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Weight and structural considerations of potential green roof growth: Media compositions for the Nigerian building industry

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Abstract:
The principal objective of this paper was to assess the physical properties and weight or structural implications of some 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 respectively. Six substrate blends based on laterite stones, ory and empirical field evaluation methods. The results revealed that the granite-based blend is the heaviest sample with 1,713.30 kg/m³ in its saturated state, while the lightest in weight is the pumice blend with 869.30 kg/m³ which is 50.7% less than the granite blend. The heaviest and the lightest outlined models were subsequently subjected to a weight analysis on a proposed reinforced concrete flat-roofed structure. The results showed that all the extensive green roof samples fall within the IBC stipulated range. The heaviest granite substrate obtained a design load of 0.951 kN/m², while the lightest pumice blend recorded a design load of 0.576 kN/m². Hence, it stands to offer an optimum alternative in green roof retrofitting projects for existing flat-roofed buildings. The study, therefore, submits that all samples evaluated involve readily available materials in the studied area and can be used with respect to their characteristic properties as presented in this study. It also serves as a reference point for all stakeholders in the research and building construction industry in Nigeria and beyond.

Keywords:
green roof, growth-media composition, substrate weight, lightweight construction

INTRODUCTION

Green roof technology is still in its incipient and exploratory stage in the Nigerian built environment industry. Therefore, there is limited knowledge on the weight and structural implication of using green roof on buildings which is one of the most challenging aspects of using such a system both in new and retrofitted projects. The dismal level of knowledge and patronage the system suffers locally is evidently attributed to a lack of common awareness of its numerous benefits, limited basic technical knowledge, and the characteristic high initial and maintenance cost of the system (Ezema et al., 2015; Salihu, 2018). However, most importantly, the green roof system is typically associated with challenges that involve its characteristic weight and the implication it has on the supporting roof system. It is therefore regarded as the most critical and challenging aspect of a green roof project which if not duly considered can lead to the partial and/or ultimate failure of the support roof owing to the excessive loading as a result of the weight of the green roof system (Schweitzer, 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 hard-core material that ensures stability and plant development capacity of the system (Vijayaraghavan, 2016).

According to the American Society for Testing and Materials (ASTM E2400, 2019); and Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) standards (2008); the growing media must functionally sustain plant life with minimum input and maintenance, and must also be locally available, possess good drainage capability, good water and nutrient-holding capacity and most importantly, it must be lightweight in nature in its saturated form to avoid failure of the main roof system of the building. Therefore, in light of this problem, this research is primarily focussed on investigating the weight attributes and their subsequent structural implication on some locally obtained growth media materials in order to obtain the categorical implication of using them as local substrate blends practicable for both new and retrofitting projects, and applying them on either lightweight or heavyweight roof systems predominantly found in the local building industry.

Although the International Building Code (ICC, 2018) has stipulated that 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/m², studies have shown that values and attributes of green roofs are location-specific and each scheme must therefore be considered as a distinct case from one setting to another (Decruz et al., 2014). The National Building Code (Federal Ministry of Housing and Urban Development Nigeria, 2006), has made provision for structural applications of various categories of predominantly used roof systems like the reinforced concrete flat roofs and different assortments of timber and steel trussed roof systems on both single and multi-storey buildings; however, no section of the building code has been found to regulate the live-load implications of using the green roof system. This study hence becomes a necessary platform for evaluating the weight implication of the outlined potential green roof growth-media compositions in Nigeria for subsequent reference and plausible adoption.

To attain categorical deductions on the efficacy of using the potential growth media with respect to their inherent weight and subsequent physical impact on the supporting roof; some outlined research questions were put forward to achieve the primary objective of the study. The research questions are:

1. What are the commonest and practicable green roof growth-media constituents attainable in the local built environment industry?
2. What is the weight and structural impact of the outlined growth media models?
3. What is the level of compliance of the prospective growth media with respect to established green roof codes and guidelines?

Mapped to the research questions, the research objectives therefore are:

1. To perform a critical selection of the potential growing media feasible for local adoption,
2. To subject the outlined growth media models to relevant evaluation and structural analysis,
3. To assess the level of compliance of the prospective growth media with respect to established green roof codes and guidelines.

LITERATURE REVIEW

Green roof benefits and major components

As shown in Fig. 1, the major components of a green roof system include; the plants, an engineered growing medium, a filter layer to contain roots and growing medium, a drainage layer, a waterproofing membrane and the main roof structure (Rakotondramiarana et al., 2015).

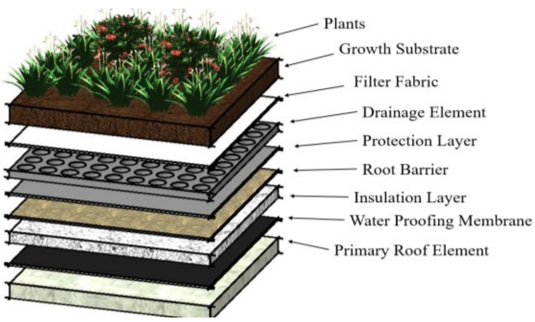

Fig. 1. Schematic diagram of the layered structure of a typical green roof system. (Source: Vijayaraghavan, 2016)

Generally, green roofs can be categorised as extensive and intensive systems depending primarily on their thickness. The extensive system has a thickness of less than 300 mm deep growing media and requires minimal irrigation with a robust low-growing plant and ground cover species on a gently sloping support roof (Berardi et al., 2013). 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 the depth of growing media of more than 300 mm, 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., 2013). They are largely limited to flat roofs in park-like areas accessible to the public that require intense maintenance needs (Getter, Rowe, 2006). When elements of both extensive and intensive categories are present in any given system, they are considered to be semi-intensive green roofs (Raji et al., 2015).

Green roofs are perceived as an effective contribution to addressing several environmental problems at the building and urban levels. In addition to the creation of a pleasant environment, green roof systems fundamentally offer numerous benefits in comparison to conventional roof installations. The roof system facilitates storm water retention to minimise flooding, noise and air pollution, mitigation of urban heat islands on a macro scale, and provides protection from temperature extremes thus helping to reduce energy requirements for cooling the building interior spaces (Speak, 2013; Collins, 2016; Sutton, 2015; Suszanowicz, Wiecek, 2019). On a more physical scale, the roof system offers economic benefits that facilitate 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).

Weight and structural challenges of the green roof substrate

Typically, 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 hard-core 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 nutrients (Cascone, 2019).

The weight of the substrate is one of the most critical domains of knowledge for establishing a long-term design and construction of green roofs (Grant, 2007). This involves the dead load, which is the final constructed weight of all built elements and all components associated with the green roof assembly; the live load, which is the weight of people and any mobile equipment; and there is also the transient load, which is that of moving, rolling or short-term loads, including wind and seismic activity (Cascone, 2019). According to IBC (ICC, 2018); and FLL (2008), an accessible green roof must have minimal capacity to support 4.79 kN/m², whereas non-occupied roofs shall be designed for live loads of 0.958 kN/m² under saturated conditions. The ASTM International (ASTM E2400, 2019) also provided a weight limitation for green roof systems to be 8.1 kg/0.09 m² for extensive green roof systems. A more applicable range for a regular extensive green roof was, however, submitted in studies by Ahmed and Alibaba (2016), and Chenani et al. (2015), which submitted that a green roof of 100 mm thickness can optimally weigh from 73 kg/m² to 122 kg/m². For the intensive green roof, however; Ahmed and Alibaba (2016) submitted that the roof must be designed to support a weight range of 171–391 kg/m².

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 so that a larger variety of vegetation can be planted (Cascone, 2019). 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. In view of this, numerous studies have been carried out to achieve minimum density with thicker substrates. 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).

As categorically stated in the structural perspective by Grant, (2007); the biggest challenge for green roof installation is the load-bearing capacity of the primary roof system upon which the growth media rests. However, bigger challenges are faced when dealing with older buildings that are subject to retrofitting and remodelling, as this may require costly structural reinforcement which evidently makes the projects excessively expensive (Wilkinson, Feitosa, 2015). The solution thus remains that if the weight of the green roof is limited to a bearable minimum, the need for structural reinforcement is also consequently reduced.

MATERIAL AND METHODS

The approach adopted for the study involves laboratory procedures and field observation of its experimental segment. Subsequently, some load analysis was conducted in an effort to establish clear-cut information on the structural implications of using the outlined growth media blends in the Nigerian built environment industry. Therefore, the dependent variables for the study, 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 growth media weight and its impact on the support roof. All the results were successively subjected to a test for compliance with the established codes and guidelines relevant to the study.

Material selection for the growth media

Tab. 1. Selected gravels for the study. (Source: Authors' fieldwork, 2023)

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

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). Specific to the mandate of the study and also used for similar lightweight requirements, other types of stones considered are pumice, shale and limestone (Tangbo et al., 2021; Momoh et al., 2018). Within the tenet of purposeful sampling using lightweight and availability as the primary criteria, all the stated stones were collected. In tune with the avocation of recycling contained within the environmentally sustainable ethics in the building industry, a blend of recycled debris from a typical building site was also considered. Tab. 1 shows the origin, qualities and mix ratios for the selected growth media blends for the study. 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.

Laboratory exercise

The apparatus used in the laboratory was a 100 kg weighing machine, calibrated cylindrical plastic jars, and a scoop as shown in Fig. 2. The sampled growing media blends were measured in a metal measuring container of 400 * 150 * 230 (0.138 m^3) in size, and 4.2 kg in weight. Therefore, the multiplying factor to obtain a cubic meter was = 72.463 m^3. The test was conducted by collecting the stones and crushing them into gravels of appropriate sizes. Dry samples of compost and soil were then collected in their natural forms and mixed with the gravel. The volume of water required to saturate each mixture was measured using the calibrated jars, and the weighing machine was set to the 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 (after addition of water). Each sample was measured three times from different portions of the larger sample to obtain an average value before recording. Fig. 3 shows the images of the samples prepared for the laboratory and field observation analysis.

Fig. 2. Laboratory measurement apparatus. (Source: Authors' fieldwork, 2023)

Fig. 3. Sampled growth media (L-R) pumice, river stone, laterite, and granite blends. (Source: Authors' fieldwork, 2023)

Sampling; Geometry and green roof models

Typically, green roofs are installed on new projects or remodelled or retrofitted buildings. This study being exploratory in nature was conducted on a proposed project that has the potential of being installed with a green roof system. The geometry selected for this study is a classroom block designed under the MDG (Millennium Development Goals) program for public primary school education in Nigeria. It is a prototypical design to be constructed in many parts of Northern Nigeria. It is therefore a befitting model for testing the efficacy of using the green roof on public buildings in such a hot dry climate. The roof design of the project is a typical reinforced-concrete flat roof; Weiler and Scholz-Barth (2009), opined that reinforced concrete is the most suitable for use in green roof systems due to the large load-bearing capacity it can withstand. Figs. 4, 5 and 6 show the floor plan, section and roof detail of the sampled geometry respectively. The roof has an area of 357 m², it is hypothetically covered with a green roof planted with sedum plants with alternating thicknesses of the growing media of different samples for relevant evaluation.

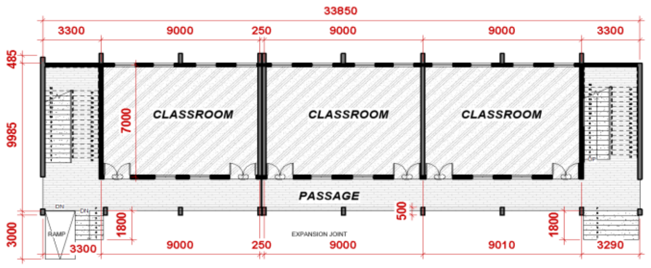

Fig. 4. Floor plan of the sampled building. (Source: MDG Projects, 2023)

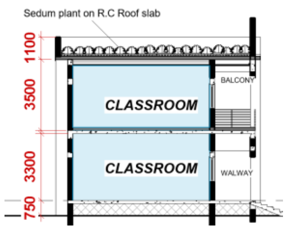

Fig. 5. Section, showing the green roof on the RC Roof. (Source: MDG Projects, 2023)

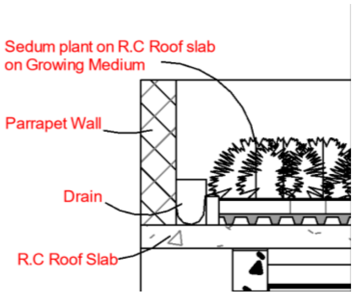

Fig. 6. Detail of the green roof components at the roof drainage. (Source: MDG Projects, 2023)

Loading, structural analysis and compliance

In order to avoid a cumbersome presentation of the load analysis for every extensive green roof model, relevant load calculations were limited to the heaviest and the lightest extensive green roofs. The samples were so selected in order to represent the embodiment of the best- and worst-case scenarios amongst the extensive green roof types. While the best cases present samples with the least problems, Kazman et al. (2002) iterated that the worst case scenarios typically express the most problematic circumstances in carrying out assessments and guarantees adequate and efficient sampling steps required to reach any theoretical saturation.

The study employed a simple structural analysis which involved using basic conservative methods to calculate load effects through simple structural models (Rücker, 2006). From this point of view, wind loading is typically considered to be negligible when acting on grass or low-lying plant life (Weiler, Scholz-Barth, 2009). Also, being an inaccessible green roof, live loads were not considered in the calculations. In contrast, transient loads which are the weight of transient water contained in the geo-composite layers is covered as part of the saturated weight of the samples as stipulated in the IBC load combinations (Gartner, 2008). Using BS8110, the study was focused on determining the compressive strength (fcu), minimum yield strength (fy), depth (d) and the resultant design load of the primary roof structure against the density of the composite nature of the green roof materials. In conclusion, the general green roof design was tested for compliance with the IBC (ICC, 2018).

RESULTS AND DISCUSSION

Results for measured growth media weight

Tab. 2 shows the measured weight of the six samples. The granite-based blend is the heaviest sample with 1,713.30 kg/m³ in its saturated state. River gravel blend and the laterite stones followed closely with 1,264.50 kg/m³ and 1052.20 kg/m³ respectively in their saturated state. The lightest in weight is the pumice blend with 869.30 kg/m³ which is a difference of 942.90 kg/m³ 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/m³. Fig. 7 shows an illustration of the weight difference between sampled growth media.

Tab. 2. Measured weight of sampled growth media (m³). (Source: Authors' fieldwork, 2023)

Blend Base	Dry (kg/m³)	Saturated (kg/m³)
Granite based	1,368.80	1,713.30
River gravel blend	1,264.50	1,603.60
Laterite stones	1052.20	1,404.43
Sandstone based	873.10	1,180.10
Debris	755.70	1,115.90
Pumice based	452.90	869.30

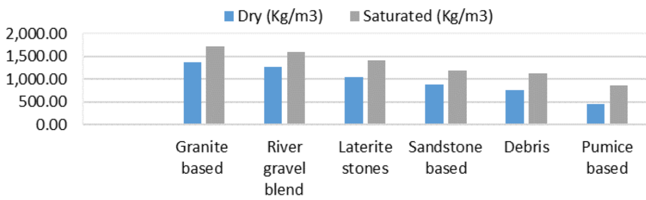

Fig. 7. An illustration of the weight difference between sampled growth media. (Source: Authors' fieldwork, 2023)

Estimated weight for typical growth media blends

Having physically measured the weight of each blend in kg/m³ a successive conversion was conducted to estimate the weight of the commonest extensive types of green roof growth media in kg/m². Tab. 3 shows the estimated weight of the 50 mm, 100 mm, 150 mm, 200 mm, 250 mm, and 300 mm growth media. Results from the conversion showed that in all cases the granite blend medium recorded the heaviest values at 85.65 kg/m² for the 50 mm and 513.90 kg/m² for the 300 mm model, followed by the river stone and laterite blends with slighter respective values. The lightest in weight is the pumice with 43.50 kg/m² for the 50 mm and 261.00 kg/m² for the 300 mm; the debris also recorded an encouraging figure at 55.80 kg/m² for the 50 mm and 334.80 kg/m² for the 300 mm model. Fig. 8 shows an illustrated difference in weight across all the growth media samples.

The results show that most of the substrate blends within the range of 50–100 kg/m² fall within the limit of an appropriate weight for the extensive green roof; which according to Ahmed and Alibaba (2016), and Chenani et al. (2015) should be between 73 kg/m² to 122 kg/m². To a reasonable extent, it also satisfies the stipulations of both the FLL (2008), and the ASTM International (ASTM E2400, 2019).

Tab. 3. Estimated weight of growth media for the green roof models. (Source: Authors' fieldwork, 2023)

	Weight of Saturated Blend (kg/m²)					
Blend (mm)	**50**	**100**	**150**	**200**	**250**	**300**
Granite	85.65	171.30	256.95	342.60	428.25	513.90
River gravel	80.15	160.30	240.45	320.60	400.75	480.90
Laterite	70.23	140.45	210.68	280.90	351.13	421.35
Sand-stone	59.00	118.00	177.02	236.02	295.03	354.03
Debris	55.80	111.60	167.40	223.20	279.00	334.80
Pumice	43.50	87.00	130.50	174.00	217.50	261.00

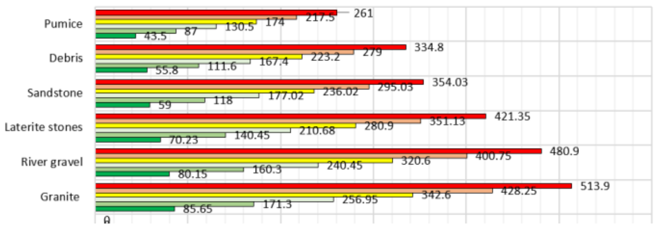

Fig. 8. An illustrated difference in weight across all the growth media samples. (Source: Authors' fieldwork, 2023)

Results from structural analysis of extensive green roof types

A structural analysis was conducted on the sampled building structure covered with a reinforced concrete roof system typical of the study area. Calculations were thus carried out on the heaviest sample from the heaviest category which is the granite blend with a saturated weight of 1,713.30 kg/m³, and the lightest sample from the lightest category which is the pumice substrate with 869.30 kg/m³. The results are shown in Tab. 4.

Tab. 4. Design parameters for a Green roof using composite materials. (Source: Authors' fieldwork, 2023)

Specimens	f_{cu}	f_y	Density	Depth (d)	Design Load
Pumice substrate	30 N/mm²	460 N/mm²	869.30 kg/m³	130mm	57.65 kN/m
Granite substrate	30 N/mm²	460 N/mm²	1713.30 kg/m³	130mm	95.10 kN/m

According to IBC, (2018); under landscaped roofs (1607.11.2.3) stipulated that where roofs are to be landscaped, the uniform design load in the landscaped area shall be 0.958 kN/m². The weight of the landscaping materials shall be considered as dead load and shall be computed on the basis of the degree of soil saturation. This implies that the saturated granite substrate having a 0.951 kN/m² design load falls within the stipulated range of the IBC, and can therefore be used in any extensive green roof project. On the other hand, the pumice blend, being the lightest substrate examined also satisfies the IBC stipulations. With a design load of 0.576 kN/m² the pumice blend will stand to offer an optimum alternative in green roof retrofitting projects for existing flat-roofed buildings.

CONCLUSION AND RECOMMENDATION

In summary, the study was able to systematically select and evaluate the physical properties of potential green roof growth media compositions that offer the positive potential to be used in the Nigerian built environment. The study was also able to assess the loading implication of all the outlined potential green roof models hypothetically tested on a reinforced concrete flat roof that happens to be one of the predominant forms of roof systems in the study area. 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 blends were mixed in a 3:1:1 ratio of natural stone-based gravels, soil and compost.

Results revealed that the granite-based blend is the heaviest sample with 1,713.30 kg/m³ in its saturated state, it was followed by the river-gravel blend and the laterite-stones substrate respectively. The lightest in weight is the pumice blend with 869.30 kg/m³ which is 50.7% less than the granite blend. Next in lightweight are the sandstone and the masonry debris blends, which can be used as more favoured choices in green roof design over their heavier counterparts. The heaviest and the lightest outlined models were subsequently subjected to a weight analysis on the proposed reinforced concrete flat-roofed structure. The results showed that all the extensive green roof samples fall within the IBC stipulated range. The heaviest granite substrate obtained a design load of 0.951 kN/m², while the lightest pumice blend recorded a design load of 0.576 kN/m². This implies that the pumice blend could be used as a potential lightweight substrate for green roof retrofitting projects for existing buildings in the Nigerian building industry.

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