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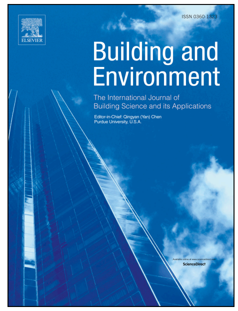

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PII: S0360-1323(18)30222-1

DOI: 10.1016/j.buildenv.2018.04.018

Reference: BAE 5414

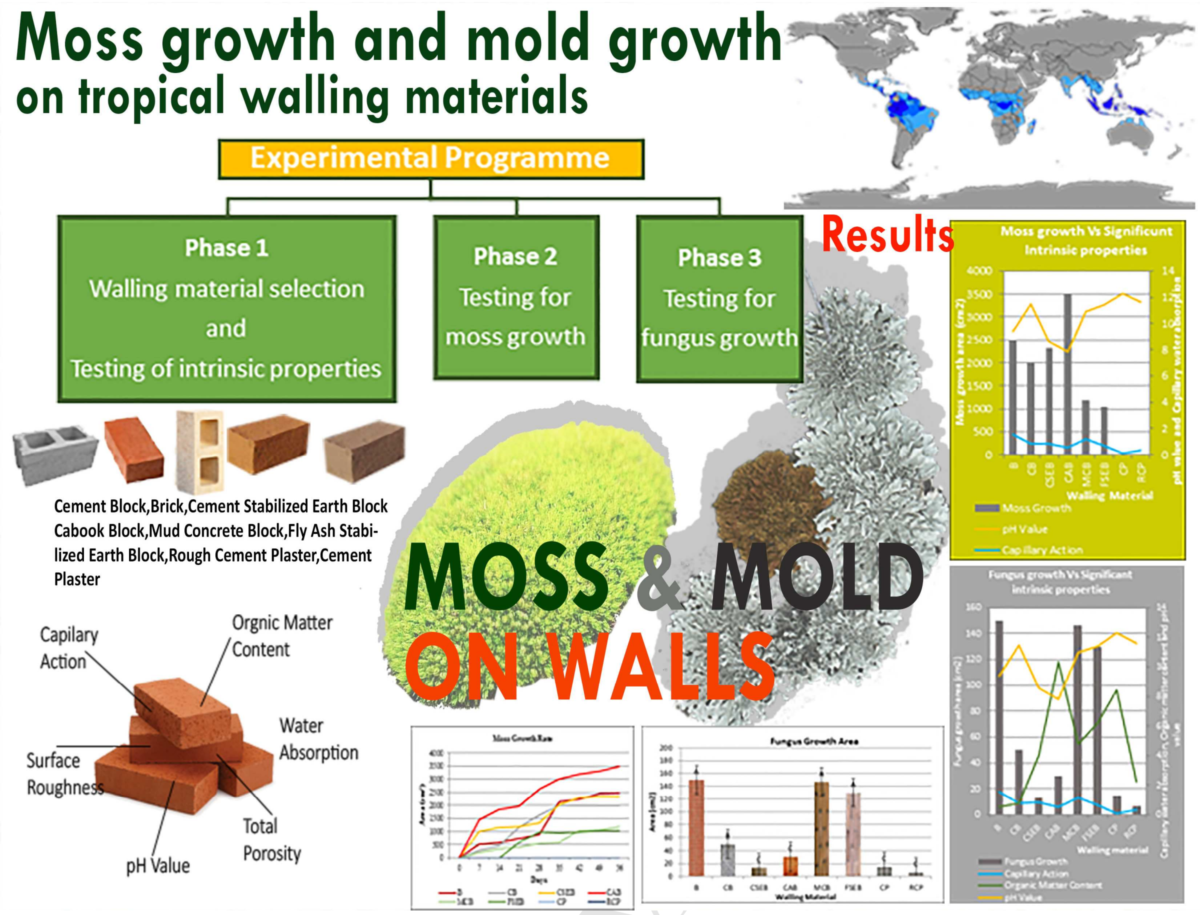
To appear in: *Building and Environment*

Received Date: 1 January 2018

Revised Date: 29 March 2018

Accepted Date: 13 April 2018

Please cite this article as: Udawattha C, Galkanda H, Ariyarathne IS, Jayasinghe GY, Halwatura R, Mold growth and moss growth on tropical walls, *Building and Environment* (2018), doi: 10.1016/j.buildenv.2018.04.018.


Moss growth and mold growth
on tropical walling materials
Experimental Programme
Phase 1
Walling material selection
and
Testing of intrinsic properties
Phase 2
Testing for
moss growth
Phase 3
Testing for
fungus growth
Cement Block,Brick,Cement Stabilized Earth Block
Cabook Block,Mud Concrete Block,Fly Ash Stabi-
lized Earth Block,Rough Cement Plaster,Cement
Plaster
Capilary
Action
Orgnic Matter
Content
Water
Absorption
Surface
Roughness
Total
Porosity
pH Value
MOSS & MOLD
ON WALLS
Results
Moss growth Vs Significant
Intrinsic properties
Walling Material
Moss Growth
pH Value
Capillary Action
Fungus growth Vs Significant
intrinsic properties
Walling material
Fungus Growth
Capillary Action
Organic Matter Content
pH Value
Moss Growth Rate
Days
Fungus Growth Area
Walling Material

Mold growth and Moss growth on tropical walls

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Abstract

The building envelop is generally considered as our third skin. Moss growth and mold growth are constrains which reduce the strength of the third skin. This study is aimed to analyze the effect of the mold growth and moss growth on different walling materials such as Brick, cement blocks, cement stabilized earth block, Cabook, Mud concrete blocks, Geo polymerized earth blocks walls and plastered walls with cement plaster and rough finish plaster in a tropical climate.

Organic matter, surface roughness, water absorption capacity, sorptivity and the capillary action of those walling materials were studied first. After which mold growth and moss growth were conducted in the real world controlled environment to accelerate the mold growth and moss growth. The growth rate and the strength reduction due to the effect of mold growth and moss growth were studied.

The results demonstrate that walling materials with high porous spaces have the high potential to grow moss and mold. The walling materials with the high organic matter also encourage moss and mold growth. Interestingly it was found that even though materials like mud concrete block and geo polymerized earth blocks have high organic matter, their less surface roughness helped to reduce the moss growth and mold growth. And also, plastering can emphatically reduce the speed of mold growth and moss growth.

Keywords: Intrinsic Properties; Mold growth; Moss growth; Tropics; walling material

1 Introduction

The tropical climatic condition is the worst climate condition for building materials [1][2][3][4]. Because, the tropics consist of rain, sun, high humid wind etc. [5][6][3]. The idea of the wall and roof are to protect human beings from these environmental constraints[4][5][6]. Hence, the capacity confronts those environmental constraints by the roof and wall are very important [7][8][9]. Not only environmental constraints but also there are other effects due to those environmental constraints such as weather degradation, scaling off the materials, natural decay, mold growth and moss growth. Molds can be found everywhere and can grow on any material in the presence of moisture. The growth of the mold is due to the pores. When the pores land on building materials they start to reproduce all over the material. Mold can be found in indoor climate as well as the outdoor climate. But the most dangerous mold can be found in indoor produced series of health problems due to a particle size of the mold [10].

Moss growth is subject to outdoor environments except in case of a water leak, which can be found in indoor climates. Moss growth is a common phenomenon in tropical climatic conditions. Moss growth is accelerated due to the rainy weather and stabilized by the materials property. For instant moss, brick is easily subjected to moss growth.

The effect and the growth rate of mold and moss are not properly studied in tropical climatic conditions *(See the table 1).* Tropical climatic condition is the most favorable climate for mold and moss growth.. Therefore it is essential to understand the causes of mold and moss growth in tropical walling Material.

Table 1: Previous studies done in different climatic conditions.

	Source	Year	Climate region	Construction Materials	Study method	Results
1.	Dubosc[11]	2001	Humid Subtropical			
2.	Tran[12]	2014	Oceanic Climate	Mortar	Accelerated growth test	Porosity has an impact on moss growth
3.	Viitanen[13]	2010	Warm Summer Continental	Building Materials and Wall Assemblies	Mold Index evaluation method	Mold growth required 80-95% RH and mold growth depend on ambient temperature, exposure time, the type and surface conditions of building material
4.	Johansson[14]	2005	Warm Summer Continental	Building Materials		Critical moisture condition for mold growth is approximately 75% and higher value for some materials
5.	Hoang[15]	2010	Tropical Wet and Dry	Green Building Materials	Natural inoculation protocol	Presence of organic matter in a building material and its equilibrium moisture content are more important predictors of fungal susceptibility
6.	Safiuddin[16]	2017	Oceanic Climate	Concrete		Concrete structures damage due to moss and mold growth under field conditions and sealers and coating systems can be used to prevent moss and fungus growth
7.	D'Orazio[17]	2014	Oceanic Climate	ETICS and Clay Bricks	Laboratory-accelerated growth test	Bio receptivity of building materials strongly affected by surface roughness and total porosity
8.	Pranjic[18]	2015	Oceanic Climate	Building Stones	Artificial colonization experiments	Bio receptivity of building stones is influenced by intrinsic properties, environmental parameters and specific microclimatic parameters
9.	Johansson[19]	2013	Warm Summer Continental	Building Materials	Laboratory test	There is a critical moisture level for mold growth on each building material
10.	Ozolins[20]	2014	Warm Summer Continental	Plywood, Wooden Logs and Aerated Concrete		Moisture have a negative influence on the building constructions and vapor barrier effectively decrease the mold growth risk
11.	Black[21]	2014	Continental Climate	Wood Frame Wall Assemblies	Laboratory – accelerated growth test	The presence of liquid water greatly reduced the time to germination, the amount of mold growth, and the rate of mold growth and the borate treatment of the plywood increased the time to germination significantly
12.	Johansson[22]	2012	Warm Summer Continental	Building Materials	Laboratory test	Microbial growth can be minimized by selecting building material which is tolerant to the expected conditions and the resistance is differ with the material type
13.	Fantucci[23]	2017	Mediterranean climate	Buildings		The fine insulation rendering coating have significant effect on the mold growth risk reduction
14.	Moller[24]	2017	Oceanic Climate	Interior Surfaces	Laboratory Experiment	Dry building materials are more resistant to mold growth at high humid conditions for a limited time period and organic materials are more prone to mold growth
15.	Wahab[25]	2013	Tropical Climate	Buildings	Condition survey method	A research is needed to study mold growth in tropical climate building and suggest a various causes of mold growth that need to be considered
16.	Stefanowski [26]	2017	Oceanic Climate	Bio based construction and insulation products	Novel screening method	Chipboard was the most susceptible to mold growth and wool the least when in direct and indirect contact with agar
17.	Johansson[27]	2014	Warm Summer Continental	Building materials	Laboratory test	Mold growth resistant building materials can be selected by determining the critical moisture level and the RH of the material
18.	Setyono[28]	2012	Tropical Climate	Cement and Fly-ash Mixture	Laboratory test	Greater the fly-ash percentage of the mixture higher the resistance of moss growth
19.	Thiis[29]	2015	Oceanic Climate	Wooden Claddings	Laboratory test	Wind, building direction and temperature and RH variation with the time are effect on moss growth
20.	Gradeci[30]	2017	Oceanic Climate	Timber Building Envelopes	Probabilistic-based approach as	The mold growth behavior is very sensitive to the decision of which parameters are considered, and consequently, attention is required when analyzing and interpreting the outcomes

Bio receptivity is also an important indicator of the durability of the construction materials. Flooding, leaky roofs, building-maintenance or indoor-plumbing problems can lead to interior mold growth. Water vapor commonly condenses on surfaces cooler than the moisture-laden air, enabling mold to flourish [5]. This moisture vapor passes through walls and ceilings, typically condensing during the winter in climates with a long heating season. Floors over crawl spaces and basements, without vapor barriers or with dirt floors, are mold-prone. The "doormat test" detects moisture from concrete slabs without a sub-slab vapor barrier [6].

On the other hand, some of the Architects and landscape designers prefer to have moss-grown materials. This is due to the beauty of the materials after the moss growth. Most of the landscaping was done after the aging the materials into moss growth surfaces. The most popular techniques are to paint curd on walls which need to be covered with moss. Therefore, the study of micro logy is very important to reduce and increase the moss growth. Moss growth occurs due to the algae growth on walling materials. Algae is pioneer colonizer, who settle and grow on rough surfaces. The growth speed is encouraged by physical factors such as relative humidity, exposure to the wind, light etc. And the growth speed is encouraged by biotic factors such as the amount of nutrients available and bio receptivity.

The concept of bio receptivity is the ability of a material to be colonized by living organisms. And it considerably counts for the materials property such as materials porosity, surface roughness capillary actionability and the pH value of the material. Natural observations show that unplastered walls with high surface rough walling materials are bio receptive than plastered and painted outdoor walls. And also, plastering and painting shall reduce the (rain) water retention capacity. By improving the surface the bio-film formation can be reduced.

A bio-film is a web sort of formation covering the surface of the walling material. It's a complex microbial population embedded in the matrix. However, the walling materials can be damaged, scaled off by the bio-film formation. And this will eventually reduce the durability of the material. This is defined as biodeterioration. Biodeterioration and the damages due to bio filming on walling materials were tested and evaluated by series of accelerated growth tests. The growth and the growing speed were quantitatively determined to achieve the research objectives.

1.1 Objectives

The objectives of this study were to understand the moss growth and mold growth effect on different walling materials in a tropical climate like Sri Lanka. The tropical climate is a harsh climate for building materials. The most common walling materials in Sri Lanka and newly invented walling materials were subjected to this study. By determining the novel walling materials is an additional objective to determine the quality of novel walling materials.

The research was initiated to understand the effect of plaster and their strength of to reduce the moss growth and mold growth. But then it was realized that economically disadvantaged people in the country cannot afford the plastering. Instead, they are using paint the rough wall and use it in raw condition. Therefore, the extensive study was conducted with naked walling materials as well in order to optimize the mold growth effect on different walling materials in Sri Lanka. However, the effect of painting weather shielding and water proofing are covering wide varieties, therefore, for this study we omitted paint works, and painted walls.

In addition to the moss and mold growth analyses, aimed at evaluating the materials physical properties which accelerate the microalgae coverage. This was done by evaluating and comparing materials properties. The study techniques included were new analytical approaches such as 3D scanning by using the3D scanner.

1.1.1 Climate and weather condition

Sri Lanka is having high humid climate. This is due to the monsoon rain and the ocean belt surrounding the island. Not only monsoon, but there are many reasons to produce regional rain during the year. The impact of the rain accelerates the moss growth and mold growth [31][32][33]. The impact of high humid is also governed by the high temperature. The country is located near the equator. Therefore, the heat radiation comes at a degree of 5^0. This is critical in some seasons when the day temperature goes beyond 35^0C and night temperature goes below 25^0C *(see the* Figure 1*).*

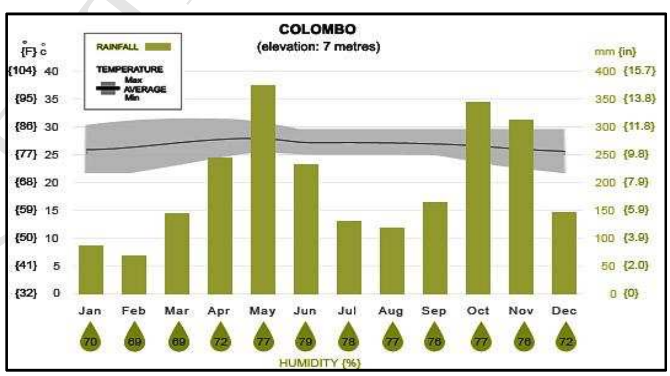


Figure 1: Climate and weather condition variation in Colombo

2 Phases, materials and methods

2.1 Phases

Experimental activities were split into three main phases: (i) material properties tests (ii) moss growth test; and (iii) mold growth test shown in Figure 2. In the first phase, materials were selected for the study and material properties were tested. Specimens of the selected materials were studied for their organic matter content, water absorption (W_a), total porosity, capillary action (as water absorption coefficient, A), pH value and surface roughness (as arithmetical mean roughness, R_a). In the second phase walling samples were constructed and moss growth under accelerated environmental conditions was assessed. In the final phase the specimens were prepared for the mold growth test and mold coverage was assessed by visual inspection.

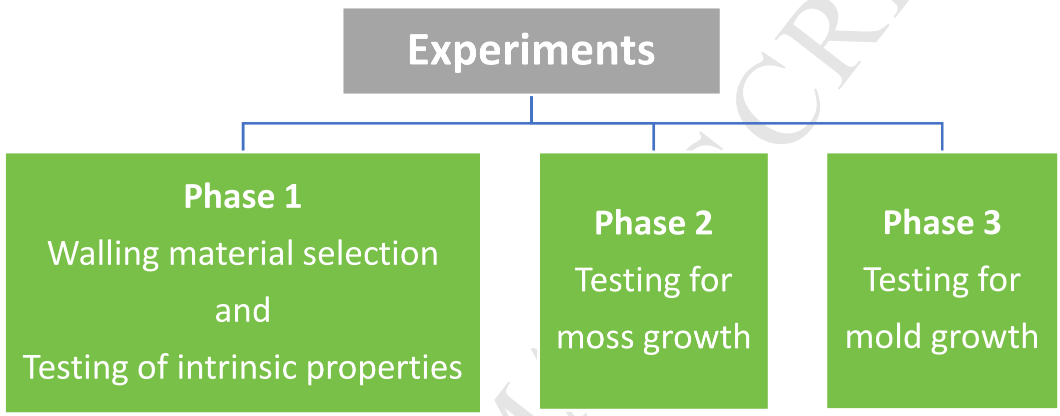


Figure 2: Three phases of this experiment

2.2 Material properties tests

2.2.1 Material selection

The basal focus of this study is to understand the durability of walling materials in tropical climates. Therefore, the most common walling materials were selected for the study such as brick, cement block and Cabook [34][35][36]. In addition to that the greenest walling materials such as cement stabilized earth blocks mud concrete blocks [37] and fly ash stabilized blocks were selected [38]. And also, the most common technology is to plaster walls with river sand or plaster walls with Portland cement [39]. Therefore, another two materials such as Portland cement putty plastering and typical rough plastering were selected. Three samples of each material were tested for each intrinsic property. All the selected walling materials and their abbreviations are shown in Table 2.

Table 2: Specimens identification.

Walling material	Specimen code	Description
Cement Block	CB	Cement block is the cheapest walling materials made by using quarry dust and cement. These materials are available in hardware stores.
Brick	B	Brick is the most common walling material made by using clay. These materials are available in hardware stores.
Cement Stabilized Earth Block	CSEB	Cement Stabilized Earth Block is a novel green walling material. These materials are supply by specific suppliers.
Cabook Block	CAB	Cabook block is a naturally extracted walling material. These materials are available in hardware stores.
Mud Concrete Block	MCB	Mud Concrete Block is a novel green waling material introduce to tropics and they were casted.
Fly Ash Stabilized Earth Block	FSEB	Fly Ash Stabilized Earth Block is a novel green waling material introduced to tropics and they were casted.
Rough Cement Plaster	RCP	Rough Cement Plaster is a common wall plaster use for tropical walls. The plaster is made using cement, sand and water.
Cement Plaster	CP	Cement Plaster is a common wall plaster use in tropics. The plaster is made using cement and water.

2.3 Organic matter content

Organic matter content is an important characteristic for bio receptivity of the material. Organic matter content of the specimens was tested according to the ASTM D2974-00 test standards[40]. Materials were grinded and dried in an oven for 24 hours' time at 100^{0}C temperature until no change of mass occurred. Oven dried samples were burned in a muffle furnace for 48 hours at 440^{0}C temperature until no change of mass occurred. The weight of the samples was measured after samples were completely ashes to determine the ash content (%). Organic matter content was calculated using following equation 1.

$$Organic matter content(\%) = 100 - Ash content\ (\%) \quad (1)$$

2.4 Water absorption

Water is the main requirement for the bio receptivity[41]. Walling materials absorb water when they are immersed in water or subject to a high relative humidity environment[15]. Water absorption test was conducted to measure the relative amount of water absorbed by specimens. ASTM C272/C272M - 12 test standards[42] were used for the test. Specimens were dried in an oven for 24 hours at 100^0C temperature. The specimens weight, length, width, and thickness were measured. Dried specimens were horizontally immersed in a water container for 24 hours. Immersion specimens' weight was measured after removing surface water. Water absorption was calculated using following equation 2.

$$Water\ absorption\ (gcm-3) = \frac{W-D}{V} \quad (2)$$

Where:

h = specimen height, cm
l = specimen length, cm
w = specimen width, cm
V = specimen volume = l × w × h, cm^3
D = pre-immersion mass of the specimen, g
W = specimen mass after immersion and blotting, g

2.5 Total porosity

Porosity is the measure of the amount of void spaces present in the material. The high porosity increase water absorption capacity of the material[43]. The total porosity (ϕ) is defined by the ratio of the volume of void space (VV) to the total, or bulk volume of the material (VT). To test total porosity specimens were dried in an oven for 24 hours at 100^{0}C temperature and specimens' weight, length, width and thickness were measured. Dried specimens were horizontally immersed in a water container for 24 hours. Immersion specimens' weight was measured after removing surface water. Absorbed water volume (cm^{-3}) by the material was calculated by dividing absorbed water mass (g) by the density of water (1 g/cm^{-3}). Absorbed water volume was used as the volume of void space of the material. Total or bulk volume of the material was calculated using specimens' length, width and thickness measurements. Total porosity was calculated using following equation,

$$Porosity(\phi) \ = \frac{VV}{VT} (3)$$

2.6 Capillary action

Capillary action test was conducted according to the ASTM C1585 - 13 test standards[44]. Specimens of each material were tested. Four side surfaces of the specimens were sealed by painting water base. The end of the specimen that will not be exposed to water was sealed using a loosely attached plastic sheet. Specimens were sealed to avoid evaporation from the specimen surfaces. Dimension of each specimen surface area, which is exposed to water, was measured and the mass of each specimen was measured. The supported device was placed at the bottom of the pan and the pan was filled with tap water and the water level was maintained at 1 to 3 mm above the top of the support device. The weight was recorded at the time periods according to the ASTM C1585 – 13 test standards. Capillary water absorption (I) was calculated by dividing the changing mass by cross-sectional area of the specimen and the density of water. Capillary water absorption coefficient was calculated using following equation 4.

$$I = \frac{mt}{(a \times d)} (4)$$

Where

I = absorption (mm)

mt = the change in specimen mass (g)

a = the exposed area of the specimen (mm-2)

d = the density of water (gmm-3) (0.001 gmm-3)

The initial rate of capillary water absorption ($mms^{-1/2}$) of the material was calculated as the slope of the line that is the best fit to I plotted against the square root of time ($s^{1/2}$).

2.7 pH value

pH value is determined by the concentration of the available hydrogen ions (H^+). pH value is measured on a negative logarithmic scale of hydrogen ion concentration. pH values are vary from 0 to 14; pH values between 0 – 7 referred as acidic, values between 7 – 14 referred as basic or alkaline and pH 7 referred as neutral. Using the pH values, acidity or alkalinity of the walling materials can be determined which is effect on the bio receptivity. Biological growth on walling materials is sensitive to the acidity, alkalinity or neutral condition of the material. Fungus and moss species vary with the pH value; because some species prefer acidic conditions and some prefer alkaline conditions while rest of others prefers neutral conditions[45][46].

pH value of walling materials were measured according to ASTM D 4972 – 95a test standards[47]. Walling materials were grinded to powder and dissolved in water. 10 g of the material was dissolved in 20 m*l* of distilled water. The mixture was thoroughly mixed and kept for 1 hour and the pH values of the solutions were measured using a pH meter.

2.8 Surface roughness

Surface of a material is the boundary that separates the material from another material or substance. Surface roughness can be defined as the measure of the texture of a material surface [48]. Surface roughness of the material is directly effect on the bio receptivity of the material. Because surface roughness determine the surface area of the material and the amount of water retains on the material surface. When the surface roughness of the material is high material surface area is high; which can provide more surfaces for the bio receptivity. Also materials with high surface roughness value can hold more amount of water on the surface; which accelerate the bio receptivity of the material [17].

Surface roughness of the material can be quantified by the vertical deviations of a real surface from its ideal form. If the deviations are great the material surface is rough and if the deviations are small material surface is smooth. Surface roughness of each material was measured by 3D scanning the material sample as shown in figure 3. This is the latest technology to measure the surface roughness and quantified the surface roughness. There are two outputs can be taken by the 3Dscanner (i) Sectional profile of the material (ii) 3D profile of the material. And also we can evaluate the walling surface property after contamination.

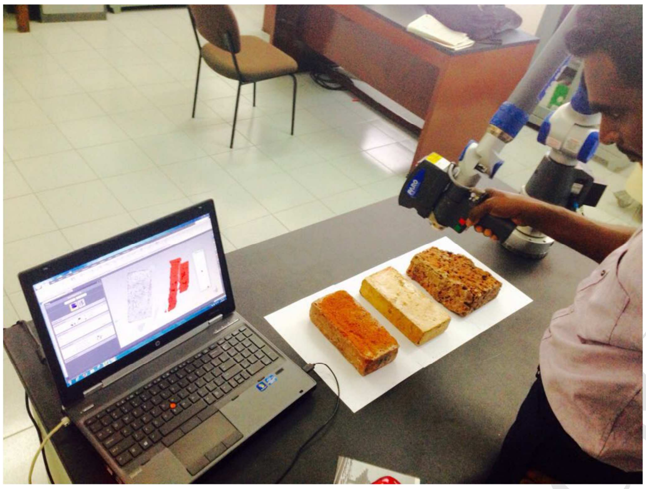


Figure 3: Studying surface roughness by using 3d scanner

3 Moss growth test

3.1 Manufacturing of walling materials for the experiment

Most of the walling materials are available in Sri Lankan construction material market such as B, CB and CAB. Therefore, they were collected from a nearby store. But there are some novel walling materials such as CSEB which can only be found from a specific supplier. MCB and FSEB were casted because they can be produced at the lab scale according to the standards.

3.2 Construction of wall samples

An area with a shade and natural sun light was selected for wall samples construction. A concrete beam with 25 cm height from the ground was constructed as the base. A bituminous paint layer was painted on the top of the base to prevent capillary rise of groundwater through walling materials. Ground water can accelerate the moss growth [49]. 1 m x 1 m wall from bricks, cement blocks, CSEB, cabook blocks, MCB, FSEB and two additional brick walls were constructed on the beam with 50 cm gaps between each wall sample. One of the additional brick wall was plastered with rough cement plaster and other one is plastered with cement plaster. A small roof was mounted on the top of each wall sample to prevent rain water accumulation on to the top of the wall *(see the* Figure 4*).*

Figure 4: Wall samples

Wall samples were constructed in a way that all walls can obtain same environmental conditions evenly. Sun direction, sun angle, shading, wind direction and all other environmental conditions were same for each wall sample.

3.3 Preparation and application of moss culture media

Materials –

- Existing sample of moss (dead or alive)Water
- Buttermilk
- A blender
- A paintbrush

Culture Media Preparation

There are four basic moss types. They are sheet moss, cushion moss, haircap moss and rockcap moss. Cushion moss is the most common moss type on walls in tropics. Therefore, we used cushion moss which was grown on a brick wall as the existing moss sample. The common method [50] used to grow moss in landscape architecture was used to moss culture media preparation.

Equal amount of water and buttermilk were measured and blended. Existing moss was added to the mixture; moss: liquid mixture ratio at 1: 4. All ingredients were blended until having a fine liquid mixture; until existing moss cannot be separated. The mixture was painted as two layers on one surface of the each wall sample as 500 ml per square meter using a paintbrush. Wall samples were wetted with water twice a day to prevent walls from drying shown in Figure 5.

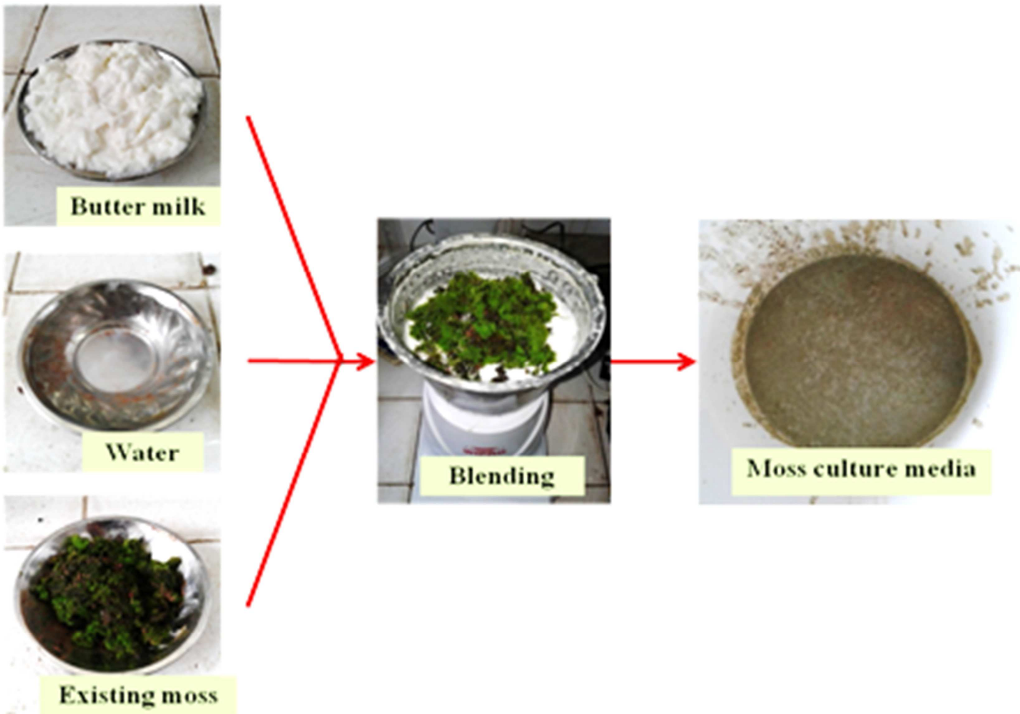


Figure 5: Preparation of moss culture media

3.4 Evaluation of moss growth

Moss growth area of each wall sample was measured weekly for period of three month (from 29th August 2017 to 2nd November 2017) time duration. Photos of walling materials were taken weekly to evaluate the color change due to the moss concentration variation with the time.

4 Mold growth test

4.1 Test specimens

Mold growth test was conducted according to the ASTM D3273-94 test standards[51][52][53]. This test evaluates the relative resistance of materials to surface mold and mildew growth in a severe environment over a 4-week period. The test utilizes a pan of moldy soil that continuously releases fungal spores in a high humidity, a warm temperature chamber, and challenging test pieces suspended above the soil for 28 days. Fungal growth is based on visual defacement using a 0 to 4 rating scale with 4 being completely covered with growth and 0 being clean. The walling samples of eight different materials were constructed according to the sample size of 150 x 100 x 7 mm^3.

4.2 Fungus culture

Potato dextrose agar media was prepared according to the procedure recommended in the Bacteriological AnalyticalManual.200g unpeeled potatoes were sliced and boiled in 1 l distilled water for 30 min and filtered through cheesecloth; saving effluent, the potato infusion. 100 ml of the infusion and other ingredients were added into a flask and ingredients were mixed and boiled to dissolve. The media was gently agitated during the heating process by shaking the flask.

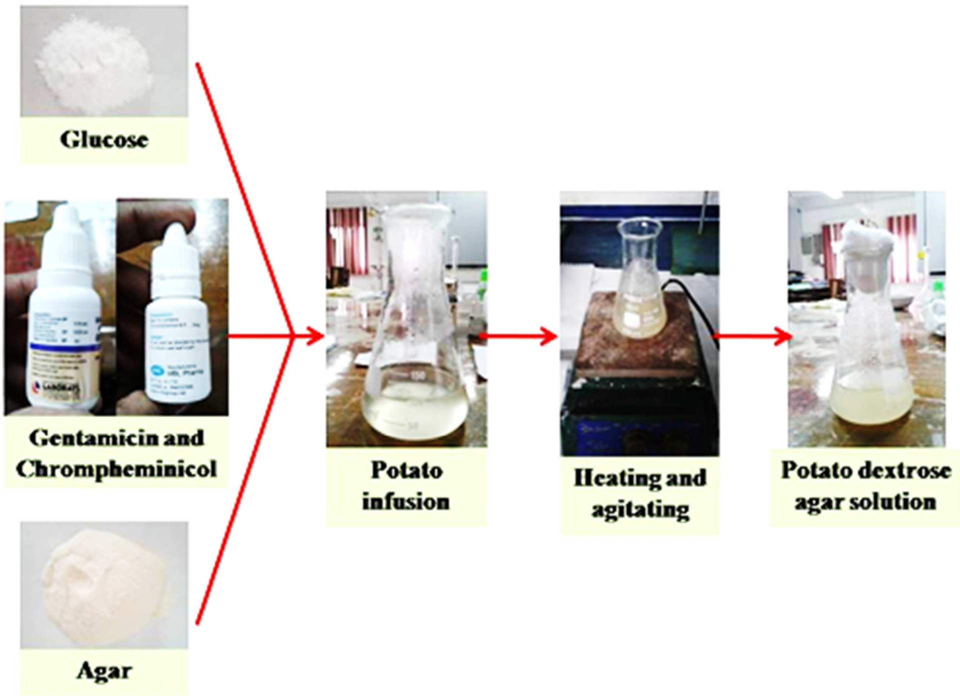


Figure 6: Preparation of potato dextrose agar solution

The flask with the media was capped loosely with cotton *(see the* **Error! Reference source not found.***)*. Media was sterilized in an autoclave for 15 min at 121^{0}C temperature and 15 psi pressure. Glassware (petri dishes) was sterilized in an autoclave for 30 min at 121^{0}C temperature and 15 psi pressure.

The flask was cooled for 20 min and the media was poured into sterilized petri dishes about one-half full. The petri dish was covered and allowed agar to solidify; see the Figure .

Figure 7: Sterilization and solidification of agar media

4.2.1 Culture Transformation

Culture transformation is shown in. Inoculating loop was flamed and cooled to disinfection. Small quantity of the stock culture was picked up using the loop. The cover of the petri dish was raised gently, and the loop was touched to the top of the dish and streaked from side to side all the way to the bottom edge to have a zigzag pattern from edge to edge. The petri dish was incubated for 7 days.

4.2.2 Environmental chamber

A glass chamber shown in figure 8 was prepared as the environmental chamber. A mold growth media was prepared by mixing top soil, coir dust and compost according to the ratio of 2:1:1. The chamber was filled with the wetted growth media at 2.5cm height. The chamber was equilibrated for 24 hours in 32^{0}C.

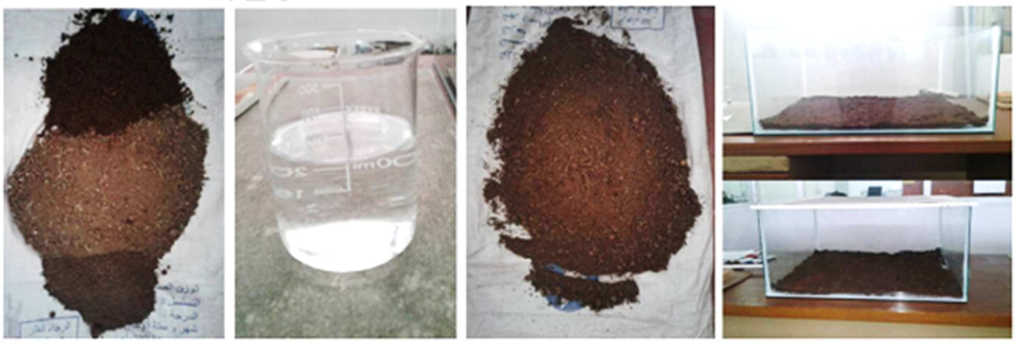


Figure 8: Preparation of fungus growth media

Prepared mold suspensions were evenly spreaded over the mold growing media and incubated for 14 days as shown in figure 9.

Figure 9: Distribution of fungus suspension and incubation

After 14 days the test specimens of three samples of each walling material were vertically hanged in the environmental chamber; from 50 mm above the media surface. The statistical design of completely randomized design (CRD) method was used to understand the mold growth rate. Environmental chamber conditions were controlled as; temperature at 27^0C and relative humidity at 98%. The experiment was conducted from 31st August 2017 to 6th October 2017.

Figure 10: Fungus test

4.2.3 Evaluation criteria

Mold growth on the surface of the specimens packed in the chamber shown in Figure was assessed weekly by visual inspection coupled with camera images. Mold covered surface area of specimens were rated according to the rating criteria of ASTM D3273-94; as in the table 3. After 4 weeks microscopic images of fungus were taken to identify the fungus species.

Table 3: Mold growth-rating criteria.

Rating	Mold coverage
0	No growth
1	0 - 10%
2	11 - 30%
3	31 - 60%
4	61 - 100%

4.3 Data Analysis

One-way ANOVA was carried out to identify the significant differences between tested eight materials considering their intrinsic properties, moss growth and fungus growth and Tukey Pairwise comparisons was carried out to indicate highly significant material. Calculated data of moss growth and fungus growth were subjected to a multiple regression analysis to identify the significant intrinsic properties. Significance of differences was defined at p-value < 0.05. Minitab 18 data analysis software was used to perform the statistical analysis. Mean separation was done by using Tukey Pairwise.

5 Results and Discussion

5.1 Intrinsic Properties

Intrinsic properties of each material were tested and porosity, surface roughness, capillary water absorption, water absorption, organic matter content and pH values were measured as shown in Table 4.

Table 4: Intrinsic properties of walling materials

(B = Brick, CB = Cement Block, CSEB = Cement Stabilized Earth Block, CAB = Cabook Block, MCB = Mud Concrete Block, FSEB = Fly-ash Stabilized Earth Block, CP = Cement Plaster, RCP = Rough Cement Plaster) ((n = 3), Means that do not share a same letter; along each column, are significantly different according to DMRT)

	Porosity (f) (%)	Surface Roughness (R_a) (μm)	Capillary Action (I) ($mms^{-1/2}$)	Water Absorption (gcm^{-3})	Organic Matter Content (%)	pH Value 5.1.1
B	28.9^{a}	133.03^{h}	1.578^{a}	0.29^{a}	0.51^{h}	9.42^{f}
CB	17.8^{b}	1149.17^{b}	0.814^{d}	0.18^{b}	0.82^{g}	11.49^{c}
CSEB	28.8^{a}	292.1^{e}	0.832^{c}	0.29^{a}	4.02^{e}	8.6^{g}
CAB	15.1^{b}	2575.65^{a}	0.568^{f}	0.15^{b}	10.36^{a}	7.81^{h}
MCB	34.5^{a}	1147.67^{c}	1.196^{b}	0.35^{a}	4.76^{d}	10.95^{e}
FSEB	13.7^{b}	197.46^{g}	0.672^{e}	0.14^{b}	6.22^{c}	11.4^{d}
CP	14.9^{b}	208.71^{f}	0.082^{h}	0.15^{b}	8.45^{b}	12.28^{a}
RCP	15.3^{b}	890.62^{d}	0.352^{g}	0.15^{b}	2.23^{f}	11.63^{b}

5.1.2 *Porosity of walling materials*

Porosity of walling materials is shown in Table 4 and the values are in the range of 13.7% - 34.5%. Mud Concrete Block has the highest porosity value and Fly Ash Stabilized Earth Block has the lowest. Porosity of Brick, Cement Stabilized Earth Block and Mud Concrete Block were not significantly different from each other and they were significantly different from other five materials. Porosity of Cement Block, Cabook Block, Fly Ash Stabilized Earth block, Cement Plaster and Rough Cement Plaster were not significantly different from each other and they were significantly different from other three materials.

5.1.3 *Surface roughness of walling materials*

Surface roughness of walling materials is shown in Table 4 and the values are in the range of 133.03µm – 2575.65µm. Cabook Block has the highest surface roughness value and Brick has the lowest. All eight materials' surface roughness values are significantly different from each other.

5.1.4 *Capillary water absorption of walling materials*

Capillary action of walling materials is shown in Table 4 and the values are in the range of 0.082mms$^{-1/2}$ – 1.578mms$^{-1/2}$. Brick has the highest capillary water absorption and Cement Plaster has the lowest. All eight materials' capillary water absorption values are significantly different from each other.

5.1.5 *Water absorption of walling materials*

Water absorption of walling materials is shown in Table 4 and the values are in the range of 0.14gcm^{-3} – 0.35gcm^{-3}. Mud Concrete Block has the highest porosity value and Fly Ash Stabilized Earth Block has the lowest. Porosity of Brick, Cement Stabilized Earth Block and Mud Concrete Block were not significantly different from each other and they were significantly different from other five materials. Porosity of Cement Block, Cabook Block, Fly Ash Stabilized Earth block, Cement Plaster and Rough Cement Plaster were not significantly different from each other and they were significantly different from other three materials.

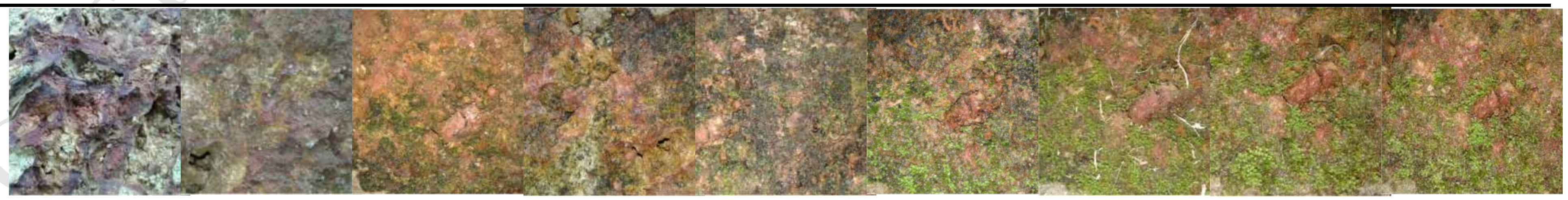
5.1.6 Organic matter content of walling materials

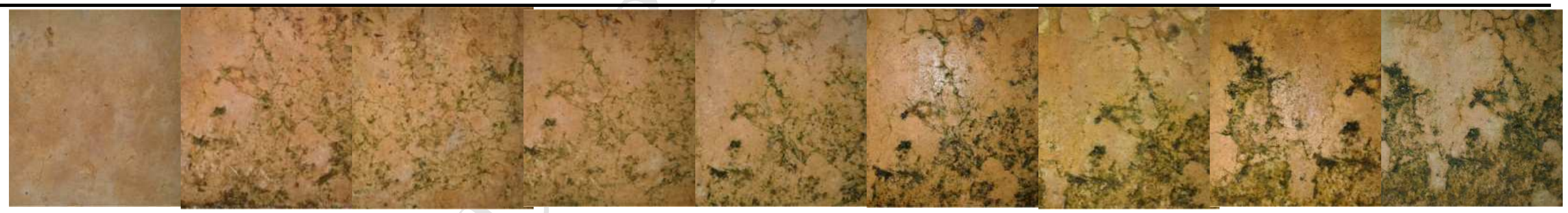
Organic matter content of walling materials is shown in Table 4 and the values are in the range of 0.51% - 10.36%. Cabook has the highest organic matter content and Brick has the lowest organic matter content. All eight materials' organic matter contents are significantly different from each other.

5.1.7 pH value of walling materials

pH values of walling materials are shown in Table 4 and the values are in the range of 7.81 – 11.63. Cement Plaster has the highest pH value and Cabook has the lowest pH value. All eight materials' pH values are significantly different from each other.

Table 6: **Comparison** of color change of walling materials (photos were taken weekly representing the worst case on each wall)

	0 days	7 days (1 week)	14 days (2 weeks)	21 days (3 weeks)	28 days (4 weeks)	35 days (5 weeks)	42 days (6 weeks)	49 days (7 weeks)	56 days (8 weeks)
B									
CB									
CSEB									
CAB									

	0 days	7 days (1 week)	14 days (2 weeks)	21 days (3 weeks)	28 days (4 weeks)	35 days (5 weeks)	42 days (6 weeks)	49 days (7 weeks)	56 days (8 weeks)
MCB									
FSEB									
CP									
RCP									

5.1.8 Comparison of moss growth area

Moss growth areas of eight wall samples were measured weekly as shown in Figure 11. Cabook wall sample has the highest moss growth and no moss growth appeared on Cement Plaster and Rough Cement Plaster wall samples during the observed two months time period. Mud Concrete Block and Fly Ash Stabilized Earth Block wall samples have comparatively low moss growth.

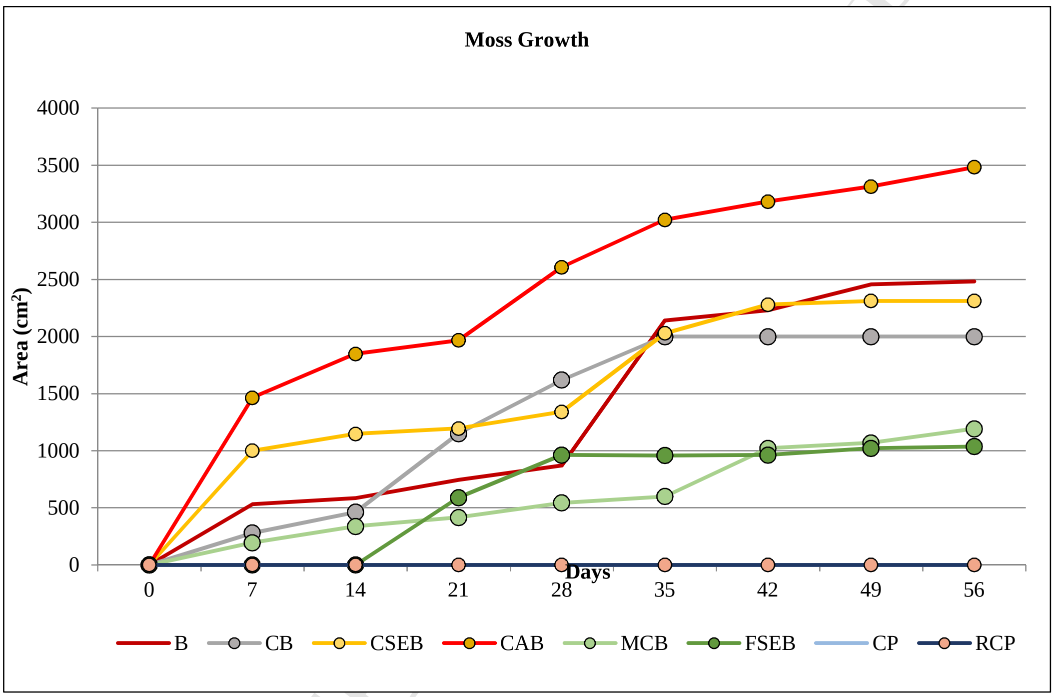


Figure 11: Moss growth rate of walling materials

(B = Brick, CB = Cement Block, CSEB = Cement Stabilized Earth Block, CAB = Cabook, MCB = Mud Concrete Block, FSEB = Fly-ash Stabilized Earth Block, CP = Cement Plaster, RCP = Rough Cement Plaster)

5.1.9 Variation of moss growth with intrinsic properties

In the experiment, p values of pH value and capillary water absorption were lower than 0.05 ($P<0.05$). pH value (P-value = 0.000) and capillary water absorption (P-value = 0.005) are the significant intrinsic properties of walling materials effect on the moss growth (Figure 12); bio receptivity of walling materials is effected by intrinsic properties of the material[18][54]. There is a positive correlation (Coef = +1288) between moss growth and capillary water absorption of the material and the correlation between moss growth and pH value is negative (Coef = -524.9) (*see the figure 12)*.

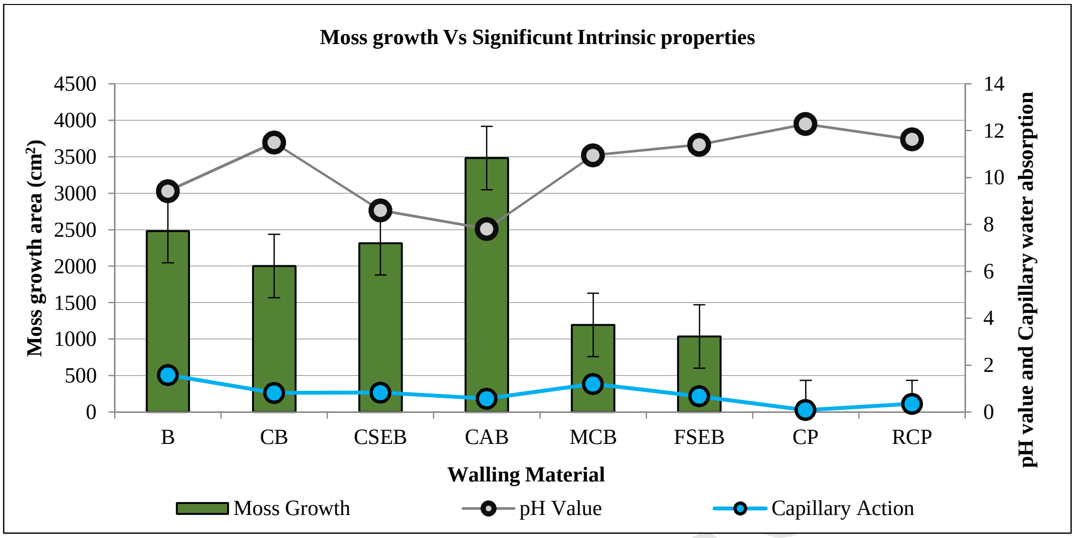
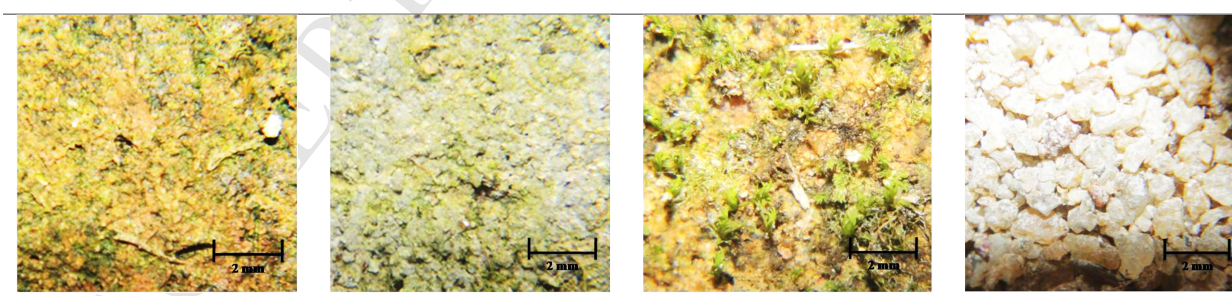


Figure 12: Moss growth Vs. Significant Intrinsic properties

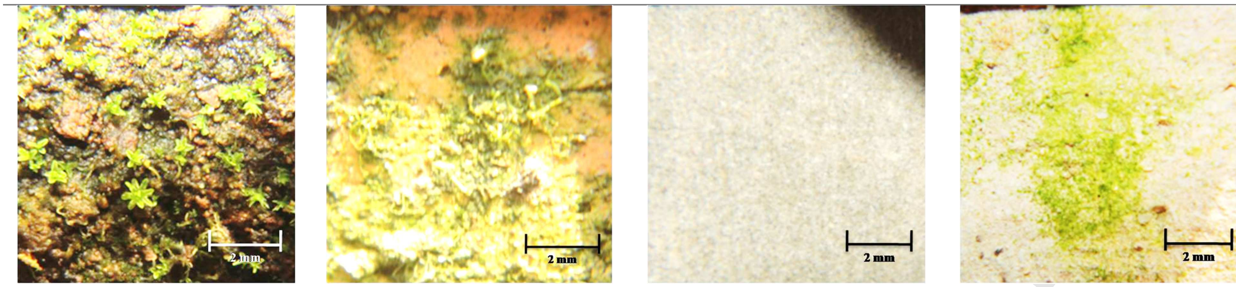
(B = Brick, CB = Cement Block, CSEB = Cement Stabilized Earth Block, CAB = Cabook, MCB = Mud Concrete Block, FSEB = Fly-ash Stabilized Earth Block, CP = Cement Plaster, RCP = Rough Cement Plaster)

5.1.10 Comparison of moss growth

At the end of the two months moss growth on walling samples were different to each other as shown in Figure 13. There was no moss grown on Cement Plaster and Rough Cement Plaster; Cement Plaster and Rough Cement Plaster is a successful moss growth preventive method on walls but it cannot be recommended due to the environmental impacts of cement production. A dense moss growth was observed on the Cabook wall sample. Comparatively thicker moss growth was observed on the Fly Ash Stabilized Earth Block wall samples.



B	CB	CSEB	RCB



CAB	MCB	CP	FSEB

Figure 13: Moss growth on walling materials after two months

5.2 Mold Growth Test results

5.2.1 Comparison of mold growth

Fungus growth height on the walling material samples were observed weekly and rated according to the rating criteria of ASTM D3273-94 as shown in the Figure 14.

Brick has the highest fungus growth and the cement stabilized earth block has comparatively low fungus growth as shown in Figure 14. The test was conducted using dry specimens; the results can differ if the specimens were wet before the study, further study is required to study fungus growth on wet specimens.

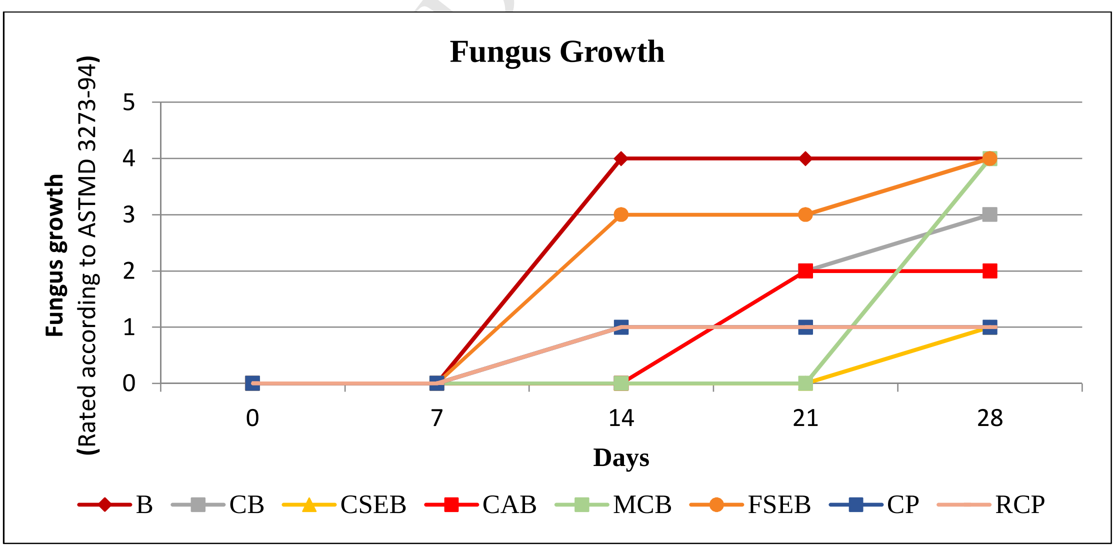


Figure 14: Fungus growth of walling materials

(B = Brick, CB = Cement Block, CSEB = Cement Stabilized Earth Block, CAB = Cabook, MCB = Mud Concrete Block, FSEB = Fly-ash Stabilized Earth Block, CP = Cement Plaster, RCP = Rough Cement Plaster)

5.2.2 Variation of fungus growth with intrinsic properties

In the experiment, p values of organic matter content, pH value and capillary water absorption were lower than 0.05 (P<0.05). Organic matter content (P-value = 0.003), pH value (P-value = 0.001) and capillary water absorption (P-value = 0.000) are the significant intrinsic properties of walling materials effect on the fungus growth (Figure 16); bio receptivity of walling materials is effected by intrinsic properties of the material [17][18]. . There is a positive correlation between fungus growth and intrinsic properties (organic matter content (Coef = +11.56), capillary water absorption (Coef = +217) and pH value (Coef = +26.61)) of the material.

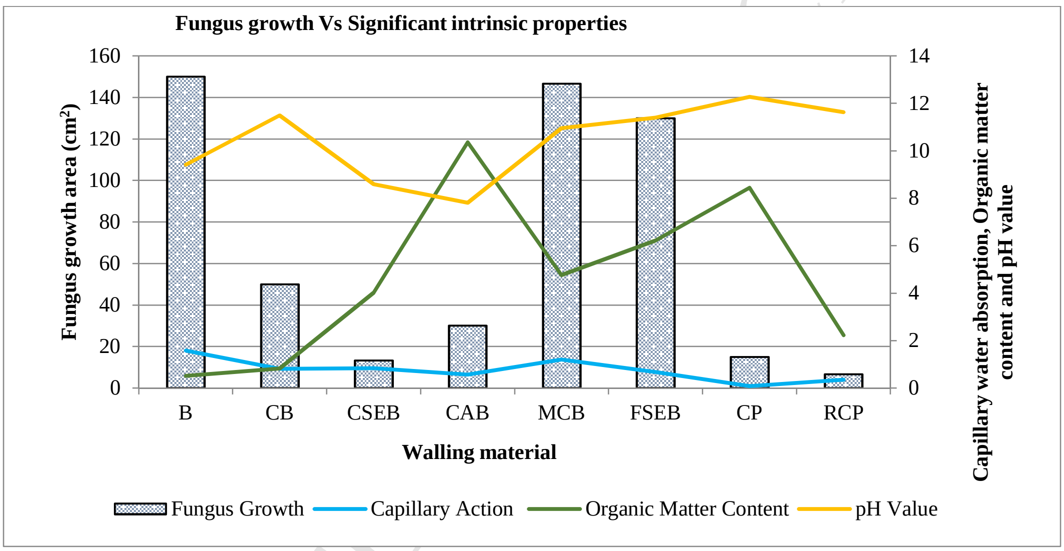


Figure 15: Fungus growth Vs. Significant intrinsic properties

The figure 15 shows the results of intrinsic properties and the mold growth effect of different walling materials. The pH value shows significant impact on mold growth. According to literature, the pH content directly helps to enhance the mold growth. But on the other hand there are mold species accelerated the growth due to pH and some are discouraged by pH content.. Figure 15 clearly shows there is a positive relationship between capillary action and mold growth. The mold needs some moisture. Usually these walling materials are dry. But the connection to the ground can create water absorption from the bottom to the roof depending on the capillary capacity. Therefore, this finding is interesting the fact that water absorption and capillary action can increase the mold growth on walling materials. Mould growth required moisture for the growth on the material surface. Materials with high water holding capacity (high surface roughness value) supports mold growth. Materials with high surface roughness and low organic matter content facilitate mold growth rather than materials with low surface roughness and high organic matter content. Therefore the findings show that materials with smooth surfaces are more resistant to mold growth even though they contain high organic matter. But actually organic matter may cause the mold growth is the surface organic matter. However, the result doesn't show any significant relationship between organic matter and mold growth.

6 Conclusion

Walling materials are prone to fungus and moss growth under the tropical climatic conditions. Moss does not growth on cement plaster and rough cement plaster and the fungus growth is lower on cement plaster and rough cement plaster. Cement plaster and rough cement plaster protect walling materials from fungus and moss growth under tropical climatic conditions; cement plaster and rough cement plaster cannot be recommended as a sustainable solution due to the environmental impacts and high cost of cement usage.

Porosity of walling materials varied in the range of 13.7% - 34.5%. Water absorption of walling materials varied in the range of $0.14gcm^{-3}$ – $0.35gcm^{-3}$. Surface roughness of walling materials varied in the range of 133.03**μ**m – 2575.65**μ**m. Capillary water absorption of walling materials varied in the range of $0.082mms^{-1/2}$ – $1.578mms^{-1/2}$. Organic matter content of walling materials varied in the range of 0.51% - 10.36%. pH values of walling materials varied in the range of 7.81 – 11.63.

Cabook is the most susceptible walling material to moss growth and fly ash stabilized earth block is the least susceptible to moss growth under tropical climatic conditions. Brick is the most susceptible walling material to fungus growth and cement stabilized earth block is the least susceptible walling material to fungus growth.

Moss growth on walling material depends on the capillary water absorption and the pH value of the material. By increasing pH value and reducing capillary water absorption of the walling material moss growth resistant walling material can be produced.

Fungus growth on walling material depends on the capillary water absorption, organic matter content and the pH value of the material. By reducing capillary water absorption, organic matter content and pH value of the walling material can produce fungus resistant walling material. Further research should be conducted to identify the major candidate for moss growth and mold growth in tropical climates and measures should be taken to mitigate the impact of them.

7 Acknowledgment

This study is based on work supported by the NSF (National Science Foundation of Sri Lanka) grant number under RG/2017/EA & ICT /02. Any options, findings and conclusions or recommendation expressed in this material are those of the authors.

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Highlights

- Building is our third skin and moss growth and mold growth is natural phenomena which shall reduce the quality of the building envelop. This study was conducted to understand how moss growth and mold growth in reference tropical climatic conditions.
- For this study most, common walling materials such as typical engineer brick(BB), cement blocks(CB), Cabook (CAB) and cement stabilized earth blocks (CSEB) were selected. Eco-friendly waling materials such as mud concrete block(MCB), fly ash stabilizes earth blocks (FSEB) were selected. Two types of plastering techniques such as rough cement plaster and cement slurry smooth plaster were selected. However, water proof techniques, weather shield paints or any other paints on walling materials were omitted since the study range is huge.
- First, intrinsic properties such as organic matter, water absorption, total porosity, capillary action, pH value and surface roughness of all the selected walling materials were studies deeply. And then mold growth study was conducted according to ASTM D3273-94 and moss growth study was conducted according to novel techniques developed by this study adopted from the literature study.
- The results show that walling materials are prone to fungus and moss growth under the tropical climatic conditions. Porosity of walling materials varied in the range of 13.7% - 34.5%. Water absorption of walling materials varied in the range of 0.14gcm-3 – 0.35gcm-3. Surface roughness of walling materials varied in the range of 133.03μm – 2575.65μm. Capillary water absorption of walling materials varied in the range of 0.082mms-1/2 – 1.578mms-1/2. Organic matter content of walling materials varied in the range of 0.51% - 10.36%. pH values of walling materials varied in the range of 7.81 – 11.63.
- Cabook is the most susceptible walling material to moss growth and fly ash stabilized earth block is the least susceptible to moss. Brick is the most susceptible walling material to fungus growth and cement stabilized earth block is the least susceptible walling material to fungus growth.
- Moss growth on walling material depends on the capillary water absorption and the pH value of the material. By increasing pH value and reducing capillary water absorption of the walling material can produce moss growth resistant walling material.
- Fungus growth on walling material depends on the capillary water absorption, organic matter content and the pH value of the material. By reducing capillary water absorption, organic matter content and pH value of the walling material can produce fungus resistant walling material. Further research should be conducted to identify the major candidate for moss growth and mold growth in tropical climates and measures should be taken to mitigate the impact of them.