing medium, drainage layer, waterproofing membrane and the main roof structure (Vijayaraghavan, 2016; Rakotondramiarana, Ranaivoarisoa, & Morau, 2016).

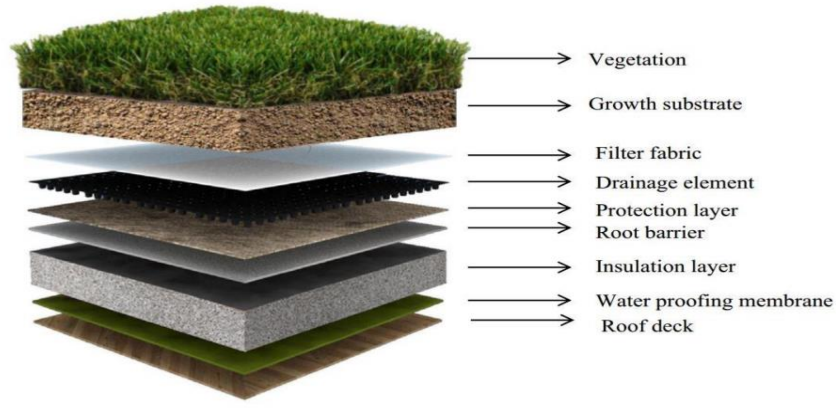

Figure 1: Schematic diagram of a typical green roof system
Source: Vijayaraghavan, (2016)

Green roofs are considered to be an effective contribution to the resolution of several environmental problems at the building and urban levels (Suszanowicz & Wiecek 2019). In addition to the creation of a pleasant environment, green roof systems fundamentally offer numerous benefits in comparison to conventional roofs installations. The roof system facilitates stormwater retention to minimise flooding, noise and air pollution, mitigation of urban heat island on a macro scale and protection from temperature extremes that aid in reducing energy requirements for cooling the building interior spaces (Speak, 2013; Collins, 2016; Sutton, 2015). On a more physical scale, the roof system offers economic benefits that facilitate in increasing the life expectancy of building's roofs by protecting them from physical damage, and improving the economy of space as it allows for the creation of utilisable commercial and recreational roof gardens and terraced areas on rooftops (Castleton *et al.*, 2010; Lyons, 2010).

Green roof construction is a very challenging endeavour in the sense that, the substrate differs from traditional garden soil where traditional moulds are mainly composed of organic materials such as peat and compost (Cascone, 2019). In the case of the green roof, caution must be exercised in moulding a growing medium that must possess a satisfactory degree of desired rigidity similar to the natural garden soil and with a comparatively lesser weight to minimise imposed loading on the supporting roof (Schweizer & Erell, 2014). Therefore, the common procedure is to select a blend of various materials with different attributes at well-defined percentages to constitute the growth substrate.

Green roofs can be categorised as extensive and intensive systems depending primarily on the thickness. The extensive system has a thickness less than 300 mm depth of growing media and requires minimal irrigation with robust low growing plant and ground cover species on a gently sloping support roof (Berardi & Hoseini 2014). Extensive green roofs are designed to be lighter in weight, relatively cheap, but not open to recreational use and require minimum maintenance (Lyons, 2010). On the other hand, the intensive green roof has more than 300 mm depth of growing media, it is generally designed to accept recreational activity and to include the widest range of vegetation from grass to shrubs and semi-mature trees (Berardi *et al*., 2014). They are largely limited to flat roofs in park-like areas accessible to the public that requires intense maintenance needs (Getter & Rowe, 2006). When elements of both extensive and intensive green roofs are found in the green roof it's considered to be a semi-intensive green roof (Raji, Tenpierik, & Dobbelsteen, 2015).

Growth Media Composition, Characteristics and Material Selection

The green roof substrate is composed of different ratios of stone-based gravel, soil and organic material; however, the most crucial constituent of the growth media that is responsible for its gross weight is the stone-based hardcore material (Chenot *et al*., 2017). In the case of a wrong choice of substrate, the consequences are compaction, imbalances between water and air, suffocation of the root apparatus, increased weight, reduction in drainage, and the alteration of the nutrients (Cascone, 2019). The growth media is characterised by two main sets of parameters: physical parameters, such as density, particle size, water permeability, maximum water volume, and maximum air volume in saturated conditions, while the chemical parameters are the quality and quantity of organic matter (Cascone, 2019; Schultz, Sailor, & Starry, 2018).

In growth media studies conducted by Best, Swadek, and Burgess, (2015) and Papafotiou *et al*. (2013), different configurations of substrate blends were tested using different sand and soil compositions, heat expanded clay, and zeolite as compost in volumetric proportions to support growth and foster plant prosperity. Tests within the study also employed the use of materials like composted pine bark and hydro-cell flakes to help in reducing the weight of the substrate; while, brick, peat, perlite, pumice and vermiculite were considered to be recommended options in forming the rigid part of the substrate for stability. Recently also, studies steered towards finding alternative uses for recycled materials in the construction sector are focused on utilising local waste material for substrates, which can make the establishment of a green roof inexpensive and an agent of reducing the embodied energy required to construct a green roof and divert waste (Eksi *et al*., 2015).

Obtaining optimal utility in a green roof system depends on the ratio of the three main constituents of soil, compost and gravel as earlier described. According to the recommendation of *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau* (FLL) standards, (2008); crushed bricks, shale, stones with similar properties, compost and soil (sandy loam soil) of the ratio of 3:1:1 is the most favoured kind of composition for areas with dry climates. This composition has been established to offer an improved level of water retention and adequate drainage characteristic for the growing media. An extensive study by Kazemi and Mohorko (2017), compiled a general summary of green roof research across climate zones under Koppen–Geiger climate classification; the extraction was carried out to present the major findings in choice of growing mediums for hot climates as shown in Table 1

Table 1: Study of growth media compositions for hot climates

Climate	Location	Depth(S)	Growing Media Blend	Major Findings
Hot Dry	Murcia, Spain	50 mm 100 mm	compost: soil: brick = 1:1:3 compost: brick = 1:4	-No irrigation resulted in the plant failure -Substrate depth was more relevant than substrate type for plant growth
Hot Dry Semiarid	USA	100 mm	heat expanded clay, peat, perlite, and vermiculite	Optimal performance recorded
Hot Dry Semiarid	Adelaide, Australia	100 mm 300 mm	1) Type I: crushed brick, scoria, coir fibre and composted organics 2) Type II: scoria, composted pine bark and hydro-cell flakes	Medium Type I performed better than Medium Type II in both growing media depths.
Hot Dry Semiarid	Denver, Colorado		Expanded shale: compost and composted bark 80:20	Greater survival of succulents was observed overgrowing seasons.
Dry Semiarid	Athene, Greece	75 mm, 150 mm	Four substrate types: a combination of sandy loam soil; pumice; peat; compost; and zeolite in volumetric proportions	Perlite amended deep substrate resulted in the least drought stress and highest cover rate on Zoysia matrella.

The Table shows that; for the green roof in hot dry climates a good growth media blend of thicknesses between 50mm to 300mm of substrate depth are suitable for all types of extensive and even intensive green roof systems; although, according to ASTM International (2014), even a 25mm thickness is sufficient to support plant growth.

Weight and Structural Considerations for Growth Media

Green roof substrates should be characterised by low dry and wet bulk densities, as they represent the main load on the roof bearing structure, especially in old buildings where the roofs were not built to accommodate green roof systems (Wilkinson & Feitosa, 2015). One of the key approaches for decreasing the weight of the substrate is to utilise low-density inorganic materials. This is because the lower the density of the substrate, the thicker the substrate can be constructed, and the larger variety of vegetation that can be planted (Cascone, 2019). In view of this, the stone-based material being the largest contributor to green roof weight that constitutes more than 60% of the system weight becomes the major point of concern. Numerous studies have been carried out to achieve a minimum density with the thicker substrate. An example of this is a study that shows that the bulk density of perlite was stated to be 9.4 times less than that of conventional garden soil (Wilkinson & Feitosa, 2015).

Another weight-related aspect of the green roof that impacts greatly on its density on saturation is its water holding capacity (WHC). This variable is essential for the endurance of the vegetation since it helps the plants to withstand drought conditions (Du, Arndt, and Farrell, 2018). High WHC also allows for the use of non-succulent plant species, the FLL, (2008) suggests a WHC of >20% for an extensive green roof, and according to Vijayaraghavan, (2015), WHC can effectively be improved by increasing the substrate volume, depth, and organic content.

Structurally, the biggest challenge for green roof installation is the load-bearing capacity of the supporting roof (Grant. 2007). However, bigger challenges are faced when dealing with older buildings in the case of retrofitting and remodelling, as this may require costly structural reinforcement which in most cases may prove prohibitively expensive (Wilkinson & Feitosa, 2015). Therefore, the solution remains that if the weight of the green roof is reduced, the need for structural reinforcement is also consequently reduced. According to the

International Building Code (IBC) 2018, under vegetative and landscaped roofs, green roofs are computed as live loads calculated on the basis of saturation of the soil and shall be within the range of 0.958kN/m^2.

MATERIAL AND METHODS

This study is experimental in nature that involves laboratory procedures and field observation. As earlier established in the background, it is geared towards establishing categorical information on different locally attainable growing media blends suitable for use in the Nigerian built environment industry. The tests carried out were not specifically bent on merely uncovering the appropriate growth medium in terms of lightweight, but to present some evaluated and categorical values of various potential media blends in respect to functionality, cost and availability.

The dependent variables thus are the composite blends of the primary media constituents that include the stone-based gravels, soil and compost. The independent variables on the other hand are the weight and its impact on the supporting roof, plant sustenance, substrate stability and other physical deformative characteristics like clogging and leaching. The water retention period is not within the scope of this study; however, water needed to saturate the blend (WHC) was also measured. All the results were subsequently subjected to test for compliance with the established codes and guidelines relevant to the study.

Material Selection and Mix Ratio

According to studies carried out within the context of the study, the most available natural stones used for gravel in the building industry are laterite stones, sandstone, granite and river gravel (Kolawole *et al.*, 2019; Njoku *et al*., 2020). These stones were thus, selected for the study as the stone-based gravels constituent. Specific to the mandate of the study and as also used for similar lightweight requirements, other types of stones considered are pumice, shale and limestone (Tangbo, Garba, & Nensok, 2020; Momoh, Atoo, & Nwakonobi, 2018). Within the tenet of purposeful sampling using lightweight and availability as the primary criteria, all the stated stones were collected; however, limestone aggregates were left out because they are not chemically inert and interact with the nutrient solution in a manner deleterious to plant growth (Karczmarczyk, Baryła, & Ko, 2017). Within the precept of material recycling also, as gathered from the literature review, a blend of recycled debris from a typical building site was also considered. Table 2 shows the origin and qualities of the selected gravels for the study.

Table 2: Selected gravels for the study

	Type	Origin	Qualities
1.	Granite	Igneous	Strong and heavy
2.	River gravel	Location Dependant	Available and very durable
3.	Laterite stones	Igneous	Soft easy to crush, good water holding capacity
4.	Sandstone	Sedimentary Rock	Low in strength, weight and easy to crush
5.	Debris	Composite	Readily available, cuts down embodied energy
6.	Pumice	Igneous	Light in weight, not readily available

As observed in the recommendations from the FLL (2008), the study adopted the use of locally available loamy soil and compost from animal farm deposits available in the study area in a ratio of 3:1:1 respectively. Table 3 shows the samples of the selected potential growing media blend for the study labelled (A-F).

Table 3: Potential growth media blends

Sn	Sample Label	Growing Media Blend	Remark
	A.	Granite, soil and compost = 3:1:1	Readily available but costly
	B.	River gravel, soil and compost = 3:1:1	Available in riverine areas
	C.	Laterite stones, soil and compost = 3:1:1	Readily available but cheaper than granite
	D.	Sandstone, soil and compost = 3:1:1	Readily available
	E.	Debris, soil and compost = 3:1:1	Readily available in building sites
	F.	Pumice, soil and compost = 3:1:1	Not Readily available in some parts of the country

Laboratory Exercise

The apparatuses used in the laboratory were a 100kg weighing machine, calibrated cylindrical plastic jars, and a scoop as shown in Plate 1. The sampled growing media blends were measured in a metal measuring container of 400x150x230 (0.138 m^3) in size, and 4.2 kg in weight. The multiplying factor therefore to obtain the cubic meter was =72.463 m^3. The test was conducted by collecting the stones as shown in the case of pumice in Plate 3 and crushing the stones into gravels of appropriate sizes. Dry samples of compost and soil were then collected in their natural forms as shown in Plate 2 and mixed with the gravels. However, limestone collected (Plate 4) was discarded after observing its chemical behaviour and slumping tendencies when saturated. The volume of water required to saturate each mixture was measured using the calibrated jars, and the weighing machine was set to zero point and used to measure the six samples batched in the steel measuring box. Measurements carried out of the sampled blends were both in dry and saturated states. Each sample is measured three times from different portions of the larger sample to obtain an average value before recording. Plate 5 shows the images of the prepared sample for the laboratory and field observation analysis.

Plate 1: Scale, cylinders & steel box

Plate 2: unblended soil sample

Plate 3: uncrushed pumice sample

Plate 4: uncrushed limestone sample

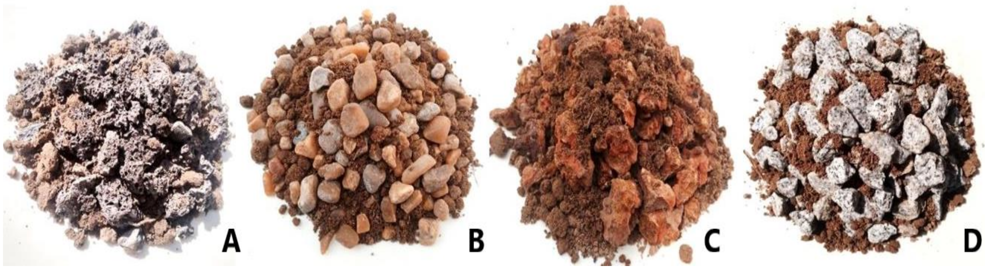

Plate 5: Sampled growth media; pumice (A), river stone (B), laterite (C) and granite blends (D).

Experimental Field Observation

A one-year physical observation was carried out to test the efficacy of using the sampled growing media blends. As demonstrated in studies by Ahmed and Alibaba, (2016) and Breuning, (2015); the green roof installation was done using the modular system of installation. In a deliberate effort to apply a rust-free material that may also serve as an insulation and drainage layer, 400mm x 600mm x 100mm aluminium trays of 0.55 thickness were used as containers for the growing medium. The base of the trays was perforated in a manner that facilitates appropriate drainage onto the support roof system as shown in Plates 6 and 7. The plant of choice in this study is Kalonchoe Integra from the *Cappridaceae* family. It has good coverage and height to provide the desired canopy and can survive drought conditions where other plants might not (Lambrinos, 2015). The planted trays were placed on a miniature wooden model portraying a small building for the relevant examination. The model is characterised by galvanised iron roof covering on timber trusses. At the end of the earmarked study period, physical observation was conducted to ascertain the condition of the growing medium based on its current state of stability, plant sustenance, impact on the supporting roof, and possible clogging and leaching.

Plate 6: Perforated Aluminium trays

Plate 7: Aluminium trays mounted on a miniature box

RESULTS AND DISCUSSION

Physical properties of the selected samples were measured under precepts of growth media weight (m^3), Water Holding Capacity, estimated weight for typical growth media blends (m^2), compliance with green roof codes and results from one-year physical field observation.

Results for Measured Growth Media Weight

The weighting process was initially conducted in cubic meters for each substrate blend for reference and record purposes. Table 4 shows the measured weight of the six samples. The record is presented in descending order from the heaviest to the lightest substrate. The granite-based blend is the heaviest sample with 1,368.80 Kg/m^3 in its dry state and 1,713.30 Kg/m^3 in its saturated state. River gravel blend and the laterite stones followed closely with a difference of 104.30Kg/m^3 and 316.00Kg/m^3 respectively in their saturated states. The lightest in weight is the pumice blend with 869.30Kg/m^3 which is a difference of 942.90 Kg/m^3 from the heaviest granite blend, implying that it is 50.7% lighter in weight, followed by the masonry debris blend with 1,115.90 Kg/m^3.

Table 4: Measured weight of sampled growth media in cubic metres

	Label	Blend Base	Dry (Kg/m^3) Average	Saturated (Kg/m^3)	Difference; sample A (Kg/m^3)
1.	**A**	Granite based	1,368.80	1,713.30	0
2.	**C**	River gravel blend	1,264.50	1,603.60	104.30
3.	**B**	Laterite stones	1052.20	1,404.43	316.60
4.	**D**	Sandstone based	873.10	1,180.10	495.70
5.	**F**	Debris	755.70	1,115.90	613.10
6.	**E**	Pumice based	452.90	869.30	942.90

Water Holding Capacity

Measurement for the WHC of sampled growth media was conducted in litres per cubic meter. The results revealed that the granite, river gravel and laterite blends have the lowest WHC. The situation improved on the sandstone blend with a difference of 17.5 l/m^3 from the granite blend. The pumice blend on the other hand recorded the highest WHC with 61.9 l/m^3 difference from the least values recorded on the granite blend; which implies that it holds 44.4 l/m^3 more than the average difference of the sandstone blend. While the masonry debris recorded a 25.7 l/m^3 difference as elaborately shown in Table 5.

Table 5: Measured WHC of growth media in litre per cubic metre

	Label	Blend Base	Water Capacity ($Litre/m^3$)	Difference; sample A ($Litre/m^3$)
1.	**A**	Granite based	344.50	0
2.	**C**	River gravel blend	339.10	5.4
3.	**B**	Laterite stones	352.23	7.73
4.	**D**	Sandstone based	327.00	17.5
5.	**F**	Debris	370.20	25.7
6.	**E**	Pumice based	406.40	61.9

Estimated Weight for Typical Growth media Blends (m^2)

Having physically measured the weight of each blend in Kg/m^3 a successive conversion was conducted to estimate the weight of the commonest extensive types of green roof growth media in Kg/m^2. Table 6 shows the estimated weight of the 50mm, 100mm, 150mm, 200mm, 250mm and 300mm growth media. Results from the conversion showed that in all cases the granite blend medium recorded the heaviest values at 85.65 Kg/m^2 for the 50mm and 513.90 Kg/m^2 for the 300mm, followed by the river stone and laterite blends with slighter respective values. The lightest in weight is the pumice with 50% less weight than the granite blend at 43.50 Kg/m^2 for the 50mm and 261.00 Kg/m^2 for the 300mm; the debris also recorded an encouraging figure at 55.80 Kg/m^2 for the 50mm and 334.80 Kg/m^2 for the 300mm.

Table 6: Estimated weight of extensive and intensive growth media

			Weight of Saturated Blend (Kg/m^2)					
	Label	**Blend base**	50mm	100mm	150mm	200mm	250mm	300mm
1.	**A**	Granite	85.65	171.30	256.95	342.60	428.25	513.90
2.	**B**	River gravel	80.15	160.30	240.45	320.60	400.75	480.90
3.	**C**	Laterite stones	70.23	140.45	210.68	280.90	351.13	421.35
4.	**D**	Sandstone	59.00	118.00	177.02	236.02	295.03	354.03
5.	**E**	Debris	55.80	111.60	167.40	223.20	279.00	334.80
6.	**F**	Pumice	43.50	87.00	130.50	174.00	217.50	261.00

Compliance

IBC (2018) and the FLL (2008) specify that green roof falls under live loads that must remain within the range of 0.958kn/m^2 (97.72kg/m^2). However, a literature review of existing and ongoing studies has resolved that a green roof of a 100mm thickness can optimally weigh from 73kg/m^2 to 122 kg/m^2. This shows that only the lighter weighed growth medium studied to satisfy the stipulations of the IBC (2018) and the FLL (2008); where 50mm, 100mm and 150mm thicknesses can be applied within the loading range on the Pumice blend, while 50mm and100mm also fall within the range for the debris blend. For all other alternative blends; however, only the 50mm thick extensive green roofs can be obtained comfortably without the requirements of sophisticated structural considerations. This also implies that only the stated alternatives can be used in extensive non-occupied green roofs on lightweight construction, all other thicker alternatives may require special and more rigorous structural analysis and heavier construction type. Figure 2 shows the array of green roof types for every growth media blend and the resultant compliance to the loading threshold earmarked by the building codes.

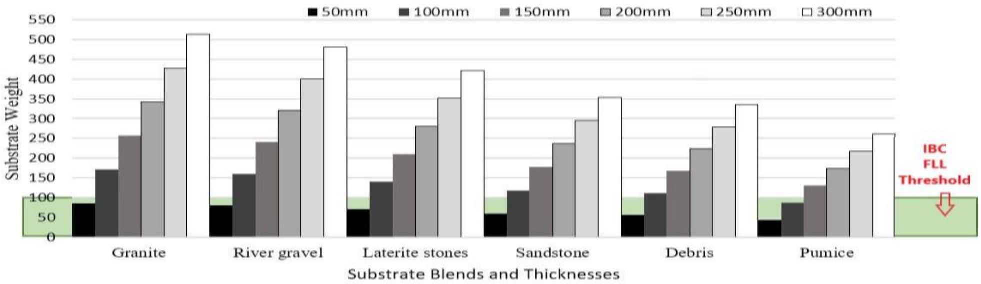

Figure 2: Thicknesses of various blends and compliance to loading conditions of the building code

Results from One-Year Observation

Results of the one-year observation showed that the weight of the green roof trays did not cast any form of deformity or damage on either the roofing sheets or the timber trusses; hence the supporting roof was deemed intact. All the green roof trays appeared to be normal and stable as in their initial structure, with no traces of any substantial clogging and leaching of the substrate. Although deliberately subjected to a 28-day watering interval during the hot season between March and June, the plant remained in good condition with a slight change of colour observed on the upper leaves. This shows that the blends have all passed the test of possessing adequate capacity in terms of plant sustenance. Plate 8 shows a pictorial image of the miniature green roof model after a year of physical observation.

Plate 8: The observed green roof blends on site

CONCLUSION AND RECOMMENDATIONS

It has been established that access to green roof information and practice is limited in the Nigerian building industry. Although this study is not geared to particularly be a ground breaking endeavour in general green roof knowledge, it is rather projected to be an essential stepping stone for green roof design and construction within the context of the study location. The study was able to develop models of growth media blends through explicit laboratory processes, after which the green roof models were constructed and tested over the study period. The study; hence submits that all the selected stone-based growth media blends are suitable for use in green roof design and construction in the Nigerian built environment industry. Records have shown that they all offer adequate rigidity, substrate stability, good WHC and satisfactory plant sustenance. However, it was, established in the research that, the pumice growth media offers the most lightweight green roof substrate, such that up to a thickness of 150mm can be attained under the regular threshold of dead load compliance of the International Building Code (2018) and many other sources of literature and ongoing research. Hence, it is the best type of blend for retrofitting and other remodelling exercises. Up to 100mm thickness of non-occupied extensive green roof can also be achieved using the blend from recycled masonry debris. All other blends of granite, river stone, laterite and sandstone can only accommodate the 50mm green roof thickness, unless on heavily constructed support roof or other special-purpose roof construction types.

The study recommends that the findings of this research be placed under further scrutiny depending on the specific benefit it is projected to offer. This study has clearly highlighted within the studied green roofs samples that, locations in the hot and dry regions of the country like Sokoto and Maiduguri at the extreme north that experience extreme hot temperatures could enjoy thermal insulation offered by the lighter substrates like that of the pumice blend and the debris. Other rapid developing urban areas like Kano and Abuja that lose a wide range of biodiversity due to the constant destruction of ecosystems that displaces nature could have their urban environments ameliorated by the use of green roofs. The lightweight blends may also be of valid environmental protection importance for the flood-prone urban cities like Lagos and Port-Harcourt; where the thicker substrates could be used to facilitate stormwater mitigation that green roofs have been known to offer. In order to practically and theoretical make further exploration into the efficacy of using the green roof system, this study advocates that further study be projected towards developing models and design frameworks that can facilitate the development of local green roof codes and guidelines that can be keyed into the National Building Code as a whole.

REFERENCES

Ahmed, R. M. & Alibaba, H. Z. (2016). An Evaluation of Green roofing in Buildings. *International Journal of Scientific and Research Publications,* 6(1), 366–373. Retrieved from Journal homepage www.ijsrp.org.

Akinwolemiwa, O. (2016). Evaluating the impact of vertical greening systems on thermal comfort in low-income residences in Lagos, Nigeria. Archi DOCT; t*he e-journal for the dissemination of doctoral research in architecture,* 3(2), 62-80. www.enhsa.net/archidoct

American Society for Testing and Materials (ASTM E 2400) 2014. *Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems.* ASTM International, West Conshohocken, PA, 4. Retrieved from www.astm.org.

Berardi, U. & Hoseini, G. (2014). State-of-the-art analysis of the environmental benefits of green roofs. *Energy and Buildings*, 115, 411–428 Retrieved from journal homepage: www.elsevier.com/locate/enbuild.

Best, B.B. & Swadek, R.K., Burgess, T.L., (2015). *Green Roof Ecosystems, Ecological Studies, Analysis and Synthesis*. Atlanta, Springer.

Breuning, J. (2015) Green Roof Types. *Green Roof Technology; Form and Function.* Retrieved on 12/12/2015 from http://www.greenrooftechnology.com /green-rooftypes

Cascone, S. (2019). Green Roof Design: State of the Art on Technology and Materials. *Sustainability,* 11/3020, 2-28. Retrieved from https://doi.org/10.3390/su11113020 on 22/10/2021 doi:10.3390/su11113020

Castleton, H. F., Stovin, V. & Beck, S. B. M. (2010). Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings*, 42, 1582–1591. https://doi.org/10.1016/j.enbuild.201 0.05.004

Chenot, J., Gaget, E., Moinardeau, C., Jaunatre, R., Buisson, E., & Dutoit, T. (2017). Substrate Composition and Depth Affect Soil Moisture Behavior and Plant-Soil Relationship on Mediterranean Extensive Green Roofs. *Water*, *9*, 817, doi:10.3390/w9110817.

Choi, Y., Lee, S., & Moon, H. (2018). Urban Physical Environments and the Duration of High Air Temperature: Focusing on Solar Radiation Trapping Effects. https://doi.org/10.3390/su10124837

Collins, S. G. (2016). *Thermal Behaviour of Green Roofs in Winter Conditions.* Unpublished Master's Thesis, University of Michigan, United States.

Du, P., Arndt, S. K., & Farrell, C. (2018). Relationships between plant drought response, traits and climate of origin for plant selection. *Ecological Applications*, 28(7), 1752–1761 https://doi.org/10.1002/eap.1782

Dvorak, B. D. (2011). Comparative Analysis of Green Roof Guidelines and Standards in Europe and North America. *Journal of Green Building*, 6(2). https://doi.org/10.3992/jgb.6.2.170 Building.

Eksi, M., Rowe, D.B., Fernández-ca, R. & Cregg, B.M. (2015). Effect of substrate compost percentage on green roof vegetable production. *Urban For. Urban Green*, *14*, 315–322, doi:10.1016/j.ufug.2015.03.006.

Eludoyin O.M. & Oluwatumise O.E. (2021) Thermal Comfort and Vulnerability of Residents to Heat Stress in Ikare, Akoko, Ondo State, Nigeria. In: Leal Filho W., Luetz J.M., Ayal D. (Eds.) *Handbook of Climate Change Management*. Springer, Cham. https://doi.org/10.1007/978-3-030-57281-5_191

Emechebe, L. C. (2020). Challenges of Achieving Sustainable Green Space in Urban Built Environment in Nigeria. *Environmental Technology & Science Journal*, 11(2), 35–43

Ezema, I. C., Ediae, J. & Ekhaese, E. N. (2015). Opportunities for and barriers to the adoption of green roofs in Lagos, Nigeria. *International Conference on African Development Issues* (CU-ICADI) 2015: Renewable Energy Track

FLL Guidelines (2008). *Introduction to the FLL Guidelines for the Planning, Construction and Maintenance of Green Roofing*. 2008 Edition of the Green Roofing Guideline 1–9. Maryland, Green Roof Service LLC.

Getter, K. L., and Rowe, D. B. (2006). The Role of Extensive Green Roofs in Sustainable Development Michigan State University, Department of Horticulture. *HortScience, East Lansing*, 41(5), 1276–1285

Grant, E.J. (2007). *A Decision-Making Framework for Vegetated Roofing System Selection*. Unpublished PhD thesis, Virginia Polytechnic Institute and State University. The United States. Retrieved from https://pdfs.semanticscholar.org/3474/0e1836e28cf9b576aacaf3e72c07d3522992. On 17/12/2016

International Building Code (2018). *International Code Council, Inc*. United States of America Retrieved on 26/12/2021 from https://codes.iccsafe.org/content/IBC2018/chapter-16-structural-design

Karczmarczyk, A., Baryła, A., & Ko, P. (2017). Design and Development of Low P-Emission Substrate for the Protection of Urban Water Bodies Collecting Green Roof Runoff, 1–16. https://doi.org/10.3390/su9101795

Kazemi, F. & Mohorko, R. (2017). Urban Forestry and Urban Greening Review on the roles and effects of growing media on plant performance in green roofs in world climates. *Urban Forestry and Urban Greening*, 23, 13–26. https://doi.org/10.1016/j.ufug.2017.02.006

Kolawole, A. A., Abdulazeez, M., Omoniyi, I. G. E. O. & Awu, B. S. (2019). Engineering Characterization of Rocks from the Minna Granitic Formation as Pavement Construction Aggregates. *7*(1), 27–32. https://doi.org/10.15640/jges.v7n1a3

Lambrinos, J.G., (2015). *Green Roof Ecosystems, Ecological Studies, Analysis and Synthesis*. vol. 223. Springer.

Lyons, A (2010). *Materials for architects and builders.* (Fourth Ed.). New York: Routledge

Momoh, E. O., Atoo, A. A., & Nwakonobi, D. (2018). Suitability of Awka-North (Nigeria) Sedimentary stones as Coarse Aggregate for Building Construction, *7*(1), 71–83. *International Journal of Engineering Science Invention (IJESI),* 7(1), 71-83 *www.ijesi.org*

Njoku, J.O., Opara, K.D., Okeke, H.M. & Ejiogu, C.C. (2020). Production and Uses of Crushed Rock Aggregate from Intrusive Igneous Rocks. *International Journal of Innovative Environmental Studies Research,* 8(1), 1-8 *www.seahipaj.org* on November 24th 2021.

Ojo-Fajuru, O., Adebayo, A. & Adebayo, P. (2018). The Paradox of Livelihood Strategies and Urban Landscape Degradation in Contested Spaces: Towards Attaining a Sustainable Green City in Ado-Ekiti, Nigeria, *International Journal of Development Research*, 08(11), 24031-24040 https://www.journalijdr.com/sites/default/files/issue-pdf/14480.pdf on 2/01/2020.

Papafotiou, M., Pergialioti, N., Tassoula, L., Massas, I. & Kargas, G., (2013). Growth of native aromatic xerophytes in an extensive Mediterranean green roof as affected by substrate type and depth and irrigation frequency. *HortScience,* 48(10), 1327–1333

Raji, B., Tenpierik, M. J. & van den Dobbelsteen, A. A. J. F. (2015). The impact of greening systems on building energy performance: A literature review. *Renewable and Sustainable Energy Reviews*, 45, 610-623. DOI: 10.1016/j.rser.2015.02.011

Salihu, M.M. (2021). *A Framework for Green Roof Design Optimised for Reduction of Cooling Load for Residential Buildings in the Hot-Dry Climate of Nigeria*. Unpublished PhD Thesis, Department Of Architecture, Faculty of Environmental Design, Ahmadu Bello University, Zaria, Nigeria.

Salihu, M.M (2018). Barriers to the Adoption of Green Roof Technology in Nigeria's Built Environment Industry. *Proceedings of the 2018 AARCHES National Conference, Trends in 21st Century Architecture and Sustainable Built Environment*, 103-116.

Santamouris, M. (2012). Cooling The Cities: A Review of Reflective and Green Roof Mitigation technologies to Fight Heat Island and Improve Comfort in Urban Environments. *Sol.*

Energy, 103, 682–703 Http://Dx.Doi.Org/10.1016/J.Solener.2012.07.003

Schweitzer, O. & Erell, E. (2014). Evaluation of the energy performance and irrigation requirements of extensive green roofs in a water-scarce Mediterranean climate. *Energy and Buildings*, 68, 25–32. http://dx.doi.org/10.1016/j.enbuild.2013.09.012

Schultz, I., Sailor, D.J. &Starry, O. (2018). Effects of substrate depth and precipitation characteristics on stormwater retention by two green roofs in Portland OR. *J. Hydrol. Reg. Stud*, *18*, 110–118, doi:10.1016/j.ejrh.2018.06.008.

Speak, A. F. (2013). *Quantification of the Environmental Impacts of Urban Green Roofs.* Unpublished PhD Thesis, University of Manchester, United Kingdom.

Sutton, R. (2015). *Green Roof Ecosystems: Ecological Studies.* Switzerland: Springer International Publishing.

Suszanowicz, D. & Wiecek, A. K. (2019). The Impact of Green Roofs on the Parameters of the Environment in Urban Areas — Review. *Atmosphere*, *10*, 2-17, doi:10.3390/atmos10120792

Tangbo, M. U., Garba, M. M., & Nensok, M. H. (2020.). Properties of Lightweight Papercrete Made with Pumice. *ATBU Journal of Environmental Technology*, 13(2), 53-63

Tiwari, S., Karmakar, V. & Sharma, S.K. (2021). Architectural Solutions to Urban Heat Island Effect. *International Journal of Engineering Research & Technology (IJERT),* 10(1), 103–106 http://www.ijert.org

Vijayaraghavan, K. (2016). Green roofs: A critical review on the role of components, benefits, limitations and trends. *Renew. Sustain. Energy Rev.,* 57, 740–752, doi:10.1016/j.rser.2015.12.119.

Wilkinson, S. & Feitosa, R.C. (2015). Retrofitting housing with lightweight green roof technology in Sydney, Australia, and Rio de Janeiro, Brazil. *Sustainability,* 7, 1081–1098, doi:10.3390/su7011081.