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Effect of Different Material Schemes on Carbon Emissions in Construction Material Production Stage

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Abstract: *Introduction*: Building energy consumption accounts for a large proportion of global energy consumption, and it is urgent to reduce building carbon emissions. There are many different components in the Building, each of which produces a somewhat different amount of carbon emissions, such as column, beam, floor, exterior wall and interior wall. This Paper is focusing on looking for the components' differences in carbon emission in order to provide some valuable advises in choosing building materials. *Methods*: Using the building information model, the sample building is divided into five parts: column, beam, floor, exterior wall and interior wall. Firstly, the quantities of each part of the building is calculated from building information model. Secondly, the method of permutation and combination is performed by choosing different materials including concrete, steel, wood, brick and glass, and then forming 14 schemes. Finally, carbon emissions at production stages are calculated of all 14 schemes by known carbon emission factors. *Conclusion*: The average proportion of each part of carbon emissions is obtained both with the carbon emissions from different materials. Choosing the lowest and highest theoretical scheme in order to analysis the influence of different materials on carbon emissions in construction production stage, so that the effective data reference for building energy saving and emission reduction can be concluded.

Keywords: Production Stage, Building Elements, Materials, Carbon Emissions

1. Introduction

Construction, industry and transportation are the three energy consumption industries in cities, among which construction accounts for about 40% of global energy consumption and 30% of greenhouse gas emissions are related to construction [1]. Accordingly, the urgent need is to calculate and analysis the building carbon emission correctly while providing reduction measures [2]. From the viewpoint of design solutions and marital selection, this paper analysis the effect of different material selection schemes on carbon emissions in material production stage [3].

Building carbon emissions are derived from four stages including material production stage, construction stage, operation stage, demolition and recovery stage [4], and the proportion of carbon emissions in each stage is about 5%-20%, 0.4%-4%, 75%-95% and 0.05%-5% respectively. Therefore, the annual carbon emissions per unit accounts for separately as 55%-90%, 2%-12%, 5%-32% and 0.2%-25% based on 50-years-building [5]. The sum of carbon emissions both in construction stage and demolition and recovery stage is only 9%, which can be ignored. Because of the large percentage of carbon emissions in material production stage, this paper is focused on the effect of different material selection schemes on carbon emissions in that particular stage.

In order to facilitate the calculation process, the building model has been hypothesized as follows: 1) from the viewpoint of foundation construction, there's no difference between varies schemes; 2) glasses are chosen for all the

windows and doors with frame and skeleton ignored; 3) if glasses are chosen for internal and external walls, vertical boat and bracket steel dosage should be ignored; 4) stairs and roofs use uniform parameters and which do not count in; 5) indoor water, electricity and heating pipelines, decoration and home decoration are consistent, which does not count in.

2. Building Sample Information

2.1. Basic Information

There are 5 floors above-ground and each floor is 3 meters high with a single storey area of 674.14 m² and a gross floor area of 3370.7 m². The model (see Figures 1 and 2) is established.

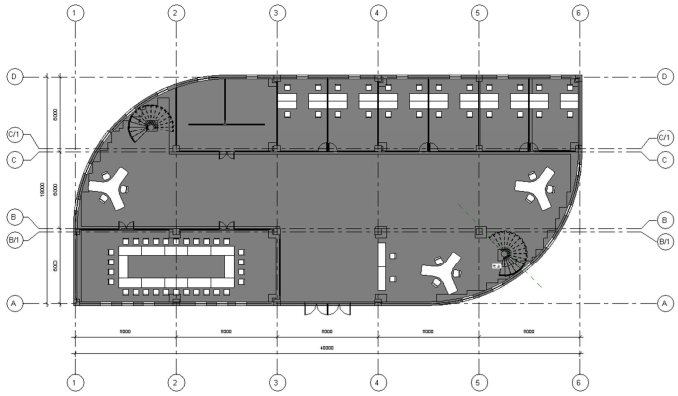

Figure 1. *Floor Plan.*

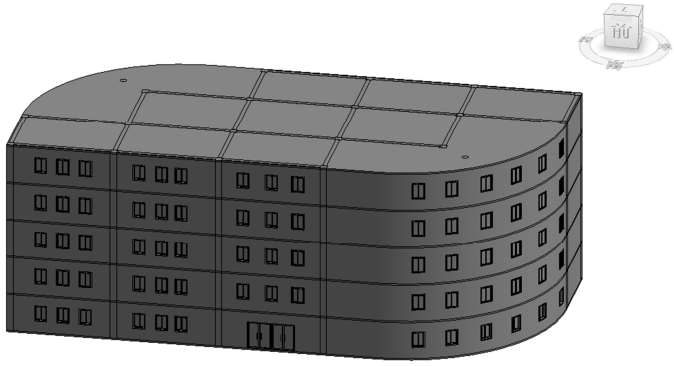

Figure 2. *Three-dimensional modeling.*

2.2. Building Data

The building is consist of five parts including columns, beams, floors, external walls and internal walls. Each material selection scheme with data is derived from the building, and shows in table 1.

Table 1. *Each material selection scheme with data.*

Serial number	Name	Material selection	volume m³	density kg/ m³	weight kg	additional reinforcement m³
1	Column	concrete	71.03	2407.31	171000.38	2.3562
		H-beam steel	/	/	41100	/
		wood	110.09	570.26	6277.07	/
2	Beam	concrete	122.35	2407.31	294631.97	5.001
		H-beam steel	/	/	56034	/
		wood	191.03	570.26	108933.92	/
3	Slab	concrete	476.66	2407.31	1147470.79	5.419
		wood	723.12	570.26	412366.41	/
4	Exterior wall	concrete block	421.62	700	295134	/
		clay brick	421.62	1800	758916	/
		wood	421.62	570.26	240433	/
		glass	42.16	2420	102032	/
5	Interior wall	concrete block	134.95	700	94465	/
		clay brick	134.95	1800	242910	/
		wood	134.95	570.26	76956.59	/
		glass	13.50	2420	32657.9	/

3. Combined Scheme Inventoried

There can be 288 combination schemes theoretically according to the material selection listed above. Considering the construction feasibility and data comparability, 14 schemes are chosen as representative to conduct detail analysis and comparison shown in Table 2.

Table 2. *Material combination list.*

scheme	column	beam	slab	Exterior wall	Interior wall
(1)	concrete	concrete	concrete	concrete block	concrete block
(2)	concrete	concrete	concrete	concrete block	wood
(3)	concrete	concrete	concrete	concrete block	clay brick
(4)	concrete	concrete	concrete	concrete block	glass
(5)	concrete	concrete	concrete	clay brick	clay brick
(6)	concrete	concrete	concrete	glass	glass
(7)	concrete	concrete	wood	glass	glass
(8)	H-beam steel	H-beam steel	concrete	concrete block	clay brick
(9)	H-beam steel	H-beam steel	concrete	clay brick	wood
(10)	H-beam steel	H-beam steel	concrete	glass	wood
(11)	H-beam steel	H-beam steel	wood	glass	clay brick
(12)	H-beam steel	H-beam steel	wood	wood	wood
(13)	wood	wood	concrete	glass	wood
(14)	wood	wood	wood	concrete block	clay brick

4. Calculation of Each Scheme

According to the statistic quantities, carbon emission for each scheme is calculated through carbon emission factor (see table 4 [6]).

Table 3. *Parameters of scheme1-14.*

Scheme	Name (1)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	Column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	Concrete block	134.95	700	94465.00	0.12	11335.80		11335.80	11.34
	other	steel	12.78	7850	100293.17	2	200586.34			/
Total							461867.64			461.87

Scheme	Name (2)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	wood	134.95	570	76956.59	0.2	15391.32		15391.32	15.39
	other	steel	12.78	7850	100293.17	2	200586.34			/
Total							465923.16			465.92

Scheme	Name (3)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	clay brick	134.95	1800	242910.00	0.2	48582.00		48582.00	48.58
	other	steel	12.78	7850	100293.17	2	200586.34			/
Total							499113.84			499.11

Scheme	Name (4)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	glass	13.50	2420	32657.90	1.4	45721.06		45721.06	45.72
	other	steel	12.78	7850	100293.17	2	200586.34			/
Total							496252.90			496.25

Scheme	Name (5)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	clay brick	421.62	1800	758916.00	0.2	151783.20		151783.20	151.78
5	Interior wall	clay brick	134.95	1800	242910.00	0.2	48582.00		48582.00	48.58
	other	steel	12.78	7850	100293.17	2	200586.34			/
Total							615480.96			615.48

Scheme	Name (6)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	glass	42.16	2420	102032.04	1.4	142844.86		142844.86	142.84
5	Interior wall	glass	13.50	2420	32657.90	1.4	45721.06		45721.06	45.72
	other	steel	12.77	7850	100260.20	2	200520.40			/
Total							603615.73			603.68

Scheme	Name (7)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	concrete	71.03	2407	171000.38	0.133	22743.05	36992.34	59735.39	59.74
2	beam	concrete	122.35	2407	294531.97	0.133	39172.75	78515.70	117688.45	117.69
3	slab	wood	723.12	570	412366.41	0.2	82473.28		82473.28	82.47
4	Exterior wall	glass	42.16	2420	102032.04	1.4	142844.86		142844.86	142.84
5	Interior wall	glass	13.50	2420	32657.90	1.4	45721.06		45721.06	45.72
	other	steel	7.36	7850	57754.02	2	115508.04			/
Total							448463.04			448.46

Scheme	Name (8)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	H-beam steel		7850	41100.00	2	82200.00		82200.00	82.20
2	beam	H-beam steel		7850	56034.00	2	112068.00		112068.00	112.07
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	clay brick	134.95	1800	242910.00	0.2	48582.00		48582.00	48.58
	other	steel	5.42	7850	42539.15	2	85078.30			/
Total							515958.00			515.96

Scheme	Name (9)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	H-beam steel		7850	41100.00	2	82200.00		82200.00	82.20
2	beam	H-beam steel		7850	56034.00	2	112068.00		112068.00	112.07
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	Concrete block	421.62	1800	758916.00	0.2	151783.20		151783.20	151.78
5	Interior wall	wood	134.95	570	76956.59	0.2	15391.32		15391.32	15.39
	other	steel	5.42	7850	42539.15	2	85078.30			/
Total							599134.43			599.13

Scheme	Name (10)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	H-beam steel		7850	41100.00	2	82200.00		82200.00	82.20
2	beam	H-beam steel		7850	56034.00	2	112068.00		112068.00	112.07
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	glass	42.16	2420	102032.04	1.4	142844.86		142844.86	142.84
5	Interior wall	wood	134.95	570	76956.59	0.2	15391.32		15391.32	15.39
	other	steel	5.42	7850	42539.15	2	85078.30			/
Total							590196.09			590.20

Scheme	Name (11)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	H-beam steel		7850	41100.00	2	82200.00		82200.00	82.20
2	beam	H-beam steel		7850	56034.00	2	112068.00		112068.00	112.07
3	slab	wood	723.12	570	412366.41	0.2	82473.28		82473.28	82.47
4	Exterior wall	glass	42.16	2420	102032.04	1.4	142844.86		142844.86	142.84
5	Interior wall	clay brick	134.95	1800	242910.00	0.2	48582.00		48582.00	48.58
	other	steel	0.00	7850	0.00	2	0.00			/
Total							468168.14			468.17

Scheme	Name (12)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	H-beam steel		7850	41100.00	2	82200.00		82200.00	82.20
2	beam	H-beam steel		7850	56034.00	2	112068.00		112068.00	112.07
3	slab	wood	723.12	570	412366.41	0.2	82473.28		82473.28	82.47
4	Exterior wall	wood	421.62	570	240433.02	0.2	48086.60		48086.60	48.09
5	Interior wall	wood	134.95	570	76956.59	0.2	15391.32		15391.32	15.39
	other	steel	0.00	7850	0.00	2	0.00			/
Total							340219.20			340.22

Scheme	Name (13)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	wood	110.09	570	62777.07	0.2	12555.41		12555.41	12.56
2	beam	wood	191.03	570	108933.92	0.2	21786.78		21786.78	21.79
3	slab	concrete	476.66	2407	1147470.79	0.133	152613.62	85078.30	237691.92	237.69
4	Exterior wall	glass	42.16	2420	102032.04	1.4	142844.86		142844.86	142.84
5	Interior wall	wood	134.95	570	76956.59	0.2	15391.32		15391.32	15.39
	other	steel	5.42	7850	42539.15	2	85078.30			/
Total							430270.29			430.27

Scheme	Name (14)	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	column	wood	110.09	570	62777.07	0.2	12555.41		12555.41	12.56
2	beam	wood	191.03	570	108933.92	0.2	21786.78		21786.78	21.79
3	slab	wood	723.12	570	412366.41	0.2	82473.28		82473.28	82.47
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12	35416.08		35416.08	35.42
5	Interior wall	clay brick	134.95	1800	242910.00	0.2	48582.00		48582.00	48.58
	other	steel		7850	0.00	2	0.00			/
Total							200813.56			200.81

The data above is sorting by carbon emission from small to large, and it is illustrated in carbon emission comparison table (see table 5) and in average carbon emission ratio chart (see Figure 3) of each different component.

Table 4. *Carbon emission factor of building materials [6].*

Name	Emission factor (kg/kg)	Data sources
Concrete	0.133	«Assessment System for Green Building of Beijing Olympic»
Steel	2	
Concrete block	0.12	
Clay brick	0.2	
Wood	0.2	
Glass	1.4	

Table 5. *Carbon emission comparison table of each component.*

Serial number	Name	Material selection	Carbon emission (t)	Conclusion
1	column	Wood	12.56	Wood<Concrete<H-beam steel
		Concrete	59.74	
		H-beam steel	82.2	
2	beam	Wood	21.79	Wood<H-beam steel<Concrete
		Concrete	117.69	
		H-beam steel	112.07	
3	slab	Wood	82.47	Wood<Concrete
		Concrete	237.69	
4	Exterior wall	Concrete block	35.42	Concrete block<Wood<Glass<Clay brick
		Wood	48.09	
		Glass	142.84	
		Clay brick	151.78	
5	Interior wall	Concrete block	11.34	Concrete block<Wood<Glass<Clay brick
		Wood	15.39	
		Glass	45.72	
		Clay brick	48.58	

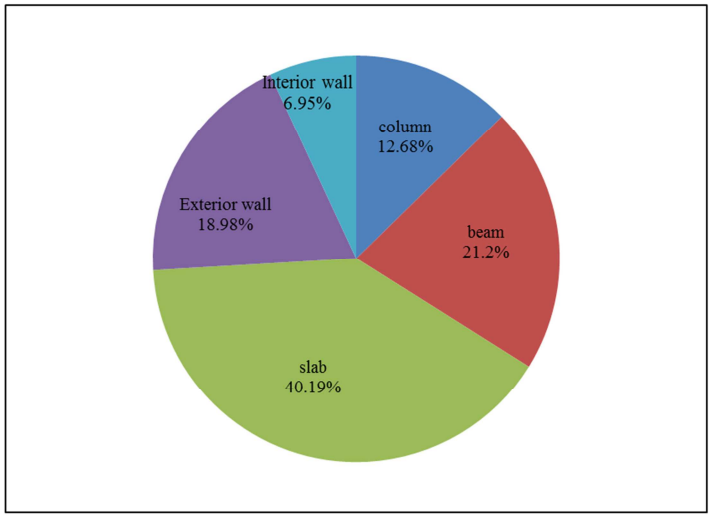

Figure 3. *Average carbon emission ratio chart of each component.*

5. Best and Worst Scheme and Comparison

The theoretical best and worst scheme (M and N) are found by the carbon emission data listed as follows:

Table 6. *Theoretical best scheme M.*

theoretical best scheme M	name	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)
1	column	Wood	110.09	570	62777.07	0.2
2	beam	Wood	191.03	570	108933.92	0.2
3	slab	Wood	723.12	570	412366.41	0.2
4	Exterior wall	Concrete block	421.62	700	295134.00	0.12
5	Interior wall	Concrete block	134.95	700	94465.00	0.12
	other	Steel	0.00	7850	0.00	2
Total						

Table 6. *Continue.*

theoretical best scheme M	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	12555.41		12555.41	12.56
2	21786.78		21786.78	21.79
3	82473.28		82473.28	82.47
4	35416.08		35416.08	35.42
5	11335.80		11335.80	11.34
	0.00			/
Total	163567.36			163.57

Table 7. *Theoretical worst scheme N.*

theoretical worst scheme N	name	material	volume (m^3)	density (kg/m^3)	weight (kg)	Carbon emission factor (kg/kg)
1	column	H-beam steel		7850	41100.00	2
2	beam	H-beam steel		7850	56034.00	2
3	slab	Concrete	476.66	2407	1147470.79	0.133
4	Exterior wall	Clay brick	421.62	1800	758916.00	0.2
5	Interior wall	Clay brick	134.95	1800	242910.00	0.2
	other	Steel	5.42	7850	42539.15	2
Total						

Table 7. *Continued.*

theoretical worst scheme N	Carbon emission (kg)	Additional reinforcement carbon emission (kg)	Carbon emission with additional reinforcement (kg)	Carbon emission (t)
1	82200.00		82200.00	82.20
2	112068.00		112068.00	112.07
3	152613.62	85078.30	237691.92	237.69
4	151783.20		151783.20	151.78
5	48582.00		48582.00	48.58
	85078.30			/
Total	632325.12			632.33

All the schemes are summarized and sorted, as shown in Figure 4.

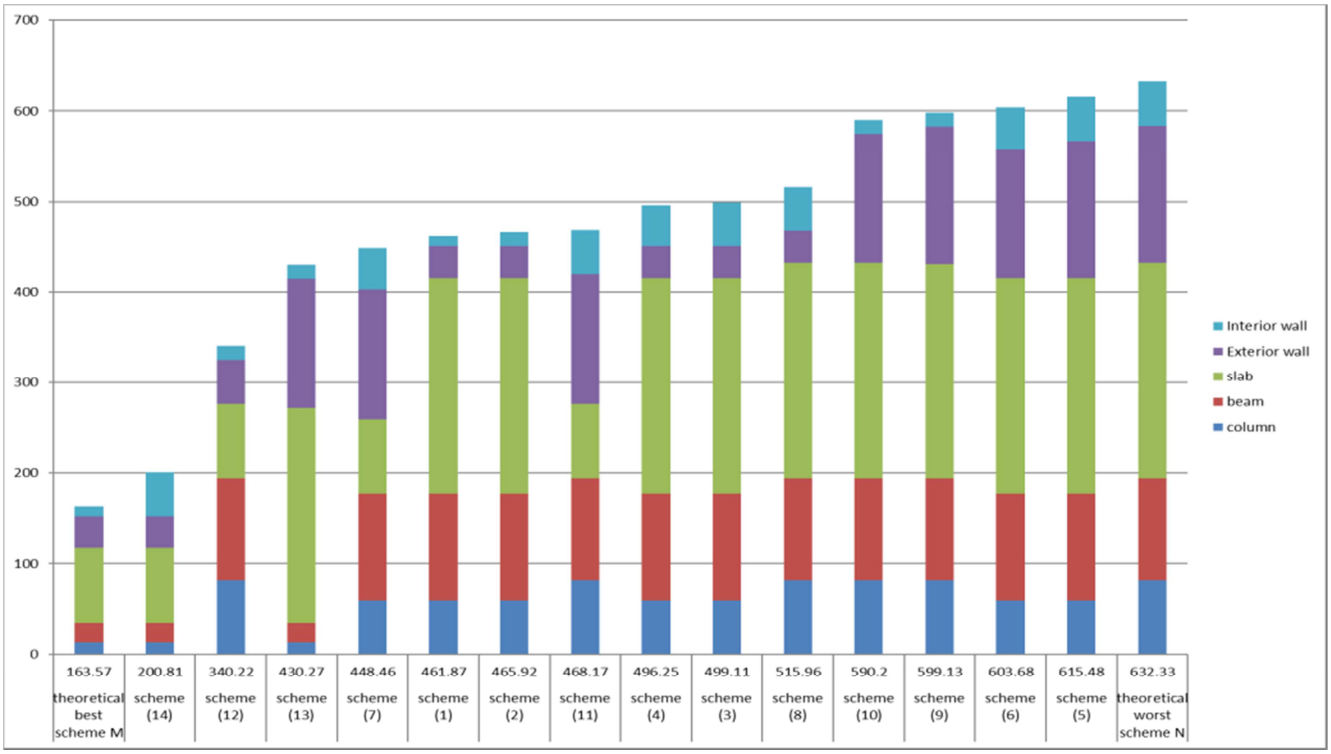

Figure 4. *Carbon emission ordination graph of all schemes.*

6. Conclusion

Building production phase is also called embodied carbon of building, in which the carbon emission is calculated through different schemes, comes out the conclusions:

(1) Low density and small carbon emission factor building materials can reduce carbon emission significantly, such as wood and concrete blocks with low density and small factor.

(2) Minimize the size of building components when meeting the function.

(3) Slab is the largest carbon emission component, which should be considered at the outset, then should be beam, external wall and column.

(4) Carbon emission of wood and concrete blocks is much lower than that of H-beam steel, concrete and clay bricks. So these two materials can be preferred when choosing building materials. Wood is a kind of renewable resource which causes little damage to ecosystem and creates less pollution than other materials such as steel and concrete.

(5) From the viewpoint of lower the carbon emission factor, improving the manufacturing technique of building materials, elevating the energy conversion efficiency in production process, and optimizing logistics allocation technology can reduce the carbon emission.

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