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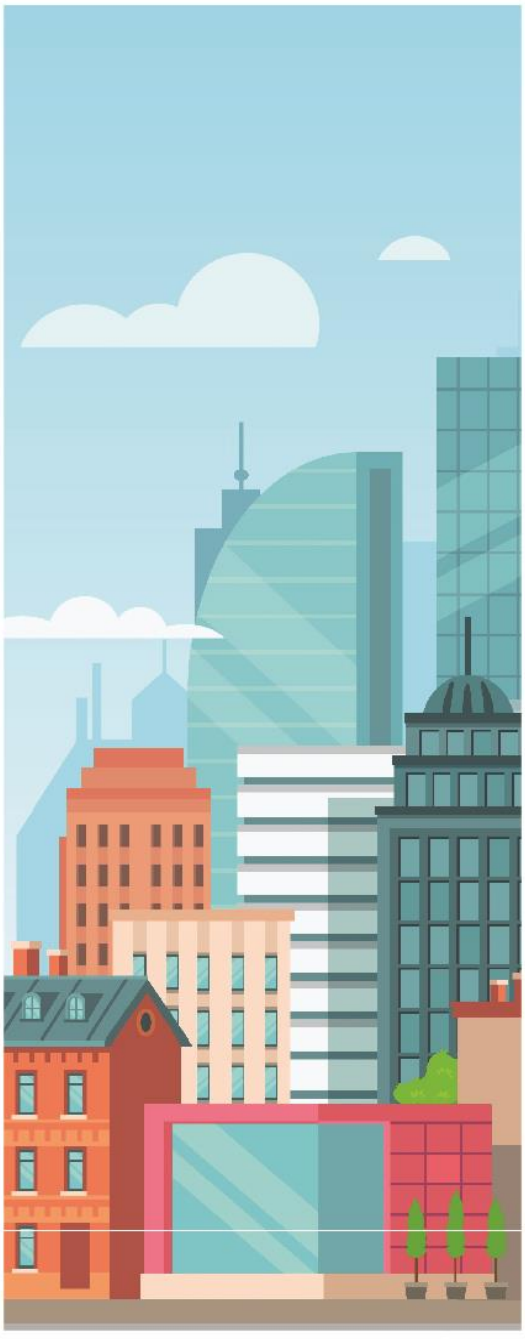

Official Journal of the Faculty of Architectuer Research Unit,Faculty of Architectuer, University of Moratuwa, Sri Lanka

About FARU

FARU is the Research Unit of the Faculty of Architecture, University of Moratuwa, Sri Lanka and its is built on the four academic Departments of the Faculty of Architecture; Dept. of Architecture, Dept. Building Economics, Dept. Town and Country Planning and Dept. Integrated Design. Thus, FARU provides a space to discuss and exchange viewpoints among researchers, professionals, academics and industry experts within allied fields of study.

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Tele/Fax: +94 11 2650216
Email: faru@uom.lk
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Editorial

We are delighted to publish this Vol.7 (Issue 01) of FARU Journal after a gap of five years. The delay helped us to revamp the journal with a more academic standing by presenting to you only the highly commended papers submitted and selected for presentation at the 'Faculty of Architecture Research Unit (FARU) Annual Research Conference (2020). This volume consists of nine out of forty research papers that were accepted for the conference and its selection was based on the reviewer recommendation, its academic standing, contribution to the field of study and presentation. We are indeed pleased that the contribution of such knowledge was not limited to local context this time but to a wider international audience. The editorial board too, this time are contributing from an international setting and possess doctorates on a range of vibrant research areas within this domain.

The overall theme of the journal is oriented to 'Space', and we discusses this within the disciplines of Build Environment, Town and Country Planning, Building Economics and Design. Here, *Space* is interpreted as an element of design in architecture, design and the build environment, or as agglomeration of urban elements, open spaces in town and country planning. *Space* is also defined as the professional space within the construction industry and, its contribution towards building economics and quantity surveying. Within this overall theme, this issue is focused to 'Dimensions of Space and its Multi-disciplinary Approaches'.

The presented papers here highlight this theme through multiple approaches within disciplines by addressing their research through explanatory and exploratory research and, most adopting experimental methods. The contribution of six research papers out of nine discusses appropriate models, frameworks and tools that can be adopted in urban planning, construction industry and construction management. Work of Munasignhe *et al* emphasizes the application of 'Space syntax method' as a model to enables planners to make certain strategies in planning and urban design decisions within the context of Sri Lanka. Similarly, Somarathna *et al,* Wijayawardana *et al,* Sandagomika *et al,* Priyaruwan *et al* also discusses their work within the context of Sri Lanka and MD. Shariful *et al* within India. Somarathna *et al* uses the 'Corporate Social Responsibility Performance (CRP) Evaluation framework' to evaluate construction organizations and Priyaruwan *et al* uses 'Aggregate based course (ABC) wastage control' to manage wastage in road construction project. The research work by Wijayawardana *et al* attempts to simulate surface runoff level in urban block at different Low impact development (LID) scenarios to envisage the flood impact in built form using a 'GIS-based simulation application'. Kalpana *et al*, on the other hand proposes a model to assess resilience as pixel representation to capture population resilience (to urban flood).

Within the context of Bangladesh and from a descriptive design approach Vismaya *et al,* discusses the capacity of lime plaster with a coating of lime wash to make indoor spaces more comfortable against lime plater with non-porous coating and explains it to be a sustainable building material for naturally ventilated spaces. This is discussed by looking at vernacular practices that is required for todays construction industry. In contrast, Sandagomika *et al* discusses the use of newer practices; Internet of Things (IoT) for successful lean implementation in the Sri Lankan construction industry and explains the reasons why it is lacking today and how it can be implemented. Another interesting paper on implementation and new practices is by MD. Shariful *et al* within the context of Indian urban plazas. The work explains the user opinion versus the degree of the openness of the plazas. To achieve this a machine learning approach was used to predict the openness of plazas in general.

The research work complied here shows multi-disciplinary approaches when fulfilling research gaps and attaining valuable findings and insights that benefits this field of study. Moreover, I would like to congratulate all authors of this publication for your tireless contribution and specially for identifying research needs that are most needed to the society and country.

Dr. Sumanthri Samarawickrama
Editor-in-Chief,
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Editorial Board

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Contents

REQUIREMENT AREA REVIEW: FLEXIBLE STUDY AREA FOR TRAFFIC IMPACT ASSESSMENTS

PATHIRAJA A.L.A.C. [1], P.C.P. DE SILVA[2] & AMILA B. JAYASINGHE[3]
[1,2,3]Department of Town & Country Planning, University of Moratuwa, Moratuwa, Sri Lanka
[1]198060E@uom.lk, amapathirajauom2018@gmail.com, [2]chameerap@uom.lk, chameera.chameera.desilva@gmail.com, [3]amilabj@uom.lk

Abstract
New developments will contribute to increased traffic to the external environment. Therefore, the majority of nations, in planning and building regulations and guidelines have adopted steps to control them beforehand. Similarly, in Sri Lanka, new developments in the approval process should be undertaken, based on their legal specifications and through a Traffic Impact Assessment (TIA). Although the management of traffic from new developments is exceedingly positive, one of the problematic sectors noted in the TIA study is a fixed study area. Consequently, a 500 m buffer area from the proposed site edges is currently being taken as the study area in Sri Lanka. The geographical extent of the traffic impact area is not a fixed bound-ary. Particularly based on a set of parameters, the true catchment area could be changed. A fixed boundary may, therefore, misdirect developers, consultants and planning authorities in decision making in situations of transport planning. Owing to this very debatable selection, almost all studies have been incorrect. Consequently, this research focuses on investigating the requirement of flexible study areas for traffic impact assessments of distinctly unique developments.

Keywords: *Flexible Study Area, TIA, Traffic Impact, Traffic Impact Area, Traffic Impact Assessment*

1. Introduction

Urban road traffic congestion is a dangerous global issue existing in every major city (Wen, Chin, & Lai, 2017). A new development, thus, essentially attracts vehicle demand for the accessible and adjacent roads and linked junctions in the vicinity (Weerasekera, 2011). Therefore, new constructions or alterations to the existing development or renovations has an impact on the extent of external traffic (Land Transport Authority, 2011). If not properly diagnosed, challenges would become increasingly severe (Ponnurangama&Umadevib, 2014). Therefore, once this was identified, numerous countries have taken different planning and building regulations and guidelines to detect and eliminate adverse effects beforehand (Cooley, Gruyter, &Delbosc, 2016). A Traffic Impact Assessment (TIA) is needed to carry out according to the legal conditions, to obtain a development permit for new developments. It identifies potential traffic impacts from the proposed development for the surrounding road network and provides corrective action to minimise them (Teodoro&Regidor, 2005).

Mega constructions in Sri Lanka too, have to submit a traffic impact assessment as laid down by the parking & traffic control (Regulation 34, Schedule III) under the City of Colombo Development Plan for development permits from 1986 onwards. While there is an enormous positive movement, questionable areas may still emerge in some areas referred to the Term of Reference (TOR) in traffic impact assessments (Director, Enforcement Division of Urban Development Authority, 2019). Delineating the true catchment area for traffic impact analysis is one of the debatable areas. The 500m buffer zone from site edges is currently taken as the study area for traffic impact assessments. This is a fixed figure similar to most other countries (Ponnurangama&Umadevib, 2014). However, the area of influenced traffic after a new development varies with different indicators (Abley, Durdin, & Douglass, 2010).

Even though there are numerous different TIA guidelines in most countries, a flexible boundary for transport impact analysis of the TIA is not well understood through the guidelines, or even at practice (Cooley, Gruyter, &Delbosc, 2016). Besides, the guidelines are included in a reasonable study area, depending on the type and scope of the development, especially in the United States. In the TIA guidelines and the TORs, a minimum study area limit should be recommended as the initial (Weller, 2007). Therefore, the flexible boundary limit should be clearly defined (Cooley, Gruyter, &Delbosc, 2016) and to understand how much the new development will affect the environment, a geographical demarcation of the traffic impact area is needed (Wen, Chin, & Lai, 2017). If not, due to this very arbitrary selection, many findings would be erroneous. In addition,

numerous experts in the transport field believe that it is essential for increasing development to have an acceptable catchment area for the evaluation of traffic impacts. Therefore, this research objects to investigate the requirement of a flexible study area for traffic impact assessments of each unique development.

2. Literature Review

Unanticipated growth is a massive concern since traffic in most countries is unbalanced (Azra&Hoque, 2014). Therefore, some kind of serious transport studies, which are commonly known as the Traffic Impact Assessment (TIA), should be carried out before the approval for construction (May , et al., 2019). Different countries and different researchers use a variety of names for this, such as transport assessment, transport impact assessment, transportation assessment, traffic impact assessment, traffic impact study, traffic report and integrated transport assessment (ITA) (Abley, Durdin, & Douglass, 2010). With certain mitigation actions and directives, this study may be rejected or accepted.

The vehicle demand from each new construction activity is usually increased in the neighbouring road network (Khade, Khode, &Bhakhtyapuri, 2017). Thus, the accumulative vehicle trip attraction from new developments will generate many adverse impacts on the street network (Ponnurangama&Umadevib, 2014). The extent of traffic impact should, therefore, be correctly estimated from any new construction of the adjacent roads and intersections. Unless properly managed, serious planning and transportation problems can arise (Abley, Durdin, & Douglass, 2010). Therefore, most cities have undertaken a traffic impact study to approve new developments and improvements to existing developments (May , et al., 2019). The TIAs is used to seek an impact on all aspects of the transportation system due to new developments (Sarkar, Maitri, & Joshi, 2015). Therefore, this assessment is more cost-effective and time-efficient to make future development decisions at the planning stage (Cooley, Gruyter, &Delbosc, 2016). The required inputs and its scope should be clearly described under the TIA study to make a sustainable transport system (Abley, Durdin, & Douglass, 2010). Accordingly, the study area or impact area is the base to conduct any impact study (Cooley, Gruyter, &Delbosc, 2016). Therefore, in a TIA study, the most important and most difficult stage is the delineation of the study area, which is also called the “impact area” (Abley, Durdin, & Douglass, 2010).

Nevertheless, planning and building approving agencies of most countries such as Bangladesh (Azra&Hoque, 2014), Philippines (Teodoro&Regidor, 2005), Canada (Engineering and Capital Infrastructure Services Infrastructure, Development & Enterprise, April 2016), China (Weller, 2007) and United Arab Emirates (Department of Transport, November 2009) etc., have failed to identify a proper mechanism to delineate the study area for the transport study. For generalization, most agencies both local and international have instructed TIA consultants to undertake a certain study area, irrespective of the development type and scale. As an example, the Land Transport Division of the Ministry of Public Infrastructure & Land Transport in Malaysia, through the TIA Guideline in November, 2015 instructs that the study area should be a 1km radius adjacent to the site. Likewise, impact levels to all the access roads, nearby roads and junctions within 1km radius from edge of the site should be studied as the direct traffic impact area under the guidelines in Mauritius (Ministry of Public Infrastructure & Land Transport, November 2015). In this instance, there is a fixed impact area under these regulations and the consultant may discuss the extent of the study area with the Ministry of Public Infrastructure & Land Transport, Mauritius. Locally, the Urban Development Authority in Sri Lanka instructs to get a 500m radius buffer area from the site edges as the traffic impact study area (TOR for TIA, 2019).

Many countries such as Malaysia (Ministry of Public Infrastructure & Land Transport, 2015), Singapore (Land Transport Authority, 2017), Australia (Department of Planning, August 2016), Mauritius (Ministry of Public Infrastructure & Land Transport, November 2015), New Zealand (Abley, Durdin, & Douglass, 2010), and United Kingdom (Department for Regional Development (DRD) & Department of the Environment (DOE), November 2006) etc. also apply a fixed study area for all developments under their own TIA guidelines. Within all the above guidelines, consultants may extend, but have to comply with, the set guideline for the minimum. Some agencies have made a positive movement by requesting the consultants to demarcate study areas

as per the development type and scale. The boundary of the study areas was clearly outlined in the TIA guidelines in many cities and municipalities in the United States, based on the use and scale of the proposed development (Azra&Hoque, 2014) such as the State of Utah (Utah Department of Transportation, February 2015), Indiana (see figure 1) (Indiana Department of Transportation, May 2015), Arizona (Town Council Of Buckeye, December 2012), Minnesota (New Prague City Council, September, 2010) and City of Visalia (Community Development Department, 2019) etc.

A minimum study area is an essential aspect under the TIA guidelines (Weller, 2007) and it should define the detailed study area limits for all development types (Cooley, Gruyter, &Delbosc, 2016). Abley, Durdin, & Douglass (2010), clearly explained that the design years are generally changing by the location, scope, and development type and therefore, it is recommended that there should be at least a 10-year space as "future assessment year". Nevertheless, all demarcations are static and no rigid dynamic ways for demarcation could be observed elsewhere. Abley, Durdin, & Douglass (2010), have explained that the scope of the TIA study should be described based on the different development types. At the same time, the minimum study area for all developments should be specified according to its use and development size (Cooley, Gruyter, &Delbosc, 2016). Subsequently, he illustrated that the flexible impact areas should be defined, based on the "scale of activity and the extent of impact". Also, many research studies discuss that the impactable boundary of each development will differ and is not fixed. Therefore, due to variations in travel patterns, socio-economic and cultural conditions, and locational characteristics, the same guideline cannot be applied to all developments (Azra&Hoque, 2014). Thus, a large number of developments will attract massive traffic around (Yayat K.D., Kombaitan B., Pradono, Purboyo H.P.H., 2015). The bare land available around is also one of the factors to change the impact proportion of the area (Chen Y. & Liu A., 2019).

According to most scholars, the extent of the true catchment area after a new development, varies with different parameters such as the proposed development type / use (Abley, Durdin, & Douglass, 2010), size / scale of the proposed development, location of the proposed development (Azra&Hoque, 2014), scale of activity of the proposed development, around land use pattern (chen y. &liu a., 2019), modes of transport facilities around, nature of transport network around, trip generation from the proposed development (Cooley, Gruyter, &Delbosc, 2016), intersection performance around, road link performance around (Weerasekera, 2011),topographical barriers, connectivity of road network, nearby trip production / attraction points, population density around (Sarkar, Maitri, & Joshi, 2015), prevailing traffic conditions on the existing road systems (Ministry of Public Infrastructure & Land Transport, 2015), considerable distance from the site, close proximity of new developments to the site (Land Transport Authority, 2017), site access points (PMK Associates, Inc., July 2006), transport related infrastructure developments (Department of Planning, August 2016), pedestrian routes and cycle routes, availability of bare land (chen y. &liu a., 2019), access road classifications, access road width and speed limits, number of lanes of the access road, walking distances to public transport connections (Engineering and Capital Infrastructure Services Infrastructure, Development & Enterprise, April 2016), drive distance (Dramowicz, 2005), drive time (Segal, 1998), trading hours (Dolega, Pavlis, & Singleton, 2015), perception of safety, parking facilities (Wegener &Fuerst, 2004), travel cost, employment, density, urban density, neighbourhood design (Leszczyc, Sinha, &Sahgal, 2004) and accessibility (Delloye, 2018) etc. Hence, a fixed border might also point in the wrong direction for the planning authorities to take transport planning decisions.

3. Methodology

This research reviewed 50 TIA reports in Sri Lanka through the cornel method, and they were analyzed to recognize the requirement of a flexible study area or fixed study area for traffic impact assessments of each development. All the TIA reports have been collected from the Urban Development Authority and randomly selected for this study. All reports, prepared by different consultants for a variety of development categories, have been submitted within the past 5 years, to obtain traffic planning clearance for a development permit.

This study used Google Earth Pro Software, Microsoft Excel and IBM SPSS Statistics software. Google Earth Pro Software was used to identify the traffic count locations and to find the direct

distances from each site edges to traffic count locations. Microsoft Excel and IBM SPSS Statistics software were applied to identify the radius of the adopted impact areas and the gap between the true catchment and adopted catchment in TIA studies.

4. Analysis and Results

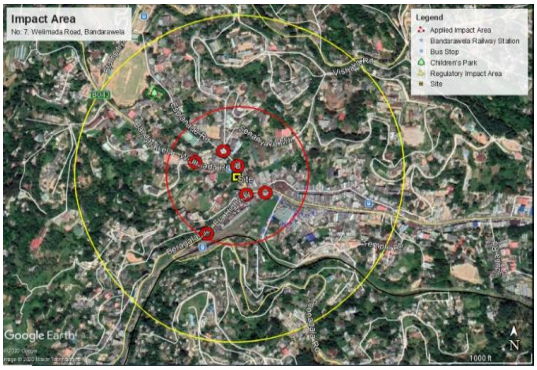

Figure 1: Impact Area - No: 7, Welimada Road,

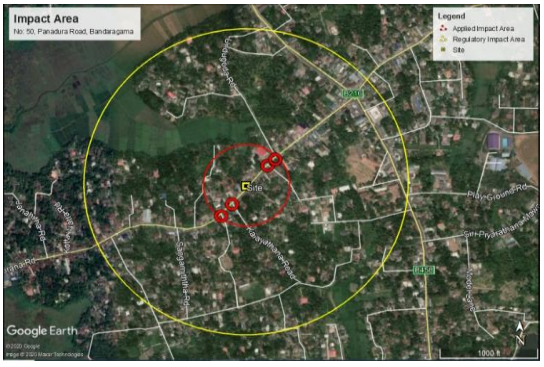

Figure 2: Impact Area - No: 50, Panadura Road,

All 50 locations of TIA reports are within different local authorities in Sri Lanka. They were taken through a random sampling technique to analyze the need for a flexible study area for TIA studies. These TIA reports are prepared for different development purposes such as retail, shopping, religious, recreational, industrial, residential, office, educational and other utilities etc., and different development scales. Further, the area, where the traffic count locations (traffic data collected and analyzed roads and junctions) in these TIA reports, are considered as the adopted impact area or "Applied Impact Area" at the practice in this study. Moreover, the direct distances in each direction from the site edges to traffic count locations will be measured and the maximum value of the radius will be taken as the radius of the applied impact areas. The 500m radius is the study area or initial impact area under the Urban Development Authority guidelines and regulations for TIAs in Sri Lanka (Urban Development Authority, 2018). Although it is a fixed study area, there is a gap between the regulatory boundary and the adopted boundaries at the practice in TIAs. It is obviously proven as below.

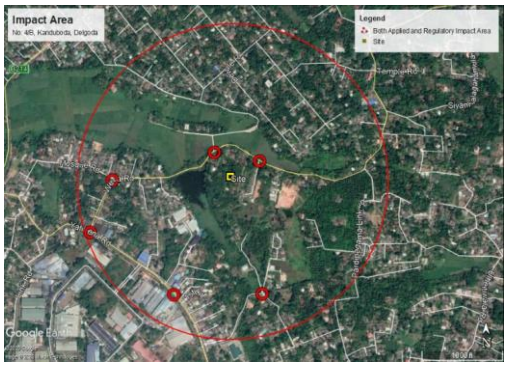

Figure 3: Impact Area - No: 4/B, Kanduboda, Delgoda

The total floor area of the proposed development in Figure 1 is 5,785.16 sqm. The TIA report was prepared on 17th September 2018 and it is now at the operational stage. The boundary of traffic count locations is the practically adopted impact area throughout this TIA study. All the traffic planning decisions have been taken based on this study area. But, the regulated study area (500m radius) is larger than the adopted impact area at the practice. Accordingly, this TIA study has taken a maximum 240m radius impact area, which is lesser than the legal requirement. It is clearly shown in Figure 1.

The total floor area of the proposed development in Figure 2 is 1,160 sqm. The TIA report was prepared in December 2017 and it is now at the operational stage. Here also, TIA study has taken a maximum of 130m radius impact area and is much less than the legal requirement. It is clearly shown in Figure 2.

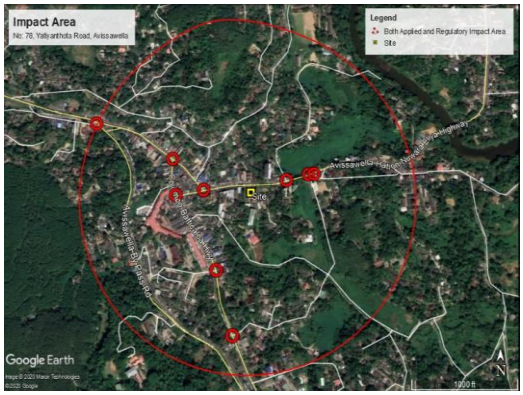

Figure 4: Impact Area - No: 78, Yatiyanthota Road,

Figure 5: Impact Area - No: 339, Kimbulapitiya Road, Akkara Panaha, Kimbulapitiya

The total gross area of the building in Figure 3 is 15,060 sqm. This TIA study has taken the maximum 500m radius impact area. Therefore, the legally required impact area and the practically adopted impact area are the same boundaries of this TIA study. Accordingly, this study has been carried out following the legal guidelines by the TIA consultant (Figure 3).

The total gross area of the building in Figure 5 is 11,516.89 sqm. This TIA study also has taken the maximum 500m radius impact area. Therefore, this study has been carried out following the legal guidelines by the TIA consultant (Figure 5).

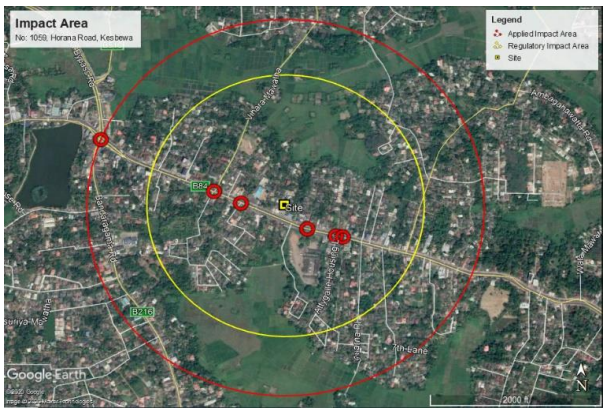

Figure 6: Impact Area - No: 1059, Horana Road, Kesbewa

The total floor area of the proposed development in Figure 4 is 1,151 sqm. The TIA report was prepared in February 2018 and is now at the operational stage. This study has taken a maximum of 740m radius impact area, and is larger than the legal requirement. It is clearly shown in figure 4.

The total floor area of the proposed development in Figure 6 is 1,186.0 sqm. The TIA report was prepared in June 2018 and it is now at the operational stage. This study has taken a maximum of 710m radius impact area and exceeds the legal requirement. It is clearly shown in Figure 6, and the table below shows the results of the study in a summary.

Table 1: Results - Radius of the Applied Study Area

No.	GPS Location	Address	Development Type	Scale of the Proposed Development (Floor Area - sqm)	Radius of the Applied Study Area (500m / < 500m / >500m)	Radius of the Applied Study Area (m)
1	6°53'59.8"N 79°51'21.6"E	No: 45, Alfred House Gardens, Colombo 3	Luxury apartment complex	15,110.00	<500	270
2	6°49'51.4"N 80°59'18.9"E	No: 7, Welimada Road, Bandarawela	Supermarket	5,785.16	<500	240

3	6°58'13.5"N 80°00'36.3"E	No: 4/B, Kanduboda, Delgoda	Hotel	15,060.00	500	500
4	6°42'42.3"N 79°59'09.9"E	No: 50, Panadura Road, Bandaragama	Supermarket	1,160.00	<500	130
5	6°54'28.1"N 80°04'34.9"E	No: 143/6, Hanwella Road, Pahala Hanwella, Hanwella	Supermarket	1,160.00	<500	190
6	7°12'15.0"N 79°51'43.9"E	No: 339, Kimbulapitiya Road, Akkara Panaha, Kimbulapitiya	Supermarket	1,151.00	>500	740
7	7°10'39.5"N 79°51'43.6"E	No: 58, Negombo Road, Kurana, Katunayake	Supermarket	1,151.00	<500	470
8	6°31'22.9"N 80°06'33.7"E	No: 185, Kalutara Road, Matugama	Supermarket	1,137.20	>500	540
9	6°45'48.5"N 79°53'50.1"E	No: 350/13, Gorakana, Panadura	Hotel	6,169.40	<500	120
10	6°49'53.4"N 80°59'16.2"E	Jummah Masjid, Welimada Road, Bandarawela	Mosque	2,892.70	>500	560
11	6°50'20.3"N 79°58'43.9"E	No: 1285, High Level Road, Makubura, Kottawa	Supermarket	1,031.22	<500	140
12	6°49'54.0"N 80°59'11.7"E	No: 21, Welimada Road, Bandarawela	Supermarket	1,140.30	>500	750
13	6°53'45.0"N 79°56'31.7"E	No: 427, Siriwedapura, Akuregoda, Battaramulla	Supermarket	1185.56	<500	360
14	6°57'07.9"N 80°12'52.7"E	No: 78, Yatiyanthota Road, Avissawella	Commercial & Office Building	11,516.89	500	500
15	7°04'32.1"N 80°00'50.7"E	No: 03, Miriswatta, Gampaha	Supermarket	1,069.47	<500	340
16	7°07'37.0"N 80°04'16.1"E	No: 120, Thihariya, Kalagedihena	Supermarket	1098.8	>500	620
17	6°54'16.0"N 79°54'48.8"E	Sethsiripaya Premises (Sethsiripaya Stage III), Battaramulla	High-Rise Office Complex - "Sethsiripaya Stage-III"	123,909.20	<500	350
18	6°54'35.0"N 79°51'01.4"E	No: 271, & 271/1, Galle Road, Colombo 3	Supermarket	567.64	<500	300
19	6°52'19.0"N 79°51'45.9"E	No: 12, 12A, 14, Rudra Mawatha, Colombo 06	Apartment	14,160	>500	570
20	6°51'41.9"N 79°53'41.2"E	No: 68, Pepiliyana Road, Gangodawila, Nugegoda	Supermarket	754	<500	410
21	6°53'34.2"N 79°53'18.4"E	No: 03, Swarna Place, Nawala Road, Rajagiriya	Office Building	4,197	500	500
22	6°02'52.9"N 80°13'18.2"E	No: 314C, 316, 318, Sirimbura road, Dangedara, Galle	Supermarket	1,082.40	<500	50
23	7°04'57.5"N 79°53'19.6"E	No: 32, Gamameda Road, Thudella, Ja-Ela	Storage Building	55.83	<500	250
24	6°47'34.4"N 79°56'48.8"E	No: 1059, Horana Road, Kesbewa	Supermarket	1,186	>500	710
25	5°56'44.6"N 80°30'54.5"E	No: 259, Sri Sunanda Mawatha, Walgama, Matara	Private School	2,677.74	<500	480
26	7°10'15.3"N 79°56'35.9"E	No: 125/1, Katunayake Road, Minuwangoda	Supermarket	4,094.70	<500	310
27	7°13'42.8"N 79°54'43.7"E	East Field Estate, Kaluwarippuwa East Village, Negombo Road, Miriswatta	Cargills Distribution Centre	26,300	<500	300
28	6°46'49.6"N 79°52'58.3"E	No: 776, Galle Road, Moratuwa	Supermarket	1,703.83	<500	480
29	6°50'10.3"N 79°52'01.5"E	No: 282, Galle Road, Mt. Lavinia	Supermarket	3,228.60	<500	380
30	6°54'47.7"N 79°56'01.7"E	No. 30, Pipe Road, Battaramulla	Apartment	27,722.90	<500	400
31	7°13'48.6"N 79°51'00.3"E	No: 254/1, Chilaw Road, Kattuwa, Negambo	Supermarket	1190.7	<500	100
32	6°56'31.1"N 79°51'56.6"E	No: 38, M. Vincent Perera Mawatha, Colombo 14	Retail Complex	3,158	<500	260
33	7°35'01.4"N 79°47'49.1"E	Lansiya Watta, Chilaw	Supermarket	1,082.40	<500	20
34	6°58'41.1"N 79°53'19.5"E	No: 85, Negombo Road, Wattala	Supermarket	1114.3	<500	130
35	6°48'56.3"N 80°57'47.5"E	Boer Road, Range View, Kahagolla, Diyathalawa	Fuel Filling Station	672.62	>500	520
36	6°55'02.5"N 79°51'39.2"E	No: 69, Hyde Park Corner, Colombo 2	Supermarket	13,154.00	<500	320
37	6°50'55.3"N 79°52'39.1"E	No.15, Rohini Road, Nikape, Dehiwala	Apartment	9,766.50	<500	430
38	6°59'09.3"N 79°53'18.3"E	No.331, Negombo Road, Wattala	Supermarket	2,772.42	>500	660
39	6°50'37.9"N 79°55'07.8"E	No. 24, Lake Road, Maharagama	Hirdaramani Discovery Lab	2,956.08	<500	450

40	6°48'09.0"N 79°53'17.2"E	No: 339 & 3, Galle Road, Moratuwa	Mixed Development	7,090.50	>500	540
41	6°57'10.2"N 79°55'47.4"E	No. 356, Biyagama Road, Gonawela, Kelaniya	Supermarket	1,098.80	<500	230
42	5°57'15.3"N 80°32'01.8"E	No. 53B, Sri Rathanapala Mawatha, Matara	Mixed Development	821.69	<500	470
43	6°52'04.8"N 79°55'48.3"E	31A, Hospital Road, Sri Jayawardenapura	Banquet Hall Complex	13,608.70	<500	320
44	6°56'10.5"N 81°09'42.7"E	Batticaloa Road, Passara	Fuel Station	827.3	<500	330
45	6°01'11.2"N 80°14'52.1"E	No: 134, Matara Road, Unawatuna	Supermarket	625.42	<500	50
46	7°13'10.3"N 79°52'06.5"E	Dawatagahawatte, Thimbirigaskatuwa, Negombo	Private School	2,877.18	>500	590
47	6°51'18.9"N 79°53'29.4"E	No: 338, Colombo Road, Pepiliyana	Supermarket	1,270.90	<500	220
48	6°51'19.3"N 79°54'44.7"E	No: 443, High Level Road, Nawinna, Maharagama	Assembly of God Church	1,432.65	>500	520
49	6°52'10.4"N 79°55'47.2"E	No: 31, Hospital Road, Madiwela, Thalapathpitiya	Apartment	48,099.23	<500	460
50	6°04'01.8"N 80°13'24.3"E	No: 572, Hirimbura Road, Karapitiya, Galle	Supermarket	660.26	<500	320

Figure 7 clearly shows the different radius values for the study area between the TIA guidelines and at practice. The scatter graph shows the different radius values of the study areas at the practice and dotted straight line shows 500m radius under the TIA guideline. Accordingly, very few studies have undertaken the 500m or a closer radius of the study area for their analysis. Besides, according to the 50 TIA case studies, most of them had been carried out with either more than or less than the 500m radius of the study area for traffic impact analysis. Hence, there is a strong gap between the true catchment areas and applied catchment areas in these TIA studies.

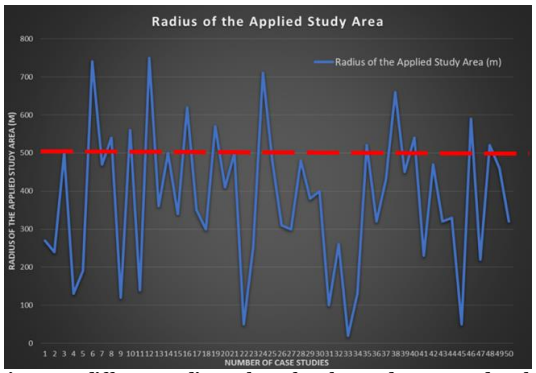

Figure 7: different radius values for the study area under the TIA guidelines and at the pactice

According to the results of the descriptive statistic analysis for the floor area of each development from BM SPSS Statistics software, the mean value is 7874.7638 sqm. There is a high range between maximum and minimum radiuses which is 123853.37 sqm. This data set which has a high variance is 357466269.668 sqm. A high standard deviation is in the data set, which is 18906.77841 sqm. Further, this data set is widely spread out.

According to the results of the descriptive statistics analysis for the radius of the applied study area from BM SPSS Statistics software, the middle value of the data set (median) is 370m. There are multiple modes in this data list and the smallest mode value is 320m and maximum mode value 500m. The applied average radius of the study area (mean) for each development is 378m. Thus, the maximum radius value of the applied study area is 750m and the minimum radius value of the applied study area is 20m. Thus, there is a high range between maximum and minimum radiuses which is 730m. This data set has a high variance, which is 33995.918m. A high standard deviation is in the data set, which is 184.37982m. Furthermore, this data set is widely spread out. Therefore, the application of a fixed radius for different development types misdirects the planning decisions in a city.

Table 2: Results of the Descriptive Statistics Analysis

Statistics

Floor_Area_sqm

N	Valid	50
	Missing	0
Mean		7874.7638
Median		1351.7750
Mode		1082.40[a]
Std. Deviation		18906.77841
Variance		357466269.668
Range		123853.37
Minimum		55.83
Maximum		123909.20

a. Multiple modes exist. The smallest value is shown

Statistics

Radius_of_the_Study_Area

N	Valid	50
	Missing	0
Mean		378.0000
Median		370.0000
Mode		320.00[a]
Std. Deviation		184.37982
Variance		33995.918
Range		730.00
Minimum		20.00
Maximum		750.00

a. Multiple modes exist. The smallest value is shown

5. Conclusion

There are different problematic areas in TIA guidelines and it may negatively affect the future of town planning. Cooley, Gruyter, & Delbosc (2016), argue that although many national TIA guidelines are available, there is no proper scope to practice well. Accordingly, although planning authorities of different countries recommend adopting the TIA guidelines to prepare TIAs to assess the transport impacts (Abley, Durdin, & Douglass, 2010), many technical and operational disparities have been identified in the TIA guidelines (van Rensburg & van As, 2004). One of them is the absence of a flexible study area (Ponnurangama & Umadevib, 2014). It means that there is a gap between the regulatory boundary and the adopted boundaries at the practice in TIAs. Different kinds of literature and analytical results prove undoubtedly that there is a requirement of a flexible study area for traffic impact assessments of each distinctly unique development. Hence, this study not only shows the way to adopt or develop a new technique to define the true catchment area for traffic impact assessments, but has also helped to rectify reasonable decision making in the transport planning sector.

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DRIVERS AND BARRIERS OF USING INTRENET OF THINGS FOR SUCCESSFUL LEAN IMPLEMENTATION IN CONSTRUCTION PROJECTS IN SRI LANKA

SANDAGOMIKA, N.M.G.H.[1], SANDANAYAKE, Y.G.[2] & EKANAYAKE, B.J.[3]
[1,2,3] University of Moratuwa, Colombo, Sri Lanka
[1]helaminisandagomika94@gmail.com, [2]yasangee@yahoo.com, [3] biyankaje@gmail.com

Abstract
With the rising impact of technological advancements within all sectors, there is an increase in interest among construction industry practitioners to integrate novel technologies collaborated with concepts. Lean is one such concept, which has received growing attention of construction companies. However, past researchers have identified many barriers for successful lean implementation in global construction context, where, technological approaches seem to be a success factor. Many experts have identified Internet of Things (IoT) as an enabler for the lean implementation in construction, which is undoubtedly lacking in the Sri Lankan context. Hence, this paper aims to investigate the drivers and barriers for using IoT for successful lean implementation in Sri Lankan construction industry. Seven semi structured interviews with experts in IoT and lean construction were conducted under the qualitative approach for data collection to achieve the research aim. Findings highlighted increased product and process quality; reduced unnecessary delays in construction process; reduced unnecessary costs; enhanced inventory management system; and increased site safety as key drivers, whereas, expensive devises and high cost of implementation; resistance to change; lack of internet coverage, IT facilities and compatibility issues; difficulties to adapt due to lack of knowledge and skills; security and privacy issues; and lack of innovative culture were identified as key barriers of using IoT for successful lean implementation in Sri Lankan construction industry. Findings revealed the several similarities in drivers and barriers of using IoT for lean construction implementation both in global and Sri Lankan context.

Keywords: *Lean Construction; Internet of Things (IoT); Drivers; Barriers*

1. Introduction

Lean is a management approach, which focuses on process improvement, satisfying customer needs and achieving the best financial results for a particular business (Salah & Rahim, 2019). Lean concept has been implemented by growing numbers of construction companies who intended to reduce the cost to meet high value of productivity and overcome the competitiveness while ultimately achieving the minimisation of seven types of wastes namely overproduction, over process, transportation, defects, motion, inventory and waiting (Salah & Rahim, 2019). But many researchers worldwide have identified major barriers under managerial, cultural, technical and implementation related aspects that have an impact on successful lean implementation (Mostafa, et al., 2013). Although some barriers can be overcome through human approaches, the technological approaches seem to be important in order to reach successful implementation of lean concept in construction industry. Supporting this, Sarhan et al. (2018) highlighted that technological barriers are highly affecting the successful implementation of lean construction.

Among large numbers of technological advancements, Louis and Dunston (2018) identified that Internet of Things (IoT) has the potential to enhance the implementation of lean construction. Sens (2013) described IoT as the internet protocol technology, which is rapidly spreading to new domains. IoT has been growing widely by emerging with the lean construction as contractors are tending to spend their resources and efforts on technological tools in order to advance their work and win over their competitors (Zankoul, et al., 2018). According to Ghi and Rossetti (2016), many factors are driving the utilisation of IoT for successful lean implementation in construction industry, which are seeking the attention of contractors, several barriers are also impacting the usage of IoT applications in successful lean construction implementation.

Although, Senaratna and Wijesiri (2008) ensured that lean construction implementation is suitable and applicable to the Sri Lankan construction industry, Thilakarathna (2012) identified that Sri Lanka is behind the successful implementation of lean construction due to the lack of suitable implementation framework. In the Sri Lankan context, Ranadewa, Sandanayake and

Siriwardena (2018) identified lack of networking and collaboration as one of the root causes for the lack of successful implementation of lean concept in the construction projects in Sri Lanka. Moreover, novel technological concepts such as IoT are also available and currently practicing within the construction industry in Sri Lanka. However, there is a lack of evidence on the drivers and barriers of the application of IoT for the successful lean implementation in Sri Lankan construction projects. Therefore, this paper aims to identify the drivers and barriers of using IoT for successful implementation of lean concept in construction projects in Sri Lanka.

2. Application of IoT in Implementation of Lean Construction

Although many advantages can be achieved by lean implementation, still the sense of how to successfully implement the lean concept is lacking in most of the companies (Jadhav, et al., 2014). Some organisations are trying to implement lean in the environment, where it does not suit, whereas some other organisations are struggling with conventional approaches in the implementation process (Kolberg & Zühlke, 2015). In this context, few researchers stated that these issues can be addressed through the technological solutions (Louis & Dunston, 2018; Rossini, Costa, Tortorella, & Staudacher, 2019; Sanders et al., 2016; Zankoul et al., 2018). Considering the Sri Lankan context, Ranadewa, Sandanayake and Siriwardena (2018) elaborated the lack of new tools and technologies as a cause for non-value adding activities, which hinder the successful lean implementation in construction projects. Further, Louis and Dunston (2018) clearly stated that IoT has the capability to enhance and overcome the barriers of the implementation of lean construction.

Some researchers have provided evidence on how IoT can be used to support the successful implementation of lean in different industries. Sanders et al. (2016) identified collaborative manufacturing, better communication mechanisms, synchronisation of data, item tagging, wireless tracking of goods, smart reallocation of order, standardised interfaces, virtual organisations-synergetic cooperation as some of the areas for which IoT is used in lean manufacturing. Buer, Strandhagen and Chan (2018) stated that some fundamental lean tools such as Value Stream Mapping (VSM) is a manual “pen-paper process”, which is quite a challengeable process in data collection perspective. However, J.C. Chen and Chen (2014) identified that VSM can be enhanced through some key components of Industry 4.0 such as IoT through real time data collection. Gubbi, Buyya, Marusic and Palaniswami (2013) stated that IoT can reduce different types of wastes that comes under lean concept such as waiting, unnecessary inventory, overproduction and the defectives. Further, Dave, Koskela and Kiviniemi (2013) identified that some lean construction management systems such as VisiLean or KanBIM can be improved by using IoT standards, thus enhancing interoperability across construction projects between all major information systems and organizations. Although it is obvious that IoT can be applied to enhance lean in construction industry, there are drivers and barriers for IoT application.

3. Drivers and Barriers of using IoT for Lean Implementation in Construction Industry

This section presents the literature synthesis on drivers and barriers, which impact the application of IoT for successful lean implementation in construction industry.

3.1. DRIVERS OF USING IOT FOR LEAN CONSTRUCTION IMPLEMENTATION

There are many conceptual and empirical researches that have investigated how IoT could enhance the performance dimensions of the lean practices. Ghi and Roseetti (2016) identified reduced cost as one of the major drivers whereas Ma, Wang and Zhao (2017) highlighted the same benefit in their empirical investigation. Moreover, the nature of flexibility in construction projects is another driving factor which tends the construction professionals to use IoT in lean implementation (Sanders, et al., 2016; Kolberg & Zühlke, 2015; Wang, et al., 2016). Increased productivity of the construction projects has been highlighted as another major driving factor (Sanders, et al., 2016; Wang, et al., 2016).

Increasing the quality of the completed construction projects when using the IoT applications to lean construction implementation has drawn the attention of many construction professionals (Ghi and Roseetti, 2016; Jayaram, 2016). Further, Kolberg and Zühlke (2015) and Wagner, Herrmann and Thiedev (2017) highlighted the reduced inventory as another major driving factor. Unnecessary inventory reduction can be considered as one of the major benefits of lean construction where the IoT applications have the potential to enhance the reduction of inventory through IoT based inventory management system (Wang, et al., 2018). Moreover, the reliability has been highlighted by the researches as another driving factor (Ma, et al., 2017, Wagner, et al., 2017). Figure 1 illustrates the summary of driving factors of using IoT for lean implementation in the construction industry.

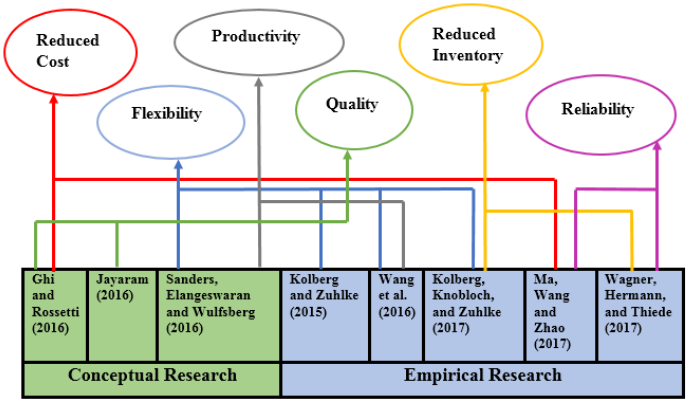

Figure 1: Drivers of using IoT for Successful Lean Implementation in Construction

3.2. BARRIERS IN USING IOT FOR LEAN CONSTRUCTION IMPLEMENTATION

Many researchers worldwide have highlighted the barriers of using IoT applications in global construction industry. However, there is lack of specific literature resources related to barriers of using IoT with related to the successful lean implementation in the global construction industry. The following table summarises the barriers that lean implementers faced when using IoT for lean implementation in different settings.

Table 1: Barriers in Using IoT for Successful Lean Implementation

Barriers in IoT adaptation	Source
Employment disruptions – a cause for a human job loss	(Gnimpieba, et al, 2015)
Additional cost for implementation – also threats of financial losses and no recovery of investments	(Heiskanen, 2017)
Organisational and process change – organization's functions and patterns might be changing	(Gnimpieba et al., 2015)
Requirement of enhanced skills – highly qualified and skilful human resources are required with prerequisite knowledge	(Li et al., 2019)
Lack of clear comprehension about IoT benefits – as several applications and technologies from IoT are still in the development stage	(Turkes, et al., 2019)
Lack of Internet coverage and IT facilities	(Fang, et al., 2016)
Security and privacy issues – due to the cybersecurity threat and data privacy issues.	(Maskuriy, et al., 2019)
Lack of standards and reference architecture – as IoT concept is novel concept	(Mueller, et al., 2017)
Seamless integration and compatibility issues – difficulties in upgrading existing machinery and equipment suit for IoT	(Li et al., 2019)
Legal and Contractual Uncertainty – become a legally independent entity in the digitalisation process	(Turkes, et al., 2019)

Regulatory Compliance issues –since taking steps to comply with applicable laws, policies, and regulations	(Maskuriy et al., 2019)
Lack of knowledge management systems –require comprehensive technical skills when switching from operational to more strategic tasks	(Frey & Osborne, 2017)

The identified drivers and barriers in the global context need to be explored for local context due to the lack of studies conducted in Sri Lanka. Hence, this paper aims to investigate the drivers and barriers of using IoT for successful lean implementation in Sri Lankan construction industry.

4. Methodology

An extensive literature review facilitated the researcher to strengthen the base of the research by congregating the prevailing knowledge around the research area. Thus, a comprehensive literature review was conducted to identify the use of IoT for successful lean implementation in construction projects, drivers and barriers of using IoT for successful lean implementation in global context through books, journals and conference proceedings.

Among several data collection techniques available, Punch (2005) highlighted interview method as one of the most commonly used data collection method when research embodies a qualitative approach. Considering the various types of interviews, semi-structured interviews were adopted as it allows the researcher to ask both structured and unstructured questions and facilitates clarifying doubts. Since the IoT and lean construction are advanced concepts and only few industry practitioners are aware of it, expert interview was conducted as the most suitable data collection method. Further, the number of experts were limited to few due to the IoT and lean concepts are grooming areas and so the experts are also limited. Hence, expert interviews were conducted using semi structured interview guidelines with seven experts in order to collect data to clarify how the identified drivers and barriers are impacting to the application of IoT for successful lean implementation in construction projects in Sri Lanka. Finally, data analysis was carried out through manual content analysis. Table 2 shows the profile of experts.

Table 2: Profile of the Experts

Expert	Description
E1	Executive Director having 10 years working experience in A reputed construction company, which is an overseas construction arm. As this organisation entails with technology and they are focusing on the lean implementation within their construction projects.
E2	Construction Manager of one of the leading construction companies in Sri Lanka with 11 years working experience. This company is one of the most innovative civil engineering organization in Sri Lanka.
E3	Assistant General Manager with 10 years of working experience in a well reputed construction company. He is currently implementing lean concept in the site and further, doing some researches on IoT applications with the intention of introducing them to their site.
E4	Director with 11 years of working experience in a reputed consultancy company in Sri Lanka. They are providing consultancy services on using the emerging technologies and lean implementation.
E5	Project QS of a one of the reputed ongoing construction projects Sri Lanka. He uses novel technological solutions and lean in the project.
E6	Director of one the leading consultancy company in Sri Lanka. He involved in implementing lean concept and has knowledge on IoT applications in both local and foreign contexts.
E7	Director of one the leading consultancy company in Sri Lanka and has both local and overseas experience. This company is currently providing their consultancy services to the large numbers of mega projects.

5. Findings and Analysis

The findings through the comprehensive literature review were referred to the experts through a semi structured interview guideline in order to identify the drivers and barriers impacting for the

application of IoT for lean construction implementation. Following sections present the findings of the study.

5.1 DRIVERS OF USING IOT FOR SUCCESSFUL IMPLEMENTATION OF LEAN CONSTRUCTION IN SRI LANKA

The expert opinion on the impact of drivers of IoT adaptation to the construction projects of Sri Lanka, which was identified in literature synthesis was investigated through the expert interviews. Eight drivers were presented through the semi structured interview guideline and experts were questioned regarding their opinion on how these drivers are impacting the successful lean implementation in Sri Lankan construction projects.

Cost effectiveness was the first driver and one responded explained that *"... minimise the unexpected failures or defective works in the construction process, so **cost effectiveness** would be a driving factor ..."*. Moreover, some experts responded as, due to the proper planning and monitoring of the IoT system, it will be a cost-effective system as it will lead for the lesser of overproduction or over processing. The experts identified **time saving** as one of the major drivers due to proper planning and monitoring of the IoT system. Some experts specifically stated that "the proper planning incorporated with the just in time (JIT) delivery would save time. **High quality of end product and service** was another identified driver and according to some responses, high quality of the end product will be secured as IoT systems will always minimise the errors. Further, respondent expressed that *"... they are having some platforms or systematic procedures to **control the quality**..."*.

As per the idea of all the experts, **improving site safety** can also be considered as another driver of IoT adaptation towards successful lean implementation. The same idea of identifying threats, giving warnings, allowing site access only for the authorized people, avoid falling and injuries to labours was expressed by few of the respondents and since, the reduction of unnecessary motions, waiting and transportation can be achieved. Hence, it is evident that **improving site safety** is a driver of IoT which would lead more towards the successful implementation of lean concept in construction projects in Sri Lanka. I**mproving the image of the construction industry** is another driver, which all the experts expressed positively that IoT concept will decrease defects and hence lead to **uplift the image of the construction projects** through innovative concepts. According to the expert's opinion, **innovative products and designs** also another driver which have a certain impact to the lean implementation through the waste minimisation in Sri Lankan construction projects. In that sense, some experts explained that IoT will surely guarantee the reliability of the designs and it will provide new ways to improve productivity and efficiency.

Reduction of wastes in and out of sites is another major driver identified by the experts and some experts mentioned *that "**the reduction of wastes in and out of sites** happens due to the proper planning and monitoring system"*. As for the last driver named as **proper inventory management** identified in the literature synthesis, all the experts responded positively as it a driving factor to use IoT applications for the lean construction implementation. Therefore, in summary, drivers of IoT application for the successful lean implementation in construction projects in Sri Lanka can be identified as follows:

- Increase product and process quality
- Reduce unnecessary delays in construction process
- Reduce unnecessary costs
- Enhance inventory management system
- Increase site safety

5.2. BARRIERS OF IOT ADAPTATION FOR THE SUCCESSFUL IMPLEMENTATION OF LEAN CONSTRUCTION IN SRI LANKA

A question based on the barriers of IoT adaptation was shown to all seven experts in order to capture their opinion on whether the identified barriers in literature in the global context for the adaptation of IoT in construction industry are also having an impact towards the successful lean implementation in the Sri Lankan construction projects. There were several barriers identified by the experts and some of the barriers were highlighted by all the seven respondents. **Additional cost for implementation** identified as one of the major barriers of IoT adaptation as the expensiveness of devises and cost of investment is considerably higher in IoT applications. **Lack of clear comprehension about IoT benefits** also highlighted by all the respondents and some experts stated that *"... as these systems are linked with new technologies and hence people are not competent enough to deal with these new technologies..."*. **Lack of knowledge management system** identified in the literature synthesis due to the requirement of comprehensive technical skills when switching from operations to more strategic tasks was another barrier highlighted by all seven experts. According to all the experts, **lack of standards and reference architecture** was another major barrier, which some experts explained that as it is a new concept, there are not any standards to be referred. **Requirement of enhanced skills** is another barrier encountered by the all seven respondents in IoT usage for lean implementation. In that sense some experts stated that *"existing manpower might not have the adequate knowledge and competency level do deal with the new technological advancements"*.

Seamless integration and compatibility issues is another barrier explained by all the respondents. According to some experts *"this will become a major barrier as there will be huge problems when we are upgrading the existing machineries while implementing the IoT concept"*. **Security and privacy issues** were another major barrier as the utilisation of IoT applications have the highest potential to lead to cybersecurity threats and data privacy issues. Some of the barriers were only accepted by the six experts and **employment disruption** was one of those barriers, which some experts highlighted as "due to the majority of worker's attitude to change with the technologies and automation processes, this can be a barrier". **Organisational and process change** can also be considered as another barrier and some experts evident this as "*this happens due to the attitudes of the human and the top management of an organisation as people are not ready for a drastic change within their organisation or occupation*". Moreover, **lack of internet coverage and IT facilities, legal and contractual uncertainties** and **regulatory compliance issues** have been identified by the experts, which can be impacting for the successful lean construction implementation.

Except to the barriers that the researcher incorporated to the interview guideline from literature synthesis, some respondents identified another four barriers that have the potential to impact the use of IoT to the successful implementation of lean construction. Specifically, all these barriers are related to the existing culture of the construction industry and those barriers can be stated as **no learning culture attitude in Sri Lanka, rigid organizational culture, no innovative culture in the Sri Lankan construction industry** and **no research and development attitude** in the construction industry to deal with new technological advancement. So, in summary, barriers for the use of IoT for the successful lean implementation in construction projects can be identified as follows:

- Expensiveness of the devises and high cost of implementation
- Resistance to change
- Lack of internet coverage, IT facilities and compatibility issues
- Difficulties to adapt due to lack of knowledge and skills
- Security and privacy issues
- Lack of innovative culture

6. Conclusions and Recommendations

Comprehensive literature review identified that lean concept can be collaborated with IoT to enhance the success of its implementation in construction industry. Numbers of IoT applications are currently available which are using to successfully implement lean construction within the

global construction industry. Literature review highlighted that IoT applications, which spread rapidly to new domains can be used to overcome the barriers of successful lean. But, when using the IoT applications, there are several drivers and barriers that the construction professionals have to encounter with in the global context. Hence, this study was aimed to identify the drivers and barriers that are impacting for the successful lean construction implementation using IoT applications.

Literature synthesis has identified the IoT applications to the lean implementation in construction projects and numbers of drivers and barriers that are impacting the successful implementation of lean construction. In the analysis of collected data, drivers of the utilisation of IoT for the successful implementation of lean construction are also evidenced the importance of integrating IoT to the successful implementation. Increases product and process quality; Reduction of unnecessary delays in construction process; Reduction of unnecessary costs; Enhanced inventory management system; Increased site safety were some of the drivers highlighted by the experts. Barriers towards the application of IoT for successful lean implementation were highlighted by the experts as Expensiveness of the devises and high cost of implementation; Resistance to change; Lack of internet coverage, IT facilities and compatibility issues; Difficulties to adapt due to lack of knowledge and skills; Security and privacy issues; Lack of innovative culture in Sri Lanka.

Further, certain recommendations can be made through the findings of this research study for industry practitioners such as understanding the possible IoT applications that can be used for lean implementation in construction projects and key benefits of using IoT applications in lean implementation. Moreover, the industry practitioners can be recommended with to understand the barriers of using IoT applications for lean implementation in construction projects and getting prepared with the strategies to overcome them.

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CORPORATE SOCIAL RESPONSIBILITY PERFORMANCE EVALUATION OF CONSTRUCTION ORGANISATIONS IN SRI LANKA

SOMARATHNA H.M.P.P.[1], MATHUSHA FRANCIS[2] & MALLAWARACHCHI H.[3]
[1]Sagacity Consultants (Pvt) Ltd
[2,3]Department of Building Economics, University of Moratuwa
[1]ppsomarathna@gmail.com, [2]mathushaf@yahoo.com, [3]hmallawarachchi@gmail.com

Abstract
Through considering social and environmental factors in organisational activities, the concept of Corporate Social Responsibility (CSR) is broadly defined as ensuring organisational effectiveness. In the construction industry in Sri Lanka, organisations are very excited to take part in CSR initiatives for sustainable business growth. The current research tends to investigate CSR performance indicators of Construction organisations and develops a CSR performance evaluation framework for construction organisations.
A comprehensive literature review was executed identifying CSR performance indicators for the construction industry. Literature review found that, CSR holds that three main dimensions as economic responsibility, social responsibility and environmental responsibility. Correspondingly, in literature review identified CSR performance indicators of those CSR dimension. Then a quantitative approach using questionnaire survey is adopted to investigate the research phenomena. Subsequently, Analytical Hierarchy Process (AHP) technique used to determine relative performance scores of each CSR dimension and CSR performance indicators. Finally, a CSR performance evaluation framework was developed for construction organisations in Sri Lanka.

Keywords: *Corporate Social Responsibility, Performance, Indicators, AHP*

1. Introduction

The construction industry involves a wide range of businesses, including contractors, customers, suppliers of materials, professional services and construction initiatives, which have a road impact on the general economy (Zaho, Zhao, Davidson, & Zuo, 2012). Nevertheless, the construction industry has a significant impact on the environment, political, financial, environmental and economic (Lim, Loosemore, Ling, & Zeng, 2008). Thus, the construction industry continuously improves social, economic and environmental indicators to improve sustainability (Ortiz, Castells, & Sonnemann, 2009).

According to Čarnogurský, Diačiková, Ďaňková and Ľach (2015), with the changing business environment, the organisations use the principle of Corporate Social Responsibility (CSR) to strengthen relationships between business and other commercial sectors. Correspondingly, Zhang, Oo and Lim (2018), mentioned that in the construction industry, CSR has gained more prominence. The application of CSR takes into account the expectations of construction companies to gain competitive advantages and show their contribution to social responsibility. As stated by Zaho, Zhao, Davidson (2018) and Zuo (2012), as competition intensifies, construction organisations use CSR as a way to improve the company's background and gain competitive advantage.

As stated by Tilakasiri (2013), Sri Lankan corporate sectors have been concerned about the concept of CSR because of the serious economic situation in the country and people, organisations, clients and other different groups who are engaged in the administration and industrial sector to improvement of the social, environmental and economic livelihoods of the people. Correspondingly, Wijerathna and Gajanayaka (2014) mentioned that, organisations in Sri Lanka are pursuing CSR approaches. Similarly, Vijayaragunathan (2016) stated that, Sri Lankan construction industry is in the initial process of implementing CSR activities. Sri Lankan organisations have to reflect different application of CSR to watch at worldwide organisations (Tilakasiri, 2013). CSR creativities are not necessary for a company to adopt, but it should bring various social advantages (McWilliams & Siegel, 2001).

Finally, CSR creativities are about making a variation. Effective CSR creativities must have optimistic effects equally on society and organisations, and also is planned to benefit society and organisations (Coombs, Sherry, & Holladay, 2012). Authors further stated that, when the CSR creativity is active, its special effects can be assessed. However, the difficulties that occur when subjectively evaluating performance of CSR can lead to different outcome paths of outcomes (Giannarakis, Litinas, & Sariannidis, 2011). Further to authors, companies have a better opportunity to recognize their strengths and weaknesses through a positive evaluation of CSR performance while it will aid in modifying their strategies and identify opportunities for further improvements. As stated by Venturelli, Caputo, Leopizzi, Mastroleo and Mio (2017), It is difficult to assess whether an organisation embraces CSR or not, and it is also difficult to determine whether CSR continuity between one company and another company. Further to the authors, there is no ordinarily acknowledged technique for evaluating the performance of CSR. Hence, the purpose of this research is to introduce a proper mechanism for evaluating the performance of CSR of Sri Lankan construction organisations.

2. Literature Review

2.1. IMPORTANCE OF CSR FOR THE CONSTRUCTION ORGANISATIONS

The corporation is a corporate entity and its management must take into account the effect of any business decision and interference to promote the public interest and contribute to the cohesion and harmony of society. Costa and Menichini (2013) stated that, in an age of growing global needs for emergency and social justice, CSR may help organisations find ways to achieve truly sustainable business as they play a dynamic part in international financial and economic stability. According to Lock and Seele (2016), the amount of frequently published professional contact content on CSR highlights its vital role in everyday business and CSR is essential to an organisation's credibility. Moreover, findings of Księżak (2017), stated that first benefit of CSR is improved relationship between companies and communities Correspondingly, Seele and Lock (2014), mentioned that CSR is focused on the management of perceptions of stakeholders through interaction and responsiveness. According to the authors, organisations can better to assess and manage potential risks by involving stakeholders.

Through planning, design and construction to use and removal, construction process has a significant effect on community, economy and climate (Murray & Dainty, 2008). In addition, construction tasks are typically labor intensive and have high levels of accidental exposure, making building workers less secure (Close & Loosemore, 2014). Xia, Olanipekun, Chen, Xie and Liu (2018), reported that the construction industry has some new social CSR activities, including social procurement, corporate volunteering, social enterprise, public service, social enterprise and indigenous reconciliation. Therefore, community procurement emphasizes the purchasing of products and services to benefit from increased social benefits and investment in the local communities where the project is located (Loosemore, 2016). Similarly, employers in the construction industry provide workers with any form of support for voluntary work and community objectives for corporate voluntary work (Loosemore & Bridgeman, 2017).

2.2. PERFORMANCE EVALUATION FOR CSR

The concept of CSR and CSR performance evaluation is getting more and more attention companies, business predictors, non-governmental organisations (NGOs) and other institutions (Grigoris, Nikolaos, & Nikolaos, 2011). According to Carroll (2000), CSR Performance evaluation is important for business enterprises and society. According to the author, in order to answer the question of whether CSR should be measured, it is pointed out that because CSR is an important topic of business and society, the importance and influence of social responsibility activities can be demonstrated by using measurement tool.

Grigoris, Nikolaos and Nikolaos (2011) stated that, subjective CSR performance assessment can lead to different results perceptions. According to the Sirgy (2002), by evaluating CSR

performance, organisations have the chance to distinguish their qualities and shortcomings, strength and weakness, adjust procedures and recognize opportunities for enhancement.

2.3 CSR INDEX OF THE CONSTRUCTION INDUSTRY

Based on stakeholder theory aspect of the construction industry and triple bottom line theory Jiang and Xue (2018), develop the CSR index for the construction industry. Further to authors, construction company stakeholders include owners, shareholders, communities, creditors, employees, subcontractors, governments, and the environment. Based on three bottom-line theories (Elkington, 2010), Jiang and Xue (2018), incorporate stakeholder responsibilities into three dimensions: economic responsibility, social responsibility, and environmental responsibility. These three detentions further classified into sub factors (refer figure 1).

In terms of economic factors, Return on Assets shows the total sum of productive capital relative to investment rate; Rate of information disclosure means the connection between information disclosure and equity costs is the fundamental interest of scholars and regulators; Rate of Assets to liabilities is the ratio of assets to liabilities, check how much of the assets of the company are made up of liabilities; Return on equity; Dividend is the return on investors as a result of the money invested in the purchase of a particular business's stock. Environment dimensions includes the sub-factors of Rate of social security coverage, Consumer satisfaction degree, Rate of staff and labour turnover, Rate of staff and labour casualty, Rate of tax to assets and tax paid, Rate of tax to assets and tax paid, Rate of timely project payment for subcontractors and Educational fund for employee whereas socio dimentions includes Investment rate on environment, Discharge rate of construction protection, Compliance rate of pollution garbage and Recycling rate of pollution.

Thus the forgoing literature revealed the Customer satisfaction can be considered as a goal or measurement tool for quality growth and customer satisfaction is an important factor in process development and customer relationships importance of CSR for construction industry and the CSR dimensions which can demine its performance. The impact of construction industry on economic, environmental and social dimensions were more important than other industries and it is good to implement a systematic method to ensure CSR. In terms of Sri Lanka, the currently the construction industry has risen with the development of the country. Further, there is a need to meet the realistic CSR performance assessment system. There were CSR indicator systems available in the world and they have implement in Sri Lankan construction organisation however those fail to evaluate CSR performance properly. Therefore, this research tends to provide proper mechanism to evaluate construction organisations CSR performance in Sri Lankan context.

3. Research Methodology

The research was conducted to build a framework to evaluate CSR performance of construction organisations in Sri Lanka. A quantitative approach using questionnaire survey was employed in this study. Based on convenience sampling, a sample of ten (10) professionals who have engaged in CSR projects of construction industry in Sri Lanka was chosen for the questionnaire survey. Considering the profile of respondents, 60% of the respondents were sustainable engineers whereas the rest are project managers. In terms of experience, 70% respondents have experience between 5-10 years and 30% have experience more than 10 years.

For relative weightage determination of the identified CSR performance, AHP analysis tool was used. The AHP provides a valuable method for evaluating the accuracy and consistency of the evaluations of the decision-maker, thus increasing the accuracy in the process of decision-making. The following steps were employed in using the AHP technique.

- Steps 1 – Ration scale: The respondents need some kind of scale in order to respond with the provided pair wise comparison.

- Step 2 - Pairwise comparison: Gathered data from the questionnaire survey was inserted into the pairwise comparison matrices. The averages of the responses and their reciprocals were recorded in the matrices and the sum of each column was calculated afterwards.
- Step 3 – Normalization of the comparison: Normalizing was carried out by dividing each element in the pairwise comparison table by the sum of each column. After normalization, the total sum of each column was determined to obtain the performance score or the relative weight of each CSR and CSR performance indicators. The performance scores can be compared to identify the important criteria as well as to give a relative weight.
- Step 4 – Consistency Ration (CR) calculation - When comparing the criteria, the respondents may supply answers with inconsistency. In the analysis of inconsistent information, wrong conclusions may be derived.

4. Data Analysis and Findings

The findings of the data collected through the questionnaire survey have been analysed using the AHP technique. CSR dimensions and CSR performance indicators of each dimension were illustrated in the hierarchy. In AHP pairwise comparison, maximum seven (7) variables will be used. AHP hierarchy of CSR dimensions and CSR performance indicators of each dimension was shown in following figure 1.

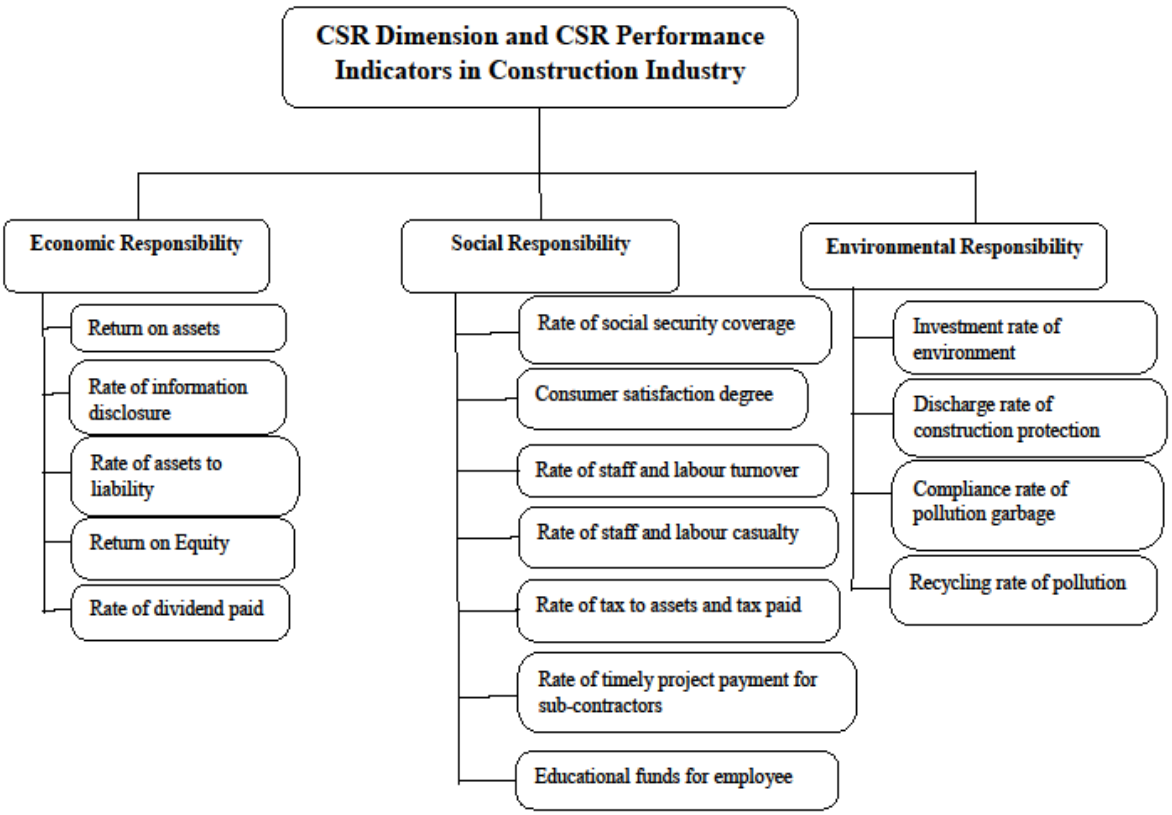

Figure 1: AHP Hierarchy

4.1. RANKINGS OF CSR DIMENSIONS

There are three CSR dimensions were identified through literature review. The main intention of this section is to analyse the relative weights (performance scores) of these dimensions. AHP technique was used to analyse these relative weights. Table 1 demonstrated ranks of the CSR dimensions by performance score. The total number of performance scores is equal to one (1) in CSR dimensions.

Table 1: CSR dimensions ranking

CSR dimensions	Performance Score	Rank
Economic Responsibility	0.7394	1
Environmental Responsibility	0.1789	2
Social Responsibility	0.0817	3

Economic responsibility has achieved a significant high performance score than other dimensions. The second and third ranked were respectively achieved by environmental responsibility and social responsibility dimensions.

4.2. RANKINGS OF ECONOMIC RESPONSIBILITY CSR PERFORMANCE INDICATORS

According to Table 2, there are five economic responsibility CSR performance indicators were identified in the literature. Table 2 illustrated ranks of CSR performance indicators of economic responsibility based on performance scores. Performance scores of CSR performance indicators for economic responsibility are equal to one (1).

Table 2: Rankings of economic responsibility CSR performance indicators

CSR performance indicators of economic responsibility	Performance Score	Rank
Return on Equity	0.5045	1
Rate of assets to liability	0.2326	2
Return on assets	0.1750	3
Rate of information disclosure	0.0473	4
Rate of dividend paid	0.0406	5

When analysing the Table 2, 'return on equity' indicator received the highest performance score which is 0.5045 and it indicates the highest relative importance. The second, third and fourth places were achieved respectively by 'rate of assets to liability' (0.2326), 'return on assets' (0.1750), 'rate of information disclosure' (0.0473) indicators. Least importance was identified for 'rate of dividend paid' indicator with a performance score of 0.0406. It can be identified that 'return on equity' indicator is approximately two (2) times relatively important than 'rate of assets to liability', which is the secondly ranked indicator. Also, 'return on equity' is approximately two (3) times relatively important than 'return on assets' which is the indicator ranked in the third place. Correspondingly, 'return on equity' is approximately two (10) times relatively important than 'rate of information disclosure' which is the indicator ranked in the fourth place. 'Rate of dividend paid' was ranked at the fifth place. There is no significant difference between the fourth and fifth ranks.

4.3. RANKINGS OF SOCIAL RESPONSIBILITY CSR PERFORMANCE INDICATORS

In literature, there are seven social responsibility CSR performance indicators were identified. Table 3 demonstrated ranks of the CSR performance indicators of social responsibility dimension. The total number of performance scores is equal to one (1) in social responsibility CSR performance indicators.

Table 3: Rankings of social responsibility CSR performance indicators

CSR performance indicators of social responsibility	Performance Score	Rank
Rate of staff and labour casualty	0.4816	1
Rate of timely project payment for sub-contractors	0.1334	2
Rate of social security coverage	0.1288	3
Rate of staff and labour turnover	0.1112	4

Consumer satisfaction degree	0.0702	5
Rate of tax to assets and tax paid	0.0522	6
Educational funds for employee	0.0226	7

The highest performance score was achieved by the 'rate of staff and labour casualty' (0.4816) indicator. The least relative weight was for 'educational funds for employee' indicator which the performances score was 0.0226. The firstly ranked indicator performance score was approximately three (21) times than the least performance score. Hence, there is a significant deviation of the relative performance scores can be recognized among the firstly ranked and the last ranked indicator. The second, third and fourth places were achieved respectively by 'rate of timely project payment for sub-contractors' (0.1334), 'rate of social security coverage' (0.1288) and 'rate of staff and labour turnover' (0.1112) indicators. There is no significant deviation can be identified between second, third and fourth ranked indicators performance scores. The fifth and sixth places were achieved respectively by 'consumer satisfaction degree' (0.0702) and 'rate of tax to assets and tax paid' (0.0522). It can be identified fifth ranked indicator approximately (1.5) times importance than sixth ranked indicator. Correspondingly, sixth ranked indicator was approximately (2) times importance than last ranked indicator. When considering the CSR performance indicators of social responsibility dimension, it can be identified that rate of staff and labour casualty have a major effect on the performance of the CSR.

4.4. RANKINGS OF ENVIRONMENTAL RESPONSIBILITY CSR PERFORMANCE INDICATORS

There are four environmental responsibility CSR performance indicators were identified through literature review. Table 4 revealed ratings of CSR performance indicators for environmental responsibility in conjunction with the performance scores. Performance scores of CSR performance indicators for environmental responsibility are equal to one (1).

Table 4: Rankings of environmental responsibility CSR performance indicators

CSR performance indicators of environmental responsibility	Performance Score	Rank
Compliance rate of pollution garbage	0.4841	1
Recycling rate of pollution	0.2478	2
Investment rate of environment	0.1714	3
Discharge rate of construction protection	0.0967	4

In the analysis of Table 4, the highest performance score was gained by the indicator 'compliance rate of pollution garbage' (0.4841). 'Recycling rate of pollution' indicator (0.2478) was ranked at second place. Ranked one indicator is approximately two (2) times important than secondly ranked indicator. Thirdly ranked indicator was 'investment rate of environment' with the performance score of 0.1714. Ranked two indicator is approximately 1.5 times important than the thirdly ranked indicator. 'Discharge rate of construction protection' indicator obtained the least performance score which is 0.0967. It can be identified first ranked indicator is approximately five (5) time important than last ranked indicator. When considering the CSR performance indicators of environmental responsibility dimension, it can be identified that 'compliance rate of pollution garbage' indicator have a major effect on the performance of CSR.

4.5. CSR PERFORMANCE EVALUATION FRAMEWORK

Evaluation score of the CSR performance indicators of the CSR dimensions were demonstrated in the Table 5.

Table 5: Evaluation scores of the CSR performance indicators

Rank	CSR dimensions and CSR performance indicators	Evaluation score
1	Economic Responsibility	73.94

1	Return on Equity	50.45
2	Rate of assets to liability	23.26
3	Return on assets	17.50
4	Rate of information disclosure	4.73
5	Rate of dividend paid	4.06
2	Environmental Responsibility	17.89
1	Compliance rate of pollution garbage	48.41
2	Recycling rate of pollution	24.78
3	Investment rate of environment	17.14
4	Discharge rate of construction protection	9.67
3	Social Responsibility	8.17
1	Rate of staff and labour casualty	48.16
2	Rate of timely project payment for sub-contractors	13.34
3	Rate of social security coverage	12.88
4	Rate of staff and labour turnover	11.12
5	Consumer satisfaction degree	7.02
6	Rate of tax to assets and tax paid	5.22
7	Educational funds for employee	2.26

The key contribution of this research for existing knowledge is the development of the above CSR performance of Sri Lankan construction organisation. Using the above framework, any construction organisation in Sri Lanka can calculate its CSR performance.

5. Conclusions and Recommendations

CSR performance evaluation is getting more and more attention amongst the all organisations including construction sector. Since the construction industry's economic, environmental and social impacts are more important than other industries, it is important to adopt a systematic approach to evaluate the CSR performance of Sri Lankan construction organisations. Further, no proper mechanism for evaluate performance of CSR in construction organisations in Sri Lanka. Hence, the research aimed to develop a CSR performance evaluation framework for construction organisations in Sri Lanka.

Literature review emphasized the importance of CSR for the construction organisation and also benefits of CSR have been identified. Most importantly literature review has addressed the CSR performance indicators for construction organisations. Economic, environmental and social responsibilities were recognised as the main CSR dimensions.

AHP tool used to analyse the collected data from questionnaire survey and obtained to relative weights for identified CSR dimensions and CSR performance indicators AHP calculation were carried out. Economic responsibility has achieved a significant high performance score than other dimensions. The second and third ranked were respectively achieved by environmental responsibility and social responsibility dimensions. Then, CSR performance model was developed for Sri Lankan construction organisation after the evaluation scores resultant from the AHP analysis. The main contribution of this research for the existing knowledge is the CSR performance evaluation framework of Sri Lankan construction organisation.

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HYGROTHERMAL PERFORMANCE OF OLD LIME PLASTERED SPACES IN A HOT AND DRY CLIMATE

VISMAYA PARALKAR.[1] & DR. RASHMIN DAMLE.[2]
[1, 2]CEPT University, Ahmedabad, India
[1]*vismaya.pg181207@cept.ac.in*, [2]*rashmin.damle@cept.ac.in*

Abstract.
Lime plaster is one of the key sustainable building materials which is also effective as a passive cooling strategy. Since it is being used for ages now, it is the most compatible material for old heritage structures. Thus, majorly used in conservation projects. In this work, the hygrothermal performance of lime plaster is observed through simulations and surveys. Residential surveys are carried out for occupied old naturally ventilated spaces. The inner surface temperature, relative humidity, and moisture content of the walls are measured. Simultaneously, the indoor air temperature, relative humidity, globe temperature, and air velocity are measured. In hygroscopic materials like lime plaster, realistic conditions like mold growth cannot be predicted through simulations. A simulation of thermal and hygrometric behavior of historical buildings is a challenge. An inaccurate simulation may lead to inadequate conclusions, which could lead to inappropriate and dangerous actions for the building's heritage conservation. An attempt is made to use the survey readings and observations to predict the phenomenon of mold growth in a space while conducting simulations. Using a combined approach of simulation and survey, it was possible to predict the mold risk of the space.

Keywords: *Lime plaster, Hygrothermal simulations, historical buildings, mold growth, surface relative humidity conditions.*

1. Introduction

Before the 20th century, lime has been the most commonly used binder in building construction. The versatile nature of lime is beneficial in construction as well as finishing on wall surfaces. Snow and Torney (2014) discussed the applicability of lime in buildings as extensive, from concrete to bedding and pointing mortars to harling and paint (limewash). Depending on the nature of the lime binder used to prepare along with the effect of additives in the mixture, the properties of a lime mortar/plaster vary.

While describing the proportions to obtain durable plaster in ancient times, De Luca *et al.* (2016) mentions that the sand is mixed in three parts to one part of slaked lime. Ravi and Thirumalini (2018) describe the organic additives used, their application technology, the process of making mortar, and the advantages of lime plaster.

Lime mortar and lime plaster are self-healing and thus prevent the formation of inner cracks. Moreover, because of its durability, it has a longer life span. This reflects the fact that the life of a cement concrete is only for around 50 years, while the life of a lime starts after 70 years. Thus, reinforcing that old historical structures that are thousands of years old are still functioning and strong.

The advantageous properties of lime are encouraging progressively more architects to opt for using lime over cement. Lime plaster and mortar is essentially used in conservation projects. It vastly adds up to the qualities of the old building. Homes, Roger, and June (2020) have specified that in old structures an important function is the breathability of ceiling and walls. The moisture must evaporate through the envelope to prevent dampness and condensation. Unfortunately, modern materials like cement-based plasters or gypsum plasters are used nowadays. These materials are non-breathable and inflexible which seal the moisture. This, in the long run, damages the structure. Thus, it is important to use the same original plaster in conservation projects which is lime plaster in most cases.

It should be tested if the presence of mold or such favorable environments affects the performance of lime plaster in that space. For such situations, it is required to know the controllable parameters

to optimize the performance of the lime plaster. The impact of using lime plaster on the indoor environment in old naturally ventilated spaces should be understood.

2. Literature Review

In the literature review the overall history, chemical structure, advantages, disadvantages, hygrothermal studies of lime plaster is understood.

LIME AS A PASSIVE STRATEGY WITH MOISTURE BUFFERING

Energy Consumption and building performance is highly dependent on the indoor air relative humidity. The influence of hygrothermal properties of building materials on the consumption of cooling load in five climate zones of India as assessed by Damle and Rawal (2018) evaluates this fact. According to Busser *et al.* (2018), it is also responsible for the indoor air quality and climate of that building. Therefore, it is necessary to maintain this relative humidity level inside. However, the moisture buffering quality of the building materials which absorb and release the moisture modulates the indoor humidity. Using the analytical methods by Liu and Shun (1991), the authors Gaur and Bansal (2002) and Hall, Hoff and Nixon (1984) derived that the humidity present in ambient air and room air can modify up to 2–3 ℃ of room temperature with respect to the amount and direction of temperature and moisture gradients. According to Labat and Woloszyn (2015), the vapor transfer and its storage have a significant impact on heat transfer, indoor comfort, and durability of the wall assemblies. So, to avoid envelope damage, repour open wall assembly is a better option over vapor-tight assembly.

Padfield (1998) experimented to understand the effectiveness of porous, water-absorbent walls performing as moisture buffers for occupied rooms at 0.5 ACH. Absorbent materials can be used as a buffer for a brief period and can substitute for mechanical ventilation. For over a longer period, the performance of the absorbent buffers is not as effective as ventilation. So, along with buffering proper ventilation must be also maintained for the effective performance of the pace.

Toniolo *et al.* (2011) recommend lime plaster as useful in 'breathing wall' construction. Along with increasing its strength eventually, it is an easy remediation to cracks and defects. It involves nontoxic chemicals for manufacturing, production can be downscaled as per need, it is recyclable in use, has a porous surface after curing, highly reflective if in natural white color. When used as an internal render, it improves the indoor air quality by absorbing low amounts of Carbon dioxide and regulating the indoor relative humidity for a prolonged period.

DECLINE AND DRAWBACKS OF LIME PLASTER

According to (Sickels, 1987), Joseph Aspdin in 1824 patented the term Portland cement. I.C. Johnson after 19 years, prepared a type of Portland cement, very similar to today's cement type. With these progresses, the use of lime mortar gradually declined. Thus, there was a shift from lime technology to cement technology.

The high risk of mold growth in lime plastered spaces is probably the other reason. In the paper by Bastien and Winther-Gaasvig (2018), best and worst-case scenarios are assessed in terms of the possible influence of rain exposure on hygrothermal performance. It is concluded that the rain exposure impact on hygrothermal performance is minor. But the impact is significant on mold index for a lime plaster assembly as compared to mineral-cement based plaster. Karaglozls *et al.* (1995) observed that materials like lime plaster have higher capillary action and its moisture content is vastly dependent on their exposure to driving rain. Although, 2% - 9% of heat losses due to latent heat and rise in thermal conductivity are found in building materials having higher moisture content. Elert *et al.* (2002) stated that the presence of moisture in or on the surface of walls invites a favorable atmosphere for mold growth. The mold damage and moisture ingress frequently occur even after the renovation of a damaged building. Fungal growth in buildings is influenced by the nutrient, relative humidity, temperature, and so on. The fungal growth inside a

space is highly influenced by the relative humidity (RH) inside the dwelling. These RH levels inside are further an effect of the moisture buffering capacity of the wall assemblies, ceiling coverings, furniture, and textiles used inside the building. Lucas *et al.* (2002) and Mendes *et al.* (2003) found that the presence of moisture is a cause of deteriorations inside buildings while affecting the latent and sensible conduction loads.

Lstiburek. (2009) states that if the rate at which moisture entering into an assembly surpasses its rate of moisture removal, the moisture starts accumulating. This furthermore results in moisture problems if the moisture accumulated is exceeding the assembly's ability to store it. Moreover, the problem of even small water leak has a significant impact if the hygric buffer capacity of the material is low while for higher hygric buffer capacity materials it's not.

Older buildings without the vapor barriers are highly prone to structural damage due to moisture diffusion inside the wall and condensation on the outside. Variations in the location of humidity sources and room ventilation rates give rise to pockets of high relative humidity. Therefore, the average relative humidity throughout the building should be maintained between 40 to 60 %.

SOLUTION TO MOLD GROWTH AND REINTRODUCTION.

While studying the use of lime Plaster on Malaysian heritage building, Sabri and Suleiman (2014) found that the use of incompatible materials like cement plaster or chemical paint on the wall causes deterioration. It traps the moisture inside and soon the walls crumble and fall off. A similar kind of observation is mentioned in Ingham and Ingham (2016).

A transition is seen in the use of lime materials for repairing historic buildings. Awareness about the use of well-suited materials in the restoration of old buildings is growing. Conservationist has recognized the unfavorable properties of Portland cement. This marks the rebirth of lime application and technology. Whereas, structures that are constructed 30 years earlier are still in service without much maintenance.

Čáchová *et al.* (2016) experimented with lime cement plasters and found that on increasing the amount of pozzolana in a mixture, the values of the water vapor diffusion coefficient went down. Thus, Govaerts *et al.* (2018) imply that renders for historical buildings should have strong buffering towards water absorption to achieve thermal comfort and reduce the risk of damage.

Doctor-pingel et al. (2019) has studied two lime plaster buildings in Auroville for its post-occupancy thermal performance. It is proved that using lime plaster as building material optimizes the thermal performance of the buildings in warm and humid climates. There was a difference of 10.7% noticed between the façade temperatures and cooler interior surfaces than the exterior by 16.8% for the case study of Language Lab.

3. Scope Of Current Work.

It is clear from the literature that lime plaster/mortar has several advantages like lower RH levels and lower indoor temperature. However, the main problem is mold growth due to its moisture absorbing capacity and use of additives. Therefore, in this study, an attempt has been made to evaluate the state of old lime plastered buildings in Ahmedabad and correlate the results in terms of the building characteristics like coatings on the wall, the moisture content of the walls, and the indoor RH levels. Simulations are also carried out to understand the hygrothermal performance of lime plaster and predict the chances of mold growth in the space.

4. Methodology

The research methodology adopted in this work is divided into two sections and each section is discussed in this chapter:

- Simulating the studied spaces with an Effective Moisture Penetration Depth (EMPD) Model using Energy Plus (2019).
- Survey of old lime plastered spaces.

The above two methods can help us derive the hygrothermal impact of lime plaster in an actual case scenario of naturally ventilated buildings. The capability of the EMPD model to predict hygrothermal performance is verified by carrying out annual simulations and contrasting the simulation results with those observed onsite. Survey's also helped to understand the factors which lead to mold growth on lime plastered surfaces in old structures.

SIMULATING THE STUDIED SPACES WITH THE EMPD MODEL.

To carry out a hygrothermal simulation with the EMPD model, hygrothermal properties of lime plaster and other base materials like (brick and concrete) are needed. Properties of the base material required for the EMPD model are available in EnergyPlus v9.1.0 (2010) data. However, there is little information about the hygric properties for lime plaster which could be used, because of its non-standardized compositions. This is one of the reasons for selecting the EMPD model which requires lesser hygric properties as compared to a detailed hygrothermal model in Energy Plus.

Lime mortar mixes are always site-specific making it a challenge to derive a universal curve for it. Therefore, moisture content values required in the input are referred from Kielsgaard (1986) catalog of building materials. To derive the sorption coefficients through these moisture content values, a close-fitting curve shown in
Figure is plotted. The values of this curve are then fed in the EMPD model and simulated.

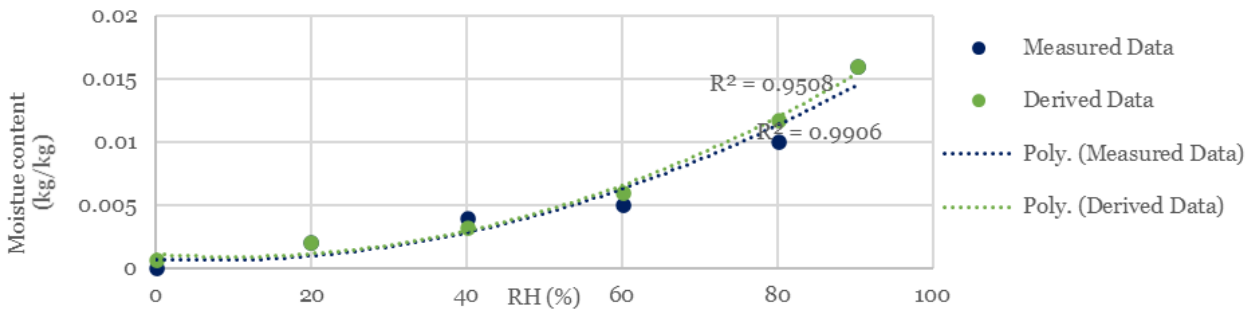

Figure 1 Best fitted sorption curve for lime plaster.

A BESTEST model referred from Judkoff and Neymark (1998) is used and validated by several other authors Woods, Winkler, and Christensen (2013), Zemanová et al. (2017), Zhang *et al.* (2017), Tran Le et al. (2010) for hygrothermal simulation. It is a single-zone shoe-box model with a continuous source of 500 grams per hour of moisture and air exchange per hour is given as 0.5 per hour.

To support the working of hygrothermal simulation in EMPD, first the model is run using thermal only and EMPD algorithm. Later, a sample study space from the survey is modeled and then simulated. The change in MRT and relative humidity through simulation can be derived. This further can help to understand the trend of the hygrothermal behavior of lime plaster in that space throughout the year.

SURVEY OF RESIDENTIAL SPACES

The heritage city of Ahmedabad majorly comprises of thousands of pols, dense cluster of residences belonging to the same caste, religion, and occupation. The houses of such a

neighborhood for more than 300 years are popularly known as Pol houses. The typical pol house has minimal frontage to a narrow lane, long shared walls, some have a central courtyard, multi-story structure. The construction of the house is of timber, brick, and lime plaster. The Pols are well known for their passive strategies of cooling. Due to the narrow lanes and dense clusters, the lanes and houses are often shaded and not so windy. Daily activities of the occupants keep the microclimate humid. The house protects the inside spaces from heat gain by providing cool surfaces, more humid air, and shade.

The point in time surveys are carried out in the afternoon when the temperatures are relatively high outside on every alternate day from the December end. A layout of the space is created considering the wall thickness, opening area, and adjacent spaces. The use and activities of the space are also noted. Table gives the details of the parameters and the location measured on-site by the respective instruments.

Table 1 List of instruments for their measured parameters

Instrument used	Parameter measured	Measurement location
Heat Stress WBGT Meter (Extech HT30)	Outside air temperature, Relative Humidity, Black Globe Temperature	Outside the survey space at a height of 1100 mm from the ground
Heat Stress WBGT Meter (Extech HT30)	Inside air temperature, relative humidity, Black Globe Temperature	At the center of survey space at a height of 1100 mm from the FFL.
Vane Anemometer (PEAKMETER MS6252A).	Air velocity	1. Near the globe thermometer perpendicular to three planer axes. 2. Perpendicular to the vertical plane of the openings inside a space.
Thermal Gun (FLIR TG165)	Surface temperature.	Inside and outside exposed surfaces of all the walls surrounding the space.
Testo 606-2 Moisture Meter (38767439/711)	Moisture Content and surface relative humidity.	Moisture content inside lime plaster and surface relative humidity near it.

5. Results

The results are described in detail for simulations and surveys in this chapter.

SIMULATION RESULTS OF BESTEST MODEL

To understand the moisture buffering of a hygrothermal model, thermal only and EMPD simulations are conducted. The simulations are done in a naturally ventilated mode using the BESTEST model. Moisture buffering can be effectively observed in Figure 2 of the relative humidity inside the space.

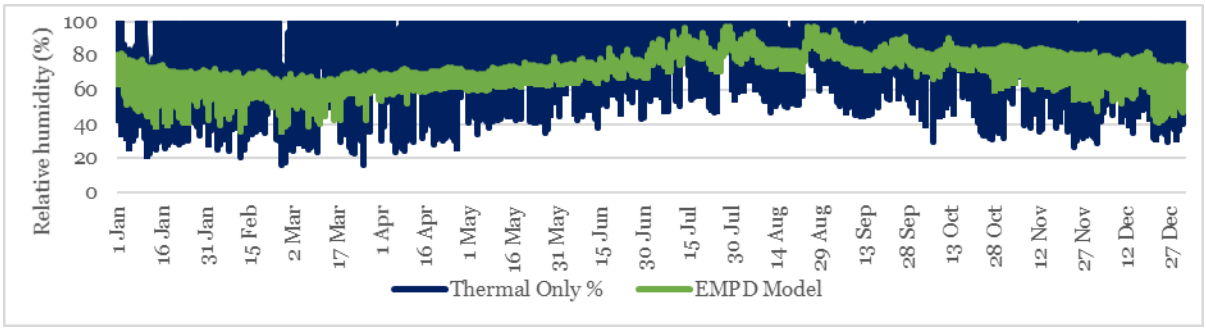

Figure 2 Relative Humidity BESTEST Model of Thermal Only and EMPD.

It can be seen that the RH levels in the case of the Thermal only model (CT) model reach 100% at times. While for the hygrothermal model of lime plaster, the RH levels are maintained between 39% to 95%. This shows that the EMPD model (EnergyPlus v9.1.0, 2010) of lime plaster is successfully showing the moisture buffering inside the space.

After verifying this behavior of the EMPD model for its realistic physical predictions, further simulations in the same EMPD are carried out for the hygrothermal performance of a sample space from the survey. Its performance in terms of MRT and RH inside is observed throughout the year.

SIMULATION RESULTS OF SURVEY SAMPLE SPACE

An onsite space (PT_B) where mold growth is observed during the survey is selected for modeling. Physical parameters similar to the actual case are created except for the lime composition as it is unknown for the actual case. In this case, there is no external source of moisture other than occupancy. Figure 3 shows the layout of the space selected for modeling.

Figure 3 Typical layout of the simulated space PT_B and onsite images.

Figure 4 shows the difference in temperature observed from outside (To) to inside ambient (Ta) throughout the year for model PT_B. The diurnal variation is decreasing from outside to inside. The outside DBT has varying amplitude with a maximum diurnal variation of 20°C in winters to a minimum variation of 7°C in monsoon. Whereas there is a variation of around 5°C for indoor air temperature. Similarly, the bandwidth (difference of maximum and minimum) of the MRT inside the space is around 2°C. Hardly any fluctuations are observed in this band and the temperature is maintained between 20 to 30°C for the given geometry.

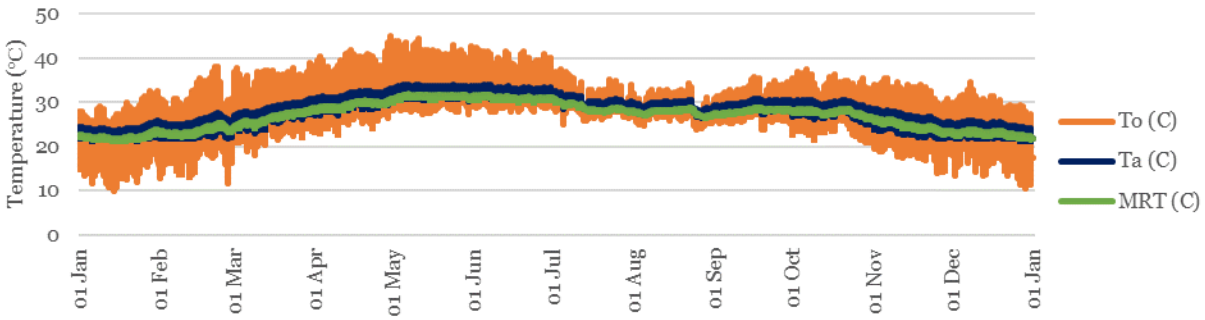

Figure 4 Simulations results showing a range of outdoor, indoor, and MRT in PT_B.

The outside relative humidity (RHo) is compared with the inside RH levels (RHi) and the surface RH (RHs) level in Figure 5. There is a difference of 11.5% from the maximum of outside to inside. Whereas 11% of difference is observed between the minimum levels of outside RH and Inside RH. Also, the difference between the first quartile and third quartile is 33% for outside RH and 24% for the Inside RH.

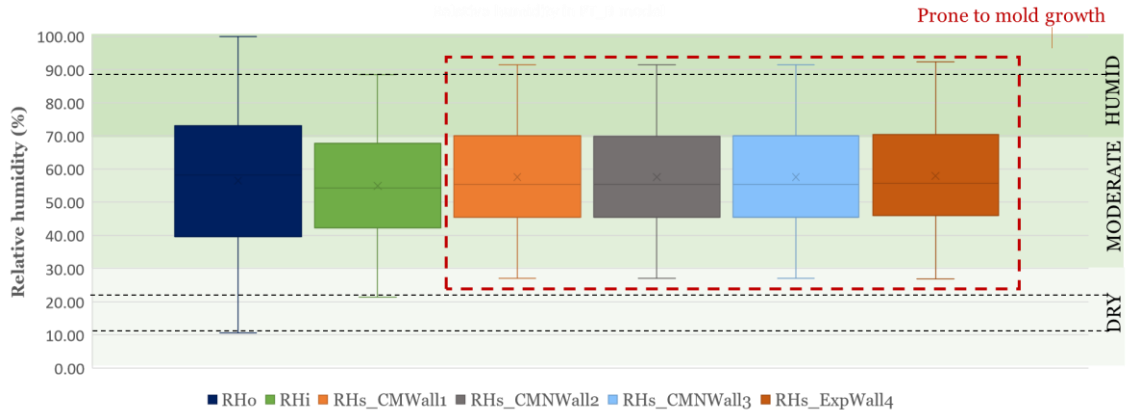

Figure 5 Relative Humidity levels of space and on the surface of the walls in PT_B.

It can be predominantly seen that the surface RH (RHs) levels are higher than the inside RH (RHi) levels. The maximum RHs values are high by 3% and a minimum of RHs are high by 7% than the maximum and minimum of RHi. ASHRAE suggests that to prevent mold growth it is necessary to keep the spaces below 60% RH (Taylor et al., 1999). However, 25% of the surface RH values are more than 70% leading to mold risk.

Figure 6 further indicates the varying RH levels throughout a year. During the monsoon months from July, the inside RH is always above 60%. While the surface RH of common wall (RHs_CMWall1) and exposed wall (RHs_ExpWall4) of the walls is always above 68%. These are the months when the wall surfaces are highly prone to mold growth.

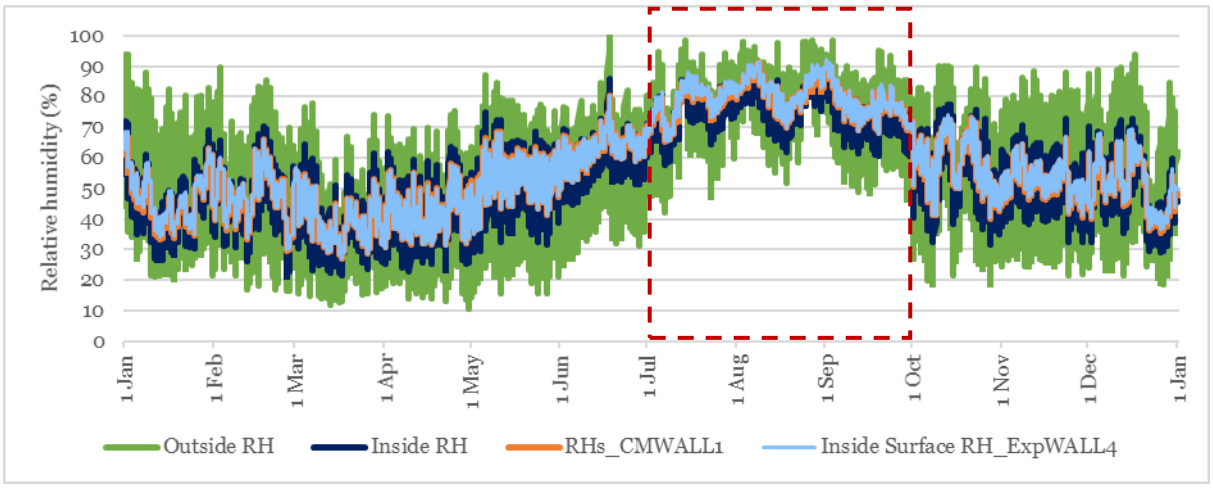

Figure 6 Varying RH levels with time throughout the year in PT_B.

The number of hours when the RH levels are favorable for mold growth can be observed in Figure 7 Out of 8760 hours, 32 to 54 hours are above 90% near the walls. Whereas, 60% of the hours are between 60 to 90%. Rest 40% is below 60% RH levels. Thus, a cumulative of more than 60% of the time the walls are at a risk of mold growth. Unlike the simulation results where an equal percentage of surface RH (RHs) on the walls is observed, the percentage of mold growth observed on-site over each wall is different indicating varying surface RH levels (RHs). This gap can be because of the several ignored factors like placement of furniture and belongings, material of the possessions inside the space, etc.

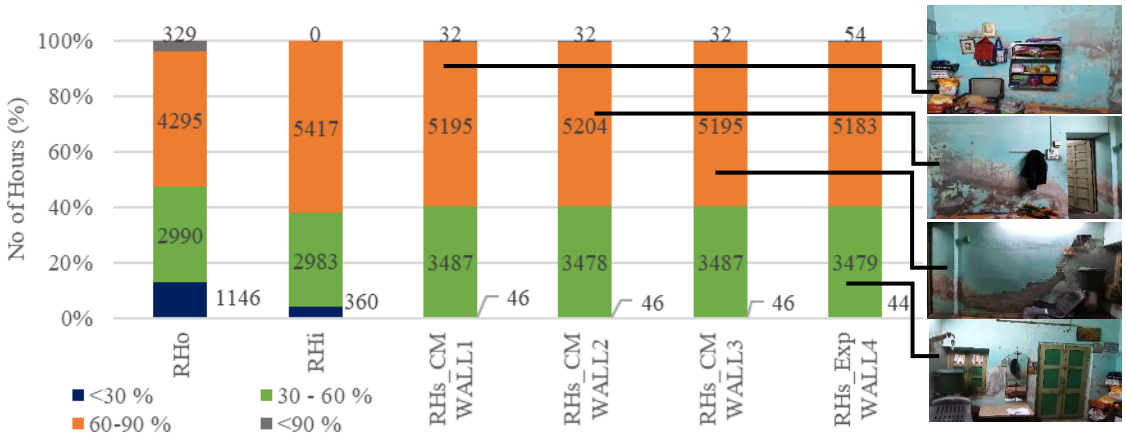

Figure 7 PT_B RH levels observed throughout the year with respect to the number hours.

6. Survey Results:

The observations in studied pol houses are categorized according to the coatings used over lime plaster. According to Figure 8, for the studied time-span from December to March the outside RH levels are between 10% to 55%. However, the minimum value is higher inside by 2.1% in limewash houses and by 1% in Non-porous paint. The median of limewash readings is higher by 3% and in non-porous it is 1% from the outside. For outside RH below 15%, the inside RH is high. The reason can be moisture buffering of the material, occupancy, and inside moisture generation rate.

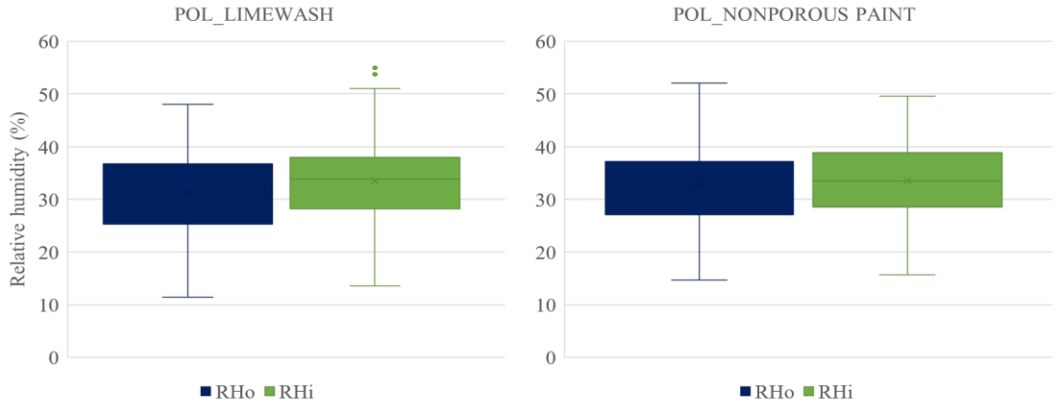

Figure 8 RH levels of studied POL houses.

The inside and outside temperatures in both cases are plotted in Figure 9. In spaces having limewash, the air temperature is lower by 1°C. For non-porous finish, the inside ambient temperature is lower by 1.4°C from the outside high. The outliers observed are the readings when the space is exposed to solar radiation. Otherwise, the rest of the spaces are always under shade.

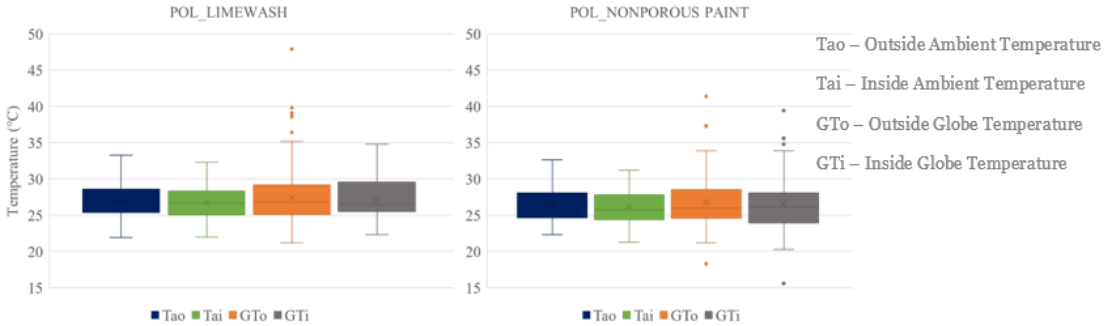

Figure 9 Temperature levels of studied POL houses.

To further examine the simulation observations for sample space PT_B, the onsite readings are analyzed. In Figure 10, the outside relative humidity is compared with the inside space RH levels and the surface RH levels from January to March.

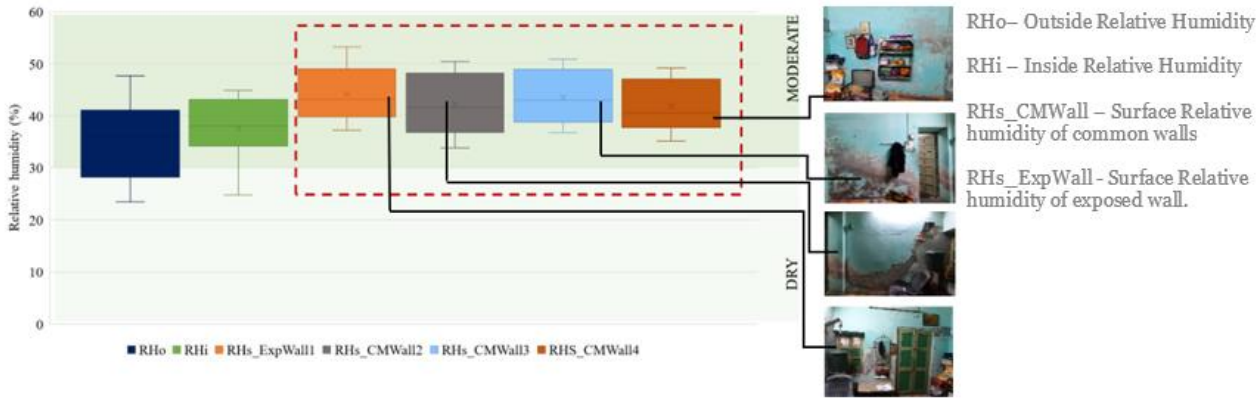

Figure 10 Onsite RH levels inside PT_B

Similar to the simulation results (refer Figure 5), surface RH (RHs) levels are higher than the inside RH (RHi) levels. The maximum of RHi is less by 2.85% from the maximum of RHo of that space. Whereas only a 1.3% of difference is observed between the minimum levels of outside (RHo) and inside (RHi) readings. Thus, moisture buffering is observed. However, 50% of the readings are higher inside than the outside indicating it to be humid inside. So, if the above pattern is followed throughout the year, whenever the space RH goes above 60%, the surface of the wall will have around 65 to 70 % RH. In the monsoon period when the outside RH levels are in the range of 80-95%, the RH inside the space can be around 91%. Similarly, RH near the walls can be predicted to reach 95 to 97%. At this RH level, if the moisture is not removed from the surface, it gets prone to mold growth.

MRT OBSERVATIONS

The percentage of time when MRT inside a space is higher than the outside in March is plotted in the graph below Figure 11. This graph indicates that 30% of the time it was hotter inside for non-porous paint spaces. For limewash coated spaces the percentage was 18.52%.

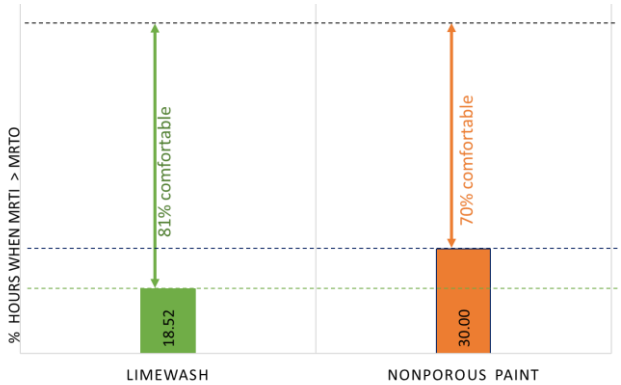

Figure 11 Percentage of readings Inside MRT > Outside MRT in March

MOLD RISK OBSERVATIONS

On conducting the survey, it is observed that the hygrothermal behavior of a space varies as per its characteristics. The spaces are identified and observed separately based on the topmost finish of the wall surface layer, air velocity inside the space, occupancy, storage, the sunlight received and the type of activity happening in that space. Moreover, these were the factors that have a high influence on the high humidity conditions inside any space. The observations analyzed that

majorly the spaces which had mold are devoid of sunlight, lacked ventilation, had a lot of storage, and had water storage nearby.

Further analysis of the moisture content recorded of the walls is shown in figure 12. The walls of the spaces where mold growth is observed are marked in orange. Majorly all the walls of the studied spaces from December to March had low moisture content below 2%. Walls below 2% moisture content are drywalls and do not poses any damage due to mold growth. However, mold growth is still observed on these walls which indicate that during the monsoon season in the past the mold growth was initiated from within. This happens when the surface relative humidity of the walls goes above 60%. Other factors like damaged construction, presence of water pipelines, low ventilation, etc. are also the reasons.

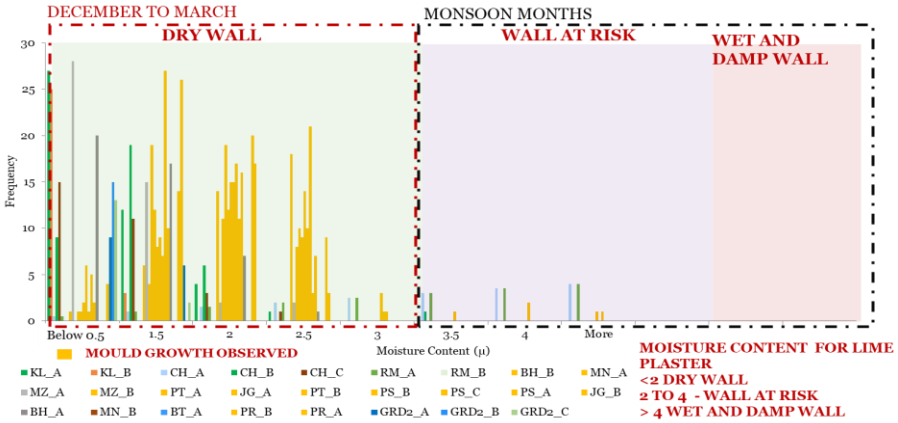

Figure 12 Moisture content of all walls studied from December to March.

7. Conclusion

This work focused on the hygrothermal performance of lime plastered traditional buildings in hot and dry climate. Simulations carried out with the EMPD model can predict the moisture buffering phenomenon on wall surfaces. Thus, it can also be used to predict the mold growth risk of different surfaces. However, more numerical analysis with hygrothermal properties of typical lime plaster used in India needs to be carried out for realistic predictions.

The point in time survey of old naturally ventilated spaces concluded that the finishing coat applied over lime plaster alters its properties and characteristics. If lime plaster is coated with nonporous coatings, that affects its hygrothermal performance. It is not able to maintain effective MRT difference from outside to inside. However, more measurements are necessary to derive definitive conclusions.

The surface RH near the walls is higher than the ambient by 5 to 6% for the surveyed spaces of hot and dry climate. Identifying the high humidity period and hours of the high RH exposure through simulations can further benefit in using preventive measures to reduce the moisture damage of those spaces. This at the design stage will prove to be an important tool to formulate the strategies for maintenance.

Lime Plaster as a building material effectively maintains the RH levels inside naturally ventilated the space. Taken the proper precautions, it is one of the most sustainable building materials that can be used in the building industry today as well. One important aspect to consider is preventing moisture from getting trapped into building fabrics.

The hygrothermal simulations are necessary for predicting the hygrothermal behavior of a material. However, to analyze the historical buildings using only simulations cannot be a good idea. Numerical simulations can just give you a rough idea of what is happening depending upon the input sources. Still, there are a lot of discrepancies with the actual case scenario. As (Akkurt *et al.*, 2020) mention, inaccurate simulations could result in inadequate conclusions, leading to

inappropriate and dangerous actions for the building's heritage conservation. Thus, in collaboration with the survey observations, this performance gap can also be narrowed down for better predictions. For conducting simulations of historical buildings, it is first necessary to collect as much preliminary data as possible for over a year. To understand and inculcate the usage of any material in a historical building the methodologies used in this work are important.

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MANAGEMENT OF AGGREGATE BASE COURSE WASTAGE IN ROAD CONSTRUCTION PROJECTS

PRIYARUWAN E.A.S.[1], SHANDRASEHARAN A.[2] & PERERA B.A.K.S.[3]
[1] University of Vocational Technology, Colombo, Sri Lanka
[2,3] University of Moratuwa, Colombo, Sri Lanka
[1]Sampathpriyaruwanea@gmail.com, [2]mvarhchana@gmail.com, [3] kanchana@uom.ac.lk

Abstract
The construction industry in a country contributes significantly to the national economy. Developing countries in Asia produce a huge amount of construction waste. Road Construction (RC) projects, which are quite risky, often end up with cost and time overruns. Construction materials account for a major portion of the cost overruns. Thus, the management of material wastage in construction projects is important. Aggregate Base Course (ABC) wastage affects the cost of RC significantly. Thus, this study was on the waste management of ABC in RC projects executed in Sri Lanka. The study adopted a qualitative research approach and the required empirical data were collected by interviewing 13 experts. The interview findings were analysed manually using content analysis. The interviews were conducted based on the findings of a literature review. The interviews findings disclosed that improper material storage in sites, material wastage during transportation, improper material utilization, and professional inefficiency as the major factors that contribute to material wastage in road projects. Material reconciliation and proper documentation were identified as the two most common strategies that can be adopted to manage the material wastage in RC projects.

Keywords: *Aggregate Base Course; Material Wastage; Road Construction Projects.*

1. Introduction

According to Manamgoda et al. (2018), infrastructure systems play a dominant role in the economic growth of a country. They further state that road networks, which are vital for the development of a country, are one of the main infrastructure systems required by a country. Sri Lanka, although still a developing country, has an extensive road network comprising 217.825 km of expressways (Class E) and 12,220.587 km of national highways (Classes A and B) (Road Development Authority [RDA] 2019). These roads are the backbone of the transportation system of the country because the socioeconomic development of the country is facilitated by the roads through the speedy transportation of both people and cargo (Manamgoda et al. 2018). Road projects are notorious for being risky, and often end up with cost overruns (Ogbu & Adindu 2019). According to a study done by Gulghane and Khandve in 2015, construction material costs account for a large percentage of the construction project cost. Wijekoon and Aththanayaka (2013) found that one of the vital factors that contribute to cost overruns is material wastage. Thus, Choudhari and Tindwani (2017) emphasized the importance of material wastage management in Road Construction (RC) projects. Road construction relies mainly on non-renewable aggregate resources (Fladvad et al. 2017). According to Choudhari and Tindwani (2017), in road projects, Aggregate Base Course (ABC), a bulky and expensive material, is used to ensure the stability of pavement surfaces. They further state that the cost of transportation of construction material becomes high because of the large distance that exists between the material source and the construction site. ABC wastage in RC occurs mainly because of the bulkiness of ABC and the largeness of the quantities required (Wang et al. 2004). Hence, the control and management of material wastage in RC projects is essential throughout the supply chain of the project (Mahajan & Aher 2017). However, only few studies have so far been carried out on the material wastage management in RC projects (Choudhari & Tindwani 2017; Wijekoon & Aththanayaka 2013), especially on ABC waste management in RC projects (Wang et al 2004). None of these studies has focused on Sri Lanka.

Therefore, the aim of this study was to explore ABC wastage management in road construction projects in Sri Lanka. The objectives of the study were to identify the factors that cause ABC waste in RC projects executed in Sri Lanka, investigate the consequences of ABC wastage in those projects, and propose suitable ABC wastage control measures. The scope of the study was confined

to Sri Lanka. The study focused on the ABC material wastage in RC projects of Classes A and B and excluded road rehabilitation projects.

2. Literature Review

2.1. MATERIAL WASTAGE AND MATERIAL WASTAGE GENERATION FACTORS

Material wastage can be observed in almost all types of construction projects (Mahajan & Aher 2017). Construction waste, which can originate from various sources, is usually found throughout a building project (Jayamathan & Rameezdeen 2014). This construction waste has become a challenge to the construction industry in the achievement of its sustainable goals (Kulatunga et al. 2006). Construction project cost largely depends on the cost of the materials used (RathinaKumar et al. 2018). Patel and Poitroda (2017) mentioned that material cost accounts to 60% –80% of the total construction cost, which is a significant percentage. Therefore, to ensure cost control, the proper management of construction materials becomes crucial (Madhavarao et al. 2018).

Akanni (2007), after studying 146 Nigerian building projects, identified ten major factors that are responsible for material wastage and their percentage contribution to the total amount of the material wastage generated. According to the author, site storage (43%), transportation and delivery to site (14%), pilfering and theft (14%), wrong specifications (6%), intra-site transits (5%), fixing (5%), wrong use (5%), conversion waste (3%), negligence (3%) and management (2%) contribute to material wastage in construction projects. Kulatunga et al. (2006) stated that the behaviour of the construction workforce affects most of the factors responsible for material wastage. They concluded that the attitudes and perceptions of the construction workforce can influence the generation of waste and the implementation of waste management strategies.

2.2. IMPORTANCE OF MATERIAL WASTAGE MANAGEMENT

Material wastage results when inaccurate quantities of materials are purchased; poor quality materials are procured; and materials are used inefficiently and ineffectively (Shen & Tam 2002). The main consequence of construction material wastage is cost overruns (Kanimozhi & Latha 2014) because construction cost estimates are generally based on a straight take off of the required quantities (Sakantu et al. 2003). Hence, the proper management of material wastage will ensure efficient and effective material use (Hwang & Yeo 2011) with the right quantity and quality (Kanimozhi & Latha 2014). This will in turn control the cost overruns of the project (Saidu & Shakantu 2017).

Mahajan and Aher (2017) stated that with proper construction material waste management, the average saving of the material cost can be as much as 8.80%. In order to effectively manage material wastage in construction projects, material waste control measures that can control cost overruns at both pre-contract and post-contract stages of a project should be introduced (Saidu & Shakantu 2017). Material reconciliation is one of the material wastage management techniques, which ensures that no difference exists between the quantity of the procured material and the quantity of material required according to the Bill of Quantities (Rameezdeen1et al. 2004). Furthermore, Ling and Nguyes (2013) emphasized that waste management in the construction industry can effectively be implemented by employing subcontractors capable of waste management; conducting training programmes; auditing and supervising subcontractors and workers closely; sequencing activities to reduce damage to completed work; setting the level of wastage allowable; and offering rewards and enforcing punishments.

2.3. RC PROJECTS AND ABC MATERIAL WASTAGE

Cost and time overruns are common in infrastructure and building construction projects (Mahamid 2011). Road construction involves the movement and relocation of large quantities of materials (Choudhari & Tindwani 2017). RC projects are considered high-risk projects because of their probable cost overruns (Ogbu & Adindu 2019), which occur mainly because of material

wastage (Wijekoon & Aththanayaka 2013). Hence, proper material management is necessary in RC projects (Choudhari & Tindwani 2017).

Use of unbound aggregates as base course layers in the construction of flexible pavements is common around the world (Patil & Pataskar 2013). The materials used in each layer of the pavement have to comply with the stipulated specifications. The main type of construction material used in RC projects is non-renewable aggregate resources. A considerable percentage of the material cost of road projects can be attributed to the aggregate cost (Ogbu & Adindu 2019). ABC is a durable and well graded aggregate, which has been moistened uniformly and stabilized mechanically through compaction (Unified Facilities Guide Specifications [UFGS] 2017). According to Arnold et al. (2007), most road controlling authorities, generally specify dense graded ABC materials for road construction because they have few voids, high strength, and high stability owing to the interlocking particles present in them. These ABC materials, which are compact, are difficult to handle and do not possess their specified strength (Arnold et al. 2007). Thus, the wastage of the ABC materials used in RC projects is high. The study of the management of ABC material wastage in RC projects is therefore important because by properly managing the ABC waste, a project can be made a success.

3. Methodology

Hammarberg et al. (2016) state the qualitative research approach is best for collecting opinions and facts from people based on their experience and behaviour. Therefore, this study used the qualitative approach to collect the data required to identify the specific factors that cause ABC wastage in RC projects, by interviewing experts in the field of road construction. Purposive sampling was used to select, as interviewees, experts who had experience in road projects. William (2015) emphasized that semi-structured interviews are more relevant to situations where the researcher requires the interviewees to have in-depth knowledge in their field of expertise. To collect the in-depth data required, thirteen experts with knowledge on ABC wastage that occurs in RC projects and a minimum of ten years' experience in RC projects were interviewed until data saturation was reached. Interviews were conducted face to face with each interview lasting for about 50 to 65 minutes. Content analysis was used to manually analyse the collected data because it allows the researcher to become familiar with the collected data and maintain a full control over the data. Table 1 below lists the details of the experts who were interviewed.

Table 1: Details of the interviewees

Expert Code	Designation	Total Experience in Years	Experience in RC in Years
a	Senior Quantity Surveyor	14	12
b	Materials Engineer	14	10
c	Quantity Surveyor	12	11
d	Senior Engineer	15	11
e	Costing Executive	10	10
f	Technical Officer	13	12
g	Senior Engineer	18	13
h	Site Engineer	15	12
i	Chief Quantity Surveyor	34	30
j	Technical Superintendent	25	20
k	Senior Material Engineer	13	10
l	Senior Engineer	17	15
m	Project Manager	18	13
RC- Road construction			

4. Analysis and Findings

4.1. MATERIAL WASTAGE AND MATERIAL WASTAGE GENERATION FACTORS

Several factors cause ABC wastage in RC projects. Table 3 shows 21 factors identified from the literature and 6 factors identified from the interviews. The experts agreed that all 21 factors identified from the literature are relevant to ABC wastage in RC projects in Sri Lanka. In Table 3,

the factors identified from the interviews are highlighted. Poor workmanship, lack of a waste management plan, and rework, which are in bold italics, were identified as factors directly responsible for ABC wastage in RC projects, as revealed by Adewuyi and Otali (2013) and Saidu and Shakantu (2017) as well. Some of the interviewees classified the other factors as indirect factors responsible for ABC wastage in RC projects. The errors in contract documents and complicated design were identified as indirect factors by the interviewees as also stated by Adewuyi and Otali (2013) and Wang et al (2004). Complicated design was considered an indirect factor by the interviewees because such a design becomes a challenge when the professionals handling the design lack the required skills.

Table 2: Key Factors responsible for ABC wastage generation in RC Projects

#	Factor	L	a	b	c	d	e	f	g	h	i	j	k	l	m
1	Design changes and client changes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	***Poor workmanship***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	Poor and wrong storage of materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Lack of on-site material control	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	Double handling of materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	Poor quality of the materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	***Lack of a waste management plan***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	Inadequate supervision	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	Complicated design	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	*Rework*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	Incorrect materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
12	Use of untrained labour	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13	Adverse weather conditions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14	Poor quality equipment and non-availability of equipment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15	Theft and vandalism	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16	Errors in contract documents	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	Wrong construction method	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
18	Manufacturing defects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
19	Ordering errors	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	Quantity surveying mistakes and over payment of allowances	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
21	Damage during transportation	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
22	**Laying ABC without construction shoulders**			✓			✓		✓	✓		✓	✓		
23	**Use of inappropriate machinery to spread ABC**			✓			✓		✓	✓			✓		
24	**Use of ABC in place of soil because ABC is easier to handle than soil**			✓					✓	✓		✓			
25	**Increased time taken for internal transport**					✓	✓		✓			✓			
26	**Material segregation during loading, unloading, and laying of mortar grader**					✓	✓			✓		✓			
27	**Uncovered materials or material storage in open areas**								✓				✓	✓	

L- Literature findings

Interviewee B did not agree that damage during transportation causes ABC wastage in RC projects as revealed by Adewuyi and Otali (2013) and Saidu and Shakantu (2017). Interviewee B was of the view that since wastage occurs during all three processes of loading, unloading, and transportation of material, naming wastage as transportation wastage is incorrect. Interviewee K also agreed with the view of Interviewee B. The interviewees also mentioned six new factors which in their opinion contribute to ABC wastage in RC projects. These six factors were not mentioned in the literature. Laying ABC without construction shoulders, using inappropriate machinery to spread ABC, using ABC in place of soil because ABC is easy to handle, increased time taken for the internal transportation of materials, segregation of materials, and storing ABC in open spaces were the six factors. Among the factors, using ABC in place of soil because ABC because of its ease of handling was identified as an indirect factor causing ABC wastage. All other factors were considered direct factors responsible for the ABC wastage in RC projects.

4.2. CONSEQUENCES OF ABC WASTAGE IN RC PROJECTS

The consequences of ABC wastage highlight the importance of proper waste management. As illustrated in Table 3, altogether 15 consequences of ABC wastage could be identified; 11 of them which were identified from the literature were accepted by the experts as being applicable to RC projects executed in Sri Lanka as well.

Table 3: Consequences of ABC wastage in RC projects

#	Consequences	L	a	b	c	d	e	f	g	h	i	j	k	l	m
1	***Cost overruns***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Quality issues	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
3	Time overruns/Delays	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Project delays	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
5	Environmental issues	✓	✓	✓	×	✓	✓	×	✓	✓	×	✓	✓	✓	✓
6	Negative effects on the society	✓	✓	✓	×	✓	✓	×	×	×	×	✓	✓	✓	✓
7	Increased material prices	✓	✓	✓	×	×	✓	✓	✓	×	×	✓	✓	✓	✓
8	Health issues of the people	✓	✓	×	×	✓	✓	×	×	×	×	✓	✓	✓	✓
9	Increased illegal dumping	✓	×	×	×	✓	✓	✓	✓	✓	×	×	✓	✓	×
10	Project termination	✓	✓	✓	×	×	✓	×	×	✓	✓	×	×	✓	✓
11	Land shortage	✓	×	✓	×	×	✓	✓	×	✓	×	×	✓	×	✓
12	**Financial issues of the contractors**			✓			✓	✓		✓		✓	✓		
13	**Increased number of government regulations**			✓			✓		✓		✓				✓
14	**Disputes among the parties**			✓	✓	✓						✓			✓
15	**Issues related to quantity calculations**								✓	✓			✓	✓	
L- Literature findings															

The four highlighted consequences were identified by the interviewees as those unique to Sri Lanka. Of the consequences identified from the literature, only cost overruns (Ogbu & Adindu 2019; Wijekoon & Aththanayaka 2013) given in bold italics was accepted by all of the interviewees as being applicable to ABC wastage in RC projects executed in Sri Lanka. Most of the interviewees agreed with the literature review findings. By contrast, financial issues of the contractors, increased number of government regulations, disputes among the parties, and issues related to quantity calculations were also identified by the interviewees as the consequences of ABC wastage encountered in RC projects executed in Sri Lanka. A majority of the interviewees did not accept project termination identified from the literature as resulting from ABC wastage in RC projects in Sri Lanka stating that parties to a contract try to avoid disputes to prevent project termination. Most of the other material wastage consequences are applicable to ABC wastage in Sri Lankan road projects.

4.3. KEY MEASURES THAT CAN BE USED TO MANAGE ABC WASTAGE IN RC PROJECTS

As illustrated in Table 4, 25 measures are available to manage ABC wastage in RC projects. Twenty measures that were identified from the literature were accepted by all of the interviewees as being applicable to ABC wastage management in RC projects in Sri Lanka as well. Measures that are highlighted were identified by the interviewees based on their experience in RC projects which are unique to ABC waste management in Sri Lanka.

Table 4: Measures that can be used to manage ABC wastage in RC Projects

#	Measures	L	a	b	c	d	e	f	g	h	i	j	k	l	m
1	***Improved material transportation***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	***Proper material storage***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	***Improved onsite construction management by the contractor***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	***Proper site control and supervision***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	***Protection of material from weather damage***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	***Use of skilled and experienced labor***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	Use of appropriate materials	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	Maintenance of proper records and	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓

#	Measures	L	a	b	c	d	e	f	g	h	i	j	k	l	m
	documentation on the materials used														
9	Ordering of correct quantities of the materials and timely delivery of the materials	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
10	Proper scheduling and planning	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	Proper onsite administration of 5 Ms (men, material, money, machines and management)	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓
12	On-site and off-site re-use/ recycle of waste, and on-site waste sorting	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
13	Efficient unloading of materials supplied in loose form	✓	✓	✓	✓	✓	✓	✓	✓	×	×	✓	✓	✓	✓
14	Procurement of material complying with the specifications	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	✓
15	Provision of easy access to delivery vehicles	✓	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	✓	✓
16	Provision of security, security lighting, and temporary fencing for the site	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓
17	Integration of waste management into construction contractor assessment	✓	✓	×	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓
18	Adoption of good material abstracting	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	×
19	Adoption of a unified method for estimating the procurement process	✓	×	×	✓	✓	×	✓	✓	✓	×	✓	✓	✓	✓
20	Obtaining insurance cover for the procured materials	✓	✓	✓	✓	×	×	×	✓	×	×	✓	✓	×	×
22	**Adoption of an innovative method for laying ABC**		✓	✓			✓			✓		✓			✓
23	**Finding an alternative for ABC that is similar in performance to ABC**			✓					✓	✓	✓			✓	
24	**Storage of materials free of dust, organic matter, clay and silt or any other matter**		✓		✓	✓							✓		
25	**Ensuring the required humidity level when storing ABC**			✓				✓	✓				✓		

L- Literature findings

Among the identified measures, improved transportation of materials, use of skilled and experienced labour, proper material storage, and proper site control and supervision were accepted by all the interviewees as being applicable to ABC wastage management in the RC projects executed in Sri Lanka. These measures are bolded and italicized in Table 4. All other measures were also accepted by most of the interviewees. However, obtaining insurance coverage for the procured material recommended by Saidu and Shakantu (2017) was not accepted by most of the interviewees as according to them although such coverage provides for the reimbursement of the cost of wasted materials it does not help manage the ABC wastage.

The interviewees identified four new measures as well, namely use of an innovative method for laying ABC; finding a good alternative for ABC that is similar in performance to ABC; storage of materials free of dust, organic matter, clay and silt or any other matter; and ensuring the required humidity level when storing ABC. Two of these measures relate to the proper storage of materials (Saidu & Shakantu 2017), while other measures focus on finding an alternative material for ABC and using an innovative method for ABC laying (Agyekum et al. 2012).

5. Conclusion and Recommendations

This study explored material wastage in road construction projects by identifying the significance of material wastage management in road construction projects, consequences of material wastage, and the measures that can be taken for wastage management. The study particularly focused on the ABC waste management in RC projects in Sri Lanka. It identified the key factors that are responsible for ABC wastage in RC projects. Poor workmanship, lack of a waste management plan, and rework were identified by all the experts who were interviewed, as the key factors that cause ABC wastage in RC projects executed in Sri Lanka. Major consequences of ABC wastage in RC projects were also revealed during the study. Cost overrun was the key consequence noted by all of the interviewees, while other consequences were also considered by them as being indirectly or directly related to cost overruns. Waste management measures were also discussed in detail. Use

of skilled and experienced labour, improved transportation of materials, proper material storage, and proper site control and supervision were highlighted by the interviewees as the measures that can be taken to manage ABC wastage in RC projects executed in Sri Lanka. Thus, this study will provide new knowledge by identifying the causes of ABC wastage and the strategies that can manage that waste. In addition, waste generation factors, and consequences and key measures of waste management of other material in RC projects are applicable to ABC. The study contributed to research by identifying the factors causing ABC waste generation, consequences of ABC waste generation and key ABC waste management measures in respect of Sri Lankan RC projects. The study will also contribute to practice by helping to reduce the cost of road construction projects by minimizing wastage, saving natural resources, and enhancing the sustainability of construction. More importantly, the study findings will be useful to other developing countries as an initial study.

ABC wastage management in RC projects in Sri Lanka can be made more effective and systematic by including ABC wastage in RC projects in the curricular of relevant study programmes to make the students aware of the value of proper ABC waste management techniques; conducting continuous professional development programmes to help industry professionals gain knowledge of ABC wastage in RC projects and the new trends and technologies of ABC wastage management in RC projects; facilitating research and development on ABC waste management in RC projects to ensure the continuous growth of road development in Sri Lanka; initiating action by government agencies like Road Development Authority to highlight the importance of ABC waste management in RC projects in their annual reports and publications, which will help to build awareness among both the professionals and the public, about the importance of ABC waste management. The major limitation of the study is the confining of the interviews only to Sri Lanka making it difficult to generalize the results to developed countries, which are economically, environmentally, technically, socially, and financially more advanced than Sri Lanka. Further research could be conducted on the use of modern technologies, such as building information modelling (BIM), that will ensure accurate quantity calculations in ABC waste management in RC projects (use of BIM in ABC waste management in RC projects).

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AN ALTERNATIVE APPROACH TO ASSESS THE RESIDENTIAL POPULATION RESILIENCE TO URBAN FLOODING

KALPANA. L.D.C.H.N.[1], JAYASINGHE. A.B.[2], ABENAYAKE. C.C [3] & WIJAYAWARDANA. P.N.P.[4]
[1, 2, 3,4]Department of Town and Country Planning, Faculty of Architecture, University of Moratuwa, Sri Lanka.
hnhasinthanawod@gmail.com[1], amilab@uom.lk[2], chethika@uom.lk[3], naduniwi@gmail.com[4]

Abstract
Community resilience assessments and minimizing the anticipated disruptions to vulnerable communities, is a broad topic in disaster studies. In common practice, most of the indicator-based resilience assessment studies rely on statistical aggregation methods of tabular data collected for macro administrative units, as it is readily available in most of the countries. However, this method confronts severe drawbacks in converting such data into micro-scale geospatial units. To address those issues, this study proposes to utilize the Dasymetric Mapping Technique in the geospatial population resilience assessments, as it is capable of identifying the micro level impact to the population distribution as a pixel representation. In order to geospatially demonstrate the population exposure, the study has selected three major flooding events occurred in Colombo, Sri Lanka. The results revealed a great applicability of the proposed method as a statistical approach which estimates the exposed population by over 90% accuracy. Therefore, the proposed method is recommended to be utilized as an efficient tool of community resilience assessment as it is highly accurate in downscaling the spatial distribution of population data.

Keywords: *Community Resilience Assessment, Disaster Management, Dasymetric Mapping Technique, Urban Flooding*

1. Introduction

Flooding is considered a global threat, as it disrupts the livelihood in many dimensions and makes a significant impact on the people, the economy and the environment. It is estimated that 47% of flood and storm-related events have affected 2.3 billion people in the world during the last decade (1995 – 2015); (Wahlstrom & Guha-Sapir, 2015). In 2010 alone, 178 million people were affected and the total economic loss exceeded USD 40 billion. (WMO, 2015). Extreme rainfall events or uncertainties, an agglomeration of population, unplanned urban development, increasing imperviousness and poorly maintained drainage systems lead to frequent flooding, causing damage to the population and these conditions triggers their vulnerability at a higher rate. (Singh, et al., 2018); (Pregnolato , et al., 2016); (Jha, et al., 2012); (Dover, 2015). Therefore, resilience building has become an important way for city planners and decision makers to manage flood risks (Abenayake, et al., 2016). Many global agendas such as Sendai Framework for Disaster Risk Reduction 2015-2030, the Sustainable Development Goals (SDG) for 2030, and the World Humanitarian Summit Commitments to Action and the New Urban Agenda emphasize the importance of such measures (UN-Habitat, 2017).

In the ecological domain, the term 'resilience' is defined as "the measure of the persistence of systems and their ability to absorb change and disturbance, yet maintain the same relationships between populations or state variables" (Holling, 1973). Thus, nowadays it is commonly used in many disciplines and in resilience building studies, and is mainly considered the functionality of the system under a disaster driven situation in order to understand the impact on the vulnerable communities (Serre, 2018). Hence, this insight will elaborate the understanding of practitioners to improve the degree of susceptibility (Hammond, et al., 2015). Thus, the corresponding studies examines the community resilience to urban flooding and the applicability of the methodology to assess population resilience to urban flooding.

Considering the Sri Lankan situation, floods are identified as the most frequent natural disaster, where thousands of people island-wide are affected every year. According to the DMC and UNOCHA records, the 15th of May 2016 flooding event affected 301,602 people in the whole country causing more than 104 deaths; and 99 people were reported missing (UNOCHA, 2016). Floods in 2017 may have caused distress to 879,778 of the population where 219 deaths and 74 missing persons were reported (DMC, et al., 2017); (UNOCHA, 2016). These statistics also highlight the increasing flood vulnerability of urban areas. The predominant causes of flooding are identified as the rapid growth of population and unplanned urban development activities which have disrupted the natural flow of rain water circulation and topography. These flooding events are defined as urban flooding (Papagiannaki, et al., 2017); (Yin, et al., 2016); and this particular study

focuses on assessing the population resilience for flooding urban areas, as those areas account for the higher portion of active labor force and economic contribution to the GDP and hence, extremely important to the socioeconomic development of the country.

Although ample geospatial studies have been conducted to discuss the quantitative analytical methods of measuring the infrastructure resilience of urban flooding, there have been very limited quantitative studies to assess community resilience (Abenayake, et al., 2018). This is mainly due to the contemporary analytical methodologies, complexity of the population distribution and the nature of demographic data representation in spatial platforms (Jayasinghe & Munasinghe, 2012); (Jayasinghe, et al., 2020). As shown in the Figure 1, the population data is generally represented by a choropleth map, where the statistical data is aggregated to areal units (i.e. GN Divisions), and which does not represent the actual population distribution due to the topology and landuse differentiations (Mennis, 2003); (KALPANA, et al., 2019). Hence, such measures do not adequately capture the real significance of population resilience, although several literatures have utilized them in different ways to focus on the recovery phase of the flood events to measure the population resilience (Wenjuan, et al., 2020). In order to address that gap, this research proposed an alternative approach to measure the population resilience, based on the dasymetric mapping technique (Mileua & Queirósa , 2018). The core area of Colombo was taken as the study area and recent flooding events were selected to measure the flood exposure of population.

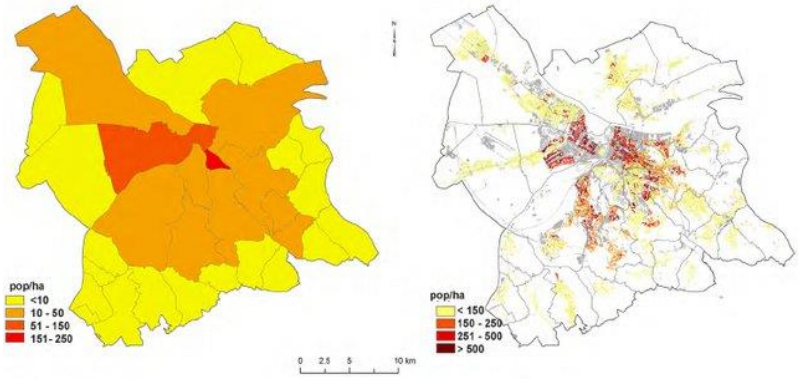


Figure 1: Population shown in Choropleth map (left) and dasymetric map (right), (Bajat, et al., 2013)

The remainder of the paper is organized as follows: The application of the dasymetric mapping method is briefly discussed in Section 2. Methodology and data description is introduced in Section 3. Analytical results and a brief discussion on findings are presented in Section 4. Finally, the summary and an outline of future research directions are provided in Section 5.

2. Dasymetric mapping method.

The dasymetric mapping technique is identified as a population downscaling technique which follows the areal interpolation method (WU, et al., 2005). It basically transfers the spatial data from one spatial zone to another based on the ancillary information, which is usually extracted from the satellite imagery classifications and landuse data registries (Nicolau, et al., 2019). Although there have been several dasymetric mapping approaches based on a variety of ancillary information, this study follows the dasymetric mapping approach proposed by Nelson and Margarida (Mileua & Queirósa , 2018)along with several model enhancements. The proposed dasymetric model was developed based on the Python Language, but the model did not respond well due to internal corruptions. Therefore, the model architecture was changed by authors and the same model was built in QGIS Model Builder environment, as it was easier to make improvements and the necessary adjustments. In order to calculate the population of each land cover cell, it follows the modified equation of (Holloway, et al., 1997).

$$P = \frac{(R_n A_n) \times N}{E} \quad (1)$$

Wherein,

P : Population of a cell
R_n : The relative density of the mapping unit population with land-cover type A
A_n : The area of mapping unit
E : The expected population of the enumeration unit calculated using relative densities
N : The actual population of the enumeration unit

The study follows the same ancillary classification to prepare the dasymetric map, as it is applicable for the Sri Lankan landuse classification. Thus, it classifies the landuse layer into four ancillary classes as: I. High-Density Residential, II. Low-Density Residential, III. Non-Urban inhabited, IV. Uninhabited and distributed in each GN Division's population, according to the GN Division's ancillary information. The study is based on the Department of Census and Statistics 2012 population census data and National Metadata Catalogue (NDSI) Landuse Data. The detailed steps of preparing the dasymetric map, are presented in the methodology section.

3. Methods and Materials

3.1 DATA DESCRIPTION

The data used for the particular study is summarized in Table 1.

Table 1: Data Description

Data Type	Year	Source	Description
Population Data	2012	Department of Census and Statistics (DCS)	GIS Files (Polygon)
Landuse Data	2015	National Metadata Catalogue (NSDI)	GIS Files (Polygon)
Flood Maps	2010, 2016 & 2017	Center for Urban Water, Sri Lanka (CUrW)	Image Files (JPEG)

3.2 STUDY FRAMEWORK

The overall method of study is illustrated in Figure 2.

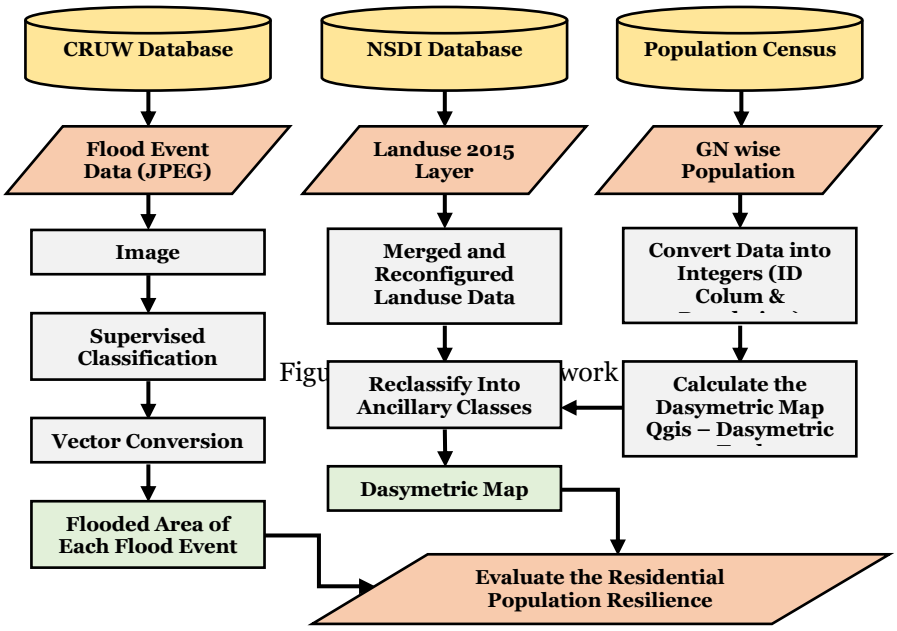


Figure 2: Study Framework

3.3 STUDY AREA

In order to demonstrate the exposed population, the study selected the core area of Colombo for the case study, which is considered a highly urbanized zone in Sri Lanka. Three consecutive urban flooding events were selected as shown in Table 2, along with the significance of each event.

Table 2: Characteristics of Selected Flood Events.

Onset of Flooding	Impacted Area	Affected Population
2010 May 17 Flood	41 Sq.km	91,000
2016 May 15 Flood	32 Sq.km	228,871
2017 May 25 Flood	22 Sq.km	21,000

4. Results And Analysis

The population dasymetric map prepared under the 250m resolution (250 Cell Size) is shown in Figure 3. The map disaggregates the population according to the ancillary information and uninhabitable areas present zero population.

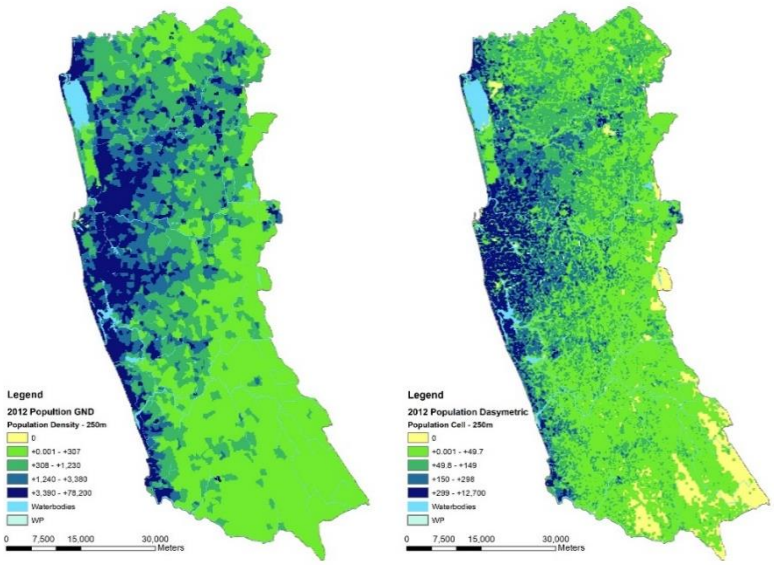


Figure 3: Population Density Distribution According to the GN Divisions (Left Map), Dasymetric Population Distribution (Right Map)

Figure 4 depicts the comparative zoomed-in density diagrams of GN division and Dasymetric mapping overplayed with the administrative boundary.

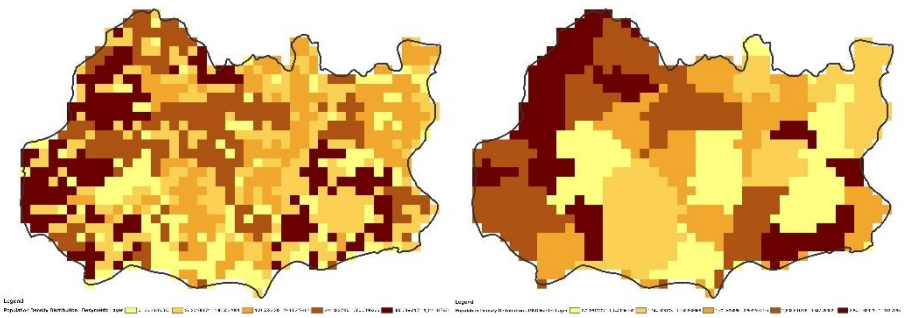


Figure 4: Zoomed View of Population Distribution, GN Division (Right) and Dasymetric Map (Left) – (Darker the color, higher the concentration of population)

In order to evaluate the population distribution obtained from the dasymetric map, the map is compared with the statistical population distribution map. It calculates the sum of each pixel which represent each GND and then the absolute difference of the two variables is calculated by subtracting the GND population. Figure 5 shows the histogram of absolute difference of the two valuables.

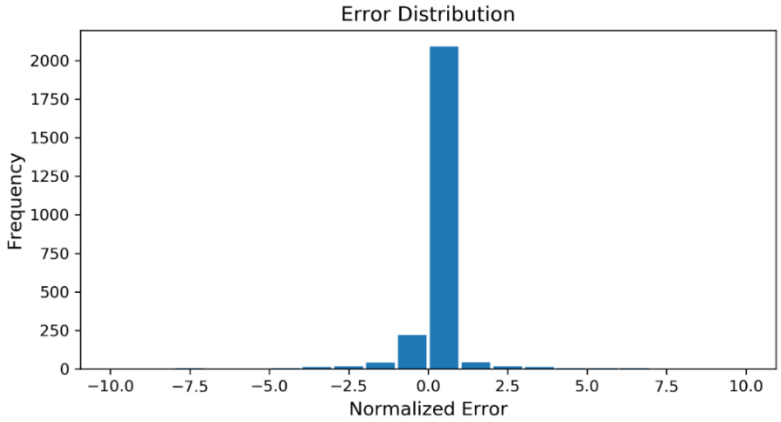


Figure 5: Absolute Difference between the GND and Dasymetric Population Distribution

The Histogram shows normal distribution, as the majority of the values are distributed near zero. Thus, the dasymetric method preserves strong validity compared to the GND population distribution.

Figure 6 shows the spatial representation of error distribution. It clearly represents the areas that incorporate complex land use actions that impact the over estimation of the population (i.e. Industrial areas and highly urbanized areas show population spillovers due to job opportunities and economic potentials but, considering the land use types those areas are not suitable for living). Similarly, several rural areas make an impact on the underestimation of the population distribution.

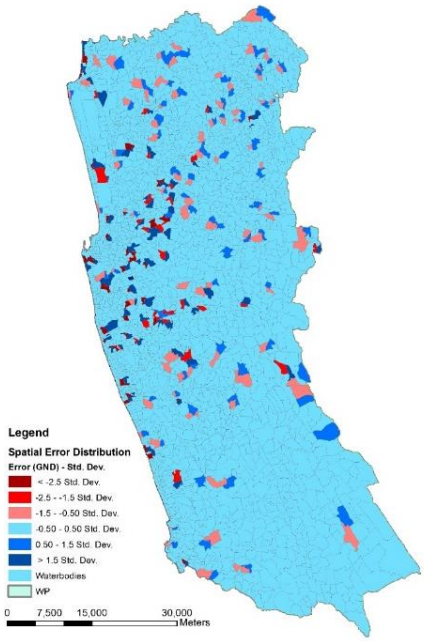


Figure 6: Error Distribution as GN Division Representation

Next, the study derived the flood inundation areas of the selected flooding events. As mentioned above, the flood data were collected as Image files (JPEG) and in order to estimate the population exposure, it is required to transfer the JPEG flood areas in to a spatial format. Therefore, the study utilized the Supervised Image Classification Techniques under the ArcGIS environment and has

derived the flood layers under the vector format. Figure 7 shows the flood inundation areas in each selected year.

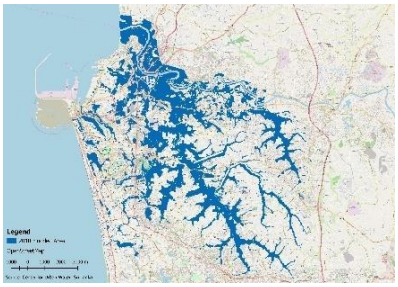
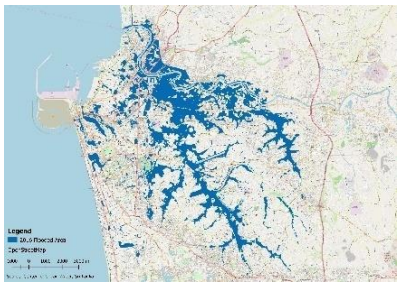
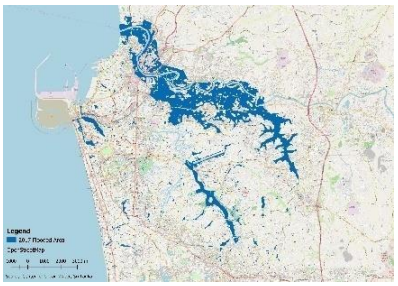
Flood Inundation Area		
2010 May 17 Flood	**2016 May 15 Flood**	**2017 May 25 Flood**
		

Figure 7: Selected Flood Events and Their Inundation Areas

In order to estimate population exposure, the study utilized the Overlaying Method of flood layers on the dasymetric map and calculates the affected population of each flooding event. This is the entry level vulnerability assessment method, but can be easily developed to resilience assessment, by adding vulnerable buffer zones and random and localized attacks to the residential layer (Julliard, et al., 2015), (Jang, et al., 2020). However, this study was limited to flood layers in order to assess the population resilience.

5. Findings and discussion

Table 3 presents population resilience under the GND and Dasymetric population distribution methods.

Table 3: Exposed Population as per the GND method and Dasymetric Methods.

Estimated Population Exposure			
Flood Event	**GND Estimation (G)**	**Dasymetric Estimation (D)**	**Over Estimation (G-D)**
Year 2010	3,562,802	334,826	3,227,976 (90.6%)
Year 2016	2,876,804	251,007	2,625,797 (91.2%)
Year 2017	2,076,872	134,135	1,942,738 (93.5%)

Results clearly revealed that the GND population-based estimation overestimates the population exposure by more than 90% in each flood event. Meanwhile, the dasymetric estimation method precisely captures the impacted population cells and estimates the population exposure. Therefore, the proposed method is more suitable in downscaling the population estimation of urban flooding exposure, as it only evaluates the actual impact of the incident. Also, the proposed method is equally applicable for applying in community resilience assessment to any natural or manmade incident, as it can precisely distinguish the direct impact to the residential population. It is important to note that, the proposed dasymetric map demonstration is only applicable for static (residential) population exposure estimation and does not encounter the indirect and dynamic (moving) nature of population.

6. Conclusion

The study proposed dasymetric mapping techniques to estimate population exposure, as the existing methods have overestimated the population resilience. The proposed method presents strong accuracy of population downscaling according to the ancillary information and is capable of

indicating the residential population resilience as a pixel representation. Therefore, the proposed method would be more applicable for the micro scale population resilience assessment.

However, the accuracy of the estimation highly depends on the dasymetric population map and resolution of the raster calculation. Hence, the detailed and precise land use feature layer affects the accurate population exposure assessment. It is also important to note that the proposed method is only applicable to the stock population resilience assessment as it is unable to incorporate the dynamic nature of population.

Furthermore, the proposed method can be easily improved to assess population exposure to other disasters due to the higher flexibility of the method. It is also applicable to the population risk forecast when adding vulnerable buffer zones, to measure the anticipated population exposure against random and localized attacks.

Therefore, the proposed procedure would be highly efficient and the method is precise, for community resilience assessment of urban flooding and other disaster driven scenarios, as it has the potentiality to capture the micro scale population disruptions.

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A GIS-BASED SIMULATION APPLICATION TO MODEL SURFACE RUNOFF LEVEL IN URBAN BLOCKS.

WIJAYAWARDANA. P.N.P. [1], ABENAYAKE. C.C. [1], JAYASINGHE. A.B. [1], KALPANA. L.D.C.H.N. [1], DIAS. N. [2], AMARATUNGA. D. [2] & HAIGH R. [2]

[1] Urban Simulation Lab, Department of Town & Country Planning, University of Moratuwa, Sri Lanka
naduniwi@gmail.com, chethika@uom.lk, amilabj@uom.lk

[2] Global Disaster Resilience Centre, University of Huddersfield, United Kingdom
n.dias@hud.ac.uk, D.Amaratunga@hud.ac.uk, R.Haigh@hud.ac.uk

Abstract

Simulation of flood inundation in urban areas longer important, given the magnitude of potential loss and disruption associated with non-river based, urban flooding. The complexity of the urban environment and lack of high-resolution topographic and hydrologic data compromise the development and implementation of models. Low impact development (LID) is technical know-how on a collection of sustainable practices that mimic natural hydrological functions including infiltration, evapotranspiration or use of surface runoff. Several studies have been carried out to discuss the impact of urbanization scenarios in reducing the urban flood risk in watershed scale in Sri Lanka. Yet, there is a gap remains in simulating the effectiveness of LID-based planning practices to reduce flood risk with the complex built form scenarios. In such a situation, this study attempts to make a significant contribution to simulate the variations of flood regulation functions under different high-intensive urban development scenarios, particularly focusing on the urban metropolitan regions. The analyses were carried out utilizing SWMM (Storm Water Management Model) which is open-source flood inundation simulation approach with the help of GIS in a more qualitative manner. The simulation results indicate that expanding built form scenarios increase the flood venerability for city functions, increasing inundation duration and LID scenarios able to reduce the surface runoff to reduce flood vulnerability at a significant level. The simulation results had been verified with the real ground situation (mean percentage change < 15.5%) which able to capture the thresholds of built form variation, as well as dynamic land uses and infrastructure supply which can be used as a tool for future planning practices and decision-making.

Keywords: *Urban Floods; LID; GIS-based simulation; Built form*

1. Introduction

Rapidly expanding urban areas predispose a huge challenge for making cities resilient to extreme weather events. Climate change has multiplied hydro-meteorological hazard events into 3,253 over the past decade (2005-2015), which was five times greater than the 743 catastrophes reported in the 1970s (WMO, 2015) (WMO, 2014) (UNDRR, 2015). Global climate change, i.e., changing rainfall patterns, increased rainfall intensity, high frequency of storms; may lead to serious urban storm water issues, including property damage, loss of lives, economic and neighbourhood impacts and perturbations to the ecosystem services as well (Chen, et al., 2017). Flash floods due to increasing urbanization pose huge challenges in urban planning for a sustainable future (Jayasinghe & Munasinghe , 2013), (Abenayake, et al., 2016). Accordingly, there is an increasing need to learn how to live with floods by mitigating their consequences, in the present and future because 55% of the world's population live in cities, and that will be risen up to 68% by 2050 by pushing down to a precipice majority of the urban population risk of urban floods (UN, 2019) (Reduction, 2018) . Limited-availability and validity of accurate methods to predict future and existing flood situation with urban expansion scenarios become a critical challenge for decision-makers and urban planners (Abenayake, et al., 2020).

Natural flood defence mechanisms perform a vital role in reducing the exposure to floods, particularly the expanse of inundation and the flood height as an ecosystem service (ES[1]) that reinforce community's resilience to flood (Abenayake, et al., 2018) (Ranjan & Abenayake, 2014).

[1] "All the benefits people obtain from ecosystems" have been defined as ecosystem services

In a forested ecosystem, surface runoff is little as 10% of precipitation due to the functions of evaporation and infiltration (EPA, 2000). Unplanned urban developments, wetlands reclamation, removing vegetation cover and deforestation for developments; weakening natural flood defence mechanisms. For example, water holding capacity of a wetland (i.e., swamps, mangrove, marshes, paddy lands, forests) is four times higher than a river which can quickly absorb excess water and gradually release by the water retention and detention functions (USGS, 2015) (Shiklomanov, 1993). The global extent of natural wetlands declined by 30% between 1970 and 2008 (UNEP, 2015). Overall, the growth of built-up areas causes the cities in downstream to expose to floods six to eightfold higher than it would have been under the natural land cover (Morris, 2020). In cities the built-up areas cover the land with impermeable surfaces such as roads, buildings, pavements that affect the natural flood defence mechanisms, particularly, infiltration and surface runoff. A typical city with over three-fourth of impervious surfaces discharges 50% of the precipitation to water bodies which is five times higher than the discharge of a natural surface (Abenayake, et al., 2016) (Aswathanarayana, 2001).Within in this context, increasing the infiltration level has become an important way to reduce storm water runoff while minimising its negative impacts (refer figure 1).

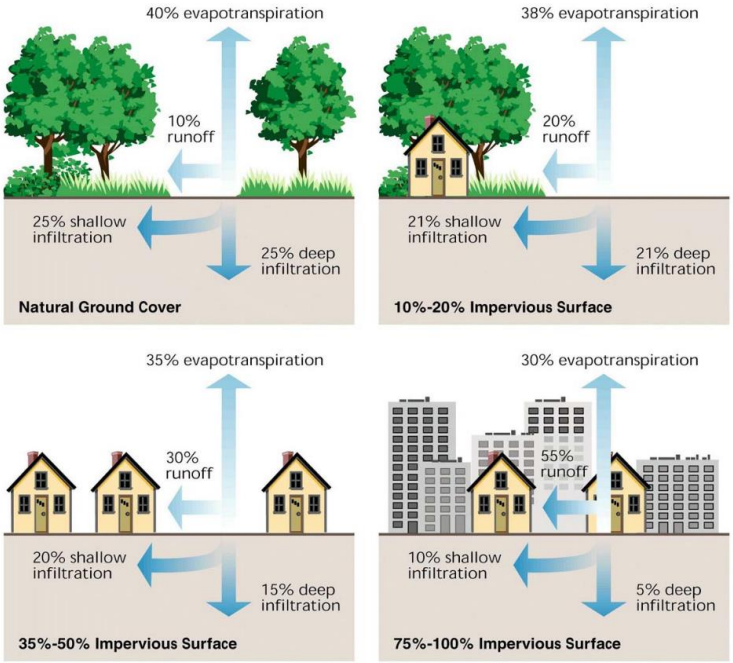

Figure 1: Effects of Imperviousness on Runoff and Infiltration
Source: (EPA, 2000).

There have been several sustainable building initiatives to reduce infiltration have been proposed globally as; water-sensitive urban design (WSUD) in Australia (Wong, 2006), (Wong & Eadie, 2000) , best management practices (BMPs) in the US and Canada (Field & Tafuri, 2006), sustainable drainage systems (SuDS) in the UK (Ashley, et al., 2015) (Stovin, et al., 2013), and Low Impact Development (LID) in the USA (EPA, 2000) to addresses the urban impact on flood regulating ESs. The LID approach has been recommended as an alternative to traditional storm water design. Some countries have already incorporated LID into urban planning regulations yet it demands more research works on popularising LID in making cities resilient (Dale & Saville, 2011) (Palla & Gnecco, 2015). In this milieu, the study is focused on research works related to the spatial simulations on the effectiveness of LIDs in reducing the fragility of natural flood defence mechanism.

Several studies have been carried out to discuss the impact of the urbanization scenarios in reducing the urban flood risk in watershed scale (Hu, et al., 2017) (Qin, et al., 2013); (Palla & Gnecco, 2015); (Zhang, et al., 2015). Moreover, rainfall-runoff, rational method, hydrograph method correlation studies, inlet methods which are outdated with accuracy and less technological

basis. Further, several urban inundation simulation models such as Mike Flood, PCSWMM2011, MOUSE GIS, Info Works ICM (Integrated Catchment Modeling), Flo-2D, and (EPA) Storm Water Management Model (SWMM), XP-SWMM used to simulate the impact of LID on hydrological aspects under flood mitigation (Wanniarachchi & Wijesekera, 2012) (Rossman, L. A, 2010). Most of them are commercial applications and the SWMM is free and open-source applications which used for urban flood simulations in this study. Understanding of the complexity of the urban land uses are essential planning practises (Jayasinghe, et al., 2015) and more case study based approaches are demanding in urban flood modelling in Sri Lankan urban context (Abenayake, et al., 2020). But none of those studies not considered the change of regulatory built form changers impact on urban flood situations and the compatibility of building regulations with projects under LID in Sri Lankan urban practices. Yet, there is a gap remains in simulating the effectiveness of LID-based planning and building regulations in building community resilience to flood. Hence, further studies are required to simulate the variations of flood regulation functions under different high-intensive urban development scenarios, particularly focusing on the urban metropolitan regions. This study is focused on assessing the effectiveness of alternative built-up scenarios along with LID-based solutions as a guide for decision-makers when determining flood-resilient built forms.

2. Method and Materials

2.1. SELECTION OF A CASE STUDY

The Colombo Municipal Council (CMC) area selected as the case study because, the major flood events occurred island-wide continuously, the highest number of affected people was reported from the Colombo district (DMC, 2018). The highest urbanization rate and highest number of flood affected population will lead the research to focus on CMC area. In CMC area 77.6 % (3/4th) of population lives in urban areas and the population density is 13,800 persons per sq.km having more than 92% covered by built-up coverage.

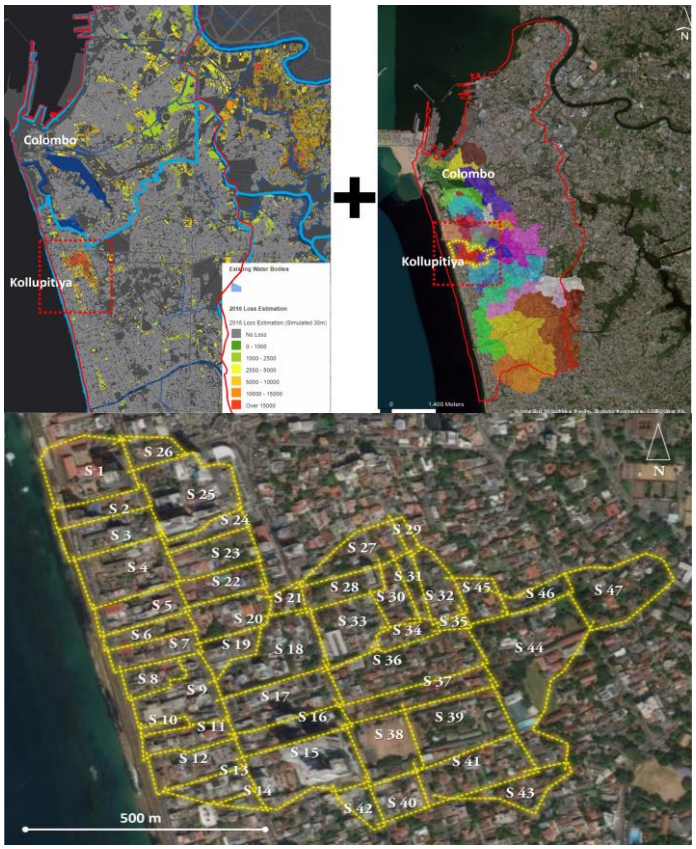

Figure 2: Selected study area
(a.) Past flood inundation areas (b.) Sub-watersheds in CMC and (c.) Selected study area.

First, the sub-watersheds have been identified using hydrology analysis using Arc GIS 10.3 (12 m resolution DEM - Alaska Satellite Facility: NASA Earth Data) in CMC. After dividing those main watersheds, into sub-watershed are considered the Floor Directions using Stream Network and Watershed Delineation in Spatial Analyst Hydrology Tools in Arc GIS 10.3. Next, refer the past flood data (i.e., 2010, 2016 and 2017) in CMC area which published by Center for Urban Water, Sri Lanka (CUrW) (Center for Urban Water, 2019) in order to identify the watershed with the highest number of affected population from urban floods. Further referred to the density zonation mechanism in 2030 Colombo Plan. After overlaying all the 03 maps, the case study area, the urban watershed will be identified for this research (Figure 2) which belongs to both high-density and low-density development zones by introduced density zonation the mechanism by 2030 Colombo Plan.

2.2. MODELLING SURFACE RUNOFF

In this study model the surface run off using the EPA SWMM (United States Environmental Protection Agency Storm Water Management Model) is a free and open access flood inundation model which can be used under deterministic modeling scenarios to simulate water inflows, outflows, and storages within a sub-catchment. Amongst urban stormwater modeling, EPA SWMM 5.1 has recorded a reliable outcome in model calibration and verification (Abenayake, et al., 2020) (Wanniarachchi & Wijesekera, 2012). This tool used by several location-specific applications in worldwide planning and urban flood analysis (i.e. CSO-LTC plans in Philadelphia, Cincinnati, Indianapolis, Seattle, city of New Haven, etc.) (EPA, 2010) (Chen, et al., 2017).

SWMM is governed by the conservation of mass and momentum Eq. (01) given below.

$$\frac{\partial Q}{\partial t} + gAS_f - 2V\frac{\partial A}{\partial t} - V^2\frac{\partial A}{\partial x} + gA\frac{\partial H}{\partial x} = 0 \qquad (01)$$

Where,
Q = Discharge through the conduit
V= Velocity in the conduit
A= Cross-sectional area of the flow
H= Hydraulic head (invert elevation plus water depth)
Sf = Friction slope

The following hypostatical assumptions were made in model simulation by applying recorded peak rainfall for Colombo, Sri Lanka.

1. There are no inflows of stormwater occurred from outside to the selected sub-catchment area.
2. The selected study area consisted of the same soil type and the same permeability rate. The infiltration mode set as Green- Ampt for the simulation model.
3. 150 mm of dally rainfall used for model simulation because that is the benchmark rainfall to issued early warning for heavy rainfalls according to the Department of Meteorology, Sri Lanka.
4. Except for building footprints, all other remaining open areas are 100 percent permeable in the study area.
5. The entire drainage network has the same capacity everywhere.

2.3. SENARIO BUILDING

The main objective of this study was to simulate surface runoff under different built form scenarios and hypothetical LID scenarios to evaluate the change of surface runoff which can be developed as a decision-making tool in predicting flood situations.

2.3.1. The proposed regulatory built form scenarios

Plot coverage based on existing built-up surfaces was considered as the Business as Usual (BAU) Scenario (i.e., Scenario 1). The average existing built-up coverage is 54.8%. As per the future proposed plot coverage by development plans, three scenarios were opted as follows (Figure 3).

Table 1: Built form scenarios

Scenario	Description
Scenario 1	Existing built-up (Existing impervious area) coverage
Scenario 2	If existing regulatory built up coverage increased up to 66% impervious.
Scenario 3	If existing regulatory built up coverage increased up to 80% impervious.
Scenario 4	If 50% of the regulatory open areas are converted to green.

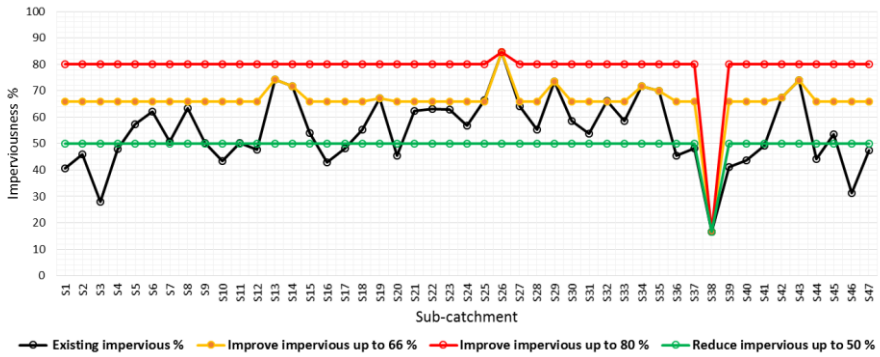

Figure 3: Change of built-up coverage (imperviousness) under each scenario

The study area has been subdivided into 47 sub-catchments (Figure 2) based on the drainage network and the plot coverage. The change of imperviousness is illustrated in Figure 3 which describes four scenarios. 150 mm of daily average rainfall was distributed into hourly rainfall hypothetically; as a normal distribution of a bell-shaped line in the model simulation. The sub-catchment no. 38 was fixed in built-up coverage under each four scenarios because it consisted of an open- playground. The plot coverage regulations generally do not applicable to mandatory open spaces. Flood simulation model parameters and their variation ranges are presented in table 2.

Table 2: Key Model Parameters

Parameter	Units	Range	Parameter	Units/ type
Area	ha	0.2 - 4.6	Infiltration model	Green Ampt.
Imperviousness	%	16.7 - 84.7	Routing Model	Dynamic Wave
Rainfall	Inches	0 – 0.88	Conduit depth	Fixed as 2 feet
N-Imperv.	Manning's n	0.01 – 0.4	Conduit shape	Circular
Time step	Seconds	10	Elevation	Meters

Secondly, the model remodelled the flood levels under three hypothetical LID scenarios as follows;

1. If the surface runoff under scenario 1 to 4 is further decreased by 50% by applying rain garden as a LID strategy.
2. If the drainage capacity under scenario 1 to 4 can be improved then the level of capacity improvement required to make each zone a flood free environment.
3. If rainwater harvesting is possible to be implemented as a LID strategy then the percentage decrease of rainfall intensity is required to make each zone a flood free environment.

2.4. DATA ACQUISITION AND STUDY FRAMEWORK

Table 3: Data acquisition for the study

Purpose	Data requirement		Data source and details
Delineating sub-watersheds	Digital Elevation Map of the area (DEM)		Alaska Satellite Facility: NASA Earth Data
Run-off Modelling	Rainfall data	Intensity	Meteorological Department

	Built form	Land uses Surface area Imperviousness	Survey Department of Sri Lanka
	Conduits (drainage network)	Names of inlets and outlet nodes Conduit length Manning's roughness Cross-sectional geometry	Website National Water Supply and Drainage Board

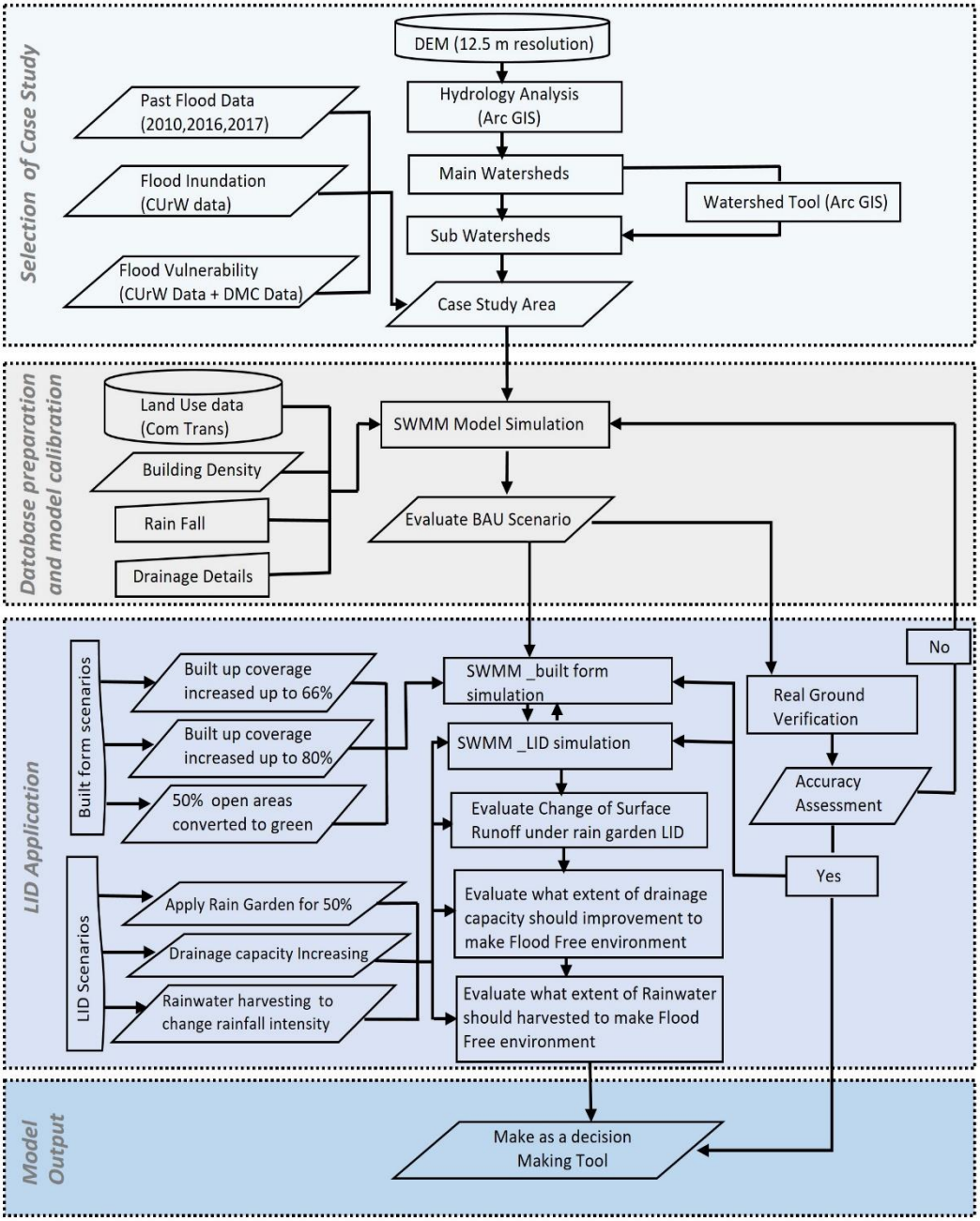

Figure 4: Study Framework

3. Analysis and Results

The main objective of this study was to simulate surface runoff under the BAU scenario (existing), three existing regulatory built form scenarios, and three hypothetical LID scenarios. Finally, verifying results in order to identify gaps if any and to statistically cross validate possible relationships between simulated results and measure flash flood heights.

3.1. FLOOD SITUATION UNDER THE PROPOSED REGULATORY BUILTFORM SCENARIOS

As per the BAU scenario, the existing total runoff is 163.06 inches. Under the regulatory scenario 2 and 3, if imperviousness increased up to 66% and 80% then the total runoff will be increased by 19.1% and 38.6% respectively. Under the regulatory scenario 4, if imperviousness is reduced up to 50%, then the existing runoff can also be reduced by 7.3%. Figure 5 clearly illustrates, how surface runoff, drainage capacity and node flooding situation under four different scenario varies. Flood retaining duration also fluctuates when changing the plot coverage. With existing imperviousness flood occurring duration is1h:40 min. with 1.75 CFS (Cubic Feet-per Second) peak flood. If imperviousness increased as 66% and 80% flood remaining duration increased as 3h: 20min and 5h: 30min respectively, with making 3.25CFS and 6.5CFS peak flood. If reduced imperviousness by 50%, flood remaining only 3min with making 0.2CFS peak flood (Figure 6).

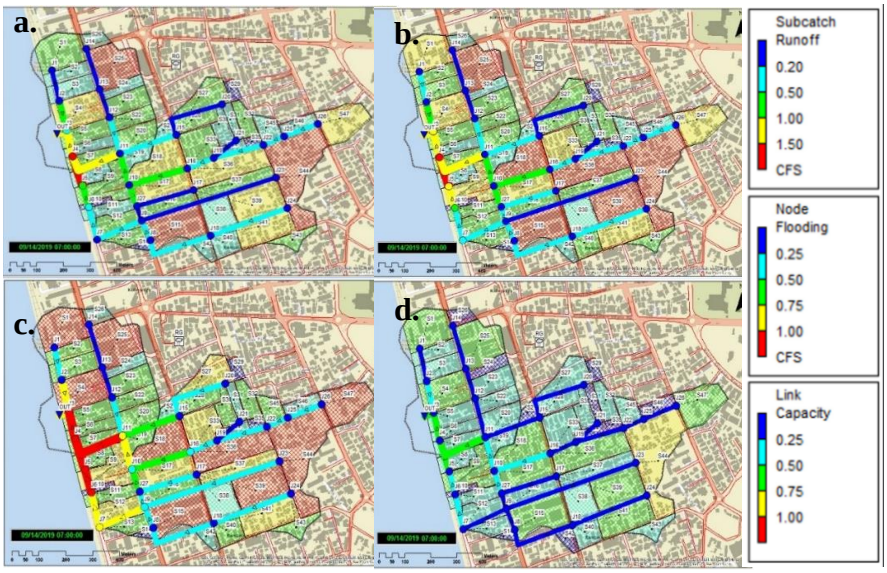

Figure 5: Runoff, node flooding and drainage capacity by changing imperviousness under scenario 1 to 4
Runoff, node flooding and drainage capacity; (a.) Scenario 1(BAS) (b.) Scenario 2 (c.) Scenario 3 (d.) Scenario 4

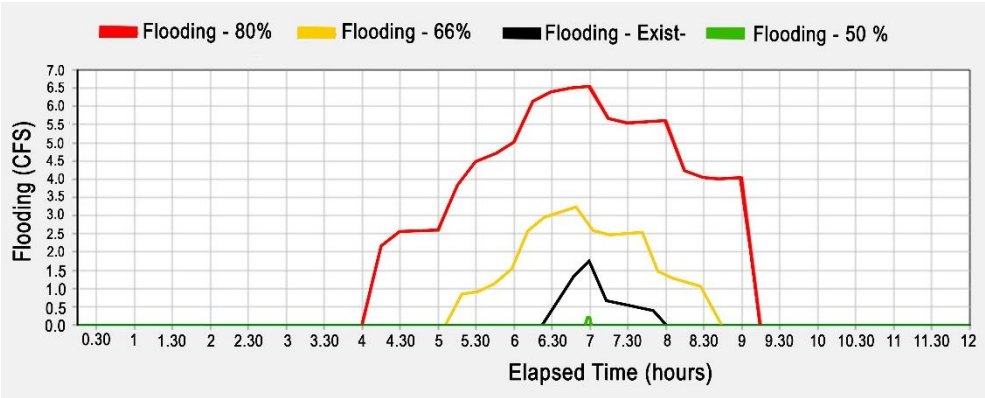

Figure 6: Duration of flooding the study area for scenarios 1 to 4
Flood retaining duration: 80% impervious (in red); 66% impervious (in yellow); existing imperviousness (in black); and 50% impervious (in green).

3.2. Flood situation under the hypothetical LID scenarios

The first LID approach simulated was to reduce surface runoff by introducing rain gardens. If 50% of the existing open area is converted into rain gardens as a LID strategy then the total runoff under scenario 1 can be minimized by 50% (81.5 inches). If the same option applied to scenario 2

and 3 then the total runoff will be decreased by 36.2% and 18.5% respectively. If the same LID strategy is applied under scenario 4, then the surface runoff can be reduced by 90.6%. Accordingly, if rain gardens were introduced, then there will be no flooding under scenario 1, 2 and 4. However, under scenario 3, there will be a minor flood of 14 min with 1 CFS flood during the peak hour (Figure 7).

Secondly, the LID was approached by assuming an improved drainage capacity. In order to make a flood free environment, the existing drainage capacity should be increased by 90%. If the plot coverage is increased by 66% and 80% (scenario 2 and 3) then the existing drainage capacity should be further increased by 120% and 135% respectively. Alternatively, if the plot coverage is reduced up to 50% as per the scenario 4, then the existing drainage capacity required a 50% improvement in order to make a flood free environment. Under all of the considered scenarios, drainage system need a major improvements where technical feasibility and cost-effectiveness should seriously be worked (Figure 8).

Thirdly, roof rainwater harvesting was assumed as the next possible LID strategy and the flood levels were remodelled under each scenario. In order to make a flood free environment, the roof rainwater harvesting systems should be installed with the capacity 52% of the total rain-fall under the scenario 1. If the imperviousness increasing by 66% and 80%, the rainfall intensity should be reduced by 67% and 78% respectively to make a flood free environment. If imperviousness reduced by 50%, the rainfall intensity should be reduced by 45% (Figure 7).

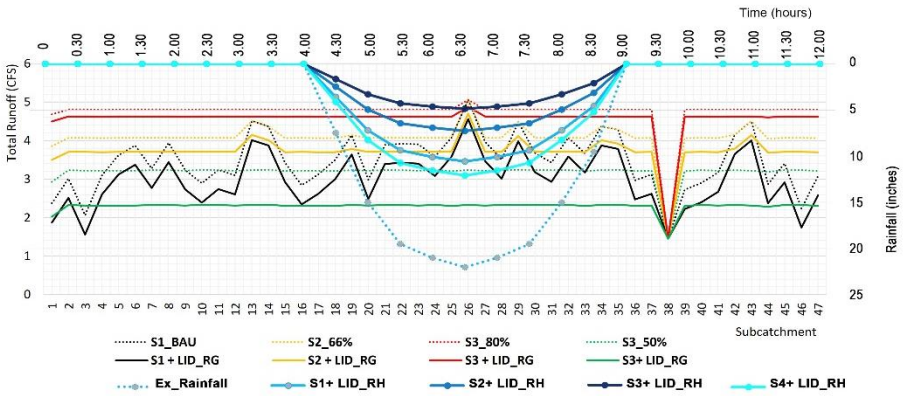

Figure 7 : LID scenarios; Rain Garden application and Rainwater Harvesting in study area.

Note: RG= Rain Gardens | RH= Rainwater Harvesting

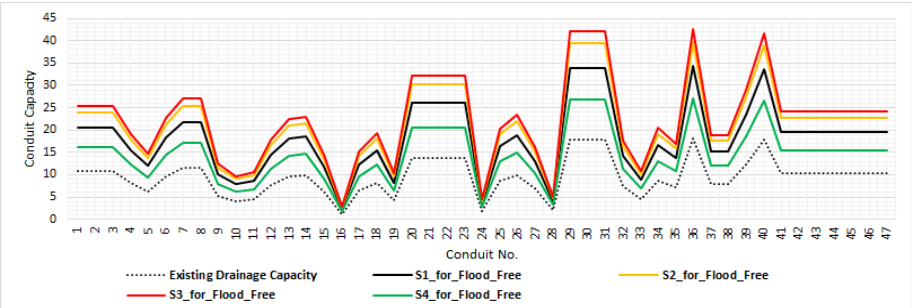

Figure 8: LID scenario; Improving drainage capacity in study area

3.3 MODEL ACCURACY VALIDATION WITH THE REAL GROUND SITUATION.

SWMM application is suitable for applying micro-level study areas with high accuracy level. The ground verification carried out under two main sections; Flood height and inundation duration.

The simulation outcome (i.e., flood height and inundation duration) was cross validated with a community participatory flood mapping. The comparison of statistical summary of the community perception survey (n= 80). The BAU simulation results close-similar to each other (mean percentage change < 15.5% for flood height and inundation duration) and there is a probability to develop this model to get a more accurate result, as a tool of urban flood modelling. Moreover, this study attempts to develop three hypothetical LID scenarios to reduce the existing flood situation by introducing a rain garden LID option, increasing drainage capacity and changing rainfall intensity to make a flood-free environment as a tool for spatial planning and decision-making.

4. Conclusion

In general, urban built-up area expansion increases the risk of urban flooding and waterlogging. In such a situation this study develop an urban flood simulation framework with alternative built-form scenarios on urban flood situations and introduce LID practises to achieved disaster resilience city as the main objective. First, this paper analysed flood levels according to the existing built-up situation and three regulatory plot coverage scenarios. As per the three built-up coverage scenarios: 66%, 80% and 50%, the third scenario which simulate a situation where 50% of the land kept unbuilt is the best for making a flood free environment in the selected sub-watershed area. Nevertheless, Colombo has high land values and increasing demand for built-up areas. Hence, the proposed development plan has increased the plot coverage up to 66%- 80% in the existing and proposed urban development plans in Colombo. Unfortunately, this situation leads to severe urban flooding situation in future. Hence, this study has simulated three hypothetical LID scenarios (i.e., 50% open spaces converted to rain gardens, increasing drainage capacity and application of roof rainwater harvesting mechanism), to examine the effectiveness in controlling urban floods while optimising the plot coverage.

Most of the cities in developing countries faces flash flooding caused by extreme rainfall event and triggered by unplanned developments, lack of planning instruments to control the built form. Hence, this study attempts to introduce an innovative approach to simulate the impact of land-use and density zoning over surface runoff with hypostatical LID approach. This model is sensitive to future scenarios of population growth, uncontrolled urbanization (sprawl), changers of built form as an advanced regulatory tool for formulating development plans in order to make flood free environment in future. But this simulation approach has high accuracy with local or site level applications rather than large scale catchment areas (i.e., regional or national level). Further, the details of the entire drainage system are essential for model simulation as the limitation of this application.

The proposed simulation approach has contributed to a qualitative technological framework for pre-evaluate disaster risk assessment by consolidating spatial indicators with a set of changing parameters as a simple analysis tool. It has the ability to compute and alteration ranges of parameters of dynamic urban land use within the user-friendly environment and visualize it geospatially with their intensity level numerically, to make cities resilient. This approach capable of catering urban planner, policymakers, academics, and researchers who more concerned with urban sprawl benefited based on the results presented in this research as well as the ability to develop as a land-use policy planning and decision-making tool. Nevertheless, more case studies (i.e., different land uses, different terrain conditions, with different LID strategies, etc.) have to be carried out to increase the accuracy level of this application.

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A MACHINE LEARNING APPROACH TOWARDS DETERMINING THE OPENNESS OF URBAN PLAZA

MD. SHARIFUL ALAM[1] & CHOWDHURY ALI IMAM[2]
[1,] Department of Architecture, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh
[2] Department of Architecture, Military Institute of Science and Technology (MIST), Dhaka, Bangladesh
[1]msalamanik@gmail.com, [2]ali.imam@arch.mist.ac.bd

Abstract
The design of urban plaza is guided by the principle of D/H ratio where D denotes distance and H denotes building façade height which provides a quantitative measure of the enclosure. Plaza has been considered as an outdoor room and the buildings are the walls. But these urban walls are not continuous. Connecting roads, voids between buildings, the variation of building heights, and the omission of building on any side of the plaza affect openness. So, maintaining the same D/H ratio the sense of enclosure can be varied. This paper aims at determining the inter-relation of openness with distance and height for better understanding the idea of enclosure of urban plaza using machine learning algorithms. Machine learning can be used to determine the non-linear relationship between multiple variables. The variables D and H are set by the author where the perforation of the surrounding elevation varied, then respondents were asked to rate the degree of openness of the plazas based on their virtual journey using a head-mounted Virtual Reality (VR) display. Utilizing their responses an inter-relation among the parameters is determined by training up an artificial Neural Network (ANN) to predict the openness of any plaza. This can be used as a process of analyzing user experience of urban plazas.

Keywords: *Machine learning, Virtual reality, D/H ratio, Neural Network, urban plaza*

1. Introduction

The urban plaza is one sort of urban open space that works as a center of social and economic activity as well as a focal point for community congregation (Liu, 2013). Urban plazas are considered as the most valuable places in a city that foster various interactions among city dwellers. (Dillard, et al., 2008)

For this great importance of urban plaza, a great number of efforts were given to understand the appropriate scale and human perception of the plaza space by architects and urban designers. Theorists tried to measure them by analyzing the spatial arrangement or the physical formation of the place. One established way to measure the quality of urban plaza is to quantify the sense of the enclosure by measuring the D/H ratio which is already supported by many empirical examples (KAHRAMAN & Cubukcu, 2017).

The term enclosure is described as an enclosed room like an outdoor space where the vertical elements like buildings create the enclosure. It is further said that buildings act as "walls" of the previously mentioned outdoor room. (Ewing & Handy, 2009) . This is also said that people can better understand the place and feel safe when they stay in an enclosed space in comparison with places where the sense of enclosure is weak (Stamps, 2005)

This is well established from the above discussion that enclosure should be provided in the well-designed urban plaza. And to measure the enclosure D/H ratio is used. To understand the argument of this paper, the following plaza conditions should be observed.

Figure 1, (left to right) the building is on only one side, voids are created by connecting road, and the plaza is defined by trees *(source: Google)*

Figure 2, one side of the plaza is defined by trees *(source: Google)*

Though buildings are considered as the urban walls, this wall is perforated. It can be seen from the above-mentioned plazas that sometimes, all the sides are not occupied by buildings, connecting roads, voids between buildings, height variation of surrounding buildings, etc. can cause openness. From this observation, it can be said that the degree of the enclosure is also affected by the perforation of the surrounding enclosure, and this paper will map how the change in surrounding elevation impact the sense of openness of urban plazas in mathematical term

2. Literature review:

Different spaces perform different functionalities. Whether the design is successful or not can only be presumed by realizing its performance respecting that function. Such as, for any mosque, the more spiritual the prayer hall is the more successful the design is. Along with wonderful outdoor views and vistas, any bedroom should have more privacy and separation. So to detect relationship, a particular space and its judging criteria should be fixed. For this paper urban plaza-like space that accumulates public activities and performances is selected to study. A clear conception about well-designed public squares are cited in “A pattern language: Towns Buildings construction” (Alexander, et al., 1977)

This is already said that the enclosure of the urban plaza is determined by the D/H ratio, where D denotes the distance from the viewpoint to the surrounding elevation, and H denotes the height of surrounding building elevation. Then, the various ratio is assigned to mark different perception of enclosure of the plaza. When the ratio is 1:1 it means full enclosure, ratio 2:1 means threshold enclosure, 3:1 means minimum enclosure, and 4:1 means loss of enclosure (Spreiregen, 1965)Though this D/H ratio is well accepted, this is argued that the sense of enclosure comprised of visual qualities such as openness, magnificence, and coziness, but the priority of the qualities depends on the context. The surrounding building elevations play a vital role in determining the qualities (Kim, 2017). Hillier cautioned that without understanding the context the enclosure shouldn't be used indiscriminately to avoid urban problems that can be associated with the wrong use of the enclosure. (Hillier, 1988)

From these arguments of the above-mentioned literature, it can be said that the enclosure must be determined based on context and the quality of the surrounding elevation is an important part of the consideration. This paper examined the quality of surrounding elevations by their degree of perforation and evaluated them to determine the openness of the plaza in relation with the D/H ratio. Then, it can be argued that, whether the generalization of perception of space is acceptable or not as different people will have a different opinion. In this regard, it is said that perception presupposes a higher degree of complexity in gathering and processing information (POP, 2013). Despite deviations, we can surely generalize our perceptions. A south-facing veranda connected with a neighborhood road is certainly preferable to many. Many architects discovered these patterns and also generated new architectural languages to follow (Alexander, et al., 1977)This paper reveals a deeper investigation of our preferences by turning qualitative values of openness perceptions into quantitive.

Now, It will be described from the literature, the usability of VR to determine the perceptual relations. The term 'virtual reality (VR)' refers to applications in which we can interact with spatial data in real-time. (Whyte, 2002)Those applications possess expressions of almost real-time experience that reduces the ambiguity we face in 2D screens. For this research VR box developed by Shinecon is used to create a head-mounted display. The Head-mounted display comprising two miniature display screens produces stereoscopic images. An optical position tracking system tracks the orientation of the observer's head in the Virtual world which matches his/her movement with the imported 360 images. A similar kind of experiment revealed that the use of VR in determining the enclosure of space (KAHRAMAN & Cubukcu, 2017) . It is undeniable that current technologies regarding VR have many limitations in mimicking actual context. As the paper focuses more on the methodology of deriving an inter-relationship, it deals with ideal conditions at the primary level, while the future advancement of technology would enhance the accuracy of its implementation.

3. Methodology:

The methodology comprised of two steps: At first Step: different plaza conditions of varying values of D(radius of the plaza) and H(height of the boundary objects) were created where the perforation of the surrounding elevation was varied. At first, the surrounding perforation was zero and the value of D and H was changed gradually. Then the perforation of the surroundings was reduced by certain percentages and the D/H ratio also changed gradually. Thus the variations of the plaza were produced using a parametric design tool called Grasshopper. Then 360-degree images of the plaza variations were prepared. After that, 32 respondents from an architectural school in Bangladesh had asked to rate them for openness after having a virtual journey using a head-mounted Virtual Reality (VR) display. Responses from experts, especially those who are connected with design studies may differ from the responses from non-designers as stated in (Avishag Shemesh, Moshe Bar, Yasha Jacob Grobman, 2015). This paper only focuses on the responses from participants associated with the architectural field.

Figure 3, Participant experiencing generated spaces through VR box *(source: Author)*

Second Step: Using the responses an artificial Neural Network was trained to predict the openness of any plaza by providing its radius, height of the surrounding elevation, and the amount of perforation of the elevation. To do so, Lunchbox is used which is a plug-in of grasshopper which assists designers to use machine learning algorithms inside a software called Rhinoceros

4. Environment Configuration:

This openness factor simultaneously fluctuates with the changes of any space-defining parameter. Very often we perceive any space performing outmost usage of our sensory organs. A slighter change in the environment may render a different expression of the same space (POP, 2013). That's why to avoid complexity, the first task is to oversimplify the space configuration. An ideal space with a circular area, bounded by 10" brick walls with cloudless general sky condition, where bricks may help to comprehend the scale for the participants. The circular area is taken to specify it by one single parameter. The sun is placed in the south-west at 3.00 pm, casting sharp shadows over the ground. The position of the observer is marked red. Space between the experimental space and the horizon is colored white. The parametric space is generated in software Rhinoceros 3D with the help of a plug-in named Grasshopper.

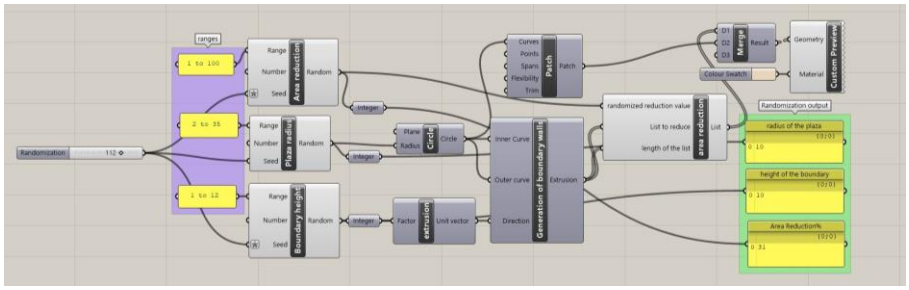

Figure 4, Script used to generate distinctive spaces of randomized values of three different parameters though Grasshopper *(source: Author)*

The outputs are visualized and exported as 360 images through another software named Lumion 8. If the radius of the space in enlarged, space may gain more marks on openness. Again the increase of the height of the boundary walls renders more confinement. At the first stage, 70 different spaces of different wall height and radius were selected. Then respondents were exposed to have a virtual journey to plazas whose value of D and H are varied randomly. As both the highest radius and heights are 35m, they were asked not to rank more than 35, which may help to find out whether the relationship is linear or polynomial.

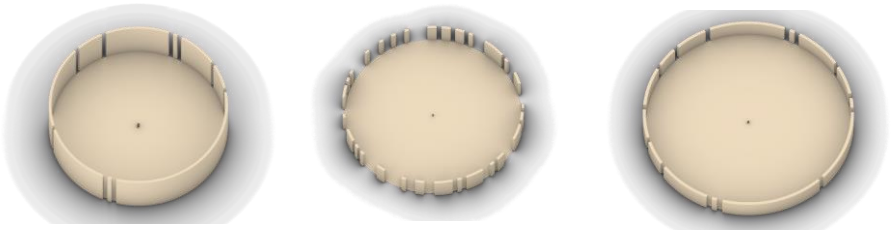

Figure 5, Three distinct spaces (left to right) Radius: 18m Height: 10m Area reduction: 7%; Radius: 32m Height: 07m Area reduction: 12%, Radius: 34m Height: 09m Area reduction: 54% *(source: Author)*

In the second stage, another parameter is added which marks exposure. The more area of the boundary wall will be reduced the more space will be dissolved. The area omitted is installed as another parameter and 110 different spaces were selected randomly. By following the previous method, now we will find a four-dimensional surface that identifies the relationship between openness, the radius of the area, height, and reduced area of the surrounding wall.

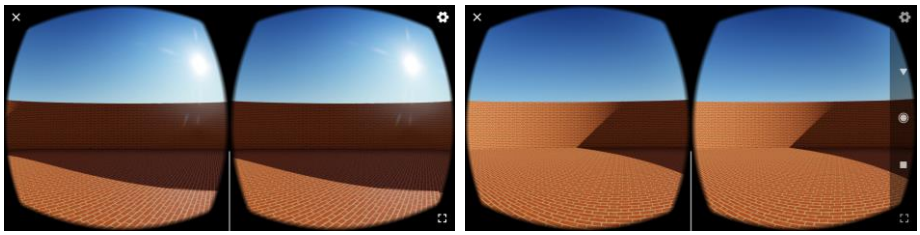

Figure 6, Virtual environment (no reduction of Area) displayed through smartphone screen *(source: Author)*

5. Deduction of mathematical expression:

Step 01: Radius, height, and openness relationship:

Non-linear Regression and Artificial Neural Network both can help us create a model that can generalize the data we get from surveying. In statistical modeling, regression analysis is a set of statistical processes to find out the relationships among the given variables. It includes many techniques for modeling and analyzing several variables. The main focus is on the relationship between a dependent variable and one or more independent variables. Here, openness is assumed

to be as the dependent variable, and radius, the height of the walls are considered as independent variables. Regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. (Linear-Regression, 2019)

First, all the survey data were imported in the software named rhinoceros 3D as individual points of which values of x, y, and z co-ordinates resemble the radius of the space, the height of the boundaries, and participants' response respectively. A plug-in named Lunchbox (by Nathan Miller) helped to generate a surface from the input data by non-linear regression. The generated surface expresses a generalized inter-relationship between the two parameters and the outcome. Any point on that surface (shown in the figure: 7) will expose the predicted outcome as the value its Z co-ordinates for the imported values of radius and height as the X and Y coordinates.

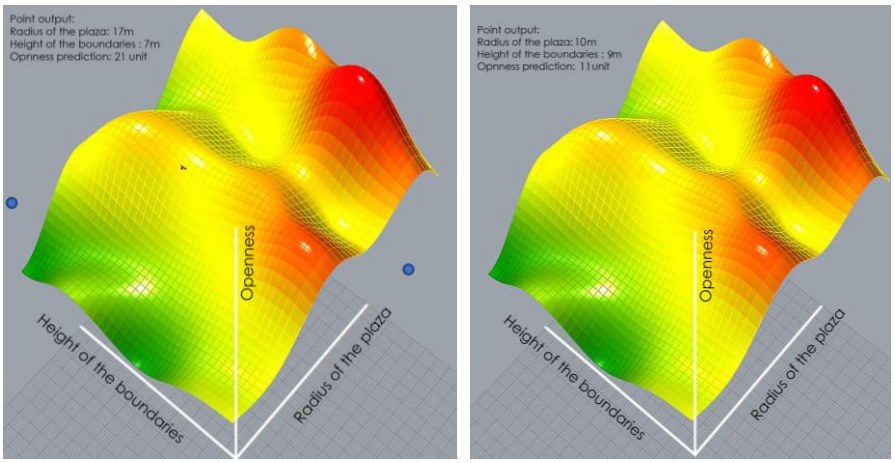

Figure 7, Prediction of openness by randomly asked values of radius and height *(source: Author)*

Step 02: Radius, height, reduced area, and openness relationship:
To add another parameter in defining the relationship Artificial Neural Network (ANN) is used. This model can provide a prediction of any given input. To capture the real-world complex relationship, we must include more data and more parameters and filter out the noise. A deeper neural network has the power to capture more complex relationships. The deep neural network has multiple layers of neural connectivity which helps to learn nonlinear relationships. (Artificial-neural-network, 2019)

In this stage, we generated 110 different spaces with different radius and height, where some portions of the boundary wall were removed randomly. The percentage of area reduced from the boundary is defined as the 3rd parameter. Space with the same radius and height of the boundary wall will render different openness output respecting the amount of the space exposed outside. Here a software named 'Visual Gene Developer' (version 1.9) is used to find out the predicted outcome of any given value of all three parameters. Responses from the participants of randomly selected spaces were imported as training value. A set of predicted data were asked to provide, while the software trained itself with the imported data. For generalization, a small deviation is noticed between the given and predicted data, but this helped to render the bigger picture in the software Rhinoceros 3D. For a stationary input of the 3rd parameter again a surface was generated by non-linear regression (*following the process showed in figure 7)* by importing the predicted values as Z coordinates of the individual points. Though this way, we can ask 'Visual Gene Developer' a set of predictions for any number of imported parameters, and by placing those prediction values in Rhinoceros 3D we can visualize their inter-relationship.

All the relationship surfaces obtained in the second phase is hard to express through one single image. With changes in the amount of reduced area, the relationship surface will acquire another formation. Here amongst all possible relationship status, 4 particular surfaces are shown to comprehend dependency of the outcome for changes in the 3rd parameter.

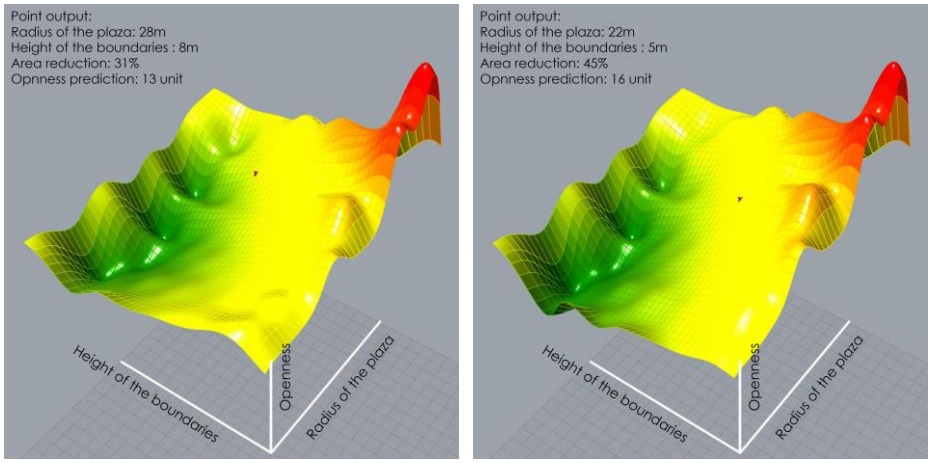

Figure 8, Prediction of openness by randomly asked values of radius and height for a fixed amount of Area reduction (source: Author)

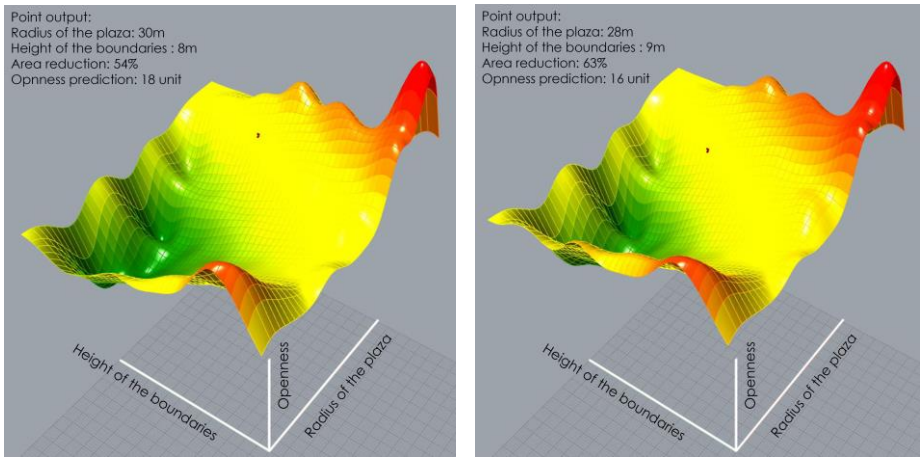

Figure 9, Prediction of openness by randomly asked values of radius and height for a fixed amount of Area reduction (source: Author)

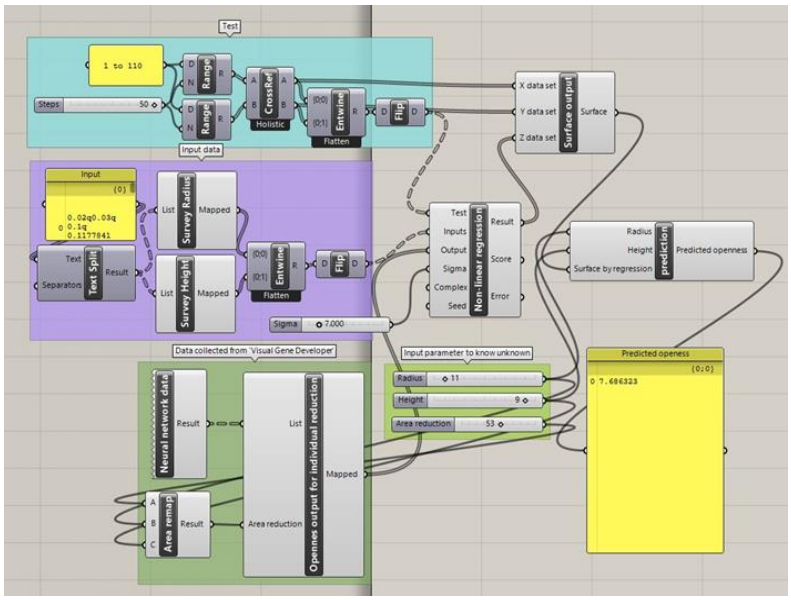

Figure 10, Scripts used in Grasshopper (a plug-in of Rhinoceros 3D) to predict openness by randomly asked values of radius, height, and percentage of area reduction (source: Author)

6. Discussions:

There is two importance of the findings:
i)When the relation of radius, height, and openness was mapped, it was found that the solution surface is undulated, that means the relationship is non-linear among them and so, using the solution surface for determining the openness is more logical rather than the D/H ratio. And when the perforation parameter was added, the solution surface was different for every particular amount of reduction, which means, for the same value of height and radius there are many possible values of openness is possible which satisfy the initial idea that varying the perforation will affect the sense of enclosure along with D/H ratio.

ii) From the Artificial Neural Network, openness can be predicted. From the examples of the above, it was seen that by providing the configuration of radius, height, and reduction of mass the openness of the plaza was obtained. The grasshopper script for predicting the openness is in fig-9 and fig-10.

The openness is counted on a scale of 1 to 35 that can't give any absolute value. This scale was applied only to comprehend their inter-relationship. But, for generative design, if there are many iterations of the plaza, obviously this scale can help designers to comparatively understand the openness of the plaza. And any remapping of the scale is possible. So, it can be considered as a process of understanding space quality by measuring empirical data and applying machine learning algorithms to predict the unknowns where multiple parameters can be examined at a time. A simulator can be developed for the perception of the urban plaza from a human perspective after counting other parameters and combining them. This paper can be considered as an important document for it.

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FINDING THE LOGIC OF LOCATION: AN ANALYSIS OF THE DISTRIBUTION PATTERN OF URBAN ACTIVITIES IN THE CITY OF COLOMBO WITH SPACE SYNTAX

MUNAISNGHE J. N.[1] & BANDARA A.[2]
[1] University of Moratuwa, Katubedda, Sri Lanka
[2] CHEC Port City (Pvt) Ltd, Colombo, Sri Lanka
[1]jagathnm@uom.lk, [2]toaruna@gmail.com

Abstract
The self-organized order of the types, scales, and locations of different activities in urban areas has throughout been a matter of concern for planning. In order to regulate 'unplanned' distribution of activities in urban areas, planning authorities used different tools, of which zoning is still the most popular. However, except under heavily regimented conditions, zoning has continuously failed to withstand the forces that empowered urban activities to find their preferred locations in an urban area. Hence, planners need more strategic approaches than conventional methods in order to deal with the location dynamics of urban activities. In this regard, a comprehensive understanding on space appropriation by urban activities and the methods in which such understanding can be effectively integrated into planning strategies, are essential in planners. In a context where the available theories were limited in serving for this purpose, the *Space Syntax* method provides planners with a more convincing method to analyze and simulate spatial dynamics of urban areas, relating to 'spatial integration', which is an attribute that emerges from the overall configuration of the physical environment. Using this method, this study explored the potential relationship between the location choices of different urban activity types, and the level of spatial integration of their current locations within the core area of the city of Colombo.

***Keywords**: Spatial Integration, Location Choices, Appropriation, Urban Activities*

1. Introduction

The pattern of distribution of formal and informal urban activities such as trade stalls, shopping centers, warehouses, administrative institutions, health and education facilities, restaurants and food outlets, entertainment centers, etc., in urban areas, be them cities or small towns, have throughout been a matter of interest to urban planners. In one front these activities cause externalities, which are internalized by other sets of activities and thereby cause a chain effect of agglomeration, enabling a shift of land uses in the respective urban locality. In another front, they attract pedestrian and vehicular traffic, thereby resulting in situations such as congestion and crowding. Moreover, they directly impact dominant land uses and property values and thereby facilitate social and cultural shifts, gentrification and the marginalization of certain communities. For all these valid reasons, formal urban planning and design interventions attempt to take control of the location decisions of different activities in urban areas.

However, planning controls are often contested by urban activities, more precisely by the firms operating those activities, because of the inherent differences between the objective functions of urban planning and business operations. Thus, a wide gap is apparent between the understanding of planners on the location attributes appropriate for urban activities and the preferences of the firms who operate them. Complaints and concerns related to the 'compatibility' of the uses are increasingly common in many urban areas, despite the regulatory measures enforced by the authorities. This situation, in a way, reflects the limitations of conventional authoritative approaches in urban planning, where planners are compelled to play more of a 'policing' role rather than a 'facilitator' role, and therefore, the necessity of more strategic interventions, than what is in practice now, to guide developments in urban areas towards desired futures. One of the most important requirements for planners in this regard is a comprehensive understanding of the spatial dynamics that govern the location choices of urban activities, which could be effectively integrated into workable planning strategies.

In this light, this study explores the potential relationship between spatial attributes surging from the overall configuration of a physical environment and the location choices of urban activities.

The study is carried out in the core area of the City of Colombo, adopting the *Space Syntax* method.

2. Background

Cities and towns, evolving freely with no formal regulatory interventions, usually result in bustling urban centers with multiple uses, high densities and crowded streets. The ongoing situation in these intensely developing built environments, characterized by heavy motor and pedestrian traffic flows, a complementary mix of uses and high densities, was regarded as 'problematic' by administrators as well as scholars since the late 19th century. It was in this background that modern planning emerged as a new specialty, and therefore, resistance towards self-organized order of urban activities is embodied in the core values of urban planning. Therefore, the 'incompatibilities' in the use of land and space by different activities, has been addressed by different tools, of which 'zoning' has been the most enforced to date.

In a broader sense, 'zoning' is the division of a city or county by legislative regulations into areas in order to specify permissible uses for real property and size restrictions for buildings within these areas – a program that implements policies of the general plan (Burack, Walls and Stewart, 2008). Originating from a court decision in Euclid, Ohio of the USA, single-use zoning, also known as Euclidean Zoning, was upheld as a necessary municipal planning instrument. Although the term 'land use zoning' implies regulation of uses, the underlying objective is to prevent various activities from interfering with one another in the use of land (Dukes, 2017).

However, zoning, as an activity segregation tool in the planning of cities, was questioned from the very early stages of its use. Jane Jacobs (1961) and Christopher Alexander (1965) were among the leading critics of mono-functional land uses enforced in modern, planned urban environments. While providing peaceful environments for those who do not want specific activities, preventive zoning leads to diseconomies of scale for activities in the absence of the required utility (Hoch, 1969). As a planning tool, the separation of activities into zones provides some technically sound benefits such as reducing traffic congestion, convenience to provide specialized infrastructure, etc., but it also leads to socially distractive, regimented, sterile environmental conditions which lack informal vitality. Zoning regulations include safety protocols to protect from fire and other hazards, but they do not include protection from crime and other social issues (Paulsen, 2013).

Increasing pressure against zoning and the legitimized urban environments resulting out of that, compelled planners to find a middle path between the segregation and integration of functionally different activities and to guide developments towards a right mix of uses in urban areas. However, deciding the right mix is not simple, because urban activities have a natural tendency to find locations most appropriate for their operations. They too have agency, behavior which is not fully amenable to the control of institutionalized planning processes or authoritative regulatory mechanisms. Hence, in order to get them organized in the desired direction, planners need to be sensitive to the natural self-organizing processes of urban activities and be more 'strategic' in their interventions to get them integrated into legitimate spatial strategies. Such endeavors highlight the need for studies on the processes by which different activities appropriate urban spaces for their operations.

3. Preceding studies

Literature on urban studies explain the growth and evolution of urban areas as an incremental agglomeration of economic activities; that is, frequent transactions among human actors and firms, engaged in producing various products and services, by locating themselves within relatively close proximities (e.g.: Glasser,1992). The location decisions that enabled the agglomerations of activities, however, are not arbitrary. Classical theories descending from Christaller's (1933) central place theory described them as a function of the 'threshold population' and the 'market ranges' approximated for each of the urban commodities. Theories emerging from urban sociology, led by E.W. Burgess's observations on the 'Concentric Zones' (Park et al., 1925) characterized by occupation of lands in and around the Central Business District of Chicago by different social

groups, implied the underlying competition among different urban activities for spaces with specific spatial attributes such as proximity, centrality and connectivity. Alfred Webber (1929) explained that firms select specific locations for their industries with three objective functions, namely, minimizing transport costs, minimizing production costs and maximizing profits. Krugman (1993) defined two types of origin of the activities in the agglomeration – the 'first nature', that is, the offspring of a natural phenomenon such as a port or a mine, and the 'second nature', that is, a secondary accumulation and a growth around an activity initiated for some other purpose.

Although these theories provide insights into the factors that affect location decisions of urban activities, they emphasize less on the means by which such dynamics could be potentially integrated in devising spatial strategies for the planning of urban areas.

The *Space Syntax* method, introduced by Hiller and Hanson (1984) and further developed by Hillier (1996), addressed this gap, demonstrating the multiple relationships that inequality of spatial attributes, resulting from the overall configuration of public spaces (mainly streets and access-ways) in an urban area, have with their activity locations, pedestrian and traffic flows, level of attraction, etc. This approach spells out the dynamic process in which different spaces attract both people and activities into them as a function of 'movement economy' and 'spatial integration' (Hiller, 1996). The 'movement economy' concept explains that humans have an inherent habit of 'economizing' movement (by choosing the shortest possible path for movement between locations) and urban activities adapt to take maximum advantage of the movement of people (Hillier and Penn, 2004). In a subsequent study, Hillier et al. (2000) studied the relationship between the pattern of commercial activities, informal settlements and the spatial limitations of the built environments in Santiago (Hiller et. al, 2000), and in a recent study Shen and Karimi (2017) emphasized the complex interrelationships between the spatial network and land-use patterns in Cairo as the major determinants of the formation of urban function regions.

Hillier and Penn (2004) proposed that in space syntax theory, land use is a dependent variable; spatial configuration influences movement and, further, the formation of centers and sub-centers, can be expected to influence land uses. Hence, the investigation of the impact of spatial configuration on land uses serves for a theoretical understanding of cities as well as for the practical importance related to location choices of different activities.

Even though some persisting limitations in accounting for distance, scale and sinuous streetscapes, highlighted by critics (e.g.: Ratti, 2004), exist, Space syntax analysis has made major contributions to the understanding of the spatial structure of cities, particularly the importance of mapping of network integration in relation to density, functional mix and street life vitality, focusing the attention of urban researchers onto the importance of the relations between the sociality and spatiality of the city (Pafka et al., 2018) .

However, despite the relatively large body of progressive studies and wide applications of space syntax available around the world, only very limited work is recorded in the Sri Lankan context. Among them, *The Evolution of the City* by Bandara and Munasinghe (2007), was the first instance where space syntax was effectively used to study an urban environment in Sri Lanka. This work recorded the evolution of the City of Colombo in a systematic investigation of continuous changes observed in the land uses in different segments of the city corresponding to the changes in the overall configuration of urban spaces with the introduction of new accessways and public spaces and the integration of new quarters extending the boundaries of the city. In another study, Bandara et al. (2009) applied the method to compare the persistent growth in and around the historic center of the city of Ratnapura, resisting the annual flood damages, as opposed to shifting urban activities from the traditional center as in the city of Galle.

4. Theoretical framework

The activity distribution pattern in an urban area can be understood as an outcome of the balancing process between the location choices of different urban activity types and space

appropriation by different forces that are in operation. In line with the propositions of widely acclaimed land use theories, it can be conceptualized that in a liberal environment, urban activities compete to find spaces which have the attributes that are most appropriate for their operations. Accessibility, centrality and visibility are among the topologically analyzed spatial attributes attractive to them. In this competition, relatively more profitable ventures acquire more economically and functionally advantageous locations in an urban environment.

According to Space Syntax theory, the competitive advantage of a given location is decided by the level of its 'spatial integration', resulted in by the axial connectivity of urban spaces. Thus, the first step in Space Syntax analysis is to reduce the composition of streets, alleyways and all other public spaces in an urban area into a composition of axial lines incidental either on one another or many others. The most economical path of movement in terms of the number of axial line connections (shortest possible path) that a person has to pass through to get to a space from another space, decides the level of connectivity of the first space in relation to the second. In this manner, the connectivity of a space into all other spaces in the urban area can be evaluated by accounting for its overall spatial configuration, and it reflects the degree to which each space is integrated into the urban area.

The method emphasizes two levels of integration of an urban space – local and global (Hillier, 1996). The *local integration* is indicative of the structural composition of public spaces at the locality level and its analysis enables to identify the locations that are most and least spatially integrated in the immediate context. Thus, the level of topological connectivity is relative within the local context but cab be normalized by means of spatial integration. The *global integration* is the indicator of the attractiveness of different public spaces at the overall spatial configuration of the city. When an urban area is analyzed at the local level, it is hypothesized that the local centers would emerge as the most integrated spaces and therefore, more competitive urban activity types would dominate the land uses in and around them. At the global level, the competition is between different segments of the city to attract more competitive uses into them, and the inequal levels of integration lead some centers to be overthrown by the more spatially integrated ones. As the city grows, the pattern of spatial configuration changes and the level of integration of individual locations too change. Thus, the attractive capacities fluctuate leading to a transformation of activity locations in the city.

In this study only the local integration is considered since the prime objective of this study is to examine the possible relationship between the distribution pattern of activity types and the varying spatial attributes of their locations.

5. The Method

Since the study uses instantaneous data, it is not possible to identify any causative relationship between the selected variables within the scope of this study. Therefore, the focus would be on the mutual interrelations between the two variables, rather than their dependency on each other.

The city of Colombo has been selected for the study partly due to its importance as the largest urban area in Sri Lanka, where planning interventions have throughout failed to effectively address the location incompatibilities of activities. On the other hand, it is due to the availability of the complex urban environment required for a study of this nature. The analysis of the interrelations was limited to the municipal boundaries of the City of Colombo, but in order to avoid the 'edge effect' in the analysis, the axial map was extended to a larger area in the city's metropolitan region. As the first step, the urban activities distributed in the city area have been observed under a pre-determined typology. For this purpose, the registers of the Urban Development Authority (UDA) of Sri Lanka was examined and out of many different activity types, a broader classification was developed based on the nature of the activity, the manner of operations and the types of goods and services provided to the public.

Nine major types that is commonly used for planning purposes have been noted:

a. Retail Trading

b. Wholesale Trading
c. Consumer Services
d. Financial and the related Services
e. Specialized Goods and Services
f. Institutions
g. Industries and Warehouses
h. Residential
i. Other

A detailed inspection of the Municipal records enabled the identification of sub-classes within these main ones and thereby, the number of types could be increased to twenty-three. The list of these types is given in table 01.

Table 01: Activity types and their sub-categories

Activity Type	**Sub-category**
Retail Trading	Textile and Fashion
	Stationeries
	Grocery
	Retail - Excl Grocery
Wholesale Trading	Wholesale
Consumer Services	Private Office
	Restaurant
	Automobile Services
	Health
	Filling Stations
	Other
Financial and the related Services	Banks and Other Financial
Specialized Goods and Services	Automobile Showrooms
	Furniture
	Branded
	Jewelry
Institutions	School
	Religious Places
Industries and Warehouses	Warehouse
Residential	Apartments
	Single Houses - Excl Under Served
	Underserved Settlements
Other	Other

In the second step, a random sample of one hundred (100) registrations were selected from each type. The sample size varied between one percent to twenty percent within the category, depending on the extensiveness of the number of registrations. The sample size was purely a decision related to convenience and may have limitations in terms of its representativeness.

In the third step, the location of each activity was recorded in a map, following the confirmation of its location as observed in a field visit. A few items of the sample had to be replaced with new entries due to the inactivity and non-availability of the registered activity at the time of observation. The locations of the activities subject to the analysis are given in figure 01.

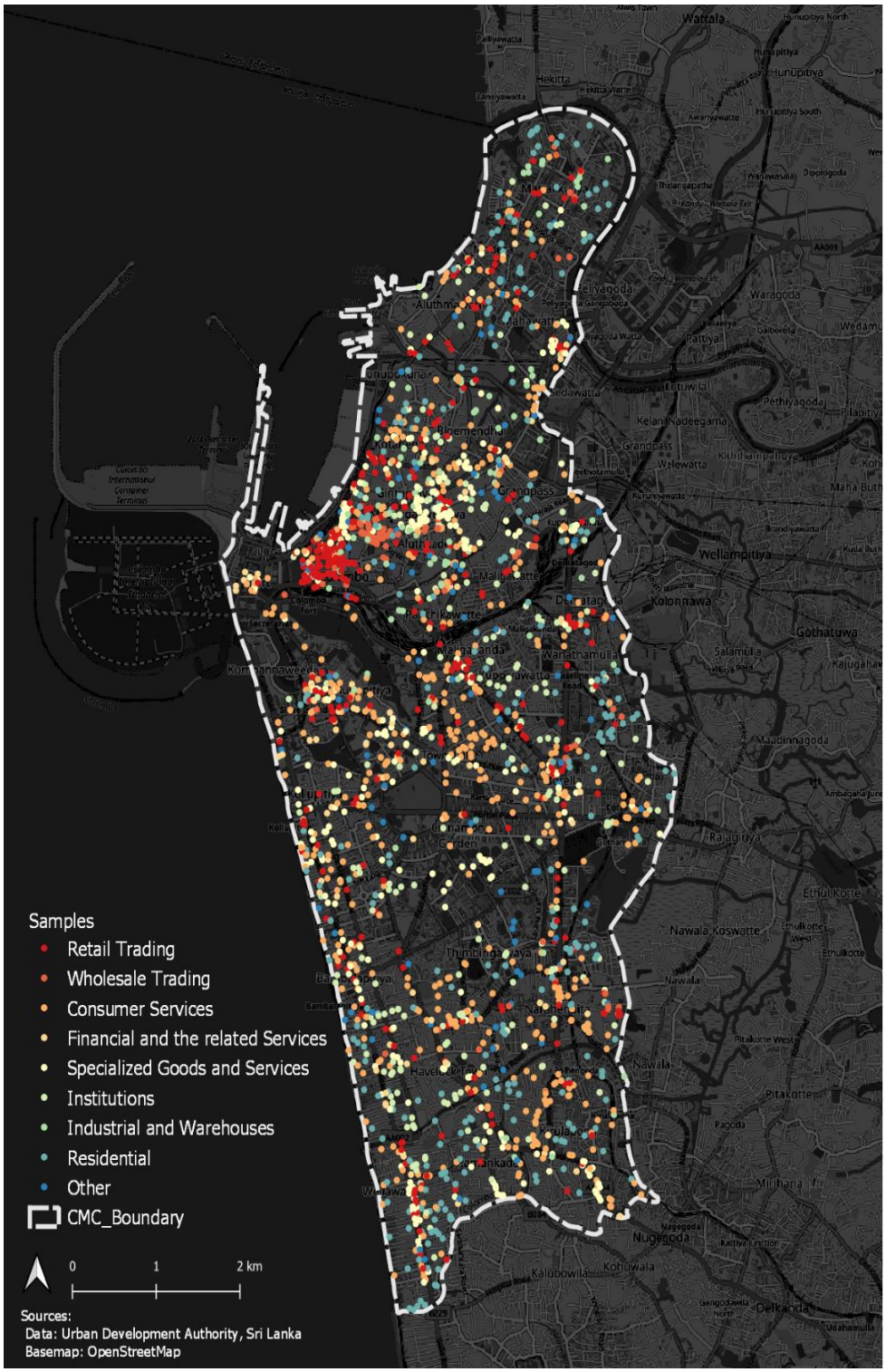

Figure 01: The locations of the sample activity units subject to this study

In the fourth step, the Space Syntax method was used to analyze the spatial configuration of the city of Colombo. The objective was to observe the 'spatial integration' value of the immediate location of the activity units. The integration values were observed both at 'local integration' (*R3*, Figure 02) and at 'global integration' (*Rn*, Figure 03), which are the widely used levels of analysis.

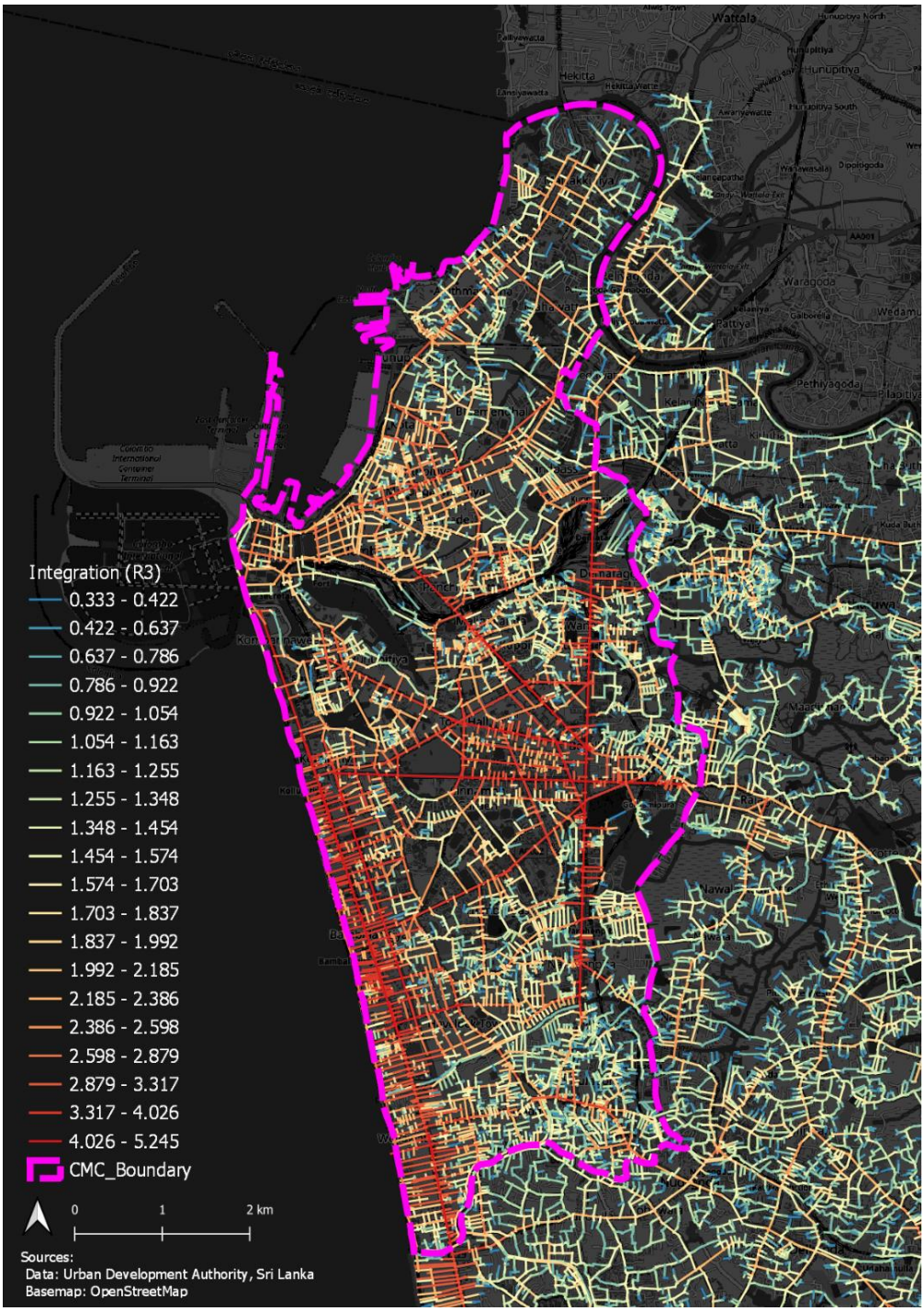

Figure 02: Analysis of Spatial Configuration: Local Integration (n3)

In the final step, the spatial integration values of all activity locations were recorded and examined for their statistical distribution. It is hypothesized that under liberal (non-regulated) conditions, the statistical mean and standard deviation of the integration values of the locations where the units of a particular activity type are located, reflect the levels of spatial integration preferred by those activity types for their smooth operation.

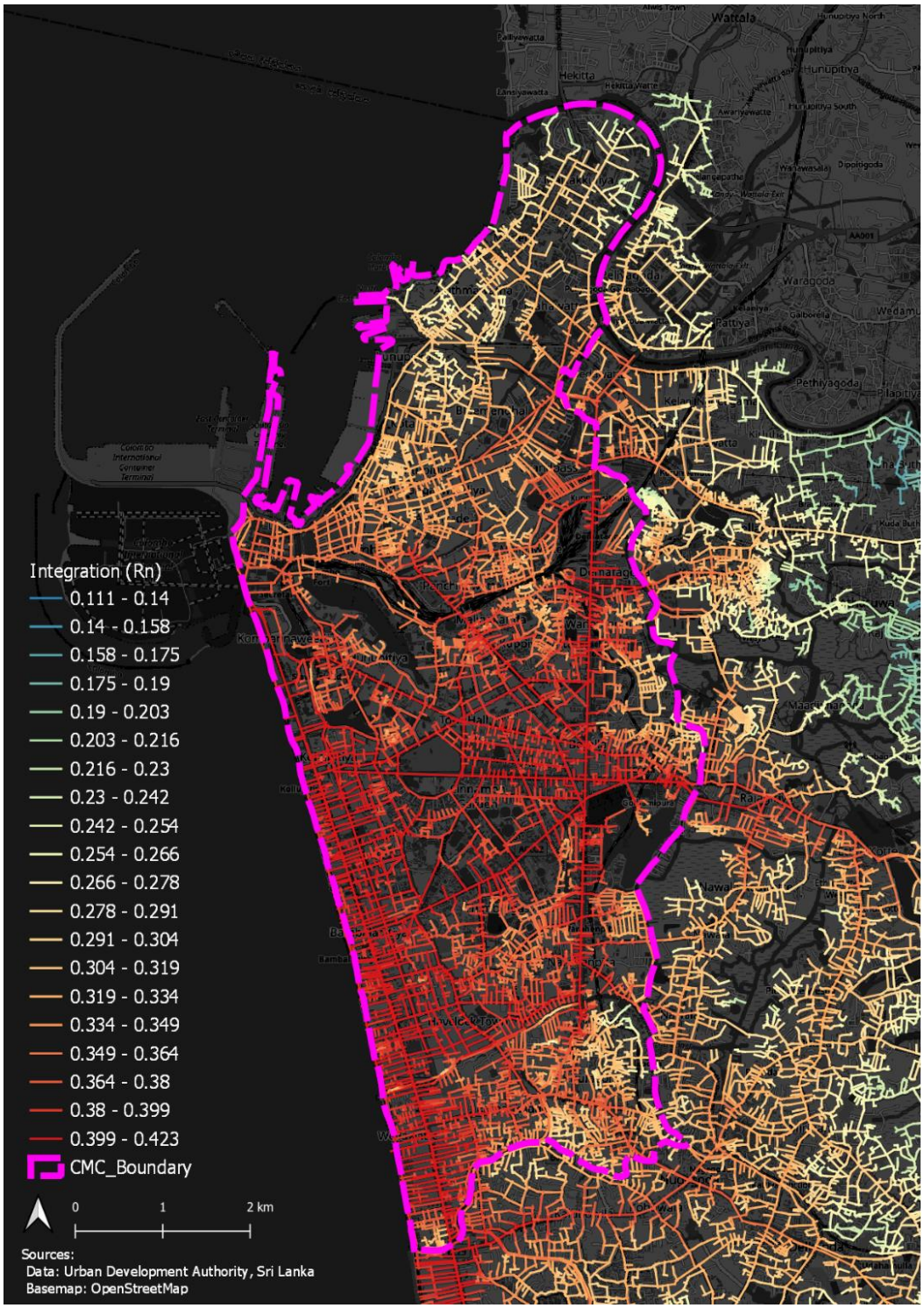

Figure 03: Analysis of Spatial Configuration: Global Integration (n)

6. The Analysis and findings

The statistical distribution of the spatial integration values of the activity locations, when plotted in their $\log_{10}$ values (SIV), exhibits a normal distribution as given in figure 04, confirming the reliability of the sample. The SIVs of the twenty-three activity types, when plotted individually, also followed the same statistical distribution pattern, confirming the reliability within types.

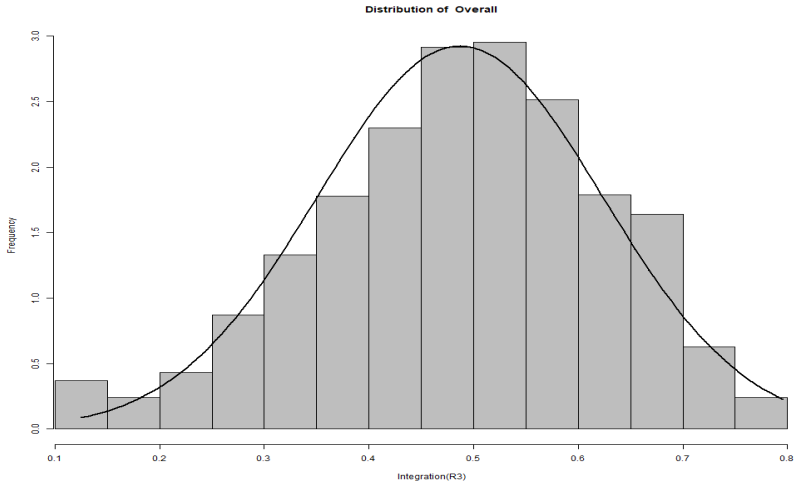

Figure 04: Statistical distribution of the spatial integration values (SIVs in $\log_{10}$) of all sample activity locations.

Figure 05 provides a summary of the distribution patterns of the SIVs across different activity types. The distribution of the SIVs of individual units within all activity types show a high level of consistency, where the standard deviation was within standard values. Such internal consistency implies that the environmental attributes resulting from the *degree of spatial integration* of urban locations is a latent consideration in the location choices of the firms who operate urban activities.

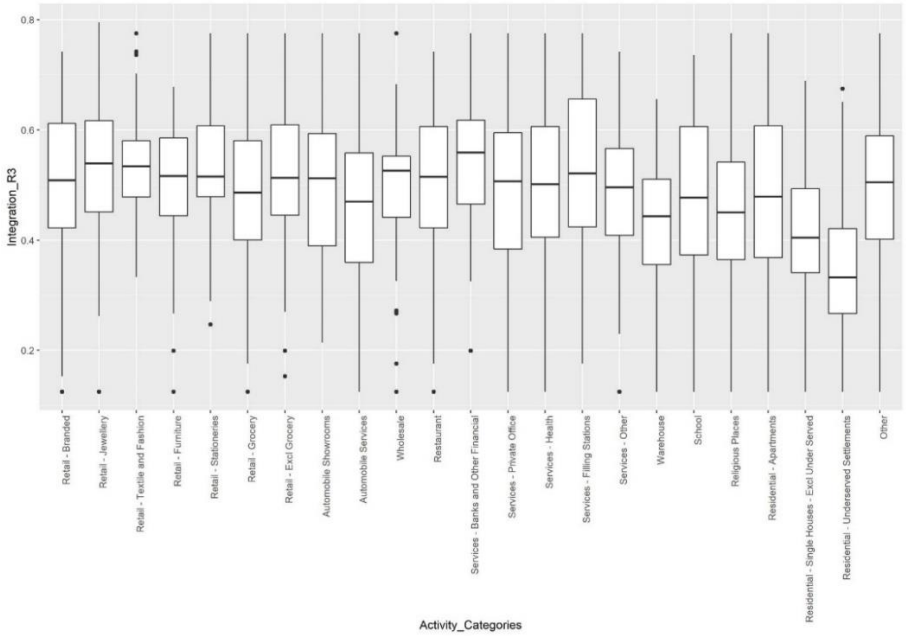

Figure 05: Box plot of the statistical distribution of SIVs of different activity types.

The means of the SIVs provided an observable hierarchy in the spatial distribution of the activity types. The Banking and Finance related activities are the predominant occupiers of the most spatially integrated locations in the City of Colombo, followed by other retail businesses. Residential and institutional activities (schools and religious places) occupy the least socially integrated locations.

At the same time, differences were observable among the statistical means of the SIVs of some activity types. On the premise that differences in SIVs reflect the variations in spatial attributes of locations in an urban area, this observation implies that the operators of activity types prefer specific spatial attributes of locations, when they exercise the location choice. In order to test the consistency and the reliability of this observation, the data set was subjected to a T-test. The T-test is a statistical process employed to determine any significant difference between the means of two

sample populations (Berenson and Levine, 1996). Hence, a pairwise comparison was employed and the hypothesis (Ho) at this instance was that there would be significant differences among the statistical distributions (mean values) of the SIVs of different activity types.

Table 02: The degree of difference between the SIVs of activity types

Activity Category	Mean	No. of categories that mean is significantly different (x)	x/Total Number of Categories (%)
Retail – Branded	0.5173953	8	34.78%
Retail – Jewellery	0.5407428	16	69.56%
Retail – Textile and Fashion	0.5390613	16	69.56%
Retail – Furniture	0.5012539	9	39.13%
Retail – Stationeries	0.5325590	15	65.22%
Retail – Grocery	0.4923181	8	34.78%
Retail - Excl Grocery	0.5209391	7	30.43%
Automobile Showrooms	0.5017417	8	34.78%
Automobile Services	0.4663775	12	52.17%
Restaurant	0.5061822	7	30.43%
Wholesale	0.4921898	8	34.78%
Services - Banks and Financial	0.5455050	17	73.91%
Services – Private Office	0.4945708	8	34.78%
Services –Health	0.5023711	7	30.43%
Services – Filling Stations	0.5268214	5	21.73%
Services – Other	0.4899807	8	34.78%
Residential –Apartments	0.4749440	9	39.13%
Residential – Single Houses	0.4073141	21	91.3%
Residential – Underserved areas	0.3312517	21	91.3%
Warehouse	0.4265894	20	86.96%
School	0.4707453	9	39.13%
Religious Places	0.4519866	12	52.17%
Other	0.4930798	7	30.43%

The results showed that out of 256 pairwise tests, 129 are significantly different at 95% confidence. In the interpretation, given in table 02, the distribution pattern of the spatial integration levels of the locations (SIVs) of all activity types show a difference from at least 30% of the other activities. The SIVs of nine types are significantly different to more than 50% of the other activities, while six types are different to more than 70% of the types.

7. Discussion and Conclusion

The results of the above can be interpreted relating to the objective of this study, i.e. to examine the possible relationship between the overall spatial configuration of the city of Colombo and the distribution pattern of its urban activities. The self-organizing of activities in an urban area is viewed as a function of the location choices of the firms or the operators of such activities and the inequality in spatial attributes of locations resulting from the overall spatial configuration of that urban area. Even though this mutual relationship between location choices and spatial attributes was discussed in previous theories, such relationships were not widely tested in a manner such that they could be progressively integrated into workable planning strategies.

In that context, this study can have valid implications. While converging the findings of preceding studies in this area of research, it enhances the reliability of space syntax as a method that can be used for urban analysis in the Sri Lankan context. The method has been used in many countries to successfully model the relationship between the spatial configuration of physical environments and several important urban characteristics, such as existing hierarchies, pedestrian and vehicular traffic flows, activity distribution patterns and land uses and values. The two main observations of this study provide valid grounds to use the space syntax method to model the probable outcome of alternative spatial decisions in planning such as the construction of new roads, opening missing links between separated spaces, etc., in an urban area.

Urban planning is essentially a decision-making process and planning decisions are mostly intuitive and inherently bound by risks, to the extent that planners work with imperfect information and value laden societies. In order to avert risks, planning professionals must be cautious, and wider public participation, expert consultation and consideration of alternatives are recommended. However, these options are limited in their predictive capacity, since they all must operate within limited foreseeable future causes of action. In order to fill this gap, space syntax provides planners with a more technically sound method that can be employed to simulate the outcome of a planning decision that affects the existing state of the physical environment of a city. This study was initiated to cater to the need for a more comprehensive understanding on urban dynamics that organizes different activities in an urban area, which is important for planners to make strategic decisions. This study provided grounds for that purpose by examining the relationship between the spatial attributes that appropriated location choices of different urban activities.

Despite the consistency of the results, the sample of the urban activities selected for this study can be questioned for its representativeness in some categories. Therefore, further studies may be required, which extend the number of activity locations with a larger sample. The study is also limited as it analyzed an instantaneous relationship. Further studies could take into account the periodic changes in the activity patterns in order to examine the causative relationship between the two variables.

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