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Carbon Footprint of Built Features and Planting Works during Construction, Maintenance and Renewal Stages at Urban Parks in Petaling Jaya, Selangor

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ABSTRACT

Carbon emissions in Malaysia are escalating due to rapid urbanisation wherein their sources are claimed to be generated by the construction industry, including urban park development. Upon completion of the urban park project, the vegetation will supposedly function immediately as a carbon sequester. However, the processes of building, maintaining, and renewing built features and plantings can emit additional carbon dioxide (CO_2) than the storage. Rigorous CO_2 release across the maintenance and renewal stages may be contributed by park management activities, such as planting grooming, built feature rectification, and park maintenance works. This study investigated carbon footprint derived from built features and planting works during the construction, maintenance, and renewal stages of park management. Taman Bandaran Kelana Jaya and Taman Aman Petaling Jaya were chosen as the study sites as they were located at urban areas. Continued use of the parks resulted in a swift deterioration of its facilities, whereby this scenario would ensure recurrent maintenance and renewal works were conducted for them. As-built drawings were utilised to identify the lists of inventories and work breakdown structure for every built feature and planting work to approximate the indirect CO_2 emissions, which was aided by EToolLCD software. This study revealed that the amount of CO_2

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sequestered by the manicured vegetation was only 28.7% out of the total CO_2 emission produced since its construction stage. Hence, urban parks can be perceived as a carbon source instead of a carbon sink medium.

Keywords: Carbon footprint, CO_2 emission, CO_2 sequestration, Project management life cycle, Urban parks

INTRODUCTION

The abundance of undesirable greenhouse gaseous remnants such as carbon dioxide (CO_2) is harmful to the climate. Malaysia's construction industry contributes 6% of CO_2 to the atmosphere owing to its rapid development of construction activities (Begum, 2017). Meanwhile, urban parks are known for their purpose as a carbon sinker, whereby the provision of urban parks and greenery is perceived as the mitigating solution towards reducing the atmospheric carbon content. Prior studies (Almeida et al., 2018; Braun & Bremer, 2019; Chen, 2015; Haq, 2011; Sun & Chen, 2017) have found that urban parks alleviate CO_2 emission within an urban setting, whereas their management procedures indirectly contribute to an additional release of atmospheric CO_2. Furthermore, other studies including Connor et al. (2011), Feltynowski et al. (2017), Pocock (2009), and Strohbach et al. (2012), have discovered that they are the source of CO_2 emission in urban areas, which originates from park management activities. Such activities include pruning, trimming, grass mowing, rubbish clearance, hardscape repairs, planting replacement, planting additions, planting treatment, soil treatment, watering, pest and disease control, weed control, and more.

Accordingly, the life cycle of urban park management consists of at least six stages, namely designing, construction, operation, maintenance, demolition, and renewal. These life cycle stages are allegedly contributing CO_2 content to the atmosphere. According to Hisham et al. (2018), a notable amount of CO_2 emissions is produced during the construction stage compared to the maintenance and operation stages. In particular, a significant one-off amount of CO_2 emitted is caused by the heavy use of machinery, transportation of materials, and labour. The stages, as mentioned earlier, often involve the use of machinery, especially during the early stage of project construction, and are associated with CO_2 emission due to fuel consumption. Moreover, the types of materials used as landscape element construction can further influence the carbon footprint of the projects. Besides, the function of urban parks as a CO_2 sink medium becomes null due to the CO_2 emitted by their maintenance activities. Figure 1 shows the conceptual framework of this study, where the studied boundary is limited to the construction, maintenance, and renewal stages (Figure 1). Meanwhile, the stages of design, operation, and demolition are dismissed due to inconsistent data records and documentation. It is hypothesised that the management of urban parks is attributable to the significant CO_2 liberation. Therefore, this study examines how much CO_2 is produced from urban park management by dissecting its life cycle stages into a detailed work breakdown structure.

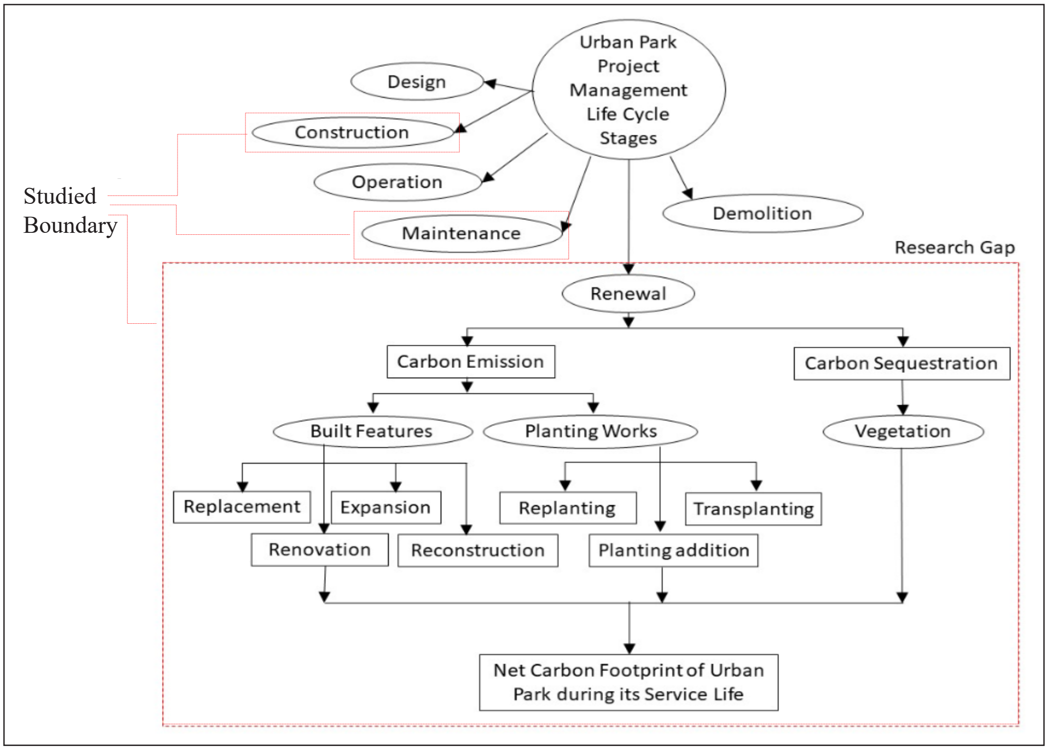


Figure 1. Urban park management carbon footprint conceptual framework

MATERIAL AND METHODS

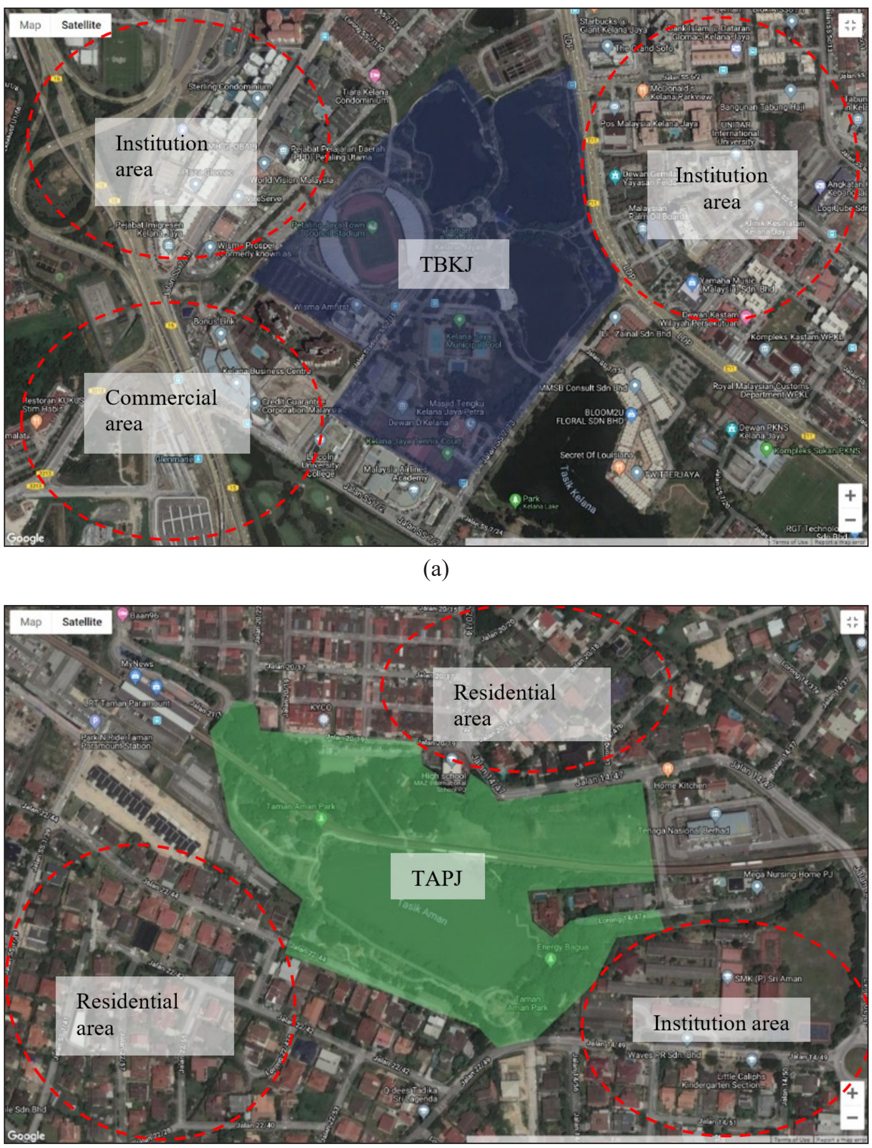
Taman Bandaran Kelana Jaya (TBKJ) and Taman Aman Petaling Jaya (TAPJ) are located in the urban part of Selangor district and thus chosen as the study sites. Table 1 shows the sizes of the parks, which are 361,169 m^2 and 80,339 m^2, respectively. Both parks possess similar built features and planting composition ranging between 10.4% to 13.5% (built features) and 86.5% to 89.5% (plantings). Figure 2 shows that these parks are located adjacent to residential, institutional, and commercial areas, thereby indicating that they are utilised frequently as an open green space for urban dwellers. The study sites are chosen according to the following factors; a) urban parks are for public usage; b) as-built drawing availability; c) unmanned aerial vehicle (UAV) drone flight use is permitted.

Table 1
Urban parks background

Park Name	Taman Bandaran Kelana Jaya	Taman Aman Petaling Jaya
Park Size, m^2	361,169	80,339
Park Age, year	24 years old (1995-2019)	18 years old (2001-2019)
Hardscape Composition	10.4%	13.5%
Softscape Composition	89.6%	86.5%

As-built Drawings of Urban Parks

Document retrieval of the old as-built drawings, construction drawings, and maintenance records was laborious. A representative of Petaling Jaya City Council (PJCC) acknowledged that they kept insufficient drawing documentation and records of preceding maintenance activities of the aged parks under their supervision. However, the parks being studied possessed sufficient as-built drawings to recognize the built features and planting inventories.



(a)

(b)

Figure 2. Site context of: (a) TBKJ; and (b) TAPJ

Work Breakdown Structure and Park Management Life Cycle

Every urban park is composed of built features and planting components. By referring to the as-built drawings, Table 2 shows the component inventory during the construction stage, which is fragmented to small-scale components, otherwise known as the work breakdown structure (WBS). The WBS was employed to predict the CO_2 content released by each urban park. Based on the construction CO_2 emission, this study predicted the CO_2 emissions for the maintenance and renewal stages accordingly. The renewal stage can be divided into two categories, namely built feature renewals and planting renewals.

Table 2
Work breakdown structure for several built features during construction stage of the studied urban parks

Built Features	Work Breakdown Structure	Work Packages (eToolLCD)
Toilet	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Services	Plumbing-100mm Insulated Pipework (22mm dia)
		Multi-Res Bedroom LED Lighting
	Floor	Concrete Floor, 125mm slab. 40MPa. 4% reo by volume
	Column	Concrete column structural, 30Mpa 3% reo by volume
	Wall	Concrete Walls (450mm, 40MPa, 25% BFS, 2% reo by volume)
		Partition wall hard resin
	Roof	Roof - TimberTruss/ClayTile/25°Pitch
	Door	Internal Door - HollowCoreTimber/WoodenJam/painted (m2)
	Finishes	External Finish - Paint(SuperStructure)
		Internal Finish - Paint (standard)
Concrete Seating	Foundation	Crushed Rock infill & compaction
	Floor	Concrete Floor, 100mm slab. 25MPa. 3.8% reo by volume
	Wall	Assembly only pour concrete
	Finishes	External Wall Finish - 10mm Render (clay)
Shelter (Gazebo)	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Floor	Concrete Floor, 125mm slab. 40MPa. 4% reo by volume
	Column	Concrete column structural, 30Mpa 3% reo by volume
	Roof	Roof - TimberTruss/ClayTile/25°Pitch
	Finishes	External Finish - Paint (SuperStructure)
Bridge	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Floor	Bridge Deck Precast concrete
	Handrail	Steel handrail 50mm diam
	Finishes	Floor Finish - Coloured Epoxy Concrete Floor Coating
Playground floor	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)

Table 2 (*continue*)

Built Features	Work Breakdown Structure	Work Packages (eToolLCD)
Playground floor	Floor	Concrete Floor - 100mm slab on ground/30MPa/1% reo by volume/no fd
	Finishes	Landscaping - Rubber Play Ground Surface
Parcourse floor	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Floor	Concrete Floor - 100mm slab on ground/30MPa/1% reo by volume/no fd
	Finishes	Landscaping - Rubber Play Ground Surface
Plaza	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Floor	Concrete Floor - 100mm slab on ground/30MPa/1% reo by volume/no fd
	Finishes	Floor Finish - Coloured Epoxy Concrete Floor Coating
Walkway	Site preparation	Small scale excavation
	Foundation	Formwork (Foundations)
	Floor	Concrete Floor - 100mm slab on ground/30MPa/1% reo by volume/no fd
	Finishes	Floor Finish - Coloured Epoxy Concrete Floor Coating
Lake	Site preparation	Bulk earthworks - cut (used on site)
Parking area	Site preparation	Large Scale Excavation Sand infill
	Floor	Paving/Road - Asphalt 80mm on 300mm aggregate base
Pole Lighting	Foundation	Crushed Rock infill & compaction
	Lighting	Lighting, 70W pedestrian area lighting on 4m pole, installed

* Work packages were derived from eToolLCD Software at www.etoollcd.com

Table 3 shows built feature renewal, which consists of four sub-stages, specifically replacement, renovation, expansion, and reconstruction. Meanwhile, Table 4 shows that the planting renewal category consists of three sub-stages, which are replanting, planting additions, and transplanting. Altogether, these seven renewal sub-stages were ranked based on the intensity of work: the amount of work performed by a team of workers divided by unit time (Kabanov, 2018).

A set of definition is justified to avoid an inconsistent understanding of the park management terminologies, construction, maintenance, and renewal. Firstly, construction in project management describes the act of erecting a large structure after which its completion is called a project. Examples of construction works include foundation excavation, flooring, column erection, beam fastening, roof works, and finishes. Regardless, the construction CO_2 emission is typically a one-off value and occurs once only throughout the entire urban park life cycle.

Table 3
Work breakdown structure for a shelter from the construction, maintenance and renewal stages

Example of Built Feature	Construction WBS	Maintenance WBS	Renewal WBS			
			Replacement WBS	Renovation WBS	Expansion WBS	Reconstruction WBS
Shelter	Site preparation	Finishes	Removal	Demolition	Foundation	Demolition
	Foundation					Site preparation
				Roof		Foundation
	Floor				Floor	Floor
	Column				Column	Column
	Roof				Roof	Roof
	Finishes		Roof	Finishes	Finishes	Finishes

Table 4
Work breakdown structure for trees from the planting installation, planting maintenance and renewal stages

Example of Planting Work	Planting Installation WBS	Planting Maintenance WBS	Renewal WBS		
			Replanting WBS	Planting addition WBS	Transplanting WBS
Tree	Site preparation	Pruning/ Fertilizer/ Pest control	Site preparation	Site preparation	Site preparation
	Planting		Planting	Planting	Planting

Next, maintenance entails the preservation of a project or the facilities in the project to its original state post-completion to avoid decomposition. Examples of maintenance works are repainting jobs on built structures, park up-keeping, debris clearance, tree pruning, fertilising, and irrigation. It usually occurs monthly for plantings and yearly for built features.

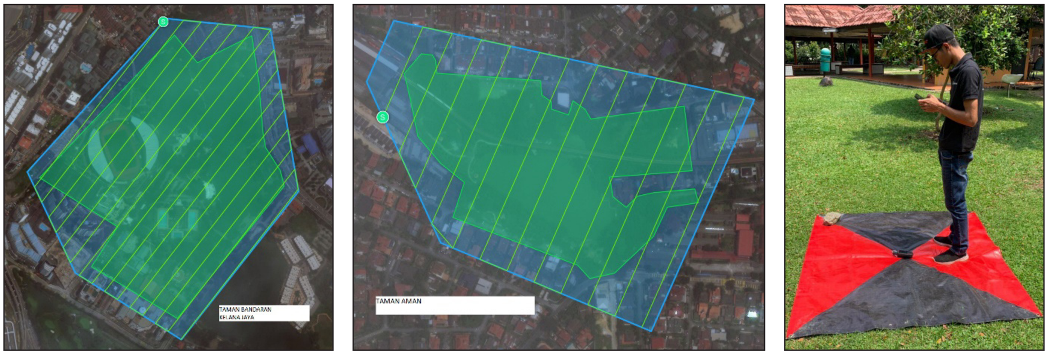
Finally, renewal is defined as the act to renew a design when it fails to meet the expectation of the users. Examples of renewal works are revamping the existing built structures, park size extension, replanting perished or frail plantings, transplanting, and replanting softscapes according to the upgraded urban park design. This study found that renewal consisted of seven significant sub-stages, namely replacement, replanting, expansion, planting addition, renovation, reconstruction, and transplanting.

Moreover, replacement refers to solely replacing any damaged and defected items, such as timber material, door, roof, playmat, and more. Meanwhile, replanting can be described as solely replanting dead trees by using the number of dead trees (1.4% mortality rate) out of total tree numbers of the park. Next, renovation refers to only renovating any decayed or damaged structures once every five years. This '5-year' period is acknowledged by the experts who had experienced in handling park management (PJCC and KSL representatives). Expansion is defined by expanding the park with the assumption of urban park components numbers added were based on the park halved amount of total previous constructed item. Planting addition refers to the number of trees added halved the total numbers of trees previously planted. Reconstruction refers to the items reconstructed in the park to equal the amount of previously constructed items in total. At a minimum of every ten years, the urban park designs are usually revamped to achieve a fresher environment. Based on Google Earth satellite images of the studied parks, changes of park morphology had been detected by comparing satellite images from parks completion year until the year 2019. Thus far, several renewal works have been done. Next, transplanting refers to the works of moving healthy or heritage trees within or outside of the urban park. The number of transplanted trees can be calculated using 1.4% of the tree mortality numbers to be replanted on the park.

Following this, patterns of CO_2 liberation during the construction stage emerged, and the WBS pattern was extrapolated during the maintenance and renewal stages for predicting the CO_2 emission in the context of other urban parks with similar microclimate, built features, plant species, and management life cycles.

Built Features Inventory

The built feature is any built form or structure in an urban park categorised as free-standing elements, horizontal and vertical surfaces (Hisham et al., 2018; Connor et al., 2011). CO_2 release estimation of these built features for TBKJ and TAPJ was done using EToolLCD Software, an online paid software that aids in calculating the WBS for construction items, including foundation, column, wall, roof, and finishes (Eslamirad & Mahdavinejad, 2018; De Wolf et al., 2017). The floor areas in square metre (m^2) of each built feature were gathered from the as-built drawings. Height, length and width dimensions were collected using an unmanned aerial vehicle (UAV) drone flights over the parks using the decided transect paths (Figure 3a and 3b). The output of the UAV flights is orthophotos. This method is termed as Structure from Motion (SfM), where a series of two dimensional (2D) orthophotos is utilised to reconstruct the three dimensional (3D) model of a built object. The 3D models of the urban parks generated by MeshLab Software were used to measure the verifiable height, length and width in metre (m). The model is reliable as it is an accurate representation of the Earth's surface. These new techniques are practical for data collection at places that are difficult to reach, such as lush vegetation in urban parks (Shashi & Jain, 2007). A DJI Phantom 4 Pro drone was used to capture low-altitude photographs, and GPS devices were used to survey the reference points (Ground Control Points) (Figure 3c). These data were processed in an SfM workflow to create elevation point cloud to derive orthophotos and canopy height models (CHM). Thus, UAV flights data collection is reliable coequal with LiDAR but at an inexpensive cost (Ngadiman et al., 2018).



(a) (b) (c)

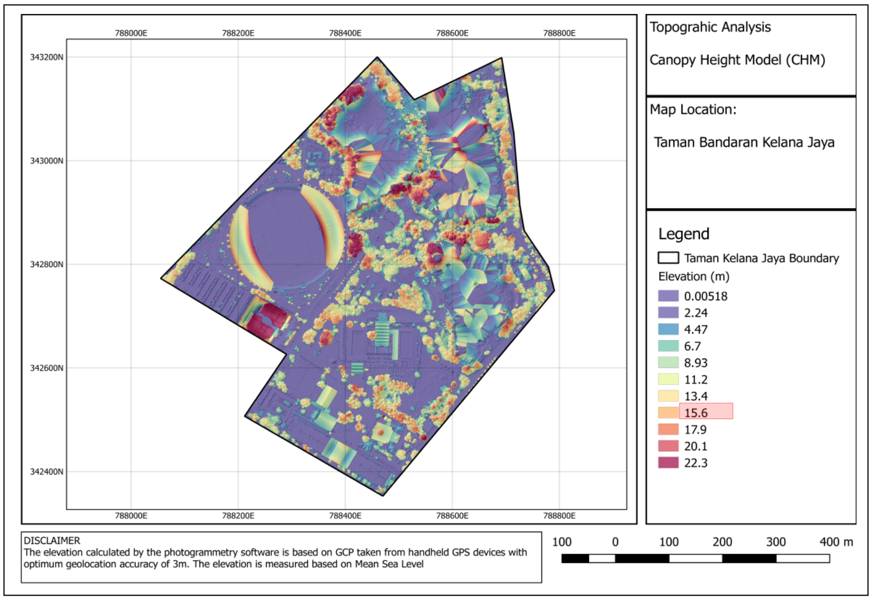
Figure 3. (a) TBKJ UAV drone transect path; (b) TAPJ UAV drone transect path; and (c) Ground Control Point coordinate tagging

Planting Inventory

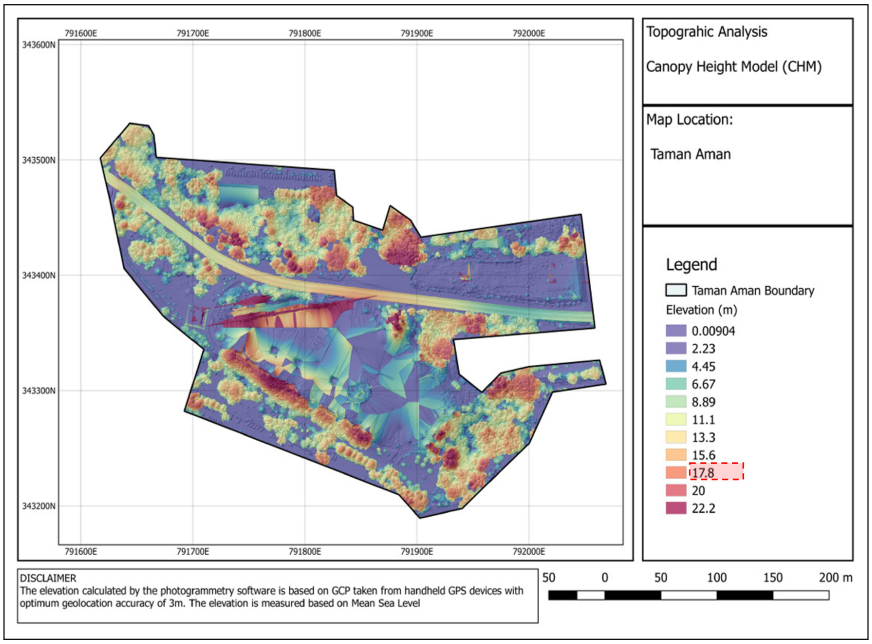
Planting is any vegetation prescribed during the design stage of an urban park, such as trees, ornamental flowers, edible plants, shrubs, groundcovers and turfs (Hisham et al., 2018). The tree numbers and species were accumulated from the as-built drawings. Tree heights and diameter at breast heights (DBH) were collected from the UAV flights and on-site measurements, respectively. The output of UAV flights was a Canopy Height Model (CHM) in which the average tree heights could be identified (Figure 4a and 4b). These urban parks have been in existence for 24 years (TBKJ) and 18 years (TAPJ) each, thereby both having matured vegetation with an average overall height of 15.6 m (Figure 4a) and 17.8 m (Figure 4b), respectively. Planting types observed were trees and turfs exclusively due to shrubs being frequently altered at the parks, and the records for any altered species and numbers altered were unavailable. Plantings CO_2 emission were calculated from the commencement of planting activities on-site until the growing process such as pruning, fertilising and weeding presently.

Trees were categorised into three; small (< 9m), medium (≤ 9 to 21m ≥) and large (> 21m) (Arbor Day Foundation, 2020). CO_2 sequestrations were calculated based on the DBH, height, numbers and years of the trees planted on the urban parks 1348 trees at TBKJ and 551 trees at TAPJ. Table 5 shows the formulae to estimate CO_2 sequestration by trees and turfs developed by Othman and Kasim (2016). Tree mortality rates depend on the year and type of microclimate where the vegetation is planted. In a tropical climate such as Malaysia, the value is low in the case of temperatures between 26.0 and 29.5 °C. This study adopted 1.40% tree mortality rate at a tropical climate out of total tree numbers at each urban park, which was as suggested by previous studies (Aleixo et al., 2019; Arellano et al., 2019; King et al., 2006).

Turf is commonly found in large areas of natural and agricultural lands. Due to urbanisation, such green spaces have been replaced with golf courses, public parks, private lawns, and sports fields (Alig et al., 2004). Five urban parks were observed between the year 2018-2019, and only two parks were presented in this paper. Based on the observation conducted onto these parks, turf height must be kept at an optimum level of approximately 2.5 cm to 4.0 cm represented as $\varkappa$ in figure 6a (Marcum, 2010).



(a)

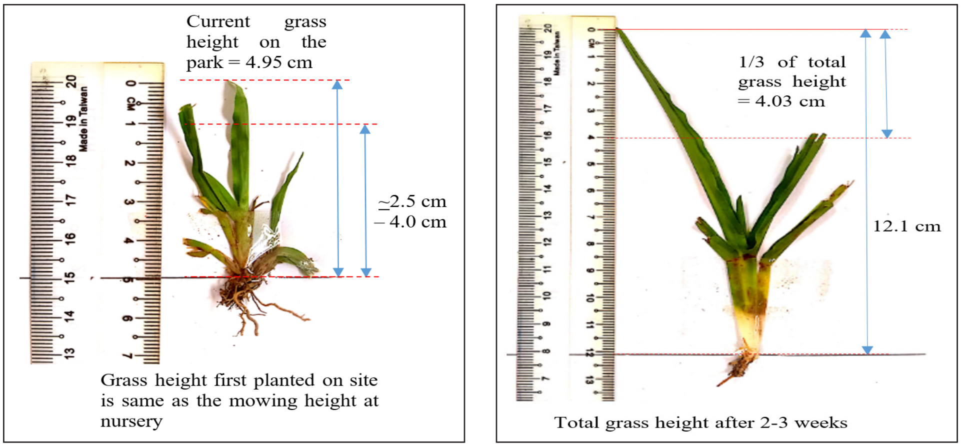


(b)

Figure 4. (a) CHM of TBKJ; and (b) CHM of TAPJ

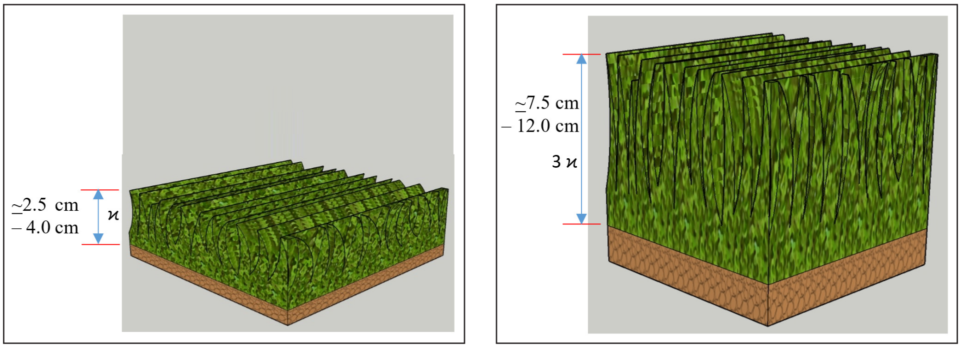
Figure 5a shows the turf specimen height was measured as 4.95 cm. After two to three weeks, the turf reached approximately 7.5 cm to 12.0 cm tall represented as $3\varkappa$ shown in Figure 6b. Turf exceeding 12.0 cm were cut and unfavourable due to pest infestation. At the optimum height, they can germinate seeds and retain moisture longer within the topsoil. At the same time, excessively short turf leads to inefficient photosynthesis, stressed root system, and is vulnerable for pathogen infestation. Thus, mowing was carried out every three weeks onto the turf at these parks.

Figure 5b shows the length of the grass cut was 1/3 of total grass height which was 4.03 cm. This cut height is equivalent to the $\varkappa$ grass height of 2.5cm to 4.0 cm delivered from nursery and previously planted on site (Figure 6a). The carbon emissions from mowing were estimated based on the number of cumulative annual mowing events (Braun & Bremer, 2019). This study applied 17 times of mowing events minimum required annually. Hence,



(a) (b)

Figure 5. (a) Turf specimen of the park post mowing = 4.95cm; and (b) length of grass blade clipped at 1/3 of total turf height represent the turf height first planted on site



(a) (b)

Figure 6. a) $\varkappa$ is turf mowing height at 2.5 cm to 4.0 cm (Marcum, 2010); and b) $3\varkappa$ is turf height after 2 to 3 weeks at 7.5 cm to 12.0 cm

Table 5
CO_2 sequestration formula for trees and turf

CO_2 Sequestration Rate formula for Trees	CO_2 Sequestration Rate formula for Turf
Total Green Weight, TGW (D=<11 in), W=0.25D^2H (1.2) Total Green Weight, TGW (D=>11 in), W=0.15D^2H (1.2) Total Dry Weight, TDW = TGW x 0.725, Total Carbon Weight, TCW = TDW x0.5 Total CO_2 Weight, TCO_2W = TCW x 3.6663 TCO_2W to date = TCO_2W x **1.4% x Tree nos	Total Dry Weight, TDW = 0.56 x area in m^2 Total Carbon Weight, TCW = TDW x 0.427 Total CO_2 Weight, TCO_2W = TCW x 3.6663 Exp 1 - TCO_2W to date = TCO_2W x 17 x park age x ***0.44 grass mortality rate

* adaptation of Othman and Kasim (2016) trees and turf sequestration
** tree mortality rate adopted from Aleixo et al. (2019)
*** grass mortality rate adopted from Lauenroth and Adler (2008)

this study adopted the formula for turf CO_2 sequestration developed by Othman and Kasim (2016) with further multiplication of 17 times mowing events, park age and 0.44% grass mortality rate as expression 1 shown in Table 5.

RESULTS AND DISCUSSION

Built Features Inventory

According to Petaling Jaya City Council and KSL representatives, an urban park may have undergone replacement, replanting, renovation, expansion, planting addition, reconstruction, and transplanting at least once throughout its service life span. Carbon emission for TBKJ (24 years) and TAPJ (18 years) were estimated as 95,325,744 $kgCO_2eq$ and 29,152,303 $kgCO_2eq$ respectively.

CO_2 emission for the construction stage is estimated as a one-off emission. Maintenance stage emission was calculated from the park cleaning, and make-good works multiplied with park age. Built feature renewal emission consisted of four substages, namely replacement, renovation, expansion and reconstruction. The CO_2 emission of replacement works was considering the repairing work such as scrapping damaged playground mat and change it to a similar mat. The emission for renovation works, including changing the existing built feature to a different shape, material and finishes. The emission for expansion works, including the enlargement of park surface areas and addition of built features quantity. The emission of reconstruction works is focusing on revamping the whole park design with a refreshed design suitable for current urban users. This study assumed that the reconstructed design followed the previous design, material, finishes and quantities.

The built features produced a total of 38,850,190 $kgCO_2eq$ (Table 6) and 8,330,614 $kgCO_2eq$ (Table 7) of CO_2 emissions during the construction stage of the urban parks. The highest CO_2 emission identified was produced by site preparation including earthworks

Table 6
Built feature inventories and CO_2 emission estimation for TBKJ during construction, maintenance and renewal stages

	Carbon Emissions for Built Feature at TBKJ					
Built Feature	Construction Stage	Maintenance Stage (24 years)	Renewal Stage			
			Replacement Stage	Renovation Stage	Expansion Stage	Reconstruction Stage
Site Preparation/ Overall works	32,279,571	39,591	15,430	21,216	383,251	32,500,099
Toilet	32,195	908	1,939	13,889	16,396	32,657
Concrete seating	6,572	1,325	19	-	3.339	6,572
Planter box	6,324	1,111	-	-	3,162	6,325
Concrete structure	115,696	8,456	50,154	57,076	35,014	115,695
Shelter	24,671	809	10,149	10,958	11,693	23,604
Pergola	24,745	1,578	12,157	20,144	12,375	24,750
Bridge	6,938	381	282	-	3,406	6,938
Playground / Play court	222,529	187,920	20,782	189,081	110,864	222,889
Parcourse	11,620	10,281	1,083	10,302	5,846	11,620
Plaza	270,456	58,915	-	-	131,714	270,456
Walkway	447,855	124,450	256,521	-	221,398	447,855
Parking area	1,619,422	-	-	-	809,711	1,619,422
Lighting	2,594,673	-	2,591,113	-	1,295,696	2,591,113
Man-Made Lake	1,186,923	-	-	-	593,461	1,186,923
Total	38,850,190	435,724	2,964,691	322,667	3,660,343	39,070,477
Overall Built Feature Carbon Emission, $kgCO_2eq$	38,850,190	10,457,376	2,964,691	322,667	3,660,343	39,070,477
	95,325,744					

* CO_2 emission estimations were done using eToolLCD Software at www.etoollcd.com

excavation and movements, drainage ditching system and electrical cabling placement, with 32,279,571 $kgCO_2eq$ and 7,180,299 $kgCO_2eq$, respectively. This emission is due to the high number of heavy machinery involved in the works. This was followed by lighting (TBKJ) and man-man lake (TAPJ) at 2,594,673 $kgCO_2eq$ and 280,792 $kgCO_2eq$, respectively. Lighting CO_2 emission was the highest value due to 400 pedestrian lighting fixtures allocated at the TBKJ. Their energy usage during the operation phase assumed that the 70W/bulb was running for 12 hours (7 pm till 7 am) daily. Similarly, the man-made lake produced the highest CO_2 emission at TAPJ due to heavy machinery used during the

Table 7
Built feature inventories and CO_2 emission estimation for TAPJ during construction, maintenance and renewal stages

Carbon Emissions for Built Feature at TAPJ						
Built Feature	Construction Stage	Maintenance Stage (18 years)	Renewal Stage			
			Replacement Stage	Renovation Stage	Expansion Stage	Reconstruction Stage
Site Preparation/ Overall works	7,180,299	11,489	8,850	4,768	85,639	7,254,583
Toilet	8,761	446	1,603	4,441	5,289	8,763
Concrete seating	3,130	114	19	-	1,539	3,130
Shelter	19,262	707	8,529	9,236	9,589	16,315
Bridge	16,726	3,137	11,819	-	27,027	16,727
Playground / Play court	183,693	153,584	16,979	154,533	90,611	182,153
Parcourse	102,504	92,754	9,688	92,759	52,450	102,503
Plaza	58,613	12,555	-	-	28,544	58,613
Walkway	256,086	67,667	142,246	-	120,406	243,532
Parking area	110,217	-	-	-	55,108	110,218
Lighting	110,531	-	110,452	-	55,344	110,530
Man-Made Lake	280,792	-	-	-	5,159,262	280,792
Total	8,330,614	342,453	310,185	265,736	5,690,809	8,390,805
Overall Built Feature Carbon Emission, $kgCO_2eq$	8,330,614	6,164,154	310,185	265,736	5,690,809	8,390,805
	29,152,303					

* CO_2 emission estimations were done using eToolLCD Software at www.etoollcd.com

construction stage. The machinery involved were the Front-End Loader (25 tonnes) (i.e. for lake excavation and backfilling), Loader (i.e. for loading bulk earthworks into the truck), and Dump Truck (i.e. for moving bulk earthworks to other sites within the construction site).

Planting Inventory

CO_2 emission for planting installation stage is also a one-time emission. Emission during the planting maintenance stage was estimated from the tree pruning, fertilizing and plant matter clearance and multiplied with park age. Planting renewal emission consisted of three substages, namely replanting, planting addition, and transplanting. The CO_2 emission of replanting works derived from the substituting sick or dead trees with similar species. The emission for planting addition works, including adding more quantities of trees of similar or different species. The emissions were derived from transplanting works, including the transplanting existing trees at renovated, expanded or reconstructed areas to other location within the urban park.

A total of 1348 trees (TBKJ) and 551 trees (TAPJ) were found along the study transects. A sum of 9,397,508 kgCO_2eq (Table 8) and 1,868,777 kgCO_2eq (Table 9) of CO_2 emissions of planting works was produced during the construction, maintenance and renewal stages of the TBKJ and TAPJ, respectively. Planting work CO_2 estimation was dependent on the tree numbers and turf surface areas. Project supervisors of Petaling Jaya City Council suggested that the related works to planting a tree involved planting pit preparation, tree

Table 8
Planting inventories and CO_2 emission estimation for TBKJ during construction, maintenance and renewal stages

Carbon Emission for Planting Works at TBKJ					
Planting Work	Planting Installation Stage	Planting Maintenance Stage (24 years)	Renewal Stage		
			Replanting Stage	Planting addition Stage	Transplanting Stage
Overall works	24,631	39,591	2,058	12,316	2,058
Tree	629,893	39,591	63,083	314,947	63,083
Turf	159,349	256,127	-	79,674	-
Total	813,873	335,309	65,141	406,937	65,141
Overall Planting Work Carbon Emission, kgCO_2eq	813,873	8,047,416	65,141	406,937	65,141
	9,397,508				

* CO_2 emission estimations were done using eToolLCD Software at www.etoollcd.com

Table 9
Planting inventories and CO_2 emission estimation for TAPJ during construction, maintenance and renewal stages

Carbon Emission for Planting Works at TAPJ					
Planting Work	Planting Installation Stage	Planting Maintenance Stage (18 years)	Renewal Stage		
			Replanting Stage	Planting addition Stage	Transplanting Stage
Overall works	7,148	11,489	848	3,574	845
Tree	257,471	11,489	25,701	128,970	25,701
Turf	33,021	53,076	-	16,511	-
Total	297,640	76,055	26,548	149,054	26,545
Overall Planting Work Carbon Emission, kgCO_2eq	297,640	1,368,990	26,548	149,054	26,545
	1,868,777				

* CO_2 emission estimations were done using eToolLCD Software at www.etoollcd.com

lifting, topsoil backfilling, staking erection, mulching and watering. These works required labour as site supervisor and operating the small electrical equipment. Such works indirectly caused CO_2 liberation. Similarly, turf installation CO_2 emissions were acquired from site supervision during soil compacting, turf laying on-site, and watering.

The total CO_2 sequestration produced at TBKJ and TAPJ were 41,371,400 $kgCO_2eq$ and 9,992,415 $kgCO_2eq$, respectively (Table 10). According to the maturity of vegetation, TAPJ had more matured vegetation despite its 18 years of park age compared to TBKJ (i.e. 24 years). Even though TBKJ was 24 years in age, the DBH and tree height were less matured compared to TAPJ.

Subsequent years of urban park completion require the parks to go through a series of maintenance and renewal stages throughout their management life cycle. These management activities are to ensure the parks are relevant to be used by visitors. Meanwhile, accumulated CO_2 emissions throughout the service life of an urban park commencing from construction, maintenance and renewal stages are justified in Table 11. The urban park itself is a carbon sink; conversely, the urban park management procedures implemented served as the carbon source.

The findings suggested that the net carbon footprint of the urban parks during the construction, maintenance, and renewal stages over 24 years (TBKJ) and 18 years (TAPJ) was not compensated for the CO_2 sequestration by its vegetation. TBKJ (146,094,652

Table 10
Planting inventory and CO_2 sequestration estimation for TBKJ and TAPJ according to age of the parks

Planting Inventory	Taman Bandaran Kelana Jaya (TBKJ)		Taman Aman Petaling Jaya (TAPJ)	
	Allometric Equation			
	Numbers, Nos	CO_2 Sequestration Estimation, $kgCO_2eq$	Numbers, Nos	CO_2 Sequestration Estimation, $kgCO_2eq$
Trees	1,348	3,272,628	551	4,121,649
U.P Age = 24 y and 18 y (1.40% tree mortality rate)	1,330	3,226,811	544	4,063,946
	Floor area, m^2	Carbon Sequestration Estimation, $kgCO_2eq$	Floor area, m^2	Carbon Sequestration Estimation, $kgCO_2eq$
Turf / year	242,368	212,481	50,225	44,032
24 y and 18 y (0.44% grass mortality rate)		38,144,589		5,928,469
Total Softscape CO_2 Sequestration, $kgCO_2eq$		41,371,400		9,992,415

* CO_2 sequestration estimations were calculated using adaptation allometric equation developed by Othman and Kasim, (2016).

$kgCO_2eq$) reported a higher CO_2 emission by 90.7% than TAPJ (14,864,511 $kgCO_2eq$) due to its regular renewal compared to TAPJ (Table 12). TBKJ is a prominent spot for outdoor recreation among urban residents as the park offers a variety of park facilities. Whereby heavy usage of its facilities contributes to frequent wearing down of the built features and facilities, subsequently causing maintenance and repairing activities to be conducted. Damaged facilities trigger intense renewal works, which indicate that more CO_2 emission is generated indirectly and derived from material transportation, machinery, and labour. Plantings such as trees, shrubs, and turfs are manicured regularly to ensure visitors' safety and avoiding pest inhabitation within the urban parks. Besides, user visitation frequency contributes to waste accumulation as well, hence requiring maintenance works to meet the cleanliness standard accepted by the users. Although TBKJ was six years older than TAPJ, its vegetation dissipated CO_2 further due to the maintenance cycle as frequent as once every three weeks. Table 12 shows the amount of CO_2 sequestered by the established vegetation, which was stochastically below 28.7% out of the total of CO_2 emission produced since its previous construction stage. This study presented facts contrary to the general opinion of landscape architects and researchers who claimed urban parks to be a carbon sink medium.

The amount of carbon footprint per square metre of the urban parks is approximately 404.5 $kgCO_2eq/m^2$ for TBKJ and 185.0 $kgCO_2eq/m^2$ for TAPJ. Therefore, the amount

Table 11
Total urban park carbon emission of TBKJ and TAPJ to date

CO_2 Emission for every Park Management Phase	Taman Bandaran Kelana Jaya (TBKJ), $kgCO^2eq$	Taman Aman Petaling Jaya (TAPJ), $kgCO^2eq$
Construction Phase	39,664,063	8,628,254
Maintenance Phase	18,504,792	1,368,990
Renewal Phase	46,554,397	14,859,682
Total Urban Park CO_2 Emission to Date, $kgCO_2eq$	104,723,252	24,856,926

Table 12
Net urban park carbon footprint of TBKJ and TAPJ up to date

Urban Park Carbon Footprint	Taman Bandaran Kelana Jaya (TBKJ), $kgCO_2eq$	Percentage, %	Taman Aman Petaling Jaya (TAPJ), $kgCO_2eq$	Percentage, %
Total Urban Park CO_2 Emission	104,723,252	71.7%	24,856,926	71.3%
Total Urban Park CO_2 Sequestration	41,371,400	28.3%	9,992,415	28.7%
Net Carbon Footprint up to Date, $kgCO_2eq$	146,094,652		14,864,511	

* Net Carbon footprint = Total Urban Park CO_2 Emission – Total Urban Park CO_2 Sequestration

of tree emission was consistent as 467.3 kgCO2eq/m^2 because of the works involved were similar such as tree pit preparation, machinery for tree lifting, and labour top-soil backfilling. In contrast, the amount of turf emission was consistent as 0.78 kgCO2eq/m^2 due to works involved in handling turf, namely labour for turf laying, top-soil backfilling and compacting, and watering.

The amount of tree sequestration was irregular at 2427 kgCO_2eq/tree (TBKJ), and 7480 kgCO_2eq/tree (TAPJ) due to the different soil type, mostly since TBKJ was previously an ex-mining site, thus causing the vegetation's slow growth to be influenced by the nutrient-deficient soil. In contrast, TAPJ vegetation consisted of species such as *Syzygium grande* (0.65gcm^{-3}), *Lagerstroemia speciose* (0.83gcm^{-3}), and *Ficus roxburghii* (0.52gcm^{-3}), which was fast-growing, suitable to local climate, and had a higher wood density. TBKJ consisted of species such as *Albizia saman* (0.46gcm^{-3}), *Cocos nucifera* (0.58gcm^{-3}), and *Acacia auriculiformis* (0.75gcm^{-3}), which had a lower wood density. Besides, TAPJ locales were at the valleys where water collection occurred, whereby the high level of moisture in its soil supported rigorous tree growth. TBKJ had low sequestration rates as the park had a higher mortality rate caused by a natural disaster such as strong winds and floods. These events were depriving trees by damaging tree branches and water ponding at root areas.

CONCLUSION

This study concluded that urban park management procedures contributed to the release of CO_2 emission by 71.3% - 71.7% derived from the construction, maintenance, and renewal stages. Carbon storage by urban vegetation was only 28.3% - 28.7% for as long as 18 to 24 years of age parks. The studied urban parks serve as the carbon source instead of a carbon sink medium in the context of the urban location. This study discovered that built features and planting works of an urban park emitted additional carbon content than that being absorbed. The aggravated stage of carbon emitted can be mitigated by reducing the maintenance and renewal frequencies conducted in an urban park.

This study suggests several ways to reduce the carbon footprint of urban parks. First, retrofitting the existing light bulb to a more energy-efficient bulb and reduce its operating hours. Second, reducing earthwork excavation to alter landforms, instead of blend and adapt the proposed design with the existing site. It is encouraging to use eco-friendly or recyclable materials for constructing the built feature so that is can reduce resource wastage. Finally, reducing planting maintenance frequencies by focusing on the areas where people used the most. The CO_2 emission allowance was based on the amount of vegetation able to sequester yearly. It is advisable to identify the amount of CO_2 sequestration by greenery at the parks and use the sequestration value as carbon emission allowance to conduct management activities.

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