

# Supplementary Materials: A Multi-Disciplinary Optimization Approach to Eco-Friendly Design Using the Response Surface Method

Cheng-Jung Yang <sup>1,\*</sup>, Lin Mei Jyun <sup>2</sup> and Jahau Lewis Chen <sup>3</sup>

**Table S1.** The environmental impact of the 50 combinations in fossil fuels.

Num.	$X_1$ (mm)	$X_2$ (mm)	$X_3$	$V_1(X)$ (mpt)
1	0.2	0.2	1	1.05
2	0.2	0.25	1	1.12
3	0.2	0.3	1	1.2
4	0.2	0.35	1	1.28
5	0.2	0.4	1	1.35
6	0.25	0.2	1	1.19
7	0.25	0.25	1	1.26
8	0.25	0.3	1	1.33
9	0.25	0.35	1	1.41
10	0.25	0.4	1	1.49
11	0.3	0.2	1	1.32
12	0.3	0.25	1	1.4
13	0.3	0.3	1	1.47
14	0.3	0.35	1	1.55
15	0.3	0.4	1	1.63
16	0.35	0.2	1	1.46
17	0.35	0.25	1	1.54
18	0.35	0.3	1	1.62
19	0.35	0.35	1	1.69
20	0.35	0.4	1	1.77
21	0.4	0.2	1	1.6
22	0.4	0.25	1	1.67
23	0.4	0.3	1	1.74
24	0.4	0.35	1	1.83
25	0.4	0.4	1	1.9
26	0.2	0.2	2	1.21
27	0.2	0.25	2	1.3
28	0.2	0.3	2	1.39
29	0.2	0.35	2	1.48
30	0.2	0.4	2	1.57
31	0.25	0.2	2	1.37
32	0.25	0.25	2	1.46
33	0.25	0.3	2	1.55
34	0.25	0.35	2	1.64
35	0.25	0.4	2	1.73
36	0.3	0.2	2	1.53
37	0.3	0.25	2	1.62
38	0.3	0.3	2	1.71

39	0.3	0.35	2	1.8
40	0.3	0.4	2	1.89
41	0.35	0.2	2	1.69
42	0.35	0.25	2	1.78
43	0.35	0.3	2	1.88
44	0.35	0.35	2	1.96
45	0.35	0.4	2	2.05
46	0.4	0.2	2	1.86
47	0.4	0.25	2	1.94
48	0.4	0.3	2	2.03
49	0.4	0.35	2	2.13
50	0.4	0.4	2	2.21

**Table S2.** Regression coefficients of first order model- the environmental impact in fossil fuels.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Standard error	Beta		
(Constant)	-0.155	0.021		-7.391	0.000
$X_1$	2.981	0.045	0.768	66.741	0.000
$X_2$	1.665	0.045	0.423	36.789	0.000
$X_3$	0.236	0.006	0.426	37.105	0.000

**Table S3.** Regression coefficients of first order model with interaction- the environmental impact in fossil fuels.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Standard error	Beta		
(Constant)	0.188	0.015		12.166	0.000
$X_1$	2.25	0.044	0.579	48.86	0.000
$X_2$	1.217	0.046	0.309	27.507	0.000
$X_3$	$1.396 \times 10^{-2}$	0.007	0.025	2.036	0.049
$X_1X_2$	0.113	0.123	0.013	0.923	0.362
$X_1X_3$	0.464	0.016	0.313	28.43	0.000
$X_2X_3$	0.276	0.017	0.188	16.707	0.000

**Table S4.** Regression coefficients of second order model- the environmental impact in fossil fuels.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Standard error	Beta		
(Constant)	0.193	0.021		9.249	0.000
$X_1$	2.293	0.094	0.590	24.469	0.000
$X_2$	1.205	0.093	0.306	12.989	0.000
$X_1X_2$	0.122	0.129	0.014	0.941	0.353
$X_1X_3$	0.464	0.017	0.313	27.775	0.000

$X_2X_3$	0.276	0.017	0.188	16.322	0.000
$X_1X_1$	$-7.762 \times 10^{-2}$	0.148	-0.012	-0.523	0.604
$X_2X_2$	$1.640 \times 10^{-2}$	0.144	0.003	0.114	0.910
$X_3X_3$	$4.652 \times 10^{-3}$	0.002	0.025	1.989	0.055

**Table S4.** The error rate of the training and validation set - first order model.

Training set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
1	1.05	1.0102	0.0379
2	1.12	1.09345	0.0237
3	1.2	1.1767	0.0194
4	1.28	1.25995	0.0157
5	1.35	1.3432	0.0050
6	1.19	1.15925	0.0258
8	1.33	1.32575	0.0032
9	1.41	1.409	0.0007
10	1.49	1.49225	0.0015
11	1.32	1.3083	0.0087
12	1.4	1.39155	0.0060
13	1.47	1.4748	0.0033
15	1.63	1.6413	0.0069
16	1.46	1.45735	0.0018
17	1.54	1.5406	0.0004
18	1.62	1.62385	0.0024
19	1.69	1.7071	0.0101
20	1.77	1.79035	0.0115
22	1.67	1.68965	0.0118
23	1.74	1.7729	0.0189
24	1.83	1.85615	0.0143
25	1.9	1.9394	0.0207
26	1.21	1.2462	0.0299
27	1.3	1.32945	0.0227
28	1.39	1.4127	0.0163
29	1.48	1.49595	0.0108
30	1.57	1.5792	0.0059
31	1.37	1.39525	0.0184
33	1.55	1.56175	0.0076
34	1.64	1.645	0.0031
35	1.73	1.72825	0.0010
36	1.53	1.5443	0.0094
37	1.62	1.62755	0.0047
38	1.71	1.7108	0.0005
40	1.89	1.8773	0.0067
41	1.69	1.69335	0.0020
42	1.78	1.7766	0.0019
43	1.88	1.85985	0.0107
44	1.96	1.9431	0.0086

45	2.05	2.02635	0.0115
47	1.94	1.92565	0.0074
48	2.03	2.0089	0.0104
49	2.13	2.09215	0.0178
50	2.21	2.1754	0.0157

Validation set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
7	1.26	1.2425	0.0139
14	1.55	1.55805	0.0052
21	1.6	1.6064	0.004
32	1.46	1.4785	0.0127
39	1.8	1.79405	0.0033
46	1.86	1.8424	0.0095

**Table S6.** The error rate of the training and validation set- first order model with interaction.

Training set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
1	1.05	1.04788	0.0020
2	1.12	1.12366	0.0033
3	1.2	1.19944	0.0005
4	1.28	1.27522	0.0037
5	1.35	1.351	0.0007
6	1.19	1.18471	0.0044
8	1.33	1.336835	0.0051
9	1.41	1.412898	0.0021
10	1.49	1.48896	0.0007
11	1.32	1.32154	0.0012
12	1.4	1.397885	0.0015
13	1.47	1.47423	0.0029
15	1.63	1.62692	0.0019
16	1.46	1.45837	0.0011
17	1.54	1.534998	0.0033
18	1.62	1.611625	0.0052
19	1.69	1.688253	0.0010
20	1.77	1.76488	0.0029
22	1.67	1.67211	0.0013
23	1.74	1.74902	0.0052
24	1.83	1.82593	0.0022
25	1.9	1.90284	0.0015
26	1.21	1.20984	0.0001
27	1.3	1.29942	0.0005
28	1.39	1.389	0.0007
29	1.48	1.47858	0.0001
30	1.57	1.56816	0.0012
31	1.37	1.36987	0.0001

33	1.55	1.549595	0.0003
34	1.64	1.639458	0.0003
35	1.73	1.72932	0.0004
36	1.53	1.5299	0.0001
37	1.62	1.620045	0.0001
38	1.71	1.71019	0.0001
40	1.89	1.89048	0.0003
41	1.69	1.68993	0.0001
42	1.78	1.780358	0.0002
43	1.88	1.870785	0.0049
44	1.96	1.961213	0.0006
45	2.05	2.05164	0.0008
47	1.94	1.94067	0.0004
48	2.03	2.03138	0.0007
49	2.13	2.12209	0.0037
50	2.21	2.2128	0.0013

Validation set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
7	1.26	1.260773	0.0006
14	1.55	1.550575	0.0004
21	1.6	1.5952	0.003
32	1.46	1.459733	0.0002
39	1.8	1.800335	0.0002
46	1.86	1.84996	0.0054

**Table S7.** The error rate of the training and validation set- second order model.

Training set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
1	1.05	1.04768	0.0022
2	1.12	1.12332	0.0030
3	1.2	1.19904	0.0008
4	1.28	1.27485	0.0040
5	1.35	1.35073	0.0005
6	1.19	1.18501	0.0042
8	1.33	1.33698	0.0053
9	1.41	1.41308	0.0022
10	1.49	1.48927	0.0005
11	1.32	1.32194	0.0015
12	1.4	1.39819	0.0013
13	1.47	1.47452	0.0031
15	1.63	1.62743	0.0016
16	1.46	1.45849	0.0010
17	1.54	1.53504	0.0032
18	1.62	1.61168	0.0051
19	1.69	1.6884	0.0001

20	1.77	1.7652	0.0027
22	1.67	1.67151	0.0009
23	1.74	1.74845	0.0049
24	1.83	1.82547	0.0025
25	1.9	1.90258	0.0014
26	1.21	1.20964	0.0003
27	1.3	1.29908	0.0007
28	1.39	1.3886	0.0010
29	1.48	1.4782	0.0012
30	1.57	1.56789	0.0014
31	1.37	1.37016	0.0001
33	1.55	1.54973	0.0002
34	1.64	1.63964	0.0002
35	1.73	1.72963	0.0002
36	1.53	1.5303	0.0002
37	1.62	1.62035	0.0002
38	1.71	1.71048	0.0003
40	1.89	1.89099	0.0005
41	1.69	1.69005	0.0001
42	1.78	1.7804	0.0002
43	1.88	1.87084	0.0049
44	1.96	1.96135	0.0007
45	2.05	2.05195	0.0010
47	1.94	1.94006	0.0001
48	2.03	2.0308	0.0004
49	2.13	2.12163	0.0039
50	2.21	2.21253	0.0012

Validation set :

Num.	Real value (mpt)	Value from the regression equation (mpt)	Error rate
7	1.26	1.26095	0.0008
14	1.55	1.55094	0.0006
21	1.6	1.59465	0.0033
32	1.46	1.45991	0.0001
39	1.8	1.80099	0.0004
46	1.86	1.8494	0.0057

**Table S8.** The von Mises stress of the 50 combinations.

Num.	X1 (mm)	X2 (mm)	X3	$V_2(X)$ ( $N/m^2$ )
1	0.2	0.2	1	432,135
2	0.2	0.25	1	416,256

3	0.2	0.3	1	404,152
4	0.2	0.35	1	375,440
5	0.2	0.4	1	378,131
6	0.25	0.2	1	339,780
7	0.25	0.25	1	319,873
8	0.25	0.3	1	312,276
9	0.25	0.35	1	300,124
10	0.25	0.4	1	285,044
11	0.3	0.2	1	268,330
12	0.3	0.25	1	253,967
13	0.3	0.3	1	244,413
14	0.3	0.35	1	234,161
15	0.3	0.4	1	225,472
16	0.35	0.2	1	215,284
17	0.35	0.25	1	203,642
18	0.35	0.3	1	198,346
19	0.35	0.35	1	188,879
20	0.35	0.4	1	185,665
21	0.4	0.2	1	172,827
22	0.4	0.25	1	167,622
23	0.4	0.3	1	161,136
24	0.4	0.35	1	152,111
25	0.4	0.4	1	151,569
26	0.2	0.2	2	432,188
27	0.2	0.25	2	416,088
28	0.2	0.3	2	403,994
29	0.2	0.35	2	375,348
30	0.2	0.4	2	377,948
31	0.25	0.2	2	339,424
32	0.25	0.25	2	319,611
33	0.25	0.3	2	311,985
34	0.25	0.35	2	299,783
35	0.25	0.4	2	284,873
36	0.3	0.2	2	267,931
37	0.3	0.25	2	253,488
38	0.3	0.3	2	244,154
39	0.3	0.35	2	233,797
40	0.3	0.4	2	226,084
41	0.35	0.2	2	214,891
42	0.35	0.25	2	204,438
43	0.35	0.3	2	197,969
44	0.35	0.35	2	188,555
45	0.35	0.4	2	186,488
46	0.4	0.2	2	172,497
47	0.4	0.25	2	167,359
48	0.4	0.3	2	160,787
49	0.4	0.35	2	151,822
50	0.4	0.4	2	151,248

**Table S9.** Regression coefficients of first order model- the von Mises stress.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Standard error	Beta		
(Constant)	683,365.192	16,920.139		40.388	.000
$X_1$	-1,199,420.3	35,923.954	-0.960	-33.388	.000
$X_2$	-196,287.756	36,386.792	-0.155	-5.394	.000
$X_3$	-133.136	5122.758	-0.001	-0.026	.979

**Table S10.** Regression coefficients of first order model with interaction- the von Mises stress.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Standard error	Beta		
(Constant)	814,125.101	64,152.317		12.691	.000
$X_1$	-1,648,210.1	190,833.162	-1.320	-8.637	.000
$X_2$	-618,513.711	183,379.892	-0.489	-3.373	.002
$X_3$	-554.836	28,403.277	-0.003	-0.020	.985
$X_1X_2$	1,444,079.254	508,385.181	0.512	2.841	.007
$X_1X_3$	-5.310	67,687.001	0.000	0.000	1.00
$X_2X_3$	1389.877	68,559.068	0.003	0.020	.984

**Table S11.** Regression coefficients of second order model - the von Mises stress.

Type	Unstandardized coefficients		Standardized coefficient	t	Significant
	B( $\beta$ )	Std. Error	Beta		
(Constant)	1,095,087.928	20,528.371		53.345	.000
$X_1$	-3,586,671.207	92,131.424	-2.872	-38.930	.000
$X_2$	-685,783.288	91,204.034	-0.542	-7.519	.000
$X_1X_2$	915,672.330	126,986.070	0.325	7.211	.000
$X_1X_3$	-5.310	16432.607	0.000	0.000	1.000
$X_2X_3$	1389.877	16,644.321	0.003	0.084	.934
$X_1X_1$	3,542,698.597	145,812.134	1.694	24.296	.000
$X_2X_2$	330,058.479	141,922.079	0.159	2.326	.026
$X_3X_3$	-184.945	2298.521	-0.003	-0.080	.936

**Table S12.** The error rate of the training and validation set - first order model

Training set :

Num.	Real value ( $N/m^2$ )	Value from the regression equation ( $N/m^2$ )	Error rate
1	432,135	404,090.4	0.0649
2	416,256	394,276.1	0.0528
3	404,152	384,461.7	0.0487
4	375,440	374,647.3	0.0021



5	378,131	364,832.9	0.0352
6	339,780	344,119.4	0.0128
8	312,276	324,490.7	0.0391
9	300,124	314,676.3	0.0485
10	285,044	304,861.9	0.0695
11	268,330	284,148.4	0.0590
12	253,967	274,334	0.0802
13	244,413	264,519.6	0.0823
15	225,472	244,890.9	0.0861
16	215,284	224,177.4	0.0413
17	203,642	214,363	0.0527
18	198,346	204,548.6	0.0313
19	188,879	194,734.2	0.031
20	185,665	184,919.8	0.0040
22	167,622	154,392	0.0789
23	161,136	144,577.6	0.1028
24	152,111	134,763.2	0.1140
25	151,569	124,948.8	0.1756
26	432,188	403,957.3	0.0653
27	416,088	394,142.9	0.0527
28	403,994	384,328.5	0.0487
29	375,348	374,514.1	0.0022
30	377,948	364,699.8	0.0351
31	339,424	343,986.3	0.0134
33	311,985	324,357.5	0.0397
34	299,783	314,543.1	0.0492
35	284,873	304,728.7	0.0697
36	267,931	284,015.3	0.0600
37	253,488	274,200.9	0.0817
38	244,154	264,386.5	0.0829
40	226,084	244,757.7	0.0826
41	214,891	224,044.3	0.0426
42	204,438	214,229.9	0.0479
43	197,969	204,415.5	0.0326
44	188,555	194,601.1	0.0321
45	186,488	184,786.7	0.0091
47	167,359	154,258.9	0.0783
48	160,787	144,444.5	0.1016
49	151,822	134,630.1	0.1132
50	151,248	124,815.7	0.1748

Validation set :

Num.	Real value ( $N/m^2$ )	Value from the regression equation ( $N/m^2$ )	Error rate
7	319,873	334,305	0.0451
14	234,161	254,705.3	0.0877
21	172,827	164,206.4	0.0499
32	319,611	334,171.9	0.0456
39	233,797	254,572.1	0.0889
46	172,497	164,073.2	0.0488

**Table S13.** The error rate of the training and validation set- first order model with interactionTraining set :

Num.	Real value ( $N/m^2$ )	Value from the regression equation ( $N/m^2$ )	Error rate
1	432,135	418,265.6	0.0321
2	416,256	401,850.2	0.0346
3	404,152	385,434.8	0.0463
4	375,440	369,019.4	0.0171
5	378,131	352,604	0.0675
6	339,780	350,295.6	0.0310
8	312,276	324,685.2	0.0397
9	300,124	311,880	0.0392
10	285,044	299,074.8	0.0492
11	268,330	282,325.6	0.0522
12	253,967	273,130.6	0.0755
13	244,413	263,935.6	0.0799
15	225,472	245,545.6	0.0890
16	215,284	214,355.7	0.0043
17	203,642	208,770.8	0.0252
18	198,346	203,186	0.0244
19	188,879	197,601.2	0.0462
20	185,665	192,016.4	0.0342
22	167,622	144,411.1	0.1385
23	161,136	142,436.5	0.1161
24	152,111	140,461.9	0.0766
25	151,569	138,487.2	0.0863
26	432,188	417,987.7	0.0329
27	416,088	401,641.8	0.0347
28	403,994	385,295.9	0.0463
29	375,348	368,949.9	0.0171
30	377,948	352,604	0.0676
31	339,424	350,017.4	0.0312
33	311,985	324,546	0.0403
34	299,783	311,810.3	0.0401
35	284,873	299,074.6	0.0499
36	267,931	282,047.2	0.0527
37	253,488	272,921.7	0.0767
38	244,154	263,796.2	0.0805
40	226,084	245,545.1	0.0861
41	214,891	214,076.9	0.0038
42	204,438	208,561.6	0.0202
43	197,969	203,046.3	0.0257
44	188,555	197,531	0.0476
45	186,488	192,015.7	0.0296
47	167,359	144,201.6	0.1384
48	160,787	142,296.5	0.115

49	151,822	140,391.4	0.0753
50	151,248	138,486.2	0.0844

Validation set :

Num.	Real value ( $N/m^2$ )	Value from the regression equation ( $N/m^2$ )	Error rate
7	319,873	337,490.4	0.0551
14	234,161	254,740.6	0.0879
21	172,827	146,385.7	0.1530
32	319,611	337,281.7	0.0553
39	233,797	254,670.6	0.0893
46	172,497	146,106.7	0.1530

**Table S14.** The error rate of the training and validation set- second order model

Training set :

Num.	Real value ( $N/m^2$ )	Value from the regression equation ( $N/m^2$ )	Error rate
1	432,135	432,226	0.0002
2	416,256	414,590	0.004
3	404,152	398,603	0.0137
4	375,440	384,267	0.0235
5	378,131	371,581	0.0173
6	339,780	341,760	0.0058
8	312,276	312,715	0.0014
9	300,124	300,668	0.0018
10	285,044	290,272	0.0183
11	268,330	269,007	0.0025
12	253,967	255,949	0.0078
13	244,413	244,541	0.0005
15	225,472	226,676	0.0053
16	215,284	213,968	0.0061
17	203,642	203,198	0.0022
18	198,346	194,080	0.0215
19	188,879	186,611	0.0120
20	185,665	180,793	0.0262
22	167,622	168,162	0.0032
23	161,136	161,332	0.0012
24	152,111	156,153	0.0266
25	151,569	152,624	0.0070
26	432,188	431,948	0.0006
27	416,088	414,381	0.0041
28	403,994	398,464	0.0137
29	375,348	384,198	0.0236
30	377,948	371,581	0.0169
31	339,424	341,482	0.0061
33	311,985	312,576	0.0019
34	299,783	300,599	0.0027
35	284,873	290,272	0.0190
36	267,931	268,728	0.0030

37	253,488	255,740	0.0089
38	244,154	244,401	0.0010
40	226,084	226,675	0.0026
41	214,891	213,689	0.0056
42	204,438	202,989	0.0071
43	197,969	193,940	0.0204
44	188,555	186,541	0.0107
45	186,488	180,792	0.0305
47	167,359	167,952	0.0035
48	160,787	161,192	0.0025
49	151,822	156,082	0.0281
50	151,248	152,623	0.0091

Validation set :

<b>Num.</b>	<b>Real value (<math>N/m^2</math>)</b>	<b>Value from the regression equation (<math>N/m^2</math>)</b>	<b>Error rate</b>
7	319,873	326,412	0.0204
14	234,161	234,783	0.0027
21	172,827	176,642	0.0221
32	319,611	326,204	0.0206
39	233,797	234,713	0.0039
46	172,497	176,363	0.0224