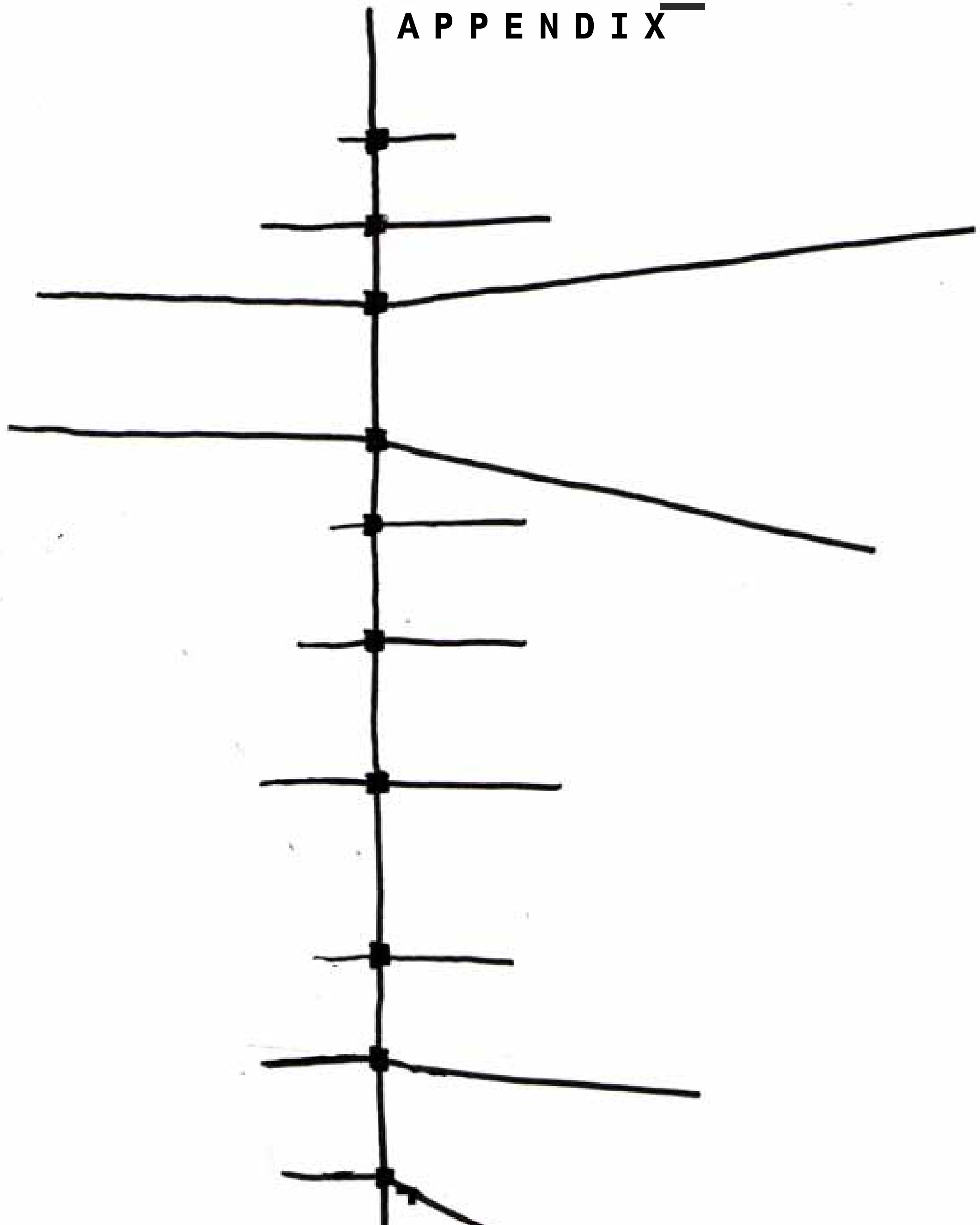
APPENDIX 13



13.1. ORIGINAL RESEARCH PROPOSAL

10.1.1 UNDP/GEF STUDENT GRANT PROJECT PROPOSAL

1. The Research Objectives

The objective is to design, with recognition of the GEF BRT Climate change requirements, a low Carbon Bus Rapid station and Auxiliary Building/s. The Site chosen is that of the existing Pretoria Main station. This station serves as an interchange not only for BRT System but also forms an integral transportation hub for other modes of transport.

The second objective of the study is to design some of the components of the Low Carbon BRT Station and Auxiliary building/s in such a way that some of the modules could be used as a prototype and/or model for other such nodal and modal interchanges.

The third objective that such a design as described above should respect the cultural and historical setting of the Pretoria Main Station and hence be sensitive to and respond to its context.

The Fourth objective is that the study should incorporate aspects of LEED [or other green building rating systems] and then also components of a design approach and normative position regarding the cradle-to grave definition of materials and their production, a low carbon footprint study, embodied energy and life-cycle performance and management of these aspects within the architectural research and design resolution.

A fifth aim is that the student and the study promoters attend a South African Green Building Council GreenStar course.

2. The anticipated approach to the research and methodology to be applied

The study will commence with a literature study and the gathering of data relevant to the design of Climate Change Sensitive low Carbon BRT station and Auxiliary building/s.

After the literature study the student will engage with the design of these structures. The design will be refined within an iterative process. The final design of the structures will be measured with a green building rating system. A set developed detail technical drawings will be provided to support the design. The designed structures are academic investigations and will culminate in a mini dissertation and two publications to be submitted for peer reviewed publication in Architecture SA.

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3. Expected interim and final deliverables and the timeframe thereof

Interim deliverables for 2010 and the first semester of 2011 are the following:

1.At the end of the first term of the University of Pretoria calendar the student should have proofed investigation including data capturing and literature study into the complexities of the following:

a. Climate change as it pertains to the urban environment and in particular Tshwane.
b. BRT systems in Tshwane.
c. BRT systems of Pretoria Main station.
d. Low carbon construction technologies.
e. The LEED or other ration systems.
f. The Cultural and historical heritage of the site.
g. The above should be presented to the supervisors at the end of the term.

2. At the end of the second term, the student should have proofed investigation and provide evidence of the study in the above as well as into the complexities of the following:

a. Design approach and normative position regarding the cradle-to-grave definition of materials and their productions, low carbon footprint, embodied energy and life cycle performance and management of the aspects.
b. A draft literature study of the work conducted to date and this should include the objectives of the study.
c. A conceptual urban framework for the design should be presented.

3. At the end of the third quarter the student should provide a preliminary design o the project that acknowledges and responds to the above two quarters and the objectives of the study with the final aim of a low carbon BRT station and auxiliary building/s.

4. The fourth quarter should be concluded with a written mini dissertation that complies with the objectives of this research project and the graduation regulation s of the Department of Architecture.

5. The first and second quarter of 2011 should result in two submitted publications [for peer review] to the Journal architecture SA based on the research conducted by the student in 2010. The student is responsible for the writing and submission of this research paper.

4. Conclusion

We trust that this research proposal will meet the requirements of the UNDP and GED for this project. The Department of Architecture is known for its stature to promote and educate students in sustainable and green architecture. The Department is thus most grateful for this opportunity to partner with the GEF and UNDP to further this integral goal and to build more capacity in the department and students that graduate from our Professional Masters programme

13.2 EMBODIED ENERGY OF MATERIALS

13.2.1 Embodied energy tables

Embodied Energy Table: Europe

Material	Weight [kg/m^3]	Durability	Loss factor [21%]	Years left as reserves	Primary energy consumption [MJ/kg]	
					North Europe	Central Europe
Aluminium [50% recycled]	2700	High	21	220	58	184
Steel [100% recycled]	8000	High	-	-	6	10
Steel [galvanised from ore]	7500	High	21	21	12	25
Stainless steel from ore	7800	High	21	21	12	25
Concrete structural	2400	High	16	-	0.6	1
Concrete Aerate prefab units	500	Medium	5	-	-	4
Concrete Lightweight prefab units	750	Medium	6	-	2	4
Lime Mortar	1700	Medium	10	-	1	1
Glass	2400	High	3	-	7	8
Fired clay Bricks	1800	Very High	10	-	2	3
Expanded Polystyrene XPS	23	Meduim	11	40	72	72
Expanded Polustyrene [PUR]	35	Low/medium	11	40	98	110
Timber	550	Meduim/High	20	Renewable	3	3
Laminated timber	550	Medium/High	-	390	4	4
Cellulose fibre insulation [100 % recycled and boric salts]	60	Medium	1	295	19	21

Table 13-01: Table indicating the different embodied energy quantities of construction materials in Europe [Source:Berge 2006: p20]

Embodied Energy Table: International

MATERIAL	EMBODIED ENERGY MJ/KG	MJ/M³
Aggregate	0.1	150
Straw bale	0.24	91
Soil-cement	0.42	819
Stone [Local]	0.79	2 030
Concrete block	0.94	2 950
Concrete [30mpa]	1.3	3 180
Concrete Precast	2.0	2 780
Lumber	2.5	1 380
Brick	2.5	5 170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5 890
Particle Board	8.0	4 400
Aluminium[recycled	8.1	21 870
Steel [recycled]	8.9	37 210
Shingles [asphalt]	9.0	4 990
Plywood	10.4	5 720
Mineral Wool insulation	14.6	139
Glass	15.9	37 550
Fibreglass insulation	90.3	970
Steel	32.0	251 200
Zinc	51.0	371 200
Brass	62.0	519 580
PVC	70.0	93 620
Copper	70.6	631 164
Paint	93.3	117 500
Linoleum	116	150 930
Polystyrene insulation	117	3770
Carpet [synthetic]	148	84 900
Aluminium	227	515 700
Note: Embodied energy is only international amounts		

Embodied Energy Table: Australia

Material	Embodied energy MJ/kg	Material	Embodied energy MJ/Kg	Material	Embodied Energy MJ/Kg
Kiln dried softwood	3.4	Stabilised Earth	0.7	Aluminium	170
Kiln dried hardwood	2.0	Imported dimension granite	13.9	Copper	100
Air dried hardwood	0.5	Local Dimension granite	5.9	Galvanised steel	38
Hardboard	24.2	Gypsum plaster	2.9	Glass	12.7
Particle board	8	Plaster board	4.4	Plastic	90
MDF	11.3	Fibre Cement	4.8	PVC	80
Plywood	10.4	Cement	5.6	Acrylic Paint	61.5
Laminated Timber	11	Insitu concrete	1.9	Synthetic Rubber	110
Glass	12.7	Precasat steam-cured concrete	2.0	Clay bricks	2.5
		Precast tilt-up concrete	1.9	Concrete blocks	1.5

Table 13-02: Embodied energy for Australian materials, list compiled in 1996 [Source: Milne & Reardon s.a. :p4]

Table 13-03: Table indicating the different embodied energy quantities of construction materials [Source: Astrup 2004 p104]

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13.2.2 Carbon footprints and embodied energy of different Construction technologies

The embodied energy and carbon footprint of different construction systems and technologies were investigated and used to guide the design process and material choice. Calculation based on figures established by life cycle assessment framework [section 4.4]. The calculations were made for the cradle to gate cycle - excluding transportation energy

Calculations for Terminal building

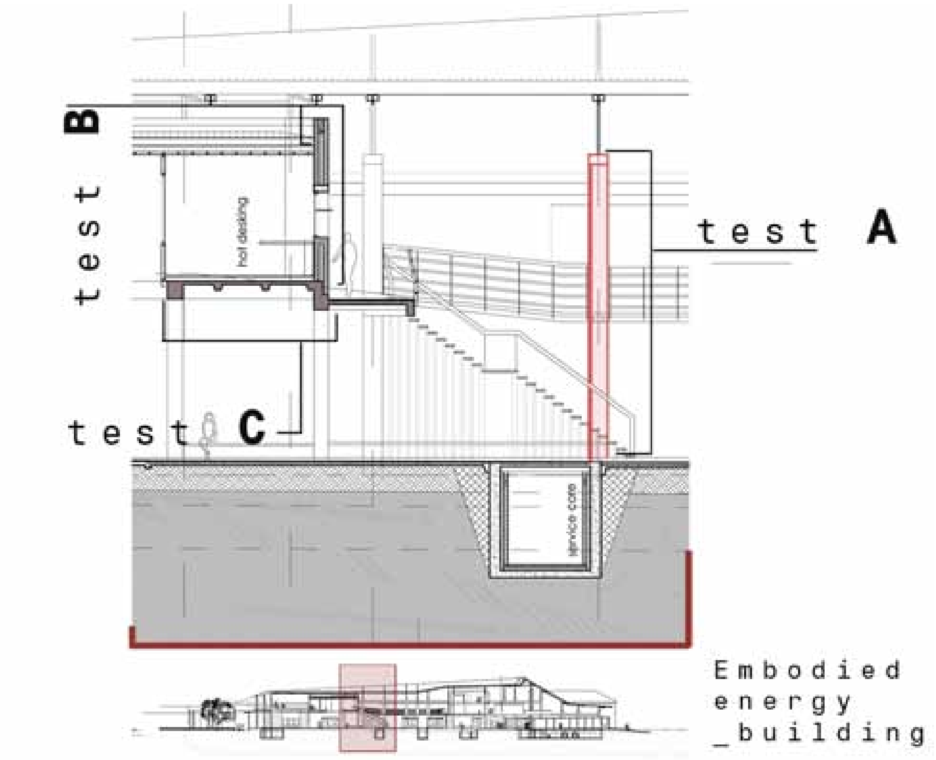


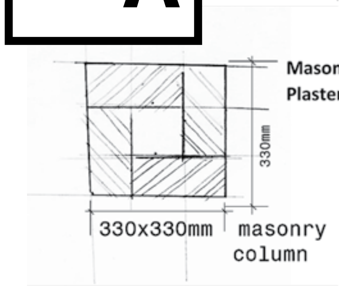
Figure 13-01: Components of the terminal building tested during technical investigation [Source: Author]

test A

COLUMN - height 4 meter

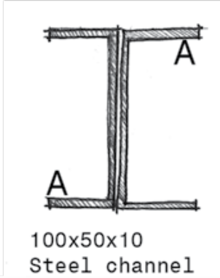
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per collumn



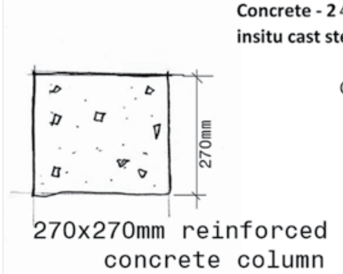
Masonry
Plastered and painted

Masonry	330x330	0.43	m^3	x	1900	kg/m^3	=	**817**	kg
		817	kg	x	3	MJ/kg	=	**2451**	MJ
		817	kg	x	0.22	$kg\ CO_2/kg$	=	**179.74**	$kg\ CO_2$
						TOTAL		**2451**	MJ
								179.74	$kg\ CO_2$



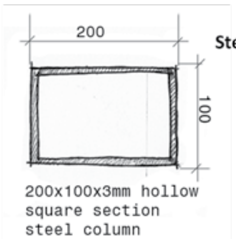
Steel column - Hot rolled channels
2 maal 100*50*11 channels welded together

steel	88	kg	x	4.8	m	=	**422.4**	kg
	422.4	kg	x	29.44	MJ/kg	=	**12435**	MJ
	422.4	kg	x	2.22	$kg\ CO_2/kg$	=	**937.73**	$kg\ CO_2$
					TOTAL		**12435**	MJ
							937.73	$kg\ CO_2$



Concrete - 2 4 meter
insitu cast steel reinforced

Collumn	270*270	0.27	m^3	x	2400	kg/m^3	=	**648**	kg
		648	kg	x	2.42	MJ/kg	=	**1568.2**	MJ
		648	kg	x	0.256	$kg\ CO_2/kg$	=	**165.89**	$kg\ CO_2$
						TOTAL		**1568.2**	MJ
								165.89	$kg\ CO_2$



Steel column _ Cold Formed hollow square section

200x100x3	0.008	m^3	x	8000	kg/m^3	=	**64**	kg
	64	kg	x	29.44	MJ/kg	=	**1884.2**	MJ
	64	kg	x	2.22	$kg\ CO_2/kg$	=	**142.08**	$kg\ CO_2$
					TOTAL		**1884.2**	MJ
							142.08	$kg\ CO_2$

Table 13-04: Test A- Calculating Embodied energy and carbon footprint of columns [Source: Author]

test B

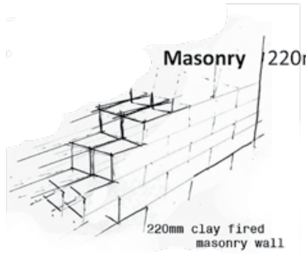
WALL

Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per square meter

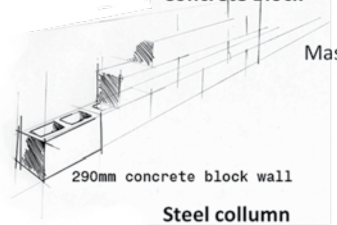
Wall - 5x2.4[h]

Masonry /220mm



Masonry	220 mm wall	12	m^2	x	1282.2	MJ/m^2 =	15386 MJ
		12	m^2	x	95.86	CO_2/m^2 =	1150.3 kg CO_2
						TOTAL	15386 MJ
							1150.3 kg CO_2

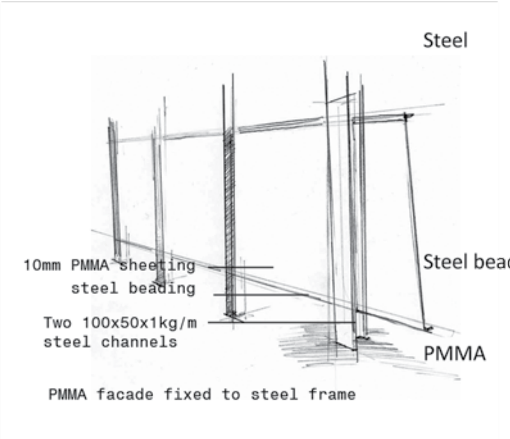
Concrete Block



Masonrry	290 mm wall	12	m^2	x	336	MJ/m^2 =	4032 MJ
		12	m^2	x	41.14	CO_2/m^2 =	493.68 kg CO_2
						TOTAL	4032 MJ
							493.68 kg CO_2

Steel collumn

2 [100x50x11kg/m] channels welded together



Steel	2 collumns used	11	kg	x	4.8	m =	52.8 kg
		52.8	kg	x	29.44	MJ/kg =	1554.4 MJ
		52.8	kg	x	2.22	kg CO_2/kg =	117.22 kg CO_2
						TOTAL	3108.9 MJ
							234.43 kg CO_2
Steel beading		0.02	m^3	x	29.44	MJ/m^3 =	0.5888 MJ
		0.02	m^3	x	2.22	CO_2/m^3 =	0.0444 kg CO_2
PMMA	10 mm wall	11.5	m^2	x	454	MJ/m^2 =	5221 MJ
		11.5	m^2	x	14	CO_2/m^2 =	161 kg CO_2
						TOTAL	8330.5 MJ
							395.48 kg CO_2

Table 13-05: Test B- Calculating Embodied energy and carbon footprint of walls [Source: Author]

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test C

REINFORCED CONCRETE SLABS- medium span

Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to square meters

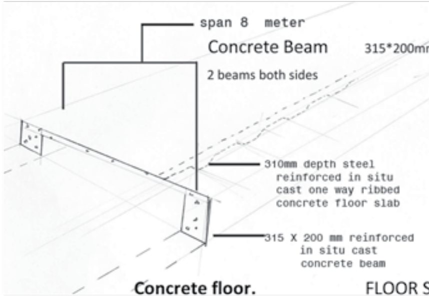
FLOOR SYSTEMS -8 meter span   length 6.3 meter

Floor area 51.2m^2

Concrete floor.

Reinforced one way ribbed floor

Concrete	310mm depth	5.5	m^3	x	2400	kg/m^3 =	13200	kg
		13200	kg	x	2.42	MJ/kg =	31944	MJ
		13200	kg	x	0.256	kg CO_2/kg =	3379.2	kg CO_2
Concrete Beam (2 beams both sides)	315*200mm depth	0.8	m^3	x	2400	kg/m^3 =	1920	kg
		1920	kg	x	2.42	MJ/kg =	4646.4	MJ
		1920	kg	x	0.256	kg CO_2/kg =	491.52	kg CO_2
						TOTAL	36590	MJ
							3870.7	kg CO_2



Concrete floor.   FLOOR SYSTEMS -6.3 meter span length 8

Reinforced one way ribbed floor

Concrete	250mm depth	4.5	m^3	x	2400	kg/m^3 =	10800	kg
		10800	kg	x	2.42	MJ/kg =	26136	MJ
		10800	kg	x	0.256	kg CO_2/kg =	2764.8	kg CO_2
Concrete Beam (share 2 beams only quantity 1)	400mm*200 beam	0.64	m^3	x	2400	kg/m^3 =	1536	kg
		1536	kg	x	2.42	MJ/kg =	3717.1	MJ
		1536	kg	x	0.256	kg CO_2/kg =	393.22	kg CO_2
						TOTAL	29853	MJ
							3158	kg CO_2

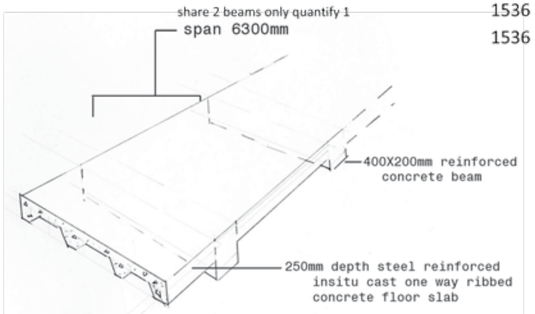
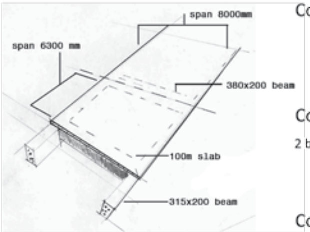


Table 13-06: Test C- Calculating Embodied energy and carbon footprint of concrete slab [Source: Author]

test C

Concrete floor. FLOOR SYSTEMS -6.3 meter span length 8

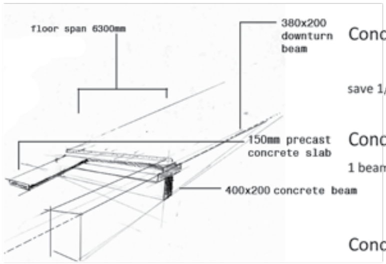
Flat cast floor beams both ways



Concrete	100mm depth	4.56	m^3	x	2400	kg/m^3	=	10944	kg
		10944	kg	x	2.42	MJ/kg	=	26484	MJ
		10944	kg	x	0.256	$kg\ CO_2/kg$	=	2801.7	$kg\ CO_2$
Concrete Beam1	315*200mm depth	0.78	m^3	x	2400	kg/m^3	=	1872	kg
2 beams both sides		1872	kg	x	2.42	MJ/kg	=	4530.2	MJ
		1872	kg	x	0.256	$kg\ CO_2/kg$	=	479.23	$kg\ CO_2$
Concrete Beam 2	380mm*200 beam	0.67	m^3	x	2400	kg/m^3	=	1608	kg
3 cross beams/2		1608	kg	x	2.42	MJ/kg	=	3891.4	MJ
		1608	kg	x	0.256	$kg\ CO_2/kg$	=	411.65	$kg\ CO_2$
						TOTAL		34906	MJ
								3692.5	$kg\ CO_2$

Concrete floor. FLOOR SYSTEMS -6.3 meter span length 8

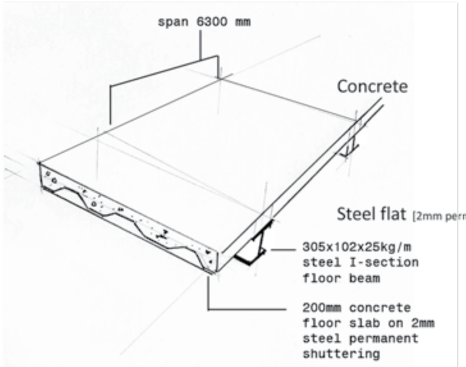
precast panel on in situ cast beams and down turn beam



Concrete	150mm depth	5.4	m^3	x	2400	kg/m^3	=	12960	kg
	standard depth	12960	kg	x	2.42	MJ/kg	=	31363	MJ
save 1/3 in concrete		12960	kg	x	0.256	$kg\ CO_2/kg$	=	3317.8	$kg\ CO_2$
Concrete Beam1	400*200mm depth	0.64	m^3	x	2400	kg/m^3	=	1536	kg
1 beams both sides		1536	kg	x	2.42	MJ/kg	=	3717.1	MJ
		1536	kg	x	0.256	$kg\ CO_2/kg$	=	393.22	$kg\ CO_2$
Concrete Beam 2	380mm*200 beam	1.152	m^3	x	2400	kg/m^3	=	2764.8	kg
3 cross beams/2	avarage of 200x900	2765	kg	x	2.42	MJ/kg	=	6690.8	MJ
		2765	kg	x	0.256	$kg\ CO_2/kg$	=	707.79	$kg\ CO_2$
						TOTAL		41771	MJ
								4418.8	$kg\ CO_2$
Concrete	150mm depth	0.768	m^3	x	2400	kg/m^3	=	1843.2	kg
	standard depth	1843	kg	x	2.42	MJ/kg	=	4460.5	MJ
save 1/3 in concrete		1843	kg	x	0.256	$kg\ CO_2/kg$	=	471.86	$kg\ CO_2$
						TOTAL		39541	MJ
								4182.8	$kg\ CO_2$

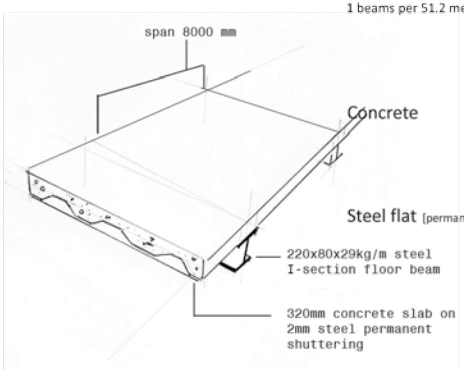
Table 13-07: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]

Steel floor composit floor - span 8 meter



Steel beam	220*80*29kg/m]								
2 beams		353.8	kg	x	7.2		=	2547.4	kg
		2547	kg	x	29.44	MJ/kg	=	74994	MJ
		2547	kg	x	2.22	$kg\ CO_2/kg$	=	5655.1	$kg\ CO_2$
Concrete	320mm depth	6.4	m^3	x	1900	kg/m^3	=	12160	kg
		12160	kg	x	1.39	MJ/kg	=	16902	MJ
		12160	kg	x	0.209	$kg\ CO_2/kg$	=	2541.4	$kg\ CO_2$
Steel flat [2mm permanent shuttering]		0.1	m^3	x	8000	kg/m^3	=	800	kg
		800	kg	x	29.44	MJ/kg	=	23552	MJ
		800	kg	x	2.22	$kg\ CO_2/kg$	=	1776	$kg\ CO_2$
						TOTAL		115449	MJ
								9972.6	$kg\ CO_2$

Steel floor composit floor - span 6.4 meter

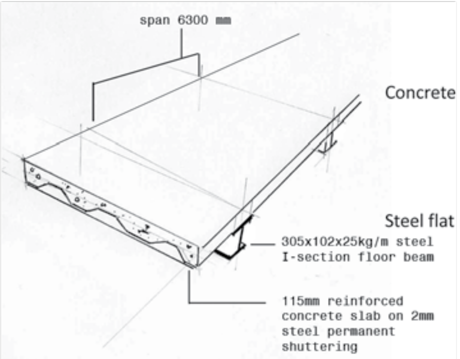


Steel beam	[305x102x25kg/m] 1.2 beams per 10 meter								
1 beams per 51.2 meter square		200	kg	x	7.2		=	1440	kg
		1440	kg	x	29.44	MJ/kg	=	42394	MJ
		1440	kg	x	2.22	$kg\ CO_2/kg$	=	3196.8	$kg\ CO_2$
Concrete	210mm depth	4.3	m^3	x	2400	kg/m^3	=	10320	kg
		10320	kg	x	2.42	MJ/kg	=	24974	MJ
		10320	kg	x	0.256	$kg\ CO_2/kg$	=	2641.9	$kg\ CO_2$
Steel flat [permanent shuttering]		0.081	m^3	x	8000	kg/m^3	=	648	kg
		648	kg	x	29.44	MJ/kg	=	19077	MJ
		648	kg	x	2.22	$kg\ CO_2/kg$	=	1438.6	$kg\ CO_2$
						TOTAL		86445	MJ
								7277.3	$kg\ CO_2$

Table 13-08: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]

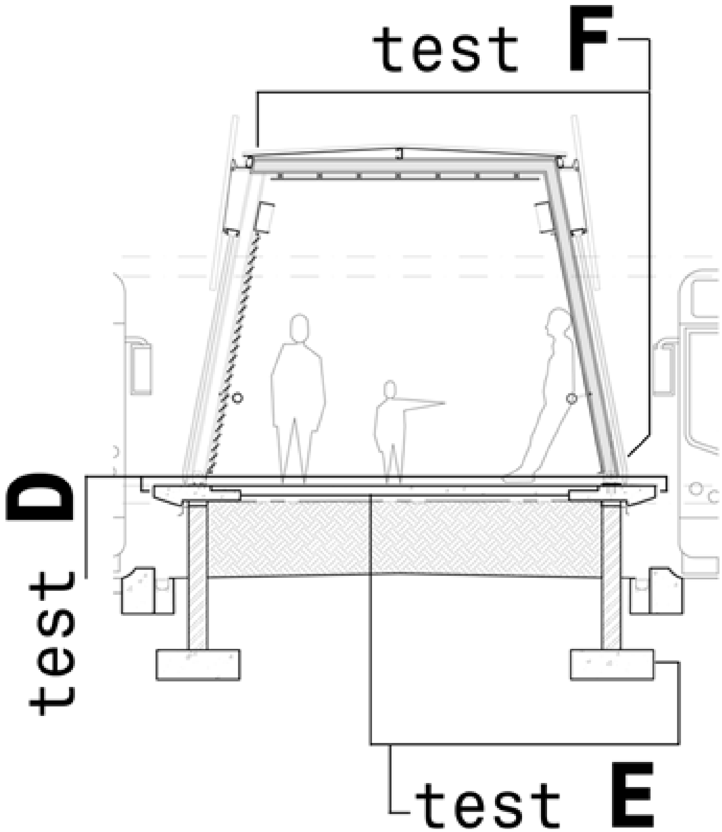
test C

Steel floor composit floor - span 6.4 meter - reinforced span 1/70



Steel beam	[305x102x25kg/m]								
	1 beams per 51.2 meter square	200	kg	x	7.2		=	1440	kg
		1440	kg	x	29.44	MJ/kg	=	42394	MJ
		1440	kg	x	2.22	kg CO_2/kg	=	3196.8	kg CO_2
Concrete	115mm depth	5.8	m^3	x	2400	kg/m^3	=	13920	kg
		13920	kg	x	2.42	MJ/kg	=	33686	MJ
		13920	kg	x	0.256	kg CO_2/kg	=	3563.5	kg CO_2
Steel flat	[permanent shuttering]	0.06	m^3	x	8000	kg/m^3	=	480	kg
		480	kg	x	29.44	MJ/kg	=	14131	MJ
		480	kg	x	2.22	kg CO_2/kg	=	1065.6	kg CO_2
					TOTAL			90211	MJ
								7825.9	kg CO_2

Table 13-09: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]



Embodied energy - PROTOTYPE

Figure 13-02: Different components tested during technical investigation [Source Author] test D

FLOOR SYSTEM

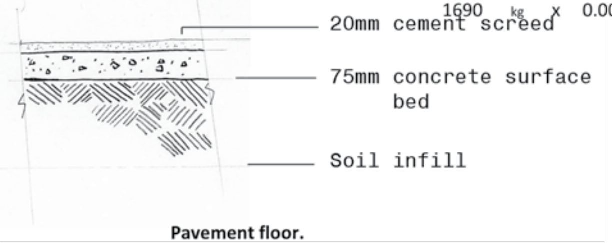
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to square meters

Floor systems worked out for 1 square meter

Concrete floor.

Screed	0.02	m^3	x	1900	kg/m^3	=	38	kg
	38	kg	x	0.6	MJ/kg	=	22.8	MJ
	38	kg	x	0.61	$kg\ CO_2/kg$	=	23.18	$kg\ CO_2$
Surface bed	0.075	m^3	x	2400	kg/m^3	=	180	kg
	180	kg	x	1.39	MJ/kg	=	250.2	MJ
	180	kg	x	0.209	$kg\ CO_2/kg$	=	37.62	$kg\ CO_2$
Infill	0.845	m^3	x	2000	kg/m^3	=	1690	kg
	1690	kg	x	0.1	MJ/kg	=	169	MJ
	1690	kg	x	0.005	$kg\ CO_2/kg$	=	8.45	$kg\ CO_2$
				TOTAL			442	MJ
							69.25	$kg\ CO_2$



Pavement floor.

Masonry	0.08	m^3	x	1900	kg/m^3	=	152	kg
	152	kg	x	3	MJ/kg	=	456	MJ
	152	kg	x	0.22	$kg\ CO_2/kg$	=	33.44	$kg\ CO_2$
Infill	0.86	m^3	x	2000	kg/m^3	=	1720	kg
	1720	kg	x	0.1	MJ/kg	=	172	MJ
	1720	kg	x	0.005	$kg\ CO_2/kg$	=	8.6	$kg\ CO_2$
				TOTAL			628	MJ
							42.04	$kg\ CO_2$

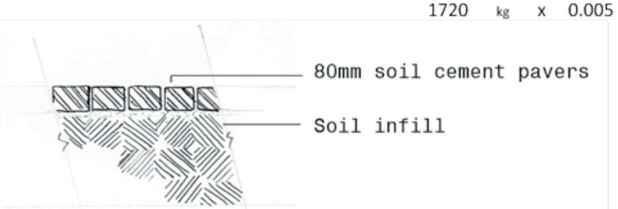
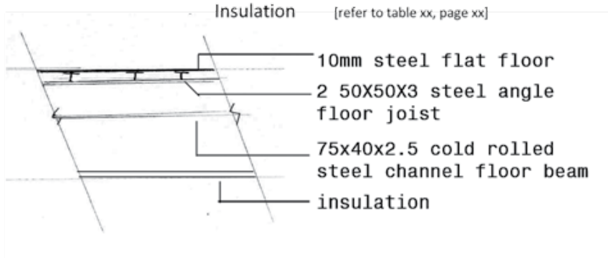


Table 13-10: Test D- Calculating Embodied energy and carbon footprint of floor systems for the BRT [Source: Author]

test D

Steel floor

Steel beam	[75x40x2.5]				two beams per 3 meter				
		2.5	kg	x	0.667		=	1.6675	kg
		1.668	kg	x	29.44	MJ/kg	=	49.091	MJ
		1.668	kg	x	2.22	$kg\ CO_2/kg$	=	3.7019	$kg\ CO_2$
Steel angle	[50x50x3]	0.00063	m^3	x	8000	kg/m^3	=	5.04	kg
		5.04	kg	x	29.44	MJ/kg	=	148.38	MJ
		5.04	kg	x	2.22	$kg\ CO_2/kg$	=	11.189	$kg\ CO_2$
Steel flat		0.01	m^3	x	8000	kg/m^3	=	80	kg
		80	kg	x	29.44	MJ/kg	=	2355.2	MJ
		80	kg	x	2.22	$kg\ CO_2/kg$	=	177.6	$kg\ CO_2$
Insulation	[refer to table xx, page xx]							70.88	MJ
								2	$kg\ CO_2$
					TOTAL			2623.5	MJ
								194.49	$kg\ CO_2$



Reinforced concrete floor.

1 meter cantilever on edge

Concrete	0.083	m^3	x	2400	kg/m^3	=	199.2	kg
	199.2	kg	x	2.42	MJ/kg	=	482.06	MJ
	199.2	kg	x	0.256	$kg\ CO_2/kg$	=	50.995	$kg\ CO_2$
Screed	0.02	m^3	x	1900	kg/m^3	=	38	kg
	38	kg	x	0.6	MJ/kg	=	22.8	MJ
	38	kg	x	0.61	$kg\ CO_2/kg$	=	23.18	$kg\ CO_2$
				TOTAL			504.86	MJ
							74.175	$kg\ CO_2$

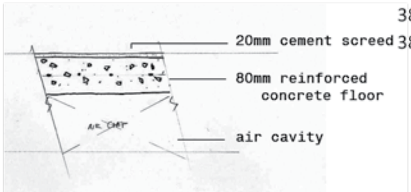


Table 13-11: Test D- Calculating Embodied energy and carbon footprint of floor systems for the BRT [Source: Author]

test E

Floor systems

Including foundation and a 300mm subsurface foundation wall

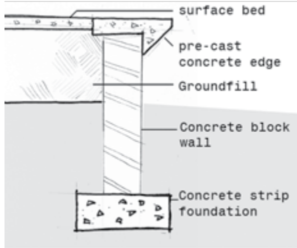
All floor calculated at 940mm above groundlevel height

Floor calculated over 8m length and 4.5 meter width

Foundation taken to be 300mm below ground level

If floor is not cast on site an added precast BRT edge is added [0.8 m^3 precast concrete]

Concrete Block wall with 100mm surface bed and ground infill



Foundation -concrete

720x300mm	cubic meter	kg/m^3	mass
	3.4	1900	6460 kg
Embodied energy	1.39 J/kg		8979.4 J
Carbon footprint	0.209 kgCo/kg		1350.14 kg CO_2

Concrete block wall

280mm	cubic meter	kg/m^3	mass
	2.4	1900	4560 kg
Embodied energy	0.81 J/kg		3693.6 J
Carbon footprint	0.098 kgCo/kg		446.88 kg CO_2

Ground fill

840mm	cubic meter	kg/m^3	mass
	41	2000	82000 kg
Embodied energy	0.1 J/kg		8200 J
Carbon footprint	0.005 kgCo/kg		410 kg CO_2

Concrete Surface bed

100mm	cubic meter	kg/m^3	mass
	3.5	1900	6650 kg
Embodied energy	1.39 J/kg		9243.5 J
Carbon footprint	0.209 kgCo/kg		1389.85 kg CO_2

Precast station edge

special	cubic meter	kg/m^3	mass
	0.8	2400	1920 kg
Embodied energy	3.7 J/kg		7104 J
Carbon footprint	0.39 kgCo/kg		748.8 kg CO_2

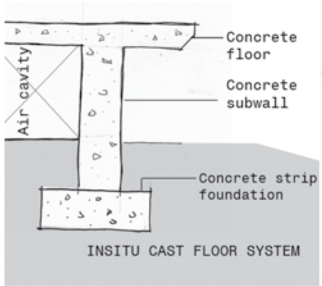
TOTAL	37220.5 J 4345.67 kg CO_2
TOTAL/M^2	**1034 J** **120.7 kg CO_2**

Table 13-12: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

test E

Reinforced concrete floor

floor with 1 meter cantilever



Foundation -concrete

900x300mm	cubic meter	kg/m^3	mass
	4.32	1900	8208
Embodied energy	1.39 J/kg		11409.12 J
Carbon footprint	0.209 kgCo/kg		1715.47 kg CO_2

Reinforced concrete subwall

300mm	cubic meter	kg/m^3	mass
	5.4	2400	12960
Embodied energy	2.42 J/kg		31363.2 J
Carbon footprint	0.256 kgCo/kg		3317.76 kg CO_2

Reinforced concrete floor

90mm	cubic meter	kg/m^3	mass
add station edge 0.8m3	4.04	2400	9696
Embodied energy	2.42 J/kg		23464.32 J
Carbon footprint	0.256 kgCo/kg		2482.17 kg CO_2

Concrete screed

20mm	cubic meter	kg/m^3	mass
	0.72	1900	1368
Embodied energy	1.39 J/kg		1901.52 J
Carbon footprint	0.209 kgCo/kg		285.91 kg CO_2

TOTAL	68138.16 J 7801.32 kg CO_2
TOTAL/M^2	**1893 J** **217 kg CO_2**

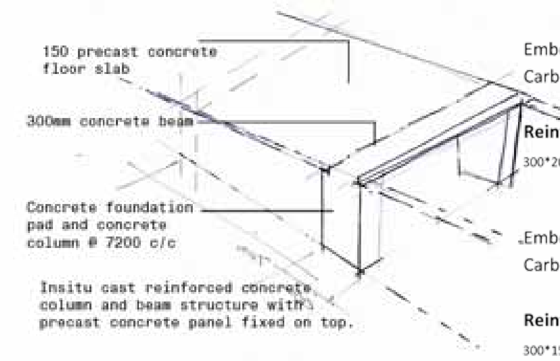
Table 13-13: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

test E

Precast Reinforced concrete floor

floor with 500mm cantilever

floor rib every 7,2 meters



Foundation pad -concrete

900x600mm	cubic meter	kg/m^3	mass
	0.324	2400	777.6
Embodied energy	2.42 J/kg	1881.79 J	
Carbon footprint	0.256 kgCo/kg	199.06 kg CO_2	

Reinforced concrete subwall

300*200mm	cubic meter	kg/m^3	mass
	0.11	2400	264
Embodied energy	2.42 J/kg	638.88 J	
Carbon footprint	0.256 kgCo/kg	67.58 kg CO_2	

Reinforced concrete beam

300*150mm	cubic meter	kg/m^3	mass
	0.2	2400	480
Embodied energy	2.42 J/kg	1161.6 J	
Carbon footprint	0.256 kgCo/kg	122.88 kg CO_2	

Precast Reinforced concrete floor

150mm	cubic meter	kg/m^3	mass
add station edge 0.8m3	6.2	2400	14880
Embodied energy	3.7 J/kg	55056 J	
Carbon footprint	0.39 kgCo/kg	5803.2 kg CO_2	

Concrete screed

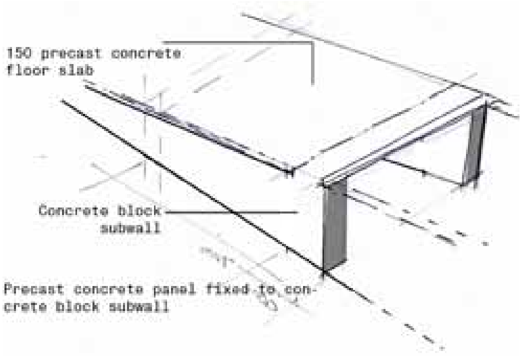
20mm	cubic meter	kg/m^3	mass
	0.72	1900	1368
Embodied energy	1.39 J/kg	1901.52 J	
Carbon footprint	0.209 kgCo/kg	285.91 kg CO_2	

TOTAL	60639.79 J 6478.64 kg CO_2
TOTAL/M^2	**1685 J 180 kg CO_2**

Table 13-14: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems [Source: Author]

test E

Concrete Block wall with 150mm precast concrete floor



Foundation -concrete

720x300mm	cubic meter	kg/m^3	mass
	3.4	1900	6460 kg
Embodied energy	1.39 J/kg	8979.4 J	
Carbon footprint	0.209 kgCo/kg	1350.14 kg CO_2	

Concrete block wall

280mm	cubic meter	kg/m^3	mass
	2.4	1900	4560 kg
Embodied energy	0.81 J/kg	3693.6 J	
Carbon footprint	0.098 kgCo/kg	446.88 kg CO_2	

Ground fill

840mm	cubic meter	kg/m^3	mass
	41	2000	82000 kg
Embodied energy	0.1 J/kg	8200 J	
Carbon footprint	0.005 kgCo/kg	410 kg CO_2	

Precast concrete floor

150mm	cubic meter	kg/m^3	mass
add station edge 0.8m3	6.2	2400	14880 kg
Embodied energy	3.7 J/kg	55056 J	
Carbon footprint	0.39 kgCo/kg	5803.2 kg CO_2	

TOTAL	75929 J 8010.22 kg CO_2
TOTAL/M^2	**2109 J 223 kg CO_2**

Table 13-15: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

test F

BRT station
TESTING DIFFERENT STRUCTURAL SYSTEMS

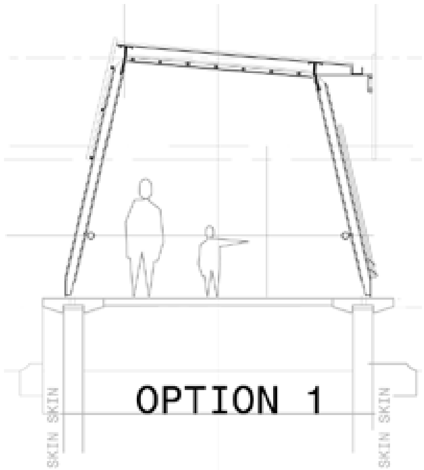
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per square meter

Section calculated over a single BRT bay

STEEL COLUMN, BEAM AND ROOF PURLIN STRUCTURE

OPTION 1 PORTAL FRAME



Column 152x152x23 — length 3.28 m

3.28	m	x	16		=	52.48	kg
52.48	kg	x	29.44	MJ/kg	=	1545.01	MJ
52.48	kg	x	2.22	kg CO_2/kg	=	116.5	kg CO_2

use 14 column 14

21630.15	MJ
1631.07	kg CO_2

bracing roof beam — length 23.8

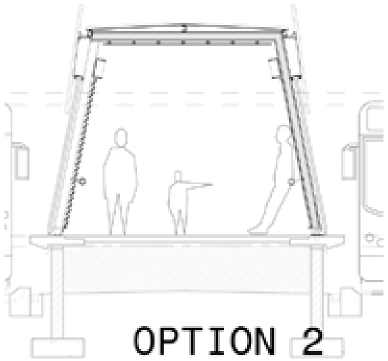
0.17	m^3	x	8000	kg/m^3	=	1360	kg
1360	kg	x	29.44	MJ/kg	=	40038.4	MJ
1360	kg	x	2.22	kg CO_2/kg	=	3019.2	kg CO_2

Roof brace

0.006	m^3	x	8000	kg/m^3	=	48	kg
48	kg	x	29.44	MJ/kg	=	1413.12	MJ
48	kg	x	2.22	kg CO_2/kg	=	106.56	kg CO_2

TOTAL		
	63081.67	MJ
	4756.83	kg CO_2

Option 2 Tapered structure with inveerted cantilever structure



Column and roof beam — length 6.3

use 152x89x16 I section beam	6.3	m	x	16		=	100.8	kg
	100.8	kg	x	29.44	MJ/kg	=	2967.55	MJ
	100.8	kg	x	2.22	kg CO_2/kg	=	223.77	kg CO_2

use 16 columns 16

47480.83	MJ
3580.41	kg CO_2

Bracing beam

4.35	kg/m	x	47.6	m	=	207.06	kg
207.06	kg	x	29.44	MJ/kg	=	6095.84	MJ
207.06	kg	x	2.22	kg CO_2/kg	=	459.67	kg CO_2

total		
	53577	MJ
	4040	kg CO_2

Table 13-16: Test F - Calculating Embodied energy and carbon footprint BRT structural systems [Source: Author]

test F

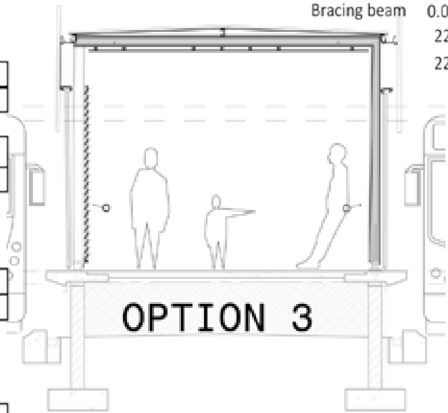
Option 3 Rectangular structure, inverted cantilever

Column and roof beam — length 6.5

7.7	m	x	23		=	177.1	kg
177.1	kg	x	29.44	MJ/kg	=	5213.82	MJ
177.1	kg	x	2.22	kg CO_2/kg	=	393.16	kg CO_2

use 16 columns 16

83421.18	MJ
6290.59	kg CO_2



Bracing beam

0.028	m^3	x	8000	kg/m^3	=	224	kg
224	kg	x	29.44	MJ/kg	=	6594.56	MJ
224	kg	x	2.22	kg CO_2/kg	=	497.28	kg CO_2

total		
	90015.74	MJ
	6787.87	kg CO_2

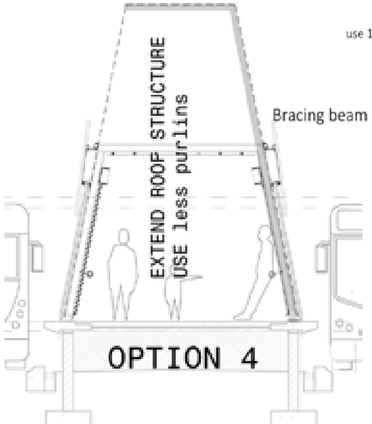
Option 4 -Extra high roof

Column and roof beam — length 6.1

7.1	m	x	23		=	163.3	kg
163.3	kg	x	29.44	MJ/kg	=	4807.55	MJ
163.3	kg	x	2.22	kg CO_2/kg	=	362.52	kg CO_2

use 16 columns 16

76920.83	MJ
5800.41	kg CO_2



Bracing beam

4.84	kg/m	x	47.6	m	=	230.38	kg
230.384	kg	x	29.44	MJ/kg	=	6782.50	MJ
230.384	kg	x	2.22	kg CO_2/kg	=	511.45	kg CO_2

total		
	83 704	MJ
	6 312	kg CO_2

13.3 BUILDING SYSTEM ANALYSES

BRT TERMINAL BUILDING
ENERGY CONSUMPTION OF LIGHTING

Lighting levels in accordance with Sans 204-08

FLOOR	AREA TYPE	AREA			ZONE		WATT	TIME USE			TOTAL DAILY		TOTAL MONTHLY
			LUX	Lumens	Lighting type	quantity							
BASEMENT													
	Ablution	64 m^2	200	12800 L	CFL 11&14 watt	20	11 w	2		hours	440 Wh	30	13200 Wh
	Movement	562 m^2	50	28100 L	CFL14 watt	35	14 w	17		hours	8330 Wh	30	249900 Wh
	Storage	104 m^2	150	15600 L	CFL14 watt	18	14 w	2		hours	504 Wh	30	15120 Wh
	Cycle parking	165 m^2	100	16500 L	CFL 18 watt	15	18 w	11	only half in day	hours	2970 Wh	30	89100 Wh
GROUNDFLOOR				L									
	Station platform	326 m^2	100	32600 L	CFL 11 watt	52	11 w	7	daylighting	hours	4004 Wh	30	120120 Wh
	Movement	908 m^2	50	45400 L	CFL14 watt	55	14 w	7	daylighting	hours	5390 Wh	30	161700 Wh
	Kiosk and tickets	73 m^2	400	29200 L	CFL 18 watt	25	18 w	7	daylighting	hours	3150 Wh	30	94500 Wh
	Retail and catering	445 m^2	250	111250 L	CFL 18 Watt	100	18 w	8.5	short hours	hours	15300 Wh	30	459000 Wh
	Service areas	65 m^2	100	6500 L	CFL 14 Wattt	7	14 w	11.25	good windows	hours	1102.5 Wh	30	33075 Wh
	Ablution	123 m^2	200	24600 L	CFL 11 Watt	39	11 w	7		hours	3003 Wh	30	90090 Wh
First floor													
	Movement	75 m^2	50	3750 L	CFL 5 watt	18	5 w	12	daylighting	hours	1080 Wh	30	32400 Wh
	Kiosks	112 m^2	400	44800 L	CFL 30 watt	23	30 w	7		hours	4830 Wh	30	144900 Wh
	Retail	85 m^2	50	4250 L	CFL 7 watt	14	7 w	8.5	daylighting	hours	833 Wh	30	24990 Wh
	Office 9-5	236 m^2	400	94400 L	CFL 30 watt	48	30 w	6.5		hours	9360 Wh	30	280800 Wh
	Boardrooms	30 m^2	400	12000 L	CFL 18 watt	11	18 w	4		hours	792 Wh	30	23760 Wh
	Service area	23 m^2	100	2300 L	CFL 11 watt	4	11 w	12		hours	528 Wh	30	15840 Wh
	Ablution	47 m^2	200	9400 L	CFL 11 Watt	15	11 w	7		hours	1155 Wh	30	34650 Wh
Second Floor	BRT Office 5-22	185 m^2	400	74000 L	CFL 30 watt	38	30 w	13		hours	14820 Wh	30	444600 Wh
	Boardroom+foyer	60 m^2	400	24000 L	CFL 30 watt	13	30 w	7		hours	2730 Wh	30	81900 Wh
	Ablution	33 m^2	200	6600 L	CFL 11 Watt	10	11 w	7.5		hours	825 Wh	30	24750 Wh
										TOTAL	81146.5 wh		2434395 wh
											81 kWh		2 430 kWh

Table 13-17: Energy consumption for lighting in terminal building [Source: Author]

TERMINAL BUILDING
- Photovoltaic energy generation

	Total energy generated per day		
		82	kwh
grid tied	efficiency rate [90%]	**0.9**	
	total energy	**90**	kwh
solar panel generation - 0.62 kw/h per m^2			
		145.16	m^2
		thus need 146m^2 for solar generation.	

Table 13-18: Terminal building - quantifying photovoltaic panels [Source: Author].

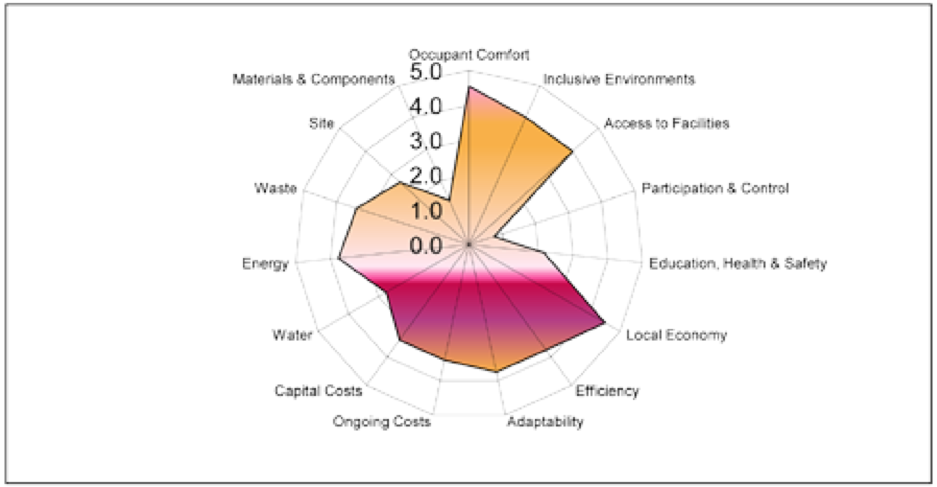
TERMINAL BUILDING
- AC/DC inverter

	82 kwh	per day
	6	sunlight hours
	13.66 kw	
Whole system need a 13 KW inverter		
Product:	SK3000-XXX inverer	
	3 KW	
use 5 inverters		

Table 13-19: Terminal building - quantifying inverter size [Source: Author].

SUSTAINABLE BUILDING ASSESSMENT TOOL (SBAT- P) V1

PROJECT		ASSESSMENT		
Project title:	BRT TERMINAL BUILDING	Date:		29-06-2010
Location:	Tshwane	Undertaken by:		JM Hugo
Building type:	BRT stations and terminal building	Company / organisation:		
Internal area (m2):	0	Telephone:	Fax:	
Number of users:	0	Email:		



Social	3.1	Economic	3.8	Environmental	2.8
Overall	3.2	Classification	Average		

Graph 13-01: SBAT assessment of the project [Source: Author].

TERMINAL BUILDING - water consumption

			frequency per day	Users	quantity	Total per day		Total per month
Toilet	6 L	per flush	20		21	2520	30	75600
Shower	40 L	per shower		30		1200	20	24000
Handwash basin	3 L	per wash	20		21	1260	30	37800
Urinal Waterless								
							Total	137400

Table 13-20: Terminal building - Water consumption [Source: Author].

TERMINAL BUILDING - RAIN WATER COLECTION

Roof size 2050m^2 10% lost — Water use: PUBLIC WC's

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	194.4	243	136.8	142.2	97.2	23.4	12.6	5.4	9	36	12.6	18
Water used kL	76	76	76	76	76	76	76	76	76	76	76	76
Used	118.4	285.4	346.2	412.4	433.6	381	317.6	247	180	140	76.6	18.6
Surplus Kl	118.4	285.4	346.2	412.4	433.6	381	317.6	247	180	140	76.6	0

Table 13-21: Terminal building - Rain water collection quantified [Source: Author].

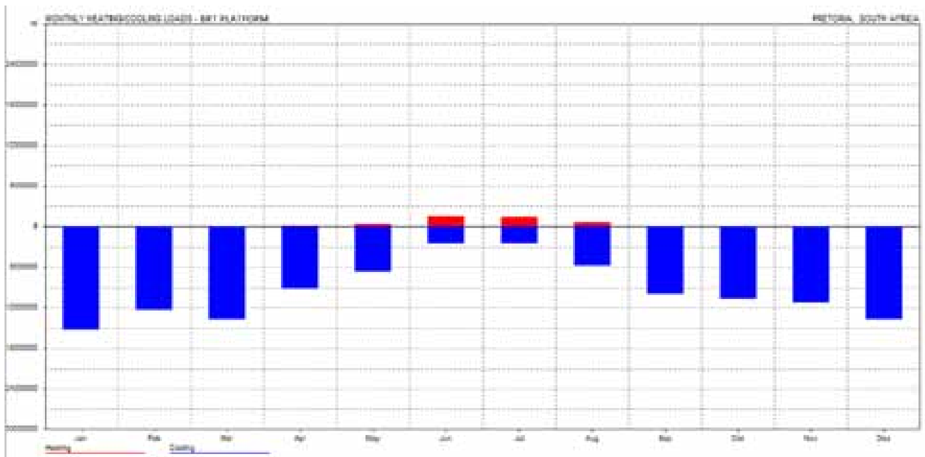
TERMINAL BUILDING -sand filter

according to Bare foot architect

1600l for 2 meters over 600x1000mm

MAX RAINWATER COLLECTED PER MONTH		234.9 kl	per month
15 Rain days per month	15	15.66 kl	per rain shower
	1.6	9.7875	for 2 meters over 0.6x1m
size		10*2*0.6m	size 10x2x1.2m
Filter area		6 m^2	
		1min	6 liter
		1 hour	360 liter
		1 day	8640 liter
Filter size	Double	12 m^2	
		1min	12 liter
		1min	720 liter
		1 day	17280 liter
	pre-filter rain water holding tank		18000 liter

Table 13-22: Terminal building - Sand filter size [Source: Author].



Graph 13-02: Heating and cooling requirements of the BRT platform [Source: Author].

TERMINAL BUILDING -Thermal energy store

Q=m*c*t

ROCK STORE	Total size	105 m^3	
C- Substance specific heat storage	Stone	4180 J/kgK	
M- Mass	Mass	1000 kg/m^3	
	mass	105000 kg	over 6months period
	temp difference	50	winter heat added
		5	summer cooled through radiation
THERMAL STORAGE CAPACITY		**21 945 000 000 J**	**winter**
		20.9 GJ	
		2 194 500 000 J	summer
		2 GJ	

Table 13-23: Thermal storage capacity of thermal energy store [Source: Author].

13.4 BRT PROTOTYPICAL ANALYSES

BRT PROTOTYPICAL STATION -Electrical equipment & consumption

ZONE	TYPE	DESCRIPTION	SIZE	physical size	ENERGY USE	QUANTITY	HOURS USED	Energy consumption per day
SALES OFFICE								
	Cash Register			drawer size		2		
	Computer	DESKTOP / Dell	1066 Kwh per year	85[w]x300[h]x330[d]	0.17 kWh	1.3	17 h	3.75 kwh
		Laptop			0.045 kWh	1.3	17 h	1.0 kwh
	Drop Safe			650H x 500W x 500D		1		
	Card Validator			265[w]X285 mm[h]X86 mm [d]	0.015 kWh	2	17 h	0.51 kwh
Technology Hub	DB Board			450[w]x300[h]x85[d]		1		
	UPS	TOTAL ENERGY - 13 kWh		160[w]x200[h]x450[d]		1		
	SERVER	ESG GROUP 12 v ports	too big?			1		3.1 kwh
	Induction Loop			small				
	Internet connection	Is it satelite						
	BATTERIES	3days 72kwh -too heavy in floor 256kg		415[h] x 262[d] x 740[w]		16		
security	CCTV		connect to server					
	RECORDING		connect to server					
	ALARM SYSTEM			300[w]x300[h]x100[d]				
			antenna - length 1 meter					
Water services								
	Waterpump					1		
	Waterfilter	Sand filter	Basement			1		
	UV-Filter	not used - 240 V energy consumption too high				0		
Ventilation								
	Air pump					1		
	Cooling chamber					1		
	Solar water heater		heat evacuating tubes			2		
Energy								
	Photovoltaic panels		Intergrated with roof					

TOTAL DAILY COSUMPTION 8.36 kwh

Table 13-24: BRT Electrical Equiptment- energy consumption [Source: Author].

BRT PROTOTYPICAL STATION -Lighting energy consumption

Zone	Area	Lux	Lumen	lumen/lamp	effiency rate	product	kWatt	Lamps used	Kw/h	hours/day	DAILY ENERGY CONSUMPTION
Office	13.1 m^2	400	5240								
sales	5.6 m^2	400	2240	380	900	CFL 7 watt	0.007	6	0.042	16	0.672 kwh
toilet	2.6 m^2	300	780	380	470	CFL 7 watt	0.007	2	0.014	2	0.028 kwh
Technology Hub	0 m^2	500	0	0	1560	ST8-SD4-765- LED LAMP	0.0235	0	0	2	0 kwh
											0.7 kwh
Tasklighting	2 unit	500									
waiting area A	149.8 m^2	100	14980	640	590	CFL 11 watt	0.011	24	0.264	8	2.112 kwh
waiting area B	288.3 m^2	100	28830	640	590	CFL 11 watt	0.011	45	0.495	8	3.96 kwh
waiting area C	432.8 m^2	100	43280	640	590	CFL 11 watt	0.011	68	0.748	8	5.984 kwh
										TOTAL A	**2.81 kwh**
										TOTAL B	**4.66 kwh**
										TOTAL C	**6.68 kwh**

ADD TOTAL DAILY CONSUMPTION	8.3 **kwh**
TOTAL	**14.98 kwh**

Table 13-25: BRT station - Lighting energy consumption [Source: Author].

BRT PROTOTYPICAL STATION -Photovoltaic energy generation

To generate **22 kWh per day**

14.9	0.7 efficiency	21.28	21.3 kwh	total generated	
21.3	0.62 per m^2	34.35	35 m^2	needed	all lighting + computers

35m^2 total photovoltaic panels

Battery bank to store energy

	energy	days	total
Store electricity for 3 days	21.3 kwh	3 =	63.9 kwh
Battery store 4.7 kwh	63.9 kwh	4.7	13.59

16 batteries needed

Table 13-26: BRT station - Photovoltaic system and battery bank store [Source: Author].

BRT PROTOTYPICAL STATION -ROCK STORE

Thermal energy storage

Q=m*c*t

Rock store total size :		1.5 m^3		
C- Substance specific heat storage	Stone	1900 J/kgK		
M- Mass	Mass	2700 kg/m^3		
	mass	4050 kg		
			Degrees Celsius	
	temp difference	50	MAX	70
			Min	20
THERMAL STORAGE CAPACITY		385 MJ		

Table 13-27: BRT station - Rock store storage capacity [Source: Author].

BRT PROTOTYPICAL STATION -RAIN WATER HARVESTING

SINGLE

Rain water collection Roof size 189m^2 **170 m^2**

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	**0.108**	**0.135**	**0.076**	**0.079**	**0.054**	**0.013**	**0.007**	**0.003**	**0.005**	**0.02**	**0.007**	**0.01**
Water collected kL	**18.36**	**22.95**	**12.92**	**13.43**	**9.18**	**2.21**	**1.19**	**0.51**	**0.85**	**3.4**	**1.19**	**1.7**
Water used kL	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Surplus kL	**14.36**	**33.31**	**42.23**	**51.66**	**56.84**	**55.05**	**52.24**	**48.75**	**45.6**	**45**	**42.19**	**39.89**
	14.36	**20**	**20**	**20**	**20**	**18.21**	**15.4**	**11.91**	**8.76**	**8.16**	**5.35**	**3.05**

DOUBLE

Rain water collection Roof size 331m^2 **298 m^2**

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	32.184	40.23	22.648	23.542	16.092	3.874	2.086	0.894	1.49	5.96	2.086	2.98
Water used kL	4	4	4	4	4	4	4	4	4	4	4	4
Surplus kL	28.184	64.414	83.062	102.604	114.696	114.57	112.656	109.55	107.04	109	107.086	106.066
	10	10	10	10	10	9.8	7.8	4.7	2.26	4.22	3.08	2.06
	15	15	15	15	15	14.8	12.8	9.7	7.26	9.22	8.08	7.06

TRIPLE

Rain water collection Roof size 472m^2 **425 m^2**

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	45.9	57.375	32.3	33.575	22.95	5.525	2.975	1.275	2.125	8.5	2.975	4.25
Water used kL	4	4	4	4	4	4	4	4	4	4	4	4
Surplus kL	41.9	95.275	123.575	153.15	172.1	173.625	172.6	169.875	168	172.5	171.475	171.725

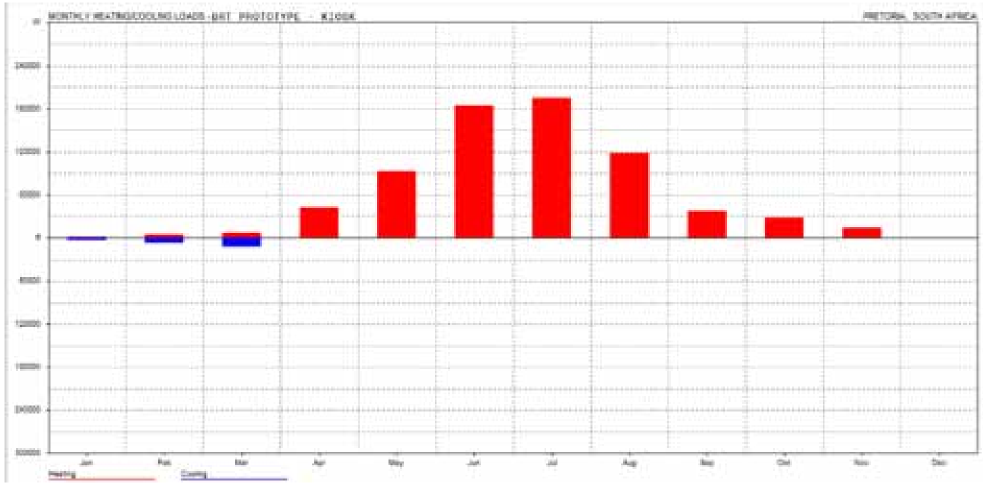
USE A 20 000 Liter storage tank - to service smallest prototype

WATER CONSUMPTION	3 workers	Twice per shift	2 shifts	1 full flush	1/5 flush	2 handwashes
		Consumption				
	6 persons	**19.5 liters**	**117 liter per day**			
			30 days			
			3510 liter/month			

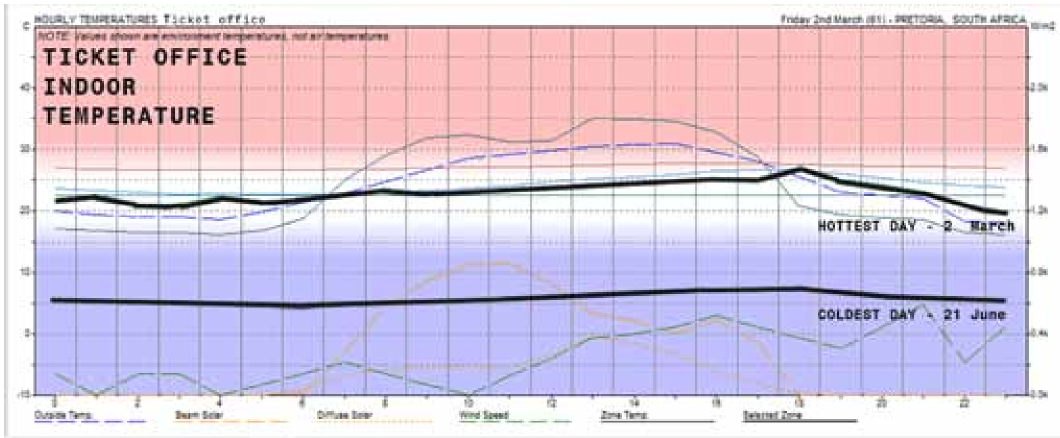
Table 13-28: BRT station -Rain water harvesting calculations [Source: Author].

BRT PROTOTYPICAL STATION -SAND FILTER		according to Bare foot architect 1600l	for 2 meters over 600x1000mm	
approx amount of water to filter per day				
MAX RAINWATER COLLECTED PER MONTH		57.3 kl	per month	
15 Rain days per month	15	3.82 kl	per rain shower	
	1.6	2.3875	for 2 meters over 600x1000mm	
Sand filter size		2.5*2*0.6		size 2.5x2x1.2m
		1.5 m^2		
			1min	1.5 liter
			1 hour	90 liter
			1 day	2160 liter
FILTER SIZE	Double	3 m^2		size 2.5x2x1.2m
			1min	3 liter
			1min	180 liter
			1 day	4320 liter
	pre filter rain water holding tank			4000 liter

Table 13-29: BRT station -Sand filter size calculated [Source: Author].



Graph 13-03: BRT station - Heating and cooling required for Kiosk station [Source: Author].



Graph 13-04: BRT station - Thermal comfort of ticket office [Source: Author].

13.5. BRT SYSTEMS INFORMATION

13.5.1 Frequency and statistics of BRT systems

Item	Line 1	Line 2	Overall Route
Corridor Length	37.3 km	33.2 km	67.6 km
Length of Dedicated Bus lanes	37.3 km	33.2 km	67.6 km
Number of Terminals	2 Terminals	2 Terminals	4 Terminals
Number of Stations	15 Stations	37 Stations	46 Stations
Average Station Separation	2,200 m	870 m	1,380 m
Number of Bays per Station	1, 2 or 3	1	
Station Length	20, 50 or 81 m	20 m	
Station Width	3.0 to 4.5 m	3.0 m	
AM Peak Hour Frequency	40 departures	40 departures	
AM Peak Hour Headway (gap)	90 seconds	90 seconds	
AM Peak Frequency - All Stops Service	12 departures	20 departures	
AM Peak Frequency – Express / Limited Stop Service	28 departures	20 departures	
Operational Speed (Max speed 90kph)	All Stops - 49 kph Limited Stop – 50 kph	All Stops - 26 kph Express - 35 kph	
Estimated System Capacity (passengers per hour)	5,200 – 6,400	5,200 – 6,400	
Estimated Fleet Size – articulated buses	60	99	159

Table 13-30: Overall information regarding the first phase development [Source: ALG, p 9]