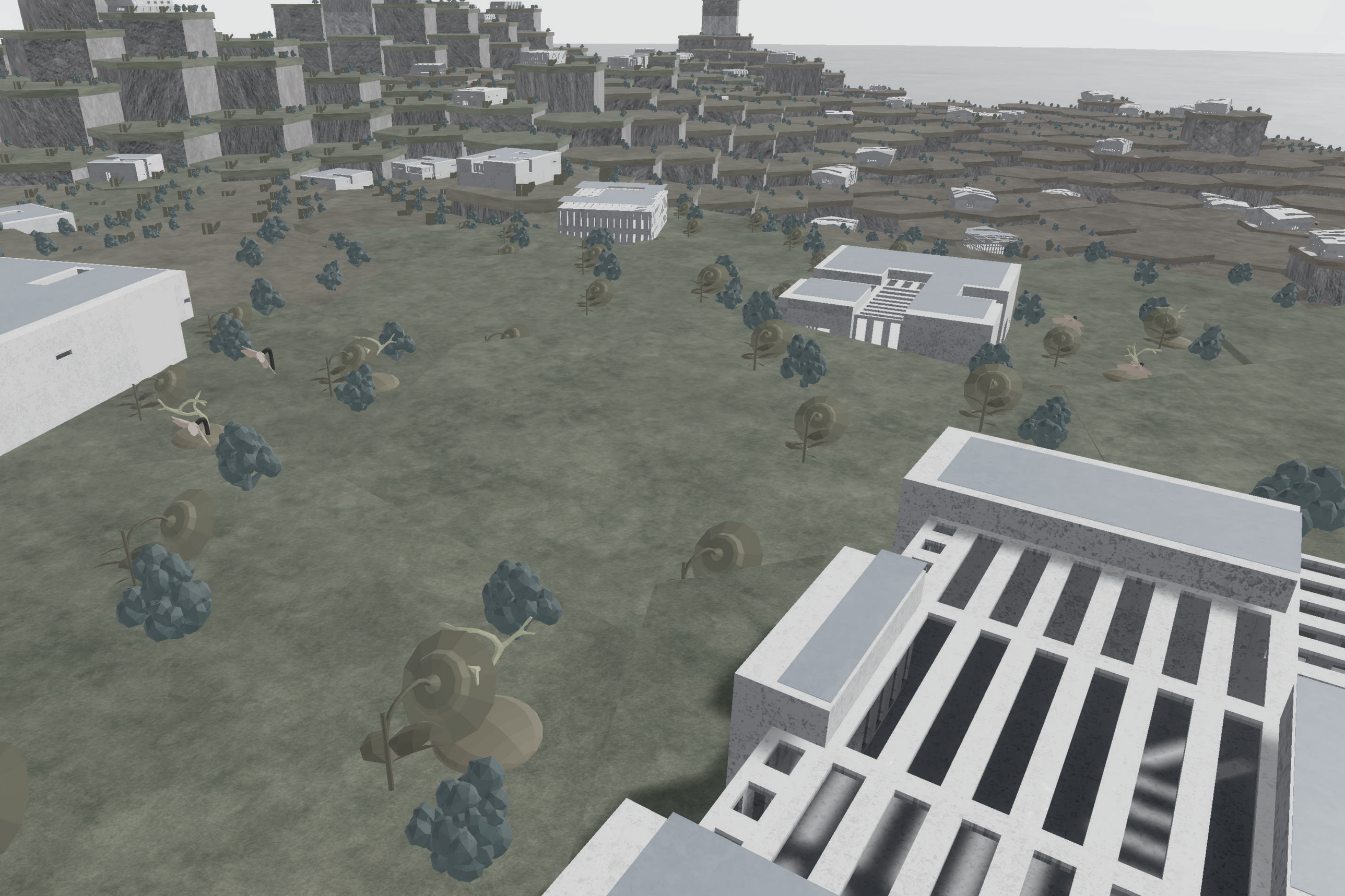


VISUAL ANALYTICS FOR GENERATIVE DESIGN EXPLORATION

A visual analytics tool for a computational design system facilitating the performance-driven design process of a nearly Zero-Energy sports hall

4210093 Jamal van Kastel

Sustainable Design Graduation Building Technology

02/02/2018 P5

Dr. Michela Turrin Computational Design

Dr. Regina Bokel Climate Design

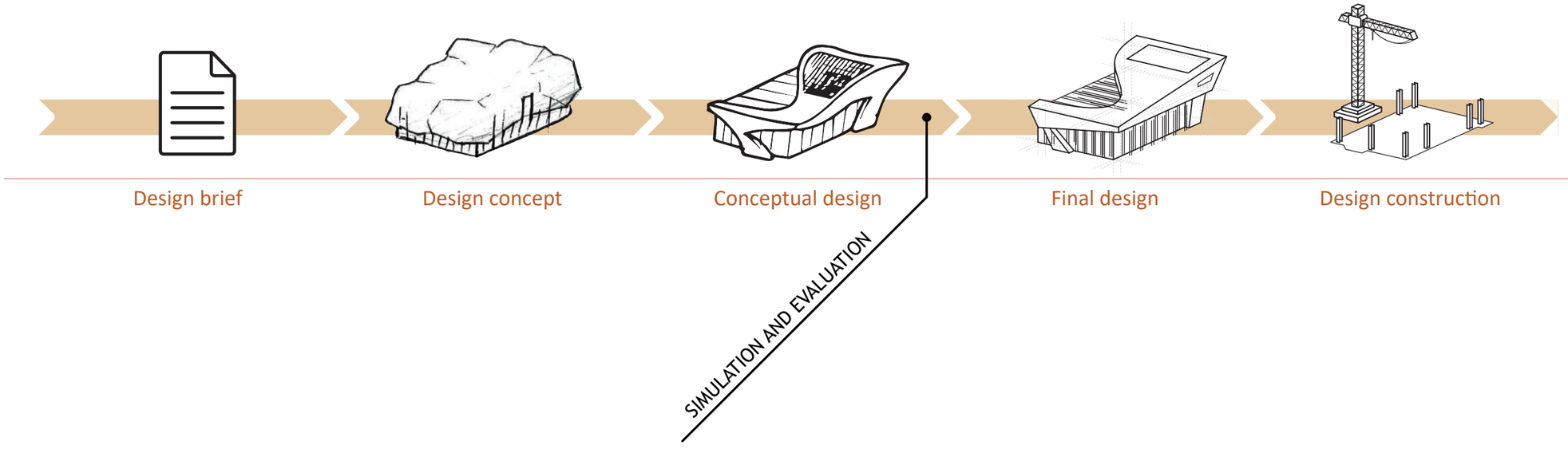
Drs. Kees Dol Delegate examiner

INTRODUCTION

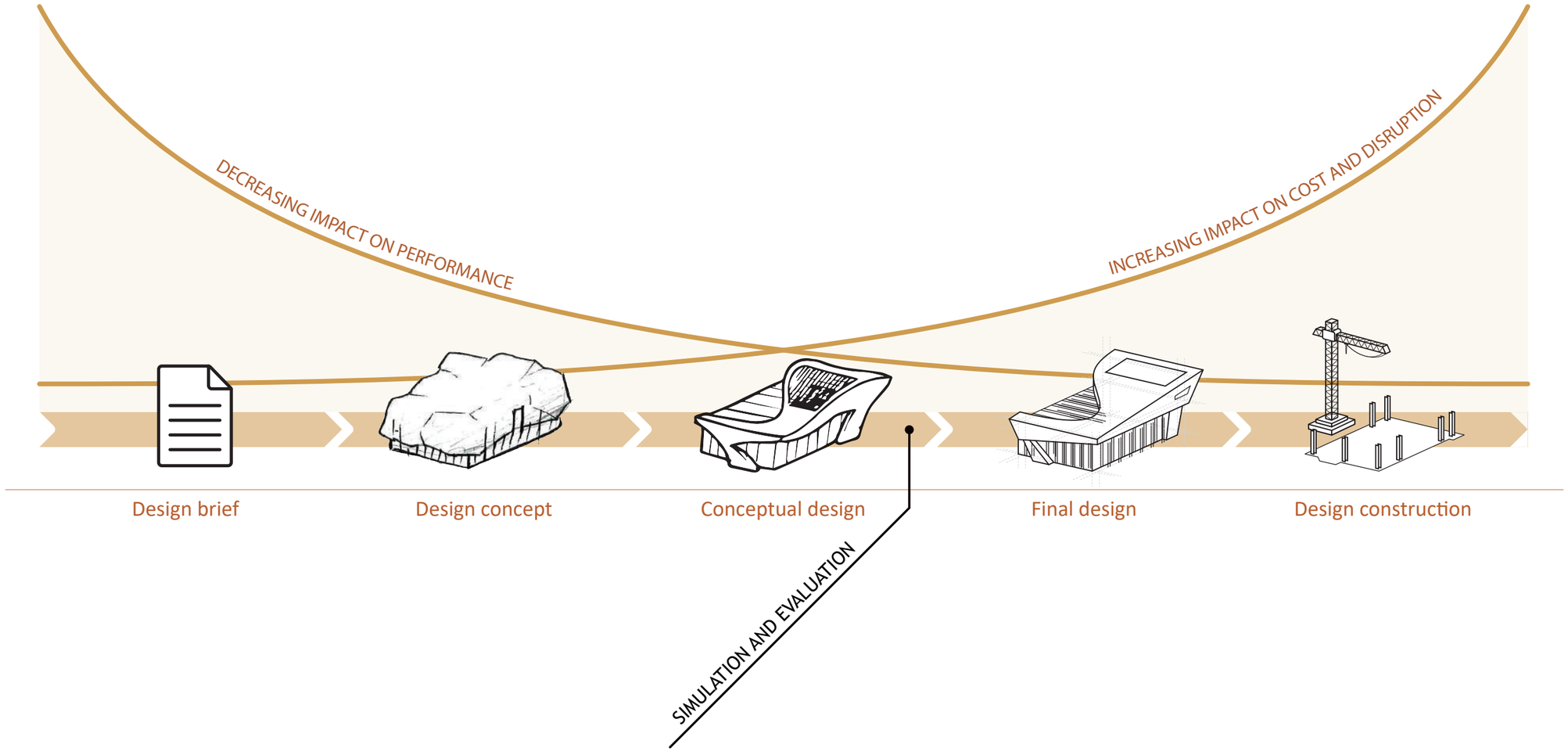
THE BUILDING SECTOR ACCOUNTS FOR 40% OF TOTAL ENERGY CONSUMPTION IN THE E.U.

DIRECTIVE 2010/31/EU, 2010, P.13

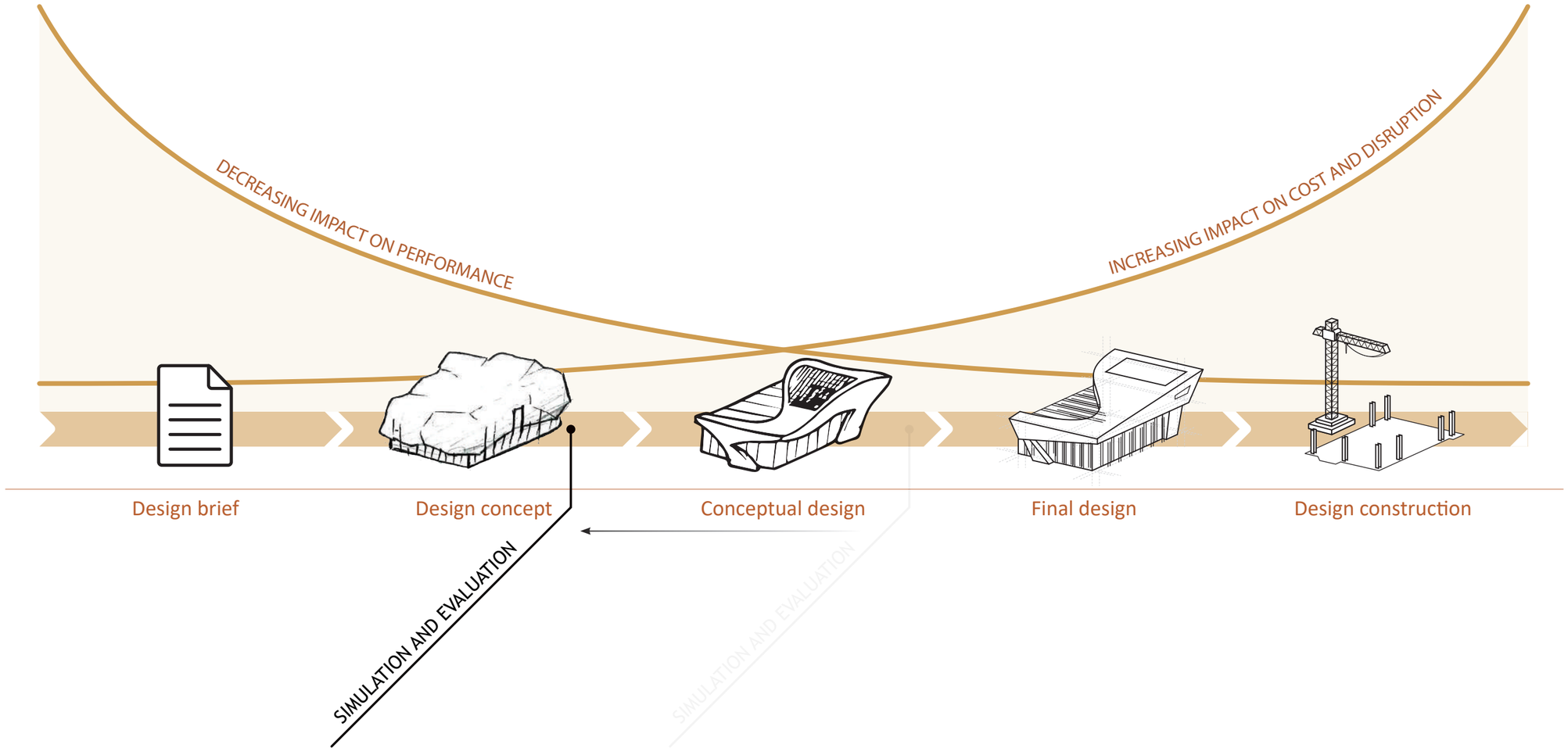
INTRODUCTION

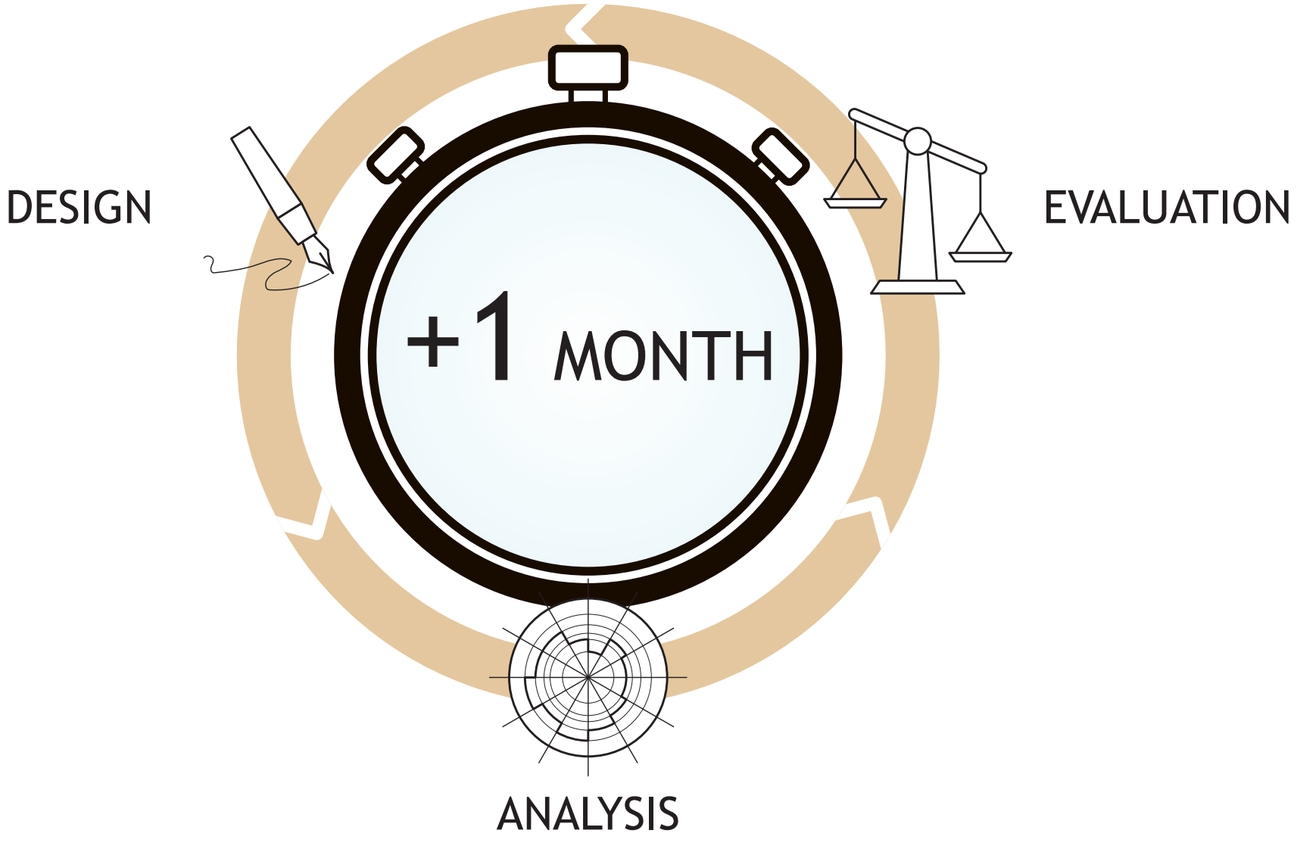


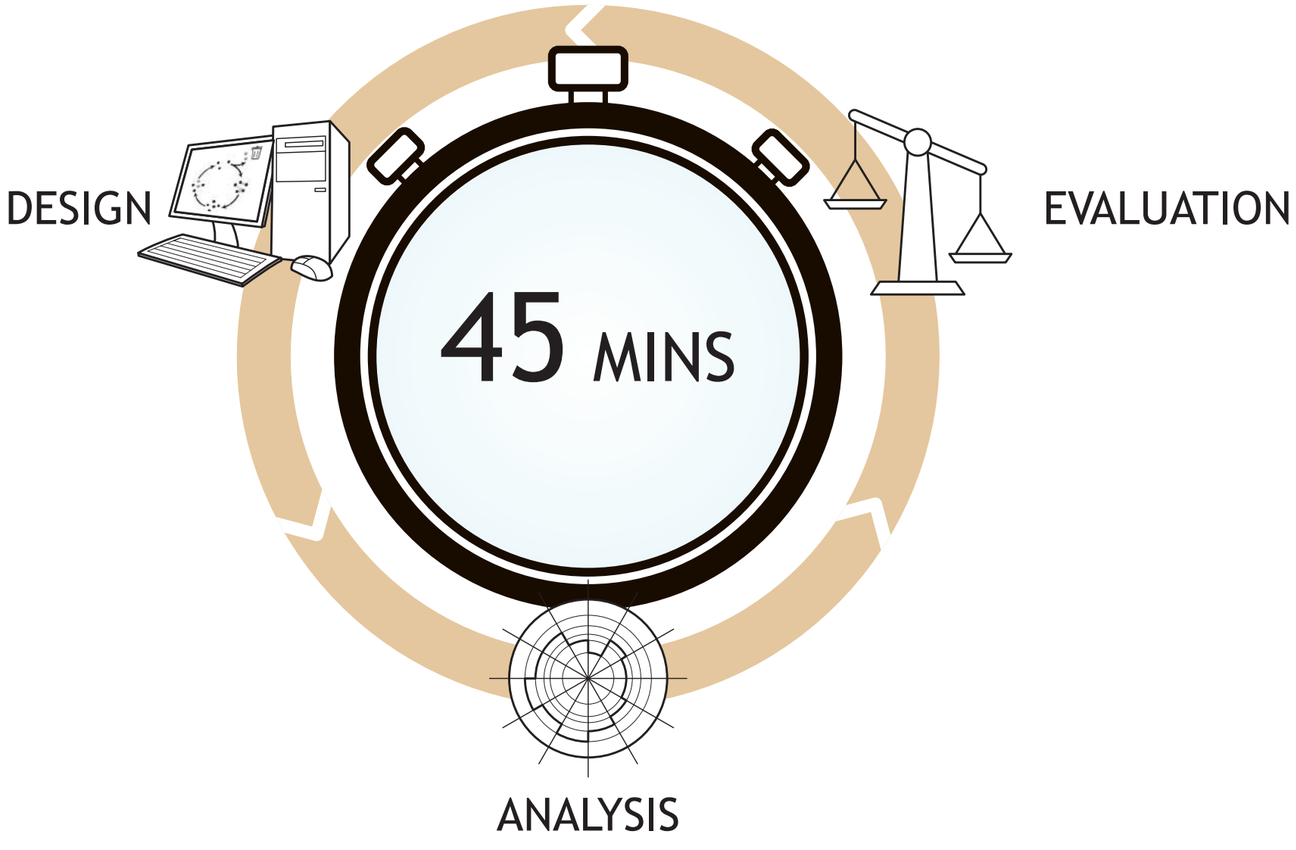

SWOOOOSH
ENERGY BILLS



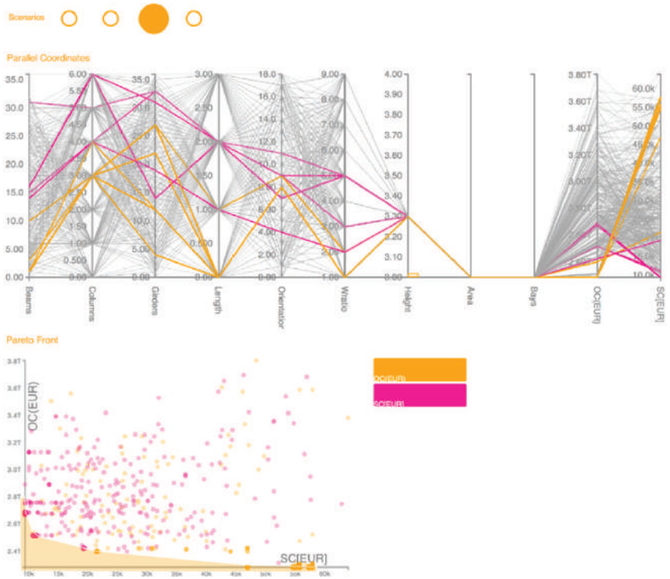
BASED ON LÖHNERT, DALKOWSKI, & SUTTER, 2003, P.6


DECREASING IMPACT ON PERFORMANCE
INCREASING IMPACT ON COST AND DISRUPTION
Design brief
Design concept
Conceptual design
Final design
Design construction
SIMULATION AND EVALUATION
SIMULATION AND EVALUATION

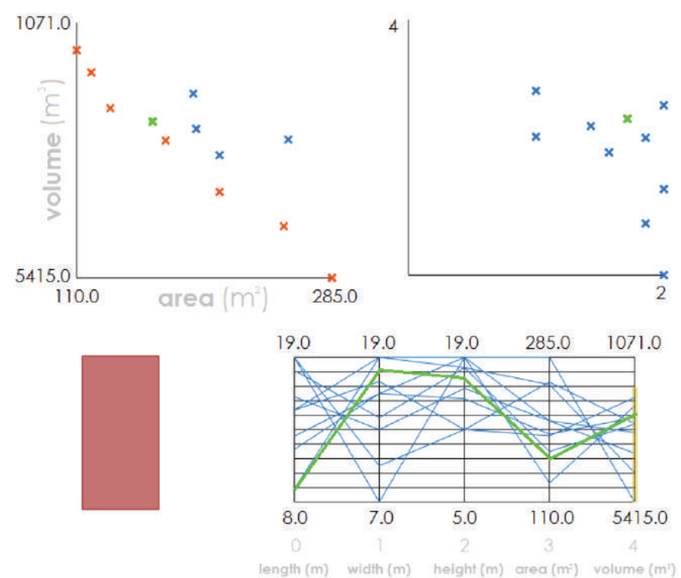

DESIGN
EVALUATION
+1 MONTH
ANALYSIS


DESIGN
EVALUATION
45 MINS
ANALYSIS

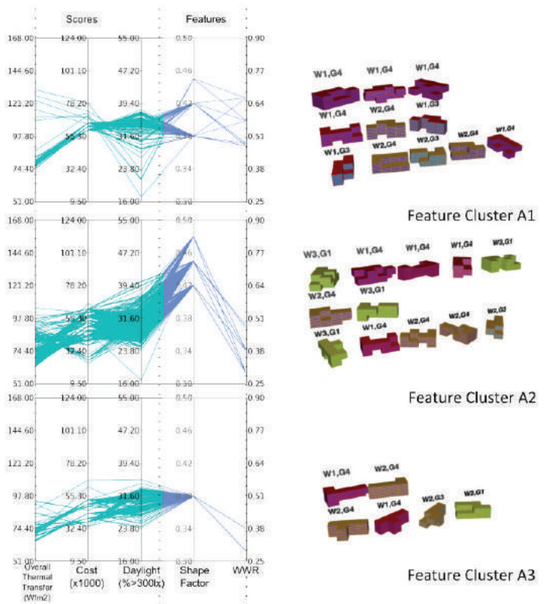
INTRODUCTION



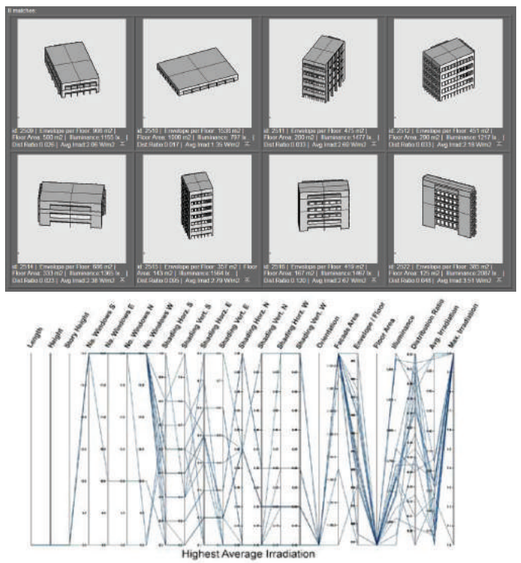
JANSEN ET AL., 2014



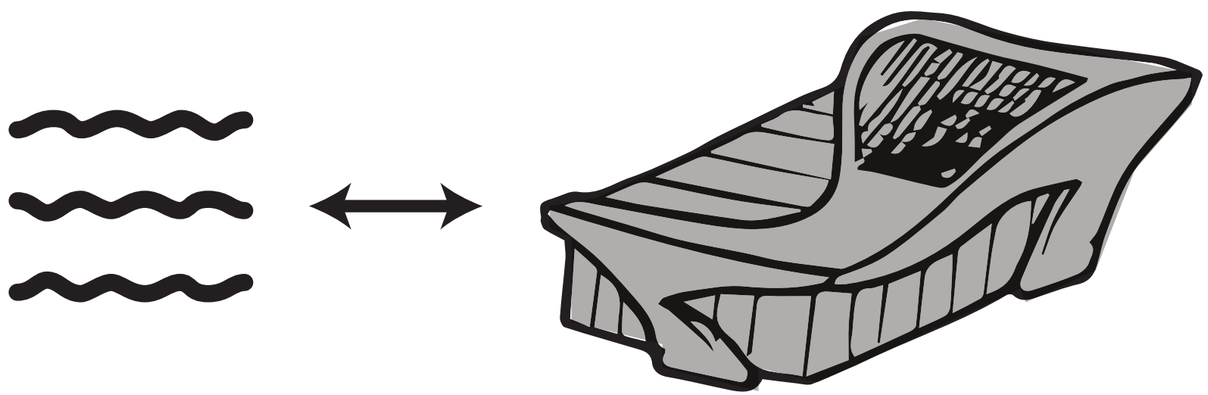
LAMPING, 2016



CHEN, JANSSEN & SCHLUETER, 2015



CHASZAR, VON BUELOW & TURRIN, 2016



Quantified performance criteria

Non-quantified performance criteria

GENERATE A LARGE NUMBER OF DESIGN ALTERNATIVES AND QUANTIFY THEIR PERFORMANCES ...

... STORE THEIR BUILDING INFORMATION TO A DATA SET ...

... PROCESS AND VISUALIZE THIS DATA TO ENABLE A PERFORMANCE-DRIVEN DESIGN PROCESS.

HOW CAN VISUAL ANALYTICS METHODS BE INTEGRATED IN A COMPUTATIONAL DESIGN SYSTEM TO MAKE MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING IN THE EARLY DESIGN STAGE ACCESSIBLE TO ARCHITECTS AND CLIMATE DESIGNERS?

GENERATE A LARGE NUMBER OF DESIGN ALTERNATIVES AND QUANTIFY THEIR PERFORMANCES ...

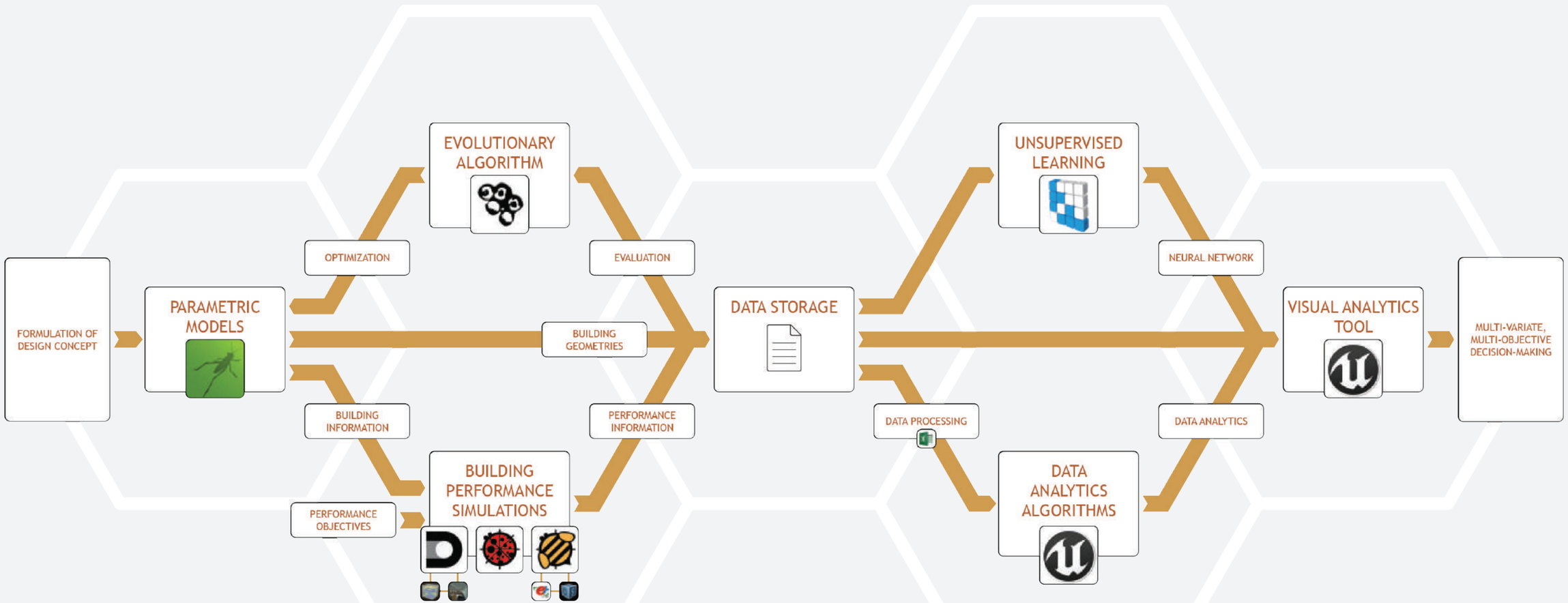
... STORE THEIR BUILDING INFORMATION TO A DATA SET ...

... PROCESS AND VISUALIZE THIS DATA TO ENABLE A PERFORMANCE-DRIVEN DESIGN PROCESS.

SUITABLE COMPUTATIONAL DESIGN SYSTEM

EFFECTIVE VISUAL ANALYTICS SYSTEM

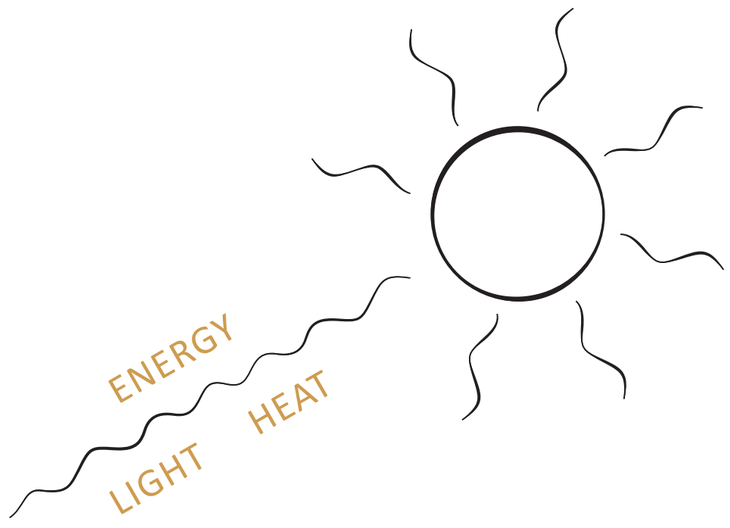
HOW CAN VISUAL ANALYTICS METHODS BE INTEGRATED IN A COMPUTATIONAL DESIGN SYSTEM TO MAKE MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING IN THE EARLY DESIGN STAGE ACCESSIBLE TO ARCHITECTS AND CLIMATE DESIGNERS?


FORMULATION OF DESIGN CONCEPT
PARAMETRIC MODELS
OPTIMIZATION
EVOLUTIONARY ALGORITHM
EVALUATION
BUILDING GEOMETRIES
BUILDING INFORMATION
PERFORMANCE OBJECTIVES
BUILDING PERFORMANCE SIMULATIONS
PERFORMANCE INFORMATION
DATA STORAGE
DATA PROCESSING
UNSUPERVISED LEARNING
NEURAL NETWORK
DATA ANALYTICS ALGORITHMS
DATA ANALYTICS
VISUAL ANALYTICS TOOL
MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING

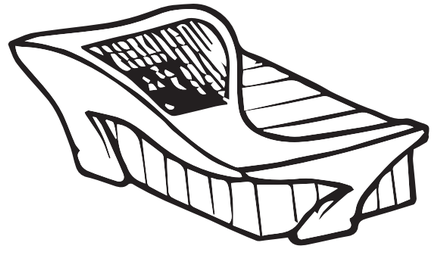
FORMULATION OF DESIGN CONCEPT

PARAMETRIC MODELS

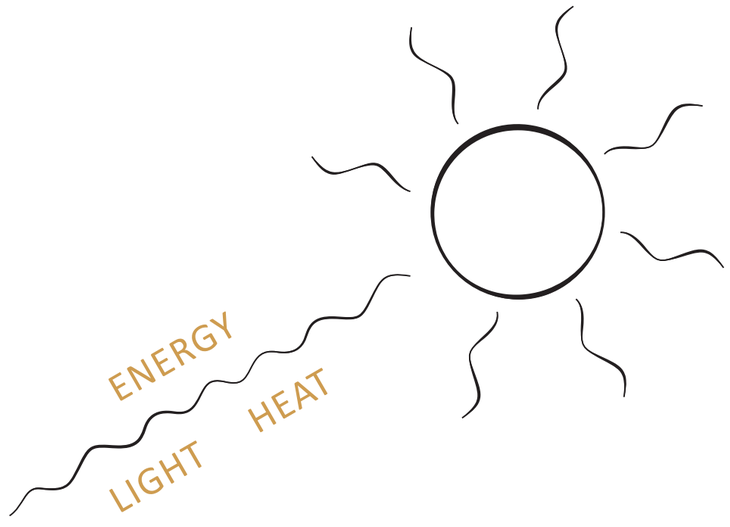
ENERGY DEMAND
THERMAL COMFORT
VISUAL COMFORT



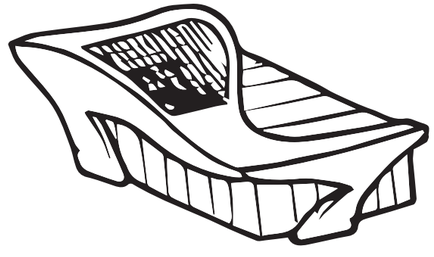
ENERGY DEMAND
THERMAL COMFORT
VISUAL COMFORT



BUILDING FORMED BY THE SUN



ENERGY DEMAND
THERMAL COMFORT
VISUAL COMFORT



BUILDING FORMED BY THE SUN

DESIGN VARIABLES

BUILDING
Orientation -
Shape -
WINDOW
Sizes -
Positions -
PV PANELS
Sizes -
Positions -

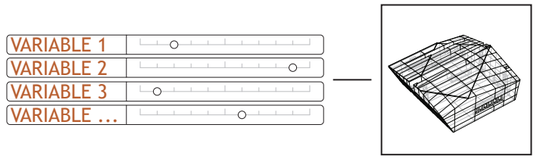
PERFORMANCE OBJECTIVES

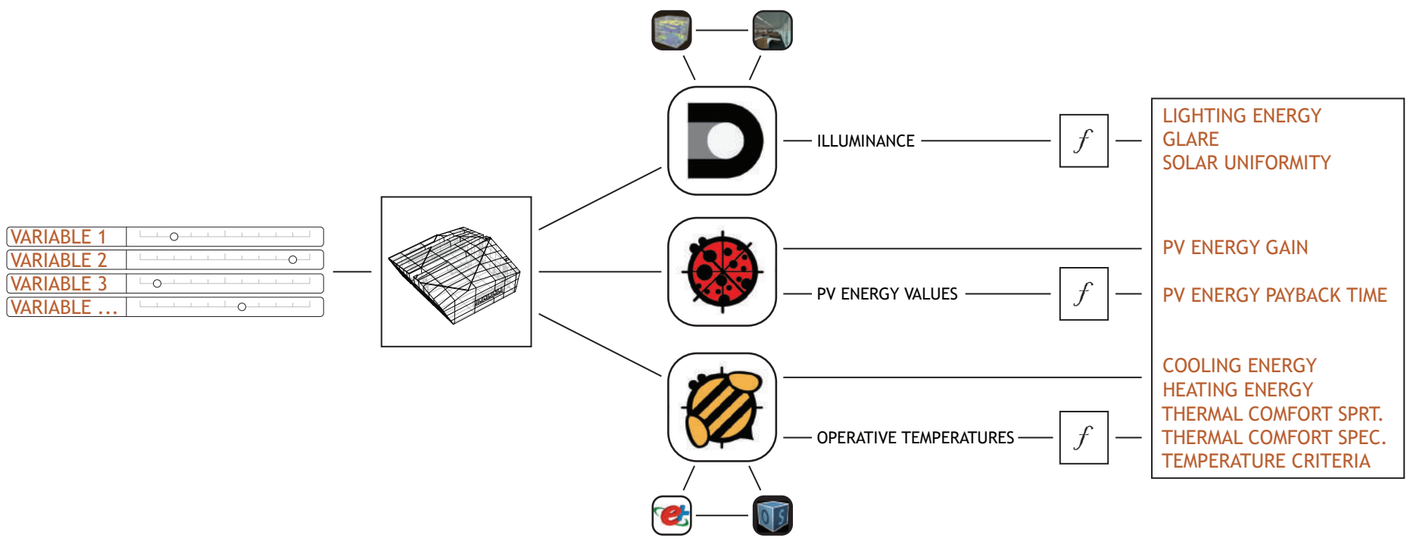
ENERGY PERFORMANCE CRITERIA
- Cooling energy demand
- Heating energy demand
- Artificial lighting energy demand
- PV panel energy gain
- PV panel energy payback time

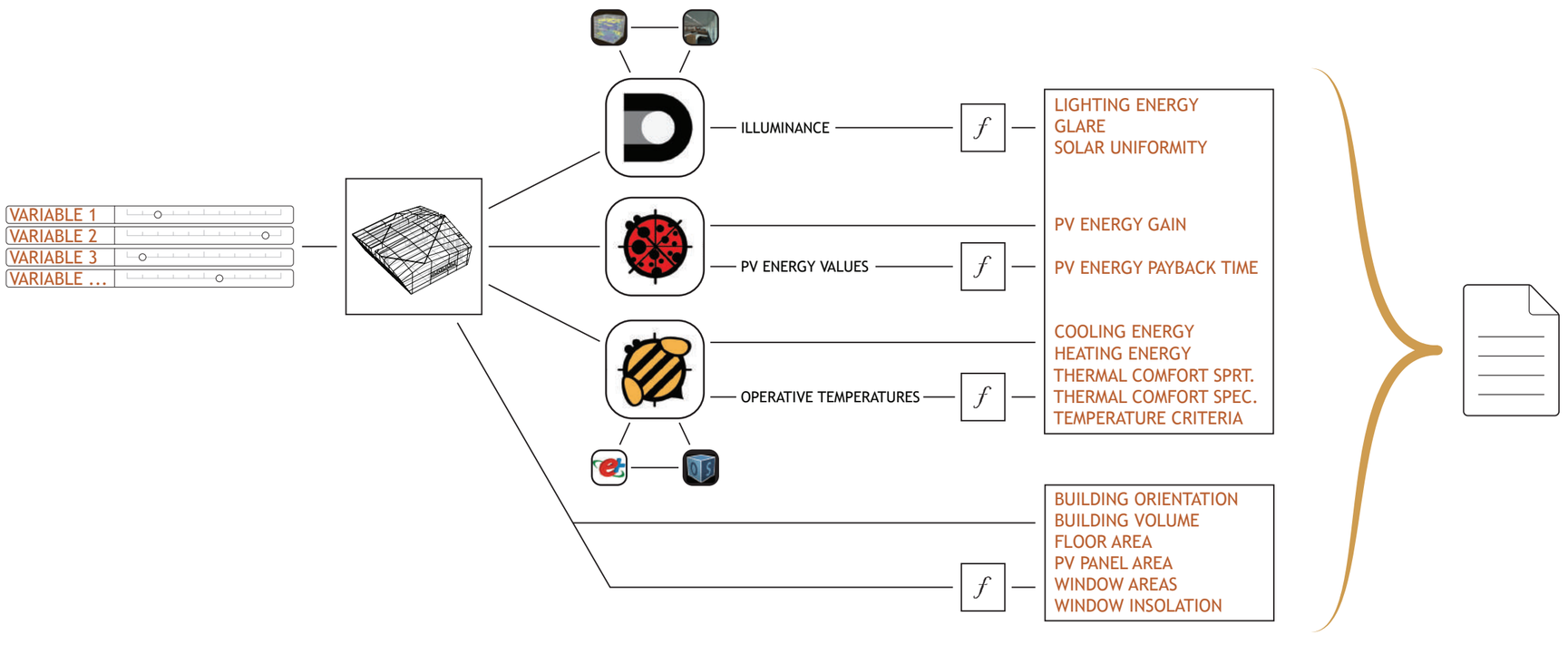
VISUAL COMFORT
- Glare
- Lighting uniformity

THERMAL COMFORT
- Thermal comfort of spectators
- Thermal comfort of sports players
- Temperature criteria

ARCHITECTURAL QUALITIES


VARIABLE 1
VARIABLE 2
VARIABLE 3
VARIABLE ...


VARIABLE 1
VARIABLE 2
VARIABLE 3
VARIABLE ...
ILLUMINANCE
PV ENERGY VALUES
OPERATIVE TEMPERATURES
f
f
f
LIGHTING ENERGY
GLARE
SOLAR UNIFORMITY
PV ENERGY GAIN
PV ENERGY PAYBACK TIME
COOLING ENERGY
HEATING ENERGY
THERMAL COMFORT SPRT.
THERMAL COMFORT SPEC.
TEMPERATURE CRITERIA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VARIABLE 3
VARIABLE ...
ILLUMINANCE
PV ENERGY VALUES
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PV ENERGY GAIN
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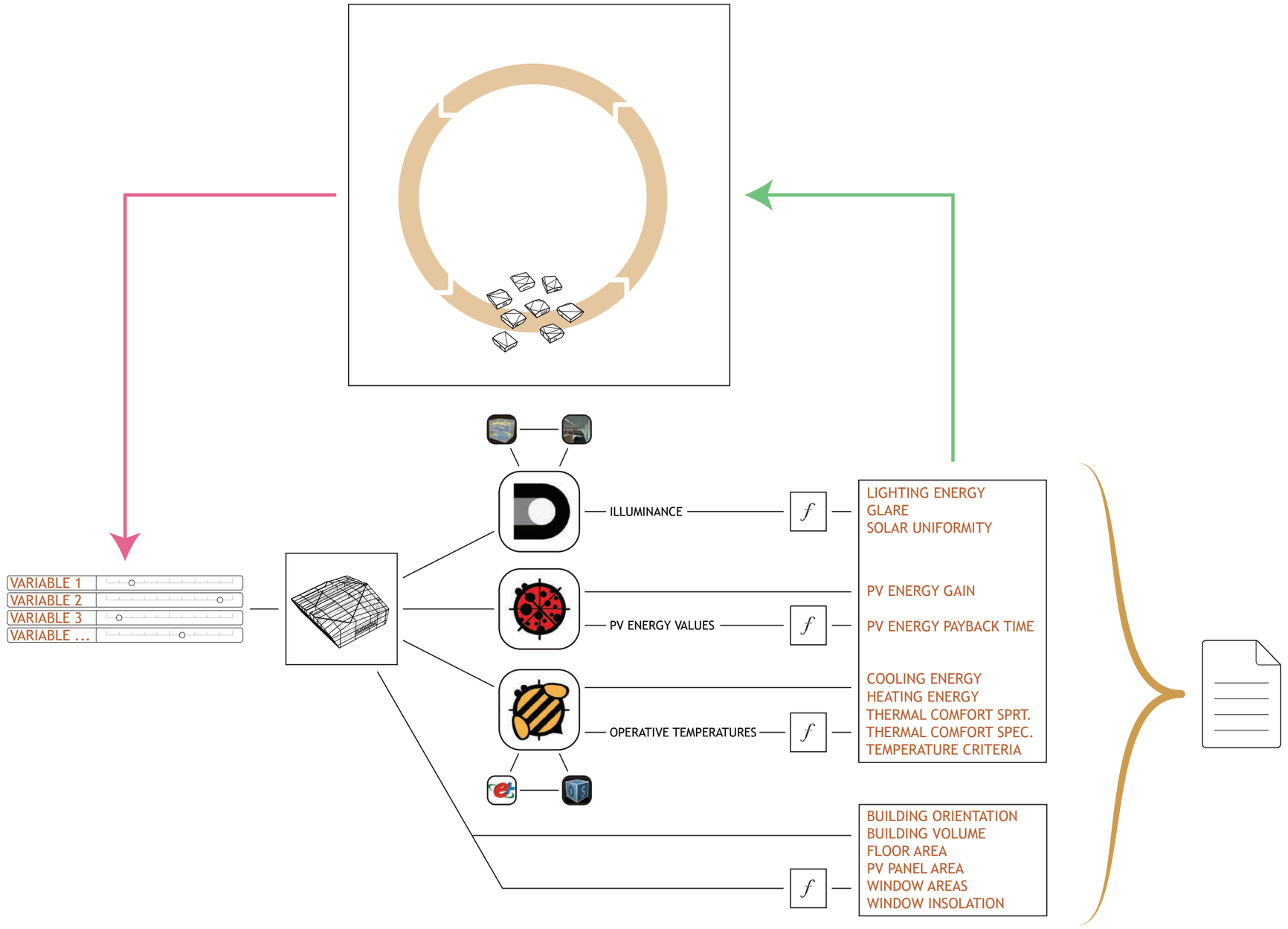
COOLING ENERGY
HEATING ENERGY
THERMAL COMFORT SPRT.
THERMAL COMFORT SPEC.
TEMPERATURE CRITERIA
BUILDING ORIENTATION
BUILDING VOLUME
FLOOR AREA
PV PANEL AREA
WINDOW AREAS
WINDOW INSOLATION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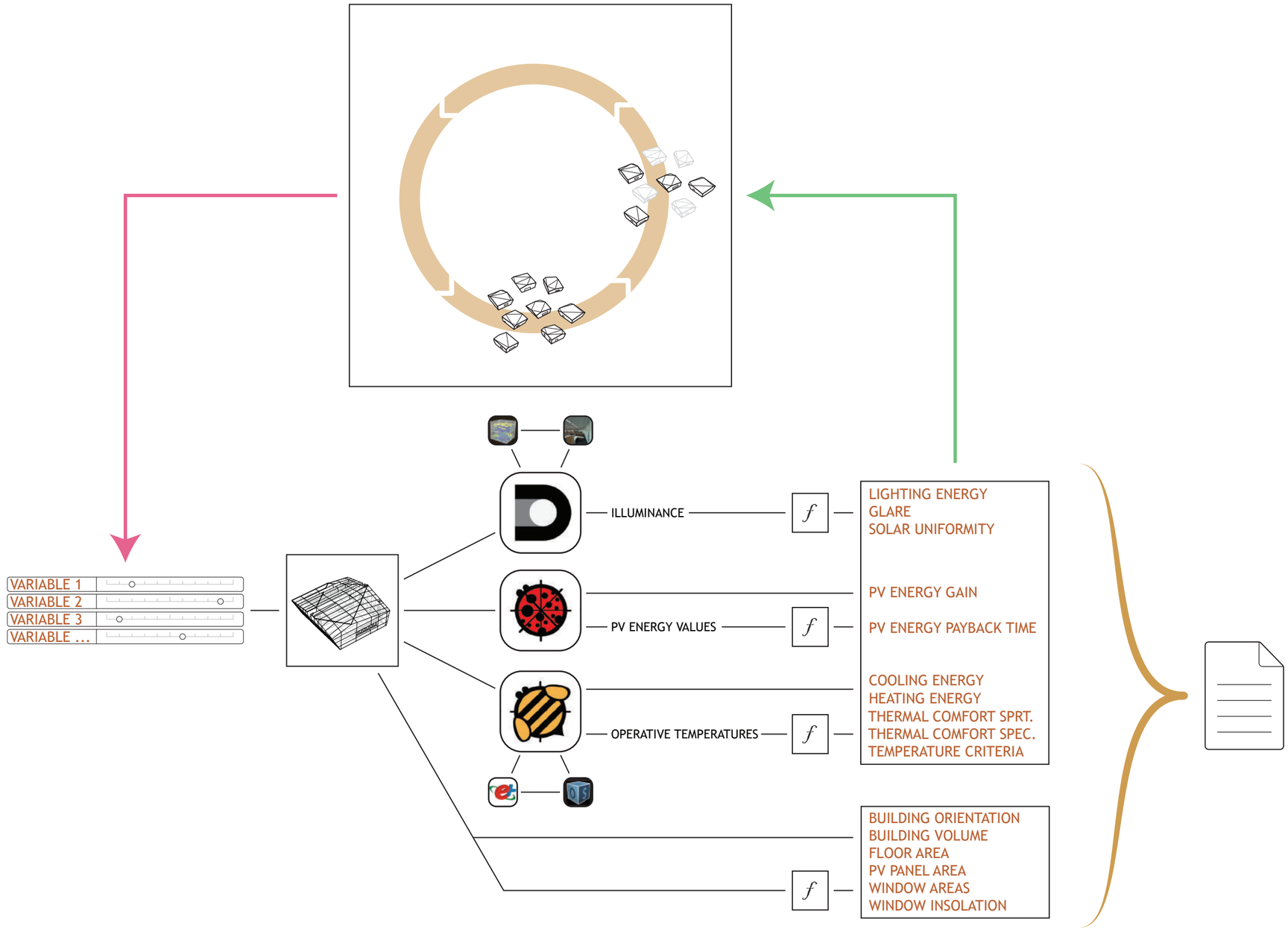
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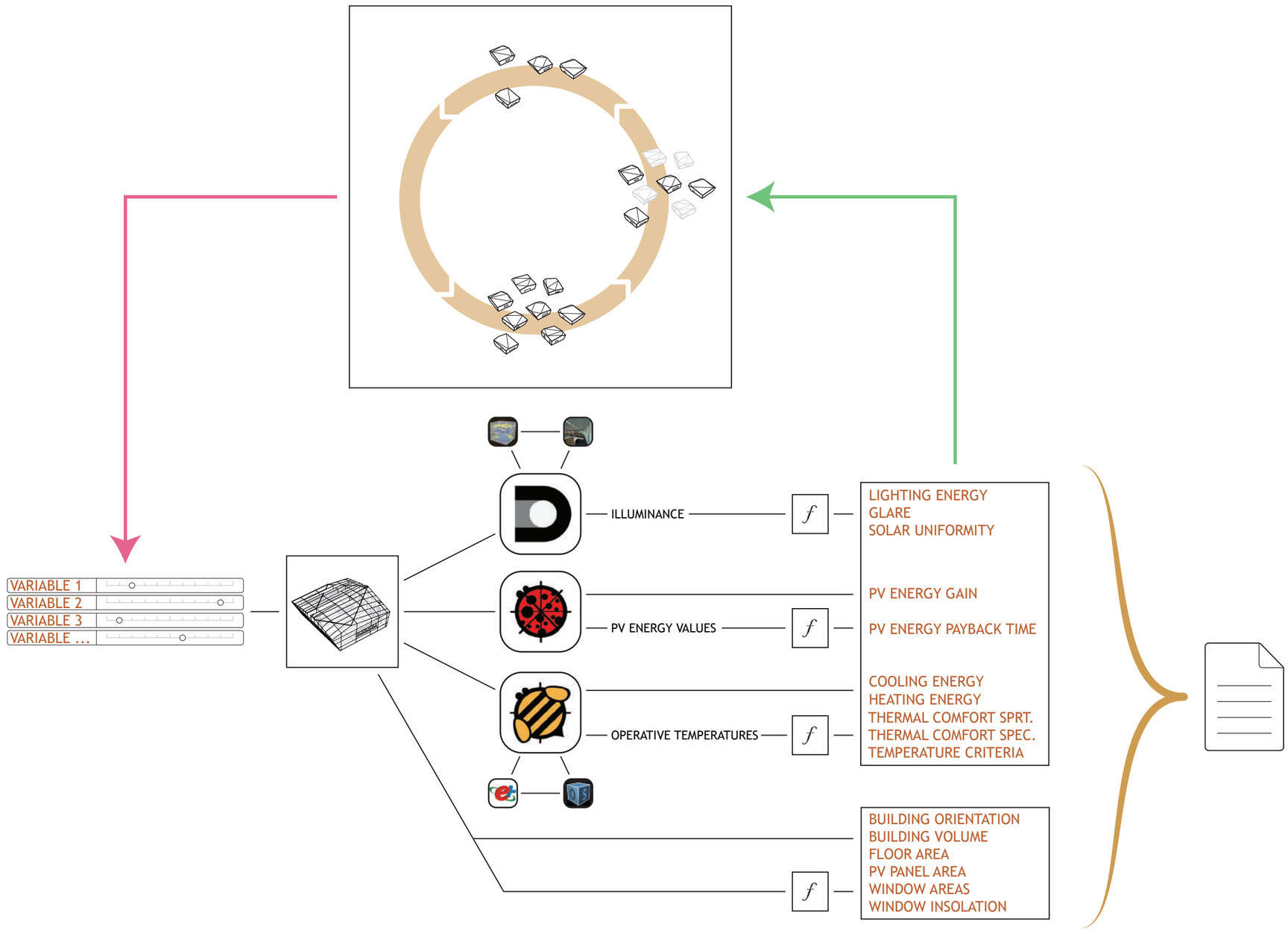
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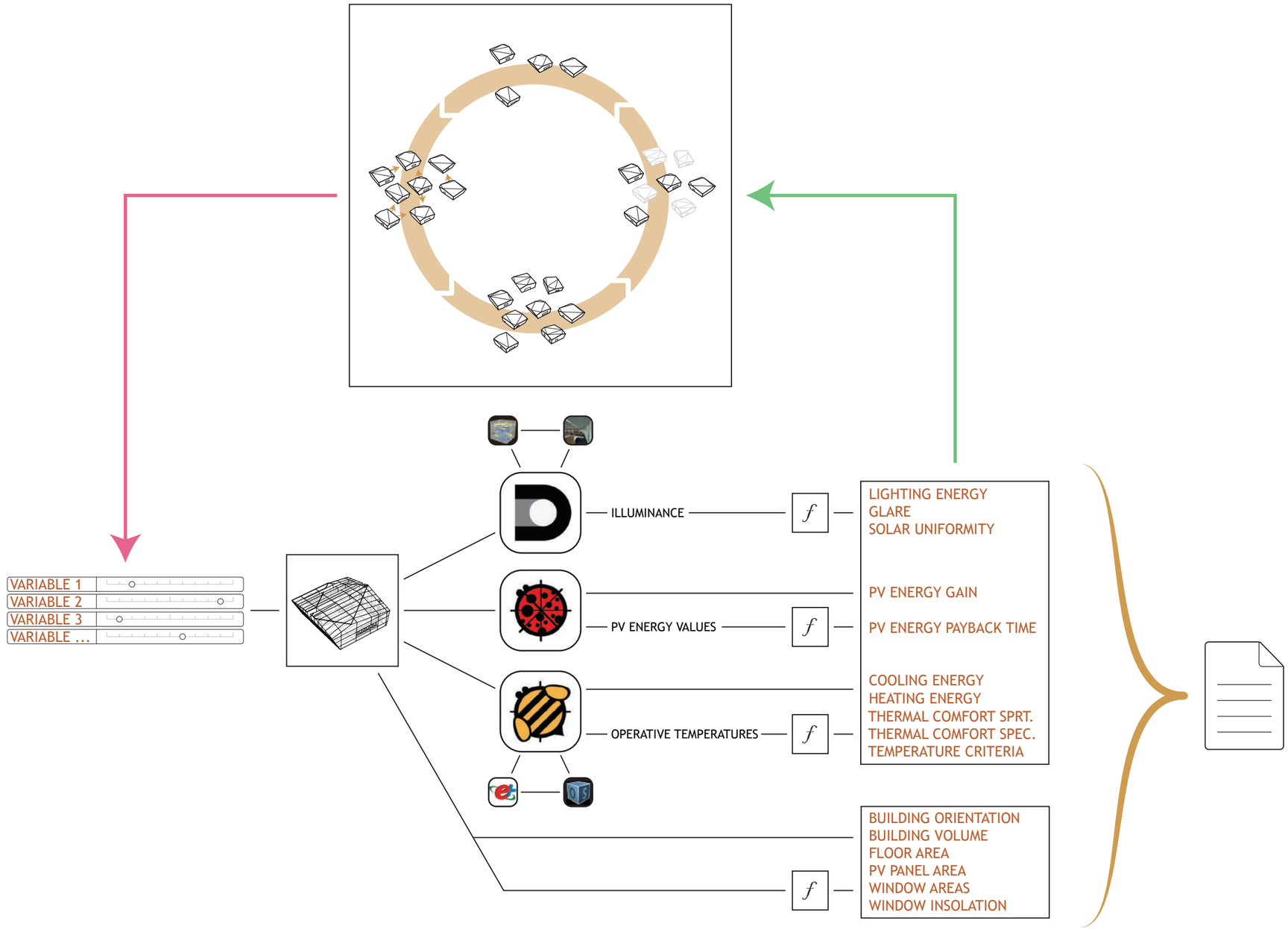
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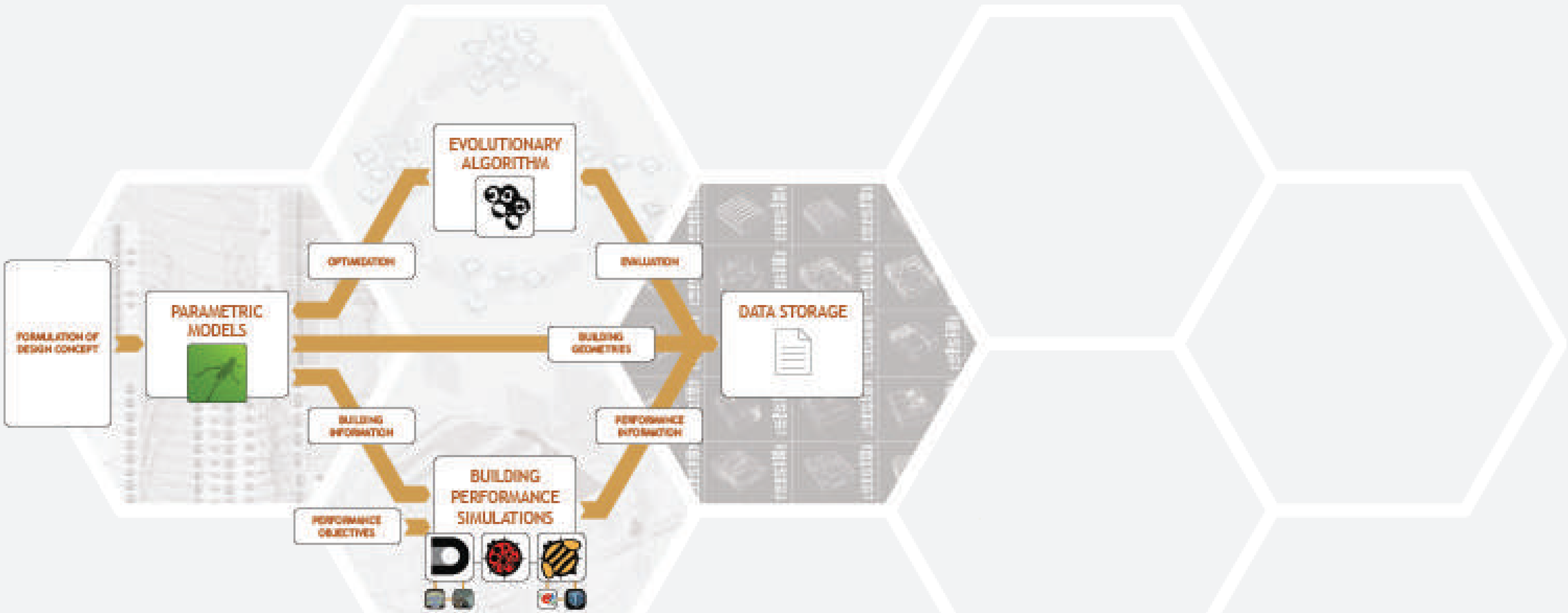
EVOLUTIONARY ALGORITHM
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BUILDING INFORMATION
PERFORMANCE INFORMATION
BUILDING PERFORMANCE SIMULATIONS
PERFORMANCE OBJECTIVES

222143	1065,86	12001	3745,51	17,34	896,23	7,42	1,68	2,44	13,14	4,39	122	703,5	2426,33	993,5	1391	1650,054	41894,11	29858,54	-95381,4
222144	1098,53	11893,69	3811,13	17,34	747,05	2,52	3,59	4,34	5,85	18,53	265,67	630,83	1882	682,86	2021,38	2040,712	41530,48	29858,54	-79505,3
222146	1085	12099,16	3709,72	17,34	877,24	3,3	10,89	2,04	31,86	12,78	161,5	730,67	2690	730,67	1665,8	2004,649	42256,84	29858,54	-93360,7
222147	1102,68	11618,89	3709,98	17,34	679,57	8,38	2,7	22,48	7,54	38,42	253,67	346,33	2088,91	2353,33	2320,68	3166,765	40243,03	29767,82	-72323,4
222148	1098,51	11895,38	3734,7	17,34	792,61	5,4	12,57	5,22	3,48	7,62	181,5	664	2542,67	1055,5	2046,63	1823,194	40021,63	29858,54	-84354
222149	1085,94	11790,68	3690,21	17,34	680,44	26,41	12,69	2,88	12,7	111,4	108,14	480,25	2491	924,5	2070,93	5998,23	44646,96	23536,8	-72416,6
222152	1043,66	11891,27	3712,65	17,34	891,85	21,11	25,57	12,64	5,58	5,46	89,11	225,62	1616,17	1305	1425,67	1754,724	45708,96	29858,54	-94915,2
222153	1052,78	11790,15	3667,38	17,34	783,92	14,98	6,66	12,11	51,34	50,06	274	234,33	1594,5	1470,71	1907,75	3609,259	44183,97	29042,37	-83428,8
222156	1097,11	11582,4	3487,32	17,34	651,46	3,21	74,79	4,32	51,27	184,08	265	1935,71	2635	469,22	2207,43	8152,103	48697,18	17370,05	-69332,4
222157	1072,94	12009,76	3700,53	17,34	858,68	7,19	19,91	2,52	36,14	25,14	33	822,2	2557	402,2	1616,33	2556,378	44234,5	29853,5	-91385,4
222158	1025,41	11434,56	3498,81	17,34	687,99	2,64	70,68	58,78	72,23	141,37	410	621,64	1687,83	1485,46	2041,9	6382,426	53393,35	15659,6	-73219,5
222159	1101	11356,53	3767,69	17,34	552,91	3,82	10,45	0,9	0,9	10,49	271,2	487,69	2369	1457	2159,23	1806,699	40208,43	29858,54	-58843,4
222161	1061,78	11558,83	3637,72	17,34	671,59	23,99	19,76	48,6	4,96	103,81	173,43	978,5	1840,79	1090	2161,89	6396,113	44606,59	19655,06	-71474,1
222162	1095,95	11855,41	3690,59	17,34	732,69	2,52	16,75	29,37	17,71	91,95	398,33	314,8	1448,2	1422,75	2047,73	4994,687	44036,73	24785,78	-77977,4
222164	1105,52	11832,25	3787,57	17,34	764,33	4,14	7,41	8,76	24,5	30,86	294,67	450	2008,25	1147,1	1864,64	2881,388	41504,97	29563,7	-81344,1
222176	1037,89	11624,44	3696,06	19,34	807,03	13,76	12,04	8,23	18,09	11,91	118	465,5	1628,75	1512,5	2192	2098,172	44769,45	29858,54	-85888,3
222179	1060,54	11727,8	3680,21	6,34	755,83	20,1	27,63	26,03	37,37	77,03	127,33	780,43	1558,17	1024,89	1965,08	4069,038	49332,9	21569,63	-80439,8
222181	1101,23	11770,68	3701,12	14,34	740,31	7,75	1,35	10,26	16,46	13,4	466,38	643	2268	985,5	1989,4	2283,705	38786,54	29858,54	-78787,9
222182	1072,3	11858,7	3637,22	14,34	780,29	29,98	29,95	35,97	6,07	75,13	155,67	373,5	1932,25	1195,33	1697,33	4897,19	44765,38	22763,16	-83042,8
222184	1093,9	12033,19	3753,14	-5,66	811,75	2,88	7,39	19,11	1,44	26,45	206	857,67	2121,13	896	1891,91	2466,762	40720,97	29800,58	-86390,7
222186	1053,77	11421,35	3534,3	6,34	597,89	3,28	54,62	41,31	32,39	166,69	371	1182,4	1915,33	1053,75	2237,65	8881,565	45512,77	16659,41	-63631
222187	1032,05	11493,63	3615,21	14,34	766,97	12,9	2,82	6,21	18,84	6,54	111,22	707	1739,33	1020,82	2149,42	1859,023	42359,29	29858,54	-81625,4
222192	1030,19	11478,89	3559,37	18,34	744,6	29,12	50,86	25,58	50,78	73,13	375,5	466,86	1534,38	1181,38	1984,47	5310,538	48603,74	19131,84	-79244,4
222196	1110	11125,11	3731,57	14,34	487,24	10,87	2,52	7,72	13,68	44,65	392,29	760,5	1884,25	1168,92	2352,52	3627,181	38336,67	29858,54	-51854,9
222199	1095,62	11767,83	3754,71	7,34	689,59	11,36	12,46	5,52	20,08	62,9	324,2	498	2580	937	2196,38	3475,25	44125,22	27055,04	-73389,9
222200	1100,7	12027,91	3815,03	14,34	803,57	2,28	1,62	11,01	2,87	13,54	506	1044	2138,57	1077,5	1482,14	1957,913	40737,35	29858,54	-85520,1
222202	1110	11383,84	3787,16	18,34	597,27	2,48	3,13	8,86	8,46	14,28	268	783	2508,91	1515,45	2315,26	2203,947	38875,88	29858,54	-63564,3
222203	1110	11860,26	3824,61	14,34	725,31	3,78	2,52	7,19	4,26	10,84	278	833,5	2079,2	842,25	2096,69	1931,837	40165,3	29858,54	-77191,8
222204	1085,36	10991,49	3753,09	14,34	571,23	4,88	6,95	4,2	9,24	11,66	348,43	575,25	2442	1041,23	2293,45	2046,232	40660,45	29858,54	-60793,9
222206	1066,31	11544,75	3586,9	10,34	658,94	24,56	33,36	9,38	43,25	106,52	420,75	496,6	1842	1258,64	2371,76	5449,722	48513,17	23103,36	-70128,2
222207	1075,17	11287,32	3671,68	8,34	570,67	10,37	16,05	7,77	17,17	35,09	389,67	852,86	2201	1000,88	2116,49	3256,279	41400,64	29830,82	-60734
222211	1039,66	11469,36	3577,78	6,34	669,87	38,37	66,94	4,26	31,89	123,08	143,4	739,33	959	842,1	2196	5821,983	52132,71	22341,69	-71291,1
222219	1067,32	11609,19	3604,85	8,34	699,48	23,04	32,41	8,7	44,23	91,04	401	520,4	1877,5	1208,27	2275,35	4815,33	48069,64	25142,36	-74442,7
222220	1105,65	12112,86	3777,87	15,34	829,08	3,94	12,28	3,94	0,74	2,53	28	713,8	1676	830,33	2006,25	1663,488	40174,52	29858,54	-88235,7
222224	1044,15	11395,2	3702,27	18,34	721,14	6,45	16,87	4,95	8,94	9,86	116,7	322,06	2373,67	1045,18	2329,31	1942,925	43523,21	29858,54	-76747,9
222225	1048,91	11984,1	3752,76	28,34	890,98	4,99	1,38	6,85	3,75	1,29	198	764	1814,82	1746	1114,5	1507,866	43225,18	29858,54	-94822,7
222227	1058,82	11632	3600,13	14,34	702,18	0,76	50,09	43,9	31,52	122,8	435	583,5	1681	1237,57	2068,56	5922,559	51041	21122,64	-74729,6
222228	1053,9	12079,46	3691,64	14,34	916,53	9,9	7,56	3,79	0,81	0,46	119,67	884,33	1521,83	371,5	0	1539,268	41780,17	29858,54	-97542,2
222231	1110	11691,88	3621,08	18,34	607,79	0	1,62	49,01	4,86	166,01	0	723	2274,33	1354	2337,61	9032,907	39911,1	18832,59	-64684,3
222233	1050,74	11801,91	3694,32	14,34	812,4	0	26,1	35,45	6,84	20,03	0	657,08	1969,73	1281	1941,8	2546,06	44087,99	29858,54	-86459,8
222242	1054,5	11815,6	3802,88	14,34	778,34	2,52	5,11	4,24	5,04	5,69	68	426,83	1681,13	1126,5	1940,71	1605,985	43876,71	29858,54	-82834,7
222257	1085,81	12133,68	3714,4	14,34	887,35	35,81	11,09	4,8	5,37	11,69	83,33	444,33	2551	1255,67	1046,86	2007,516	42458,57	29858,54	-94436,5
222258	1083,7	11725,98	3720,98	20,34	653,42	8,07	14,64	9,98	6,84	57,81	89,4	279,33	2019,6	1539,67	2294,09	3797,204	41948,95	29253,11	-69541
222260	1099,73	11968,4	3719,23	21,34	812,91	11,22	6,3	2,33	5,36	2,03	187	612,67	2466	1106,67	2053,67	1722,652	39142,98	29858,54	-86514,2
222266	1054,52	12003,38	3722,53	19,34	907,9	6,55	6	6,13	5,71	0	17,5	689	1854,71	784,8	0	1530,497	42701,3	29858,54	-96624,1
222268	1099,05	11980,7	3766,91	18,34	797,58	5,12	5,04	1,68	3,25	3,74	99	694,67	2545	895,33	2067	1673,527	39726,82	29858,54	-84882,7
222271	1060,96	12007,99	3740,7	14,34	869,58	9,44	16,88	16,83	2,22	9,24	174	653,33	1725,33	1186	1673,4	1923,08	43357,32	29858,54	-92545,9

222143	1065,86	12001	3745,51	17,34	896,23	7,42	1,68	2,44	13,14	4,39	122	703,5	2426,33	993,5	1391	1650,054	41894,11	29858,54	-95381,4
222144	1098,53	11893,69	3811,13	17,34	747,05	2,52	3,59	4,34	5,85	18,53	265,67	630,83	1882	682,86	2021,38	2040,712	41530,48	29858,54	-79505,3
222146	1085	12099,16	3709,72	17,34	877,24	3,3	10,89	2,04	31,86	12,78	161,5	730,67	2690	730,67	1665,8	2004,649	42256,84	29858,54	-93360,7
222147	1102,68	11618,89	3709,98	17,34	679,57	8,38	2,7	22,48	7,54	38,42	253,67	346,33	2088,91	2353,33	2320,68	3166,765	40243,03	29767,82	-72323,4
222148	1098,51	11895,38	3734,7	17,34	792,61	5,4	12,57	5,22	3,48	7,62	181,5	664	2542,67	1055,5	2046,63	1823,194	40021,63	29858,54	-84354
222149	1085,94	11790,68	3690,21	17,34	680,44	26,41	12,69	2,88	12,7	111,4	108,14	480,25							3 -72416,6
222152	1043,66	11891,27	3712,65	17,34	891,85	21,11	25,57	12,64	5,58	5,46	89,11								4 -94915,2
222153	1052,78	11790,15	3667,38	17,34	783,92	14,98	6,66	12,11	51,34	50,06	274								7 -83428,8
222156	1097,11	11582,4	3487,32	17,34	651,46	3,21	74,79	4,32	51,27	184,08									5 -69332,4
222157	1072,94	12009,76	3700,53	17,34	858,68	7,19	19,91	2,52	36,14	25,14									5 -91385,4
222158	1025,41	11434,56	3498,81	17,34	687,99	2,64	70,68	58,78	72,23	141,37									6 -73219,5
222159	1101	11356,53	3767,69	17,34	552,91	3,82	10,45	0,9	0,9	10,49									4 -58843,4
222161	1061,78	11558,83	3637,72	17,34	671,59	23,99	19,76	48,6	4,96	103,81									5 -71474,1
222162	1095,95	11855,41	3690,59	17,34	732,69	2,52	16,75	29,37	17,71	91,95									3 -77977,4
222164	1105,52	11832,25	3787,57	17,34	764,33	4,14	7,41	8,76	24,5	30,86									7 -81344,1
222176	1037,89	11624,44	3696,06	19,34	807,03	13,76	12,04	8,23	18,09	11,91									4 -85888,3
222179	1060,54	11727,8	3680,21	6,34	755,83	20,1	27,63	26,03	37,37	77,03									3 -80439,8
222181	1101,23	11770,68	3701,12	14,34	740,31	7,75	1,35	10,26	16,46	13,4									4 -78787,9
222182	1072,3	11858,7	3637,22	14,34	780,29	29,98	29,95	35,97	6,07	75,13									5 -83042,8
222184	1093,9	12033,19	3753,14	-5,66	811,75	2,88	7,39	19,11	1,44	26,45									3 -86390,7
222186	1053,77	11421,35	3534,3	6,34	597,89	3,28	54,62	41,31	32,39	166,69									1 -63631
222187	1032,05	11493,63	3615,21	14,34	766,97	12,9	2,82	6,21	18,84	6,54									4 -81625,4
222192	1030,19	11478,89	3559,37	18,34	744,6	29,12	50,86	25,58	50,78	73,13									4 -79244,4
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222200	1100,7	12027,91	3815,03	14,34	803,57	2,28	1,62	11,01	2,87	13,54									4 -85520,1
222202	1110	11383,84	3787,16	18,34	597,27	2,48	3,13	8,86	8,46	14,28									4 -63564,3
222203	1110	11860,26	3824,61	14,34	725,31	3,78	2,52	7,19	4,26	10,84									4 -77191,8
222204	1085,36	10991,49	3753,09	14,34	571,23	4,88	6,95	4,2	9,24	11,66									4 -60793,9
222206	1066,31	11544,75	3586,9	10,34	658,94	24,56	33,36	9,38	43,25	106,52									6 -70128,2
222207	1075,17	11287,32	3671,68	8,34	570,67	10,37	16,05	7,77	17,17	35,09									2 -60734
222211	1039,66	11469,36	3577,78	6,34	669,87	38,37	66,94	4,26	31,89	123,08									9 -71291,1
222219	1067,32	11609,19	3604,85	8,34	699,48	23,04	32,41	8,7	44,23	91,04									6 -74442,7
222220	1105,65	12112,86	3777,87	15,34	829,08	3,94	12,28	3,94	0,74	2,53									4 -88235,7
222224	1044,15	11395,2	3702,27	18,34	721,14	6,45	16,87	4,95	8,94	9,86									4 -76747,9
222225	1048,91	11984,1	3752,76	28,34	890,98	4,99	1,38	6,85	3,75	1,29									4 -94822,7
222227	1058,82	11632	3600,13	14,34	702,18	0,76	50,09	43,9	31,52	122,8									4 -74729,6
222228	1053,9	12079,46	3691,64	14,34	916,53	9,9	7,56	3,79	0,81	0,46									4 -97542,2
222231	1110	11691,88	3621,08	18,34	607,79	0	1,62	49,01	4,86	166,01									9 -64684,3
222233	1050,74	11801,91	3694,32	14,34	812,4	0	26,1	35,45	6,84	20,03								99	29858,54	-86459,8
222242	1054,5	11815,6	3802,88	14,34	778,34	2,52	5,11	4,24	5,04	5,69							85	43876,71	29858,54	-82834,7
222257	1085,81	12133,68	3714,4	14,34	887,35	35,81	11,09	4,8	5,37	11,69							16	42458,57	29858,54	-94436,5
222258	1083,7	11725,98	3720,98	20,34	653,42	8,07	14,64	9,98	6,84	57,81	89,4	279,33	2019,6	1539,67	2294,09	3797,204	41948,95	29253,11	-69541
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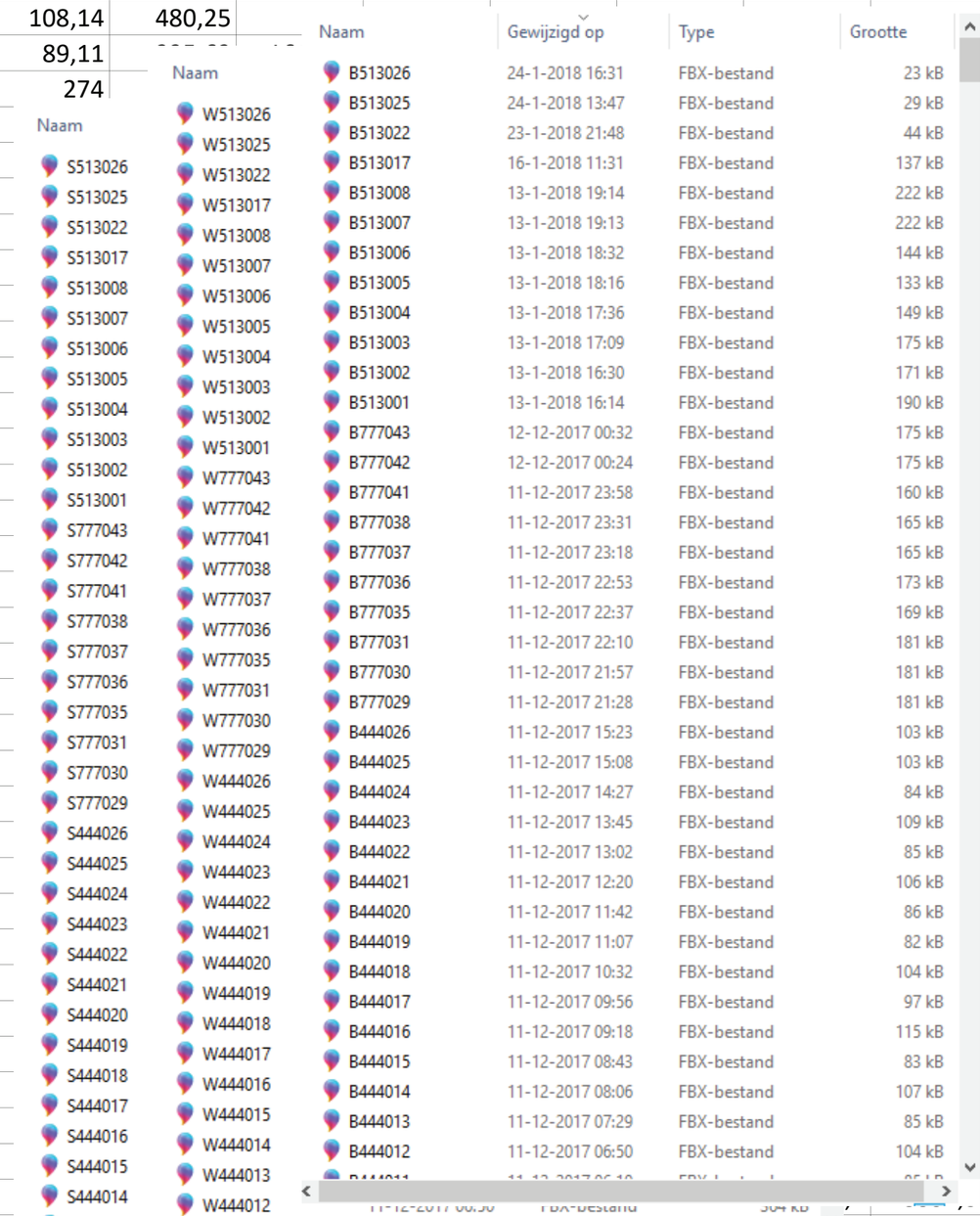
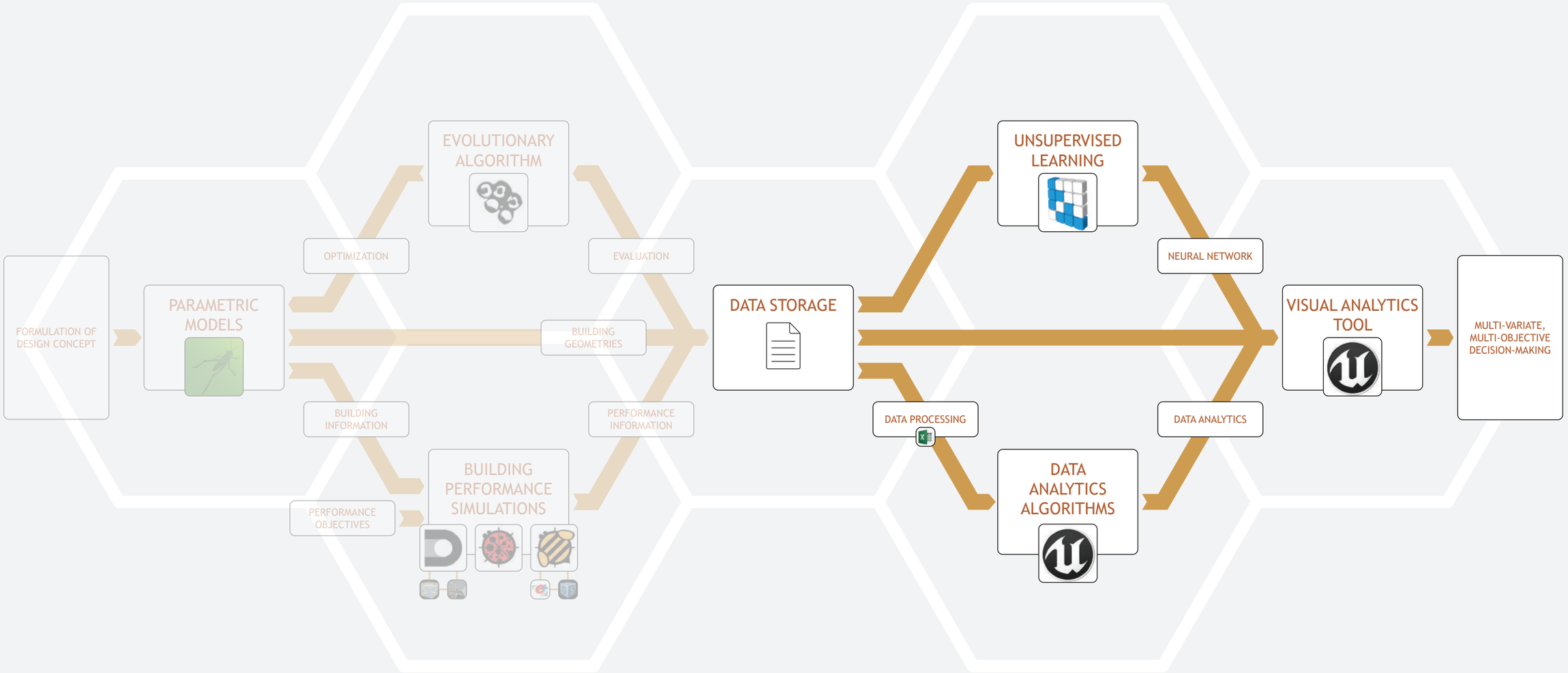
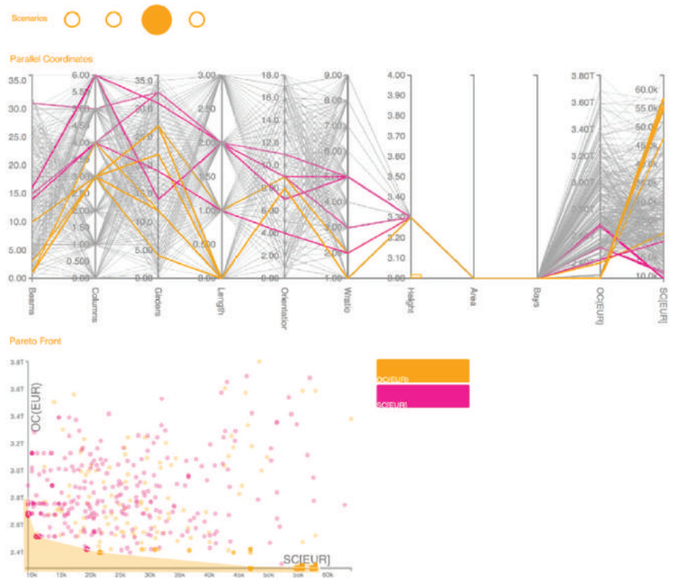
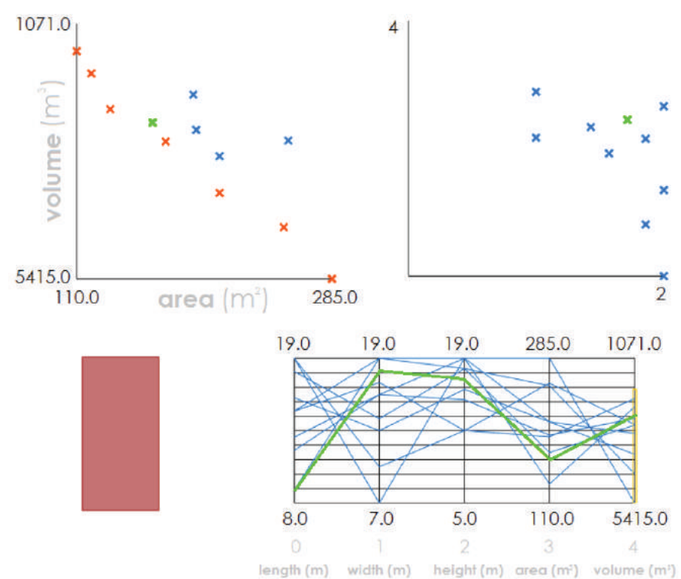
222266	1054,52	12003,38	3722,53	19,34	907,9	6,55	6	6,13	5,71	0	17,5	689	1854,71	784,8	0	1530,497	42701,3	29858,54	-96624,1
222268	1099,05	11980,7	3766,91	18,34	797,58	5,12	5,04	1,68	3,25	3,74	99	694,67	2545	895,33	2067	1673,527	39726,82	29858,54	-84882,7
222271	1060,96	12007,99	3740,7	14,34	869,58	9,44	16,88	16,83	2,22	9,24	174	653,33	1725,33	1186	1673,4	1923,08	43357,32	29858,54	-92545,9



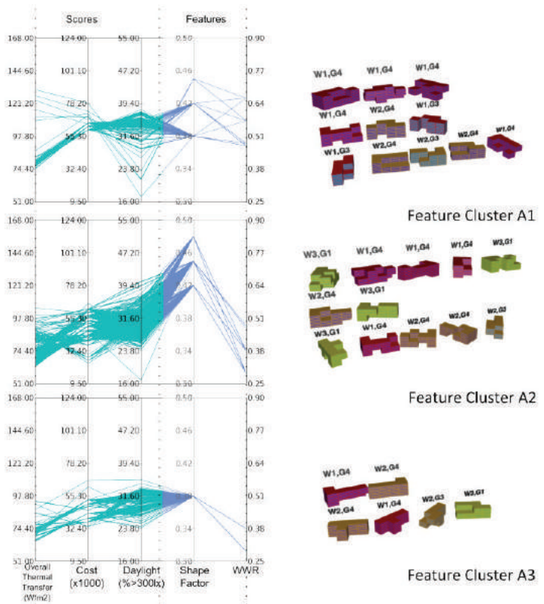

FORMULATION OF DESIGN CONCEPT
PARAMETRIC MODELS
OPTIMIZATION
EVOLUTIONARY ALGORITHM
EVALUATION
BUILDING GEOMETRIES
BUILDING INFORMATION
PERFORMANCE INFORMATION
PERFORMANCE OBJECTIVES
BUILDING PERFORMANCE SIMULATIONS
DATA STORAGE
UNSUPERVISED LEARNING
NEURAL NETWORK
DATA PROCESSING
DATA ANALYTICS
DATA ANALYTICS ALGORITHMS
VISUAL ANALYTICS TOOL
MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING



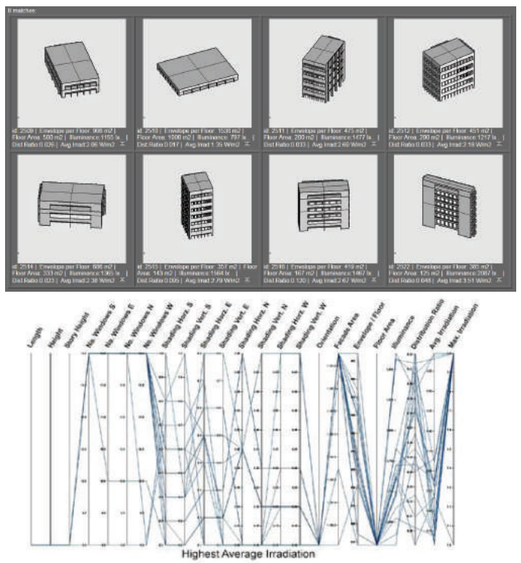
JANSEN ET AL., 2014



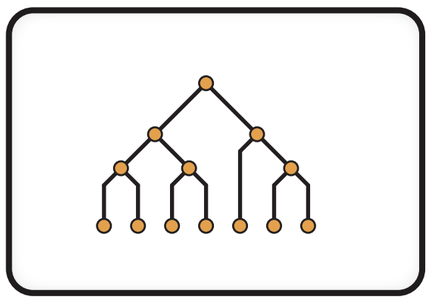
LAMPING, 2016

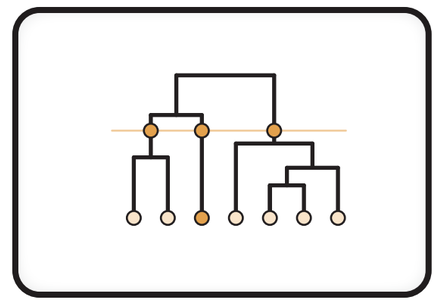


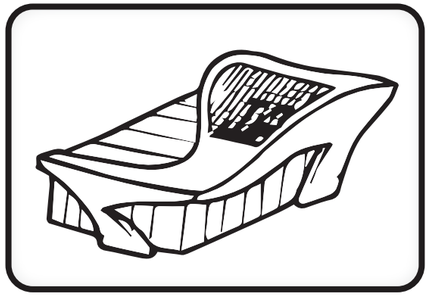
CHEN, JANSSEN & SCHLUETER, 2015

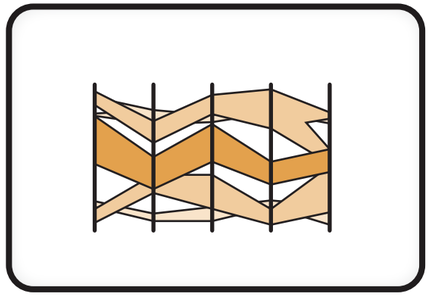


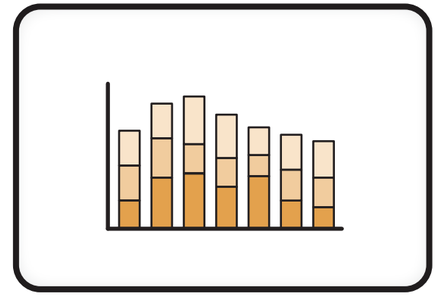
CHASZAR, VON BUELOW & TURRIN, 2016

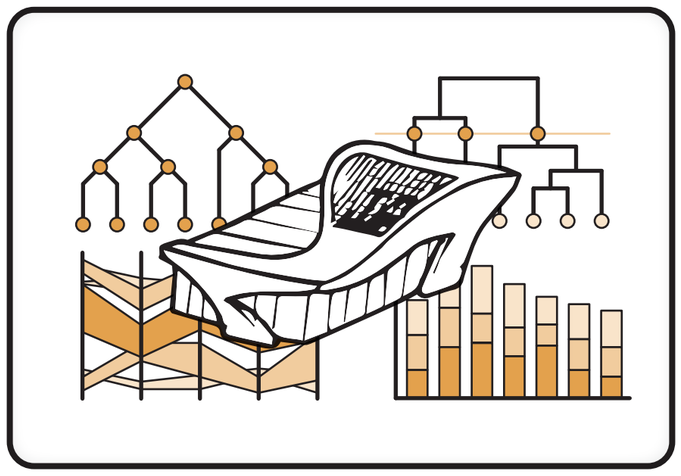




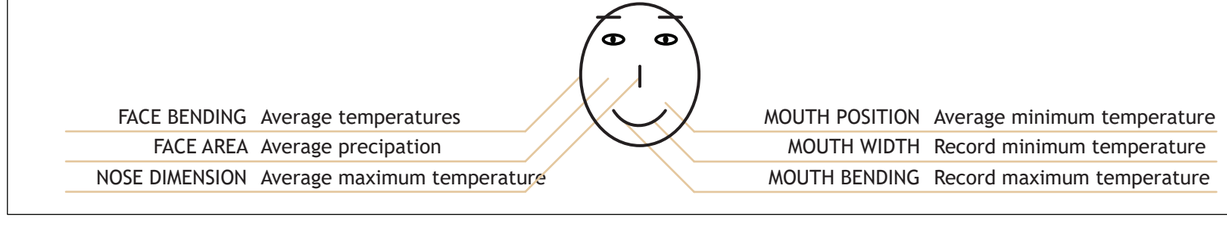




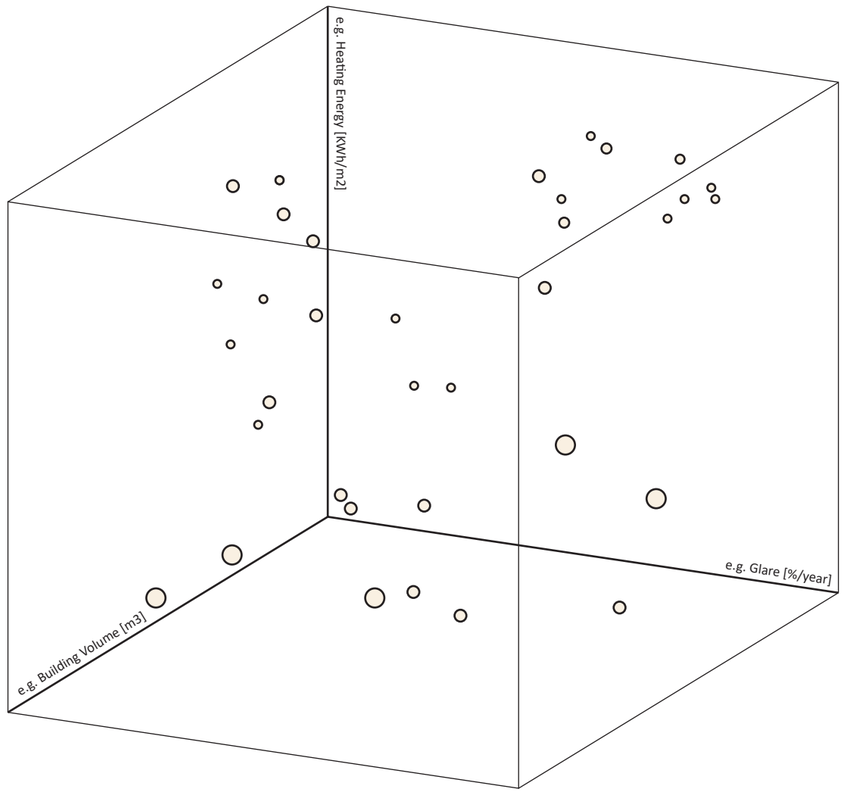


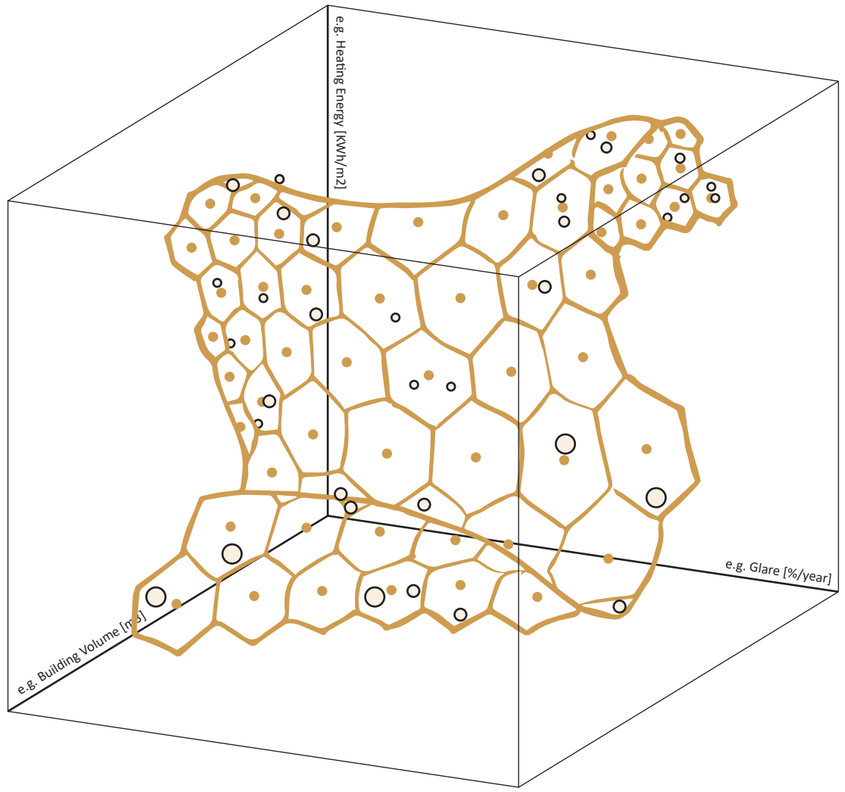


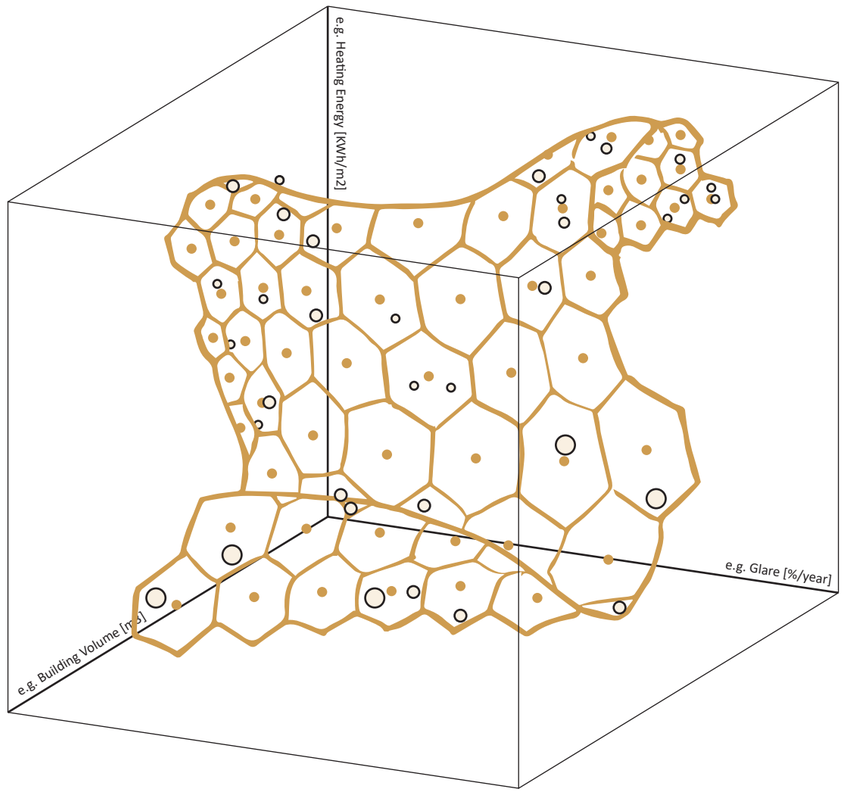
 ATHENS	 DUBLIN	 MADRID	 RIO DE JANEIRO
 BUCHAREST	 HELSINKI	 MOSCOW	 ROME
 CANBERRA	 HONG KONG	 NEW YORK	 TUNIS
 MEXICO CITY	 LONDON	 PORTO	 ZURICH

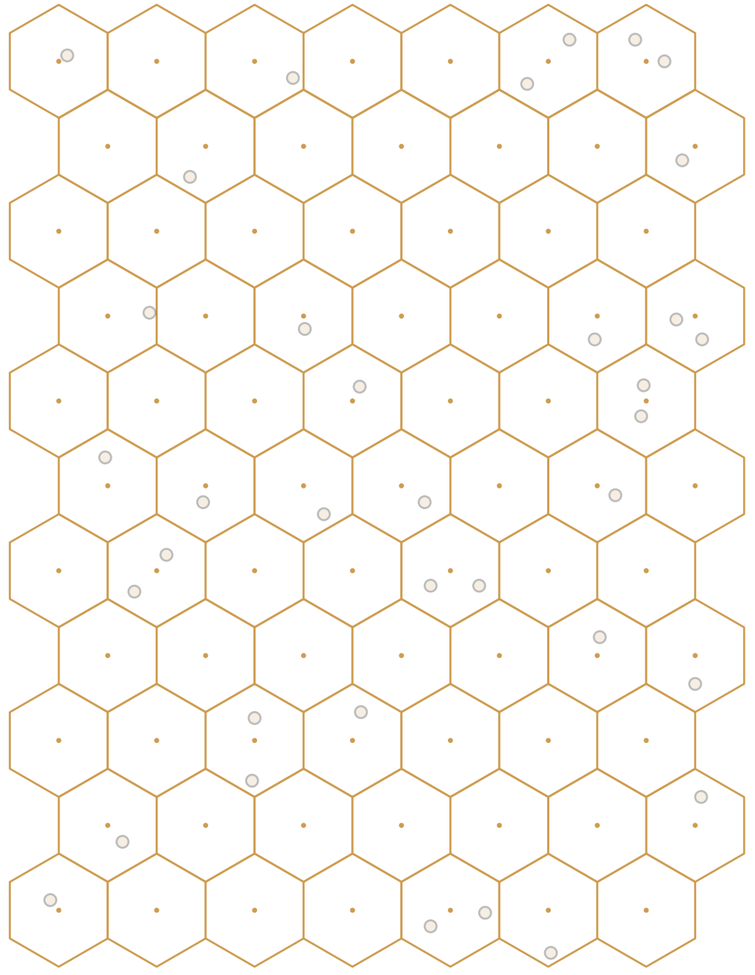


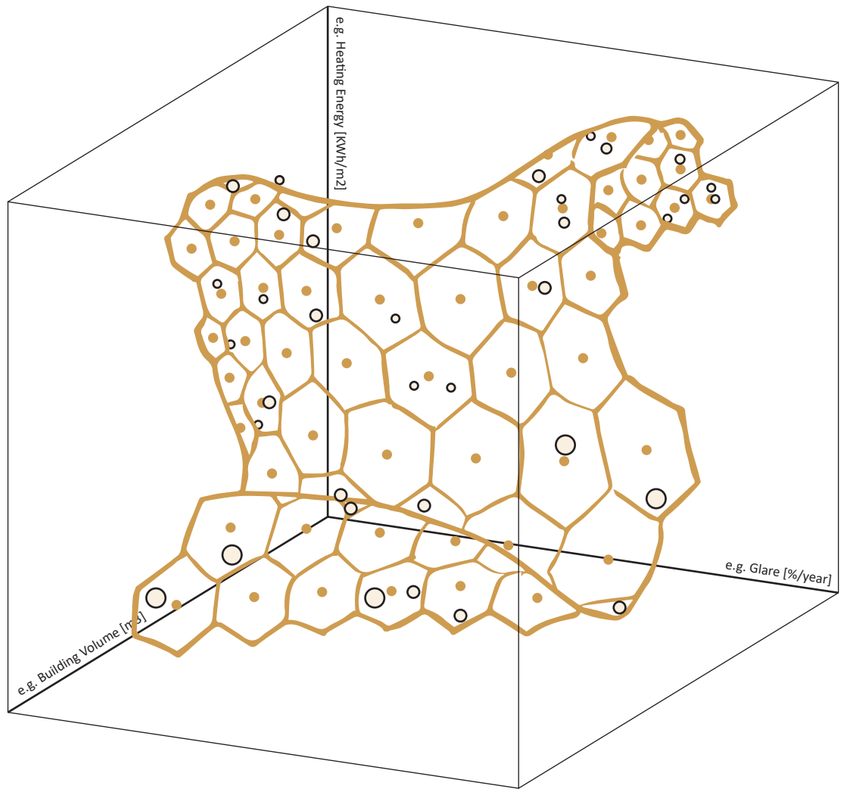
DERIVED FROM MAZZA, 2009, P.58

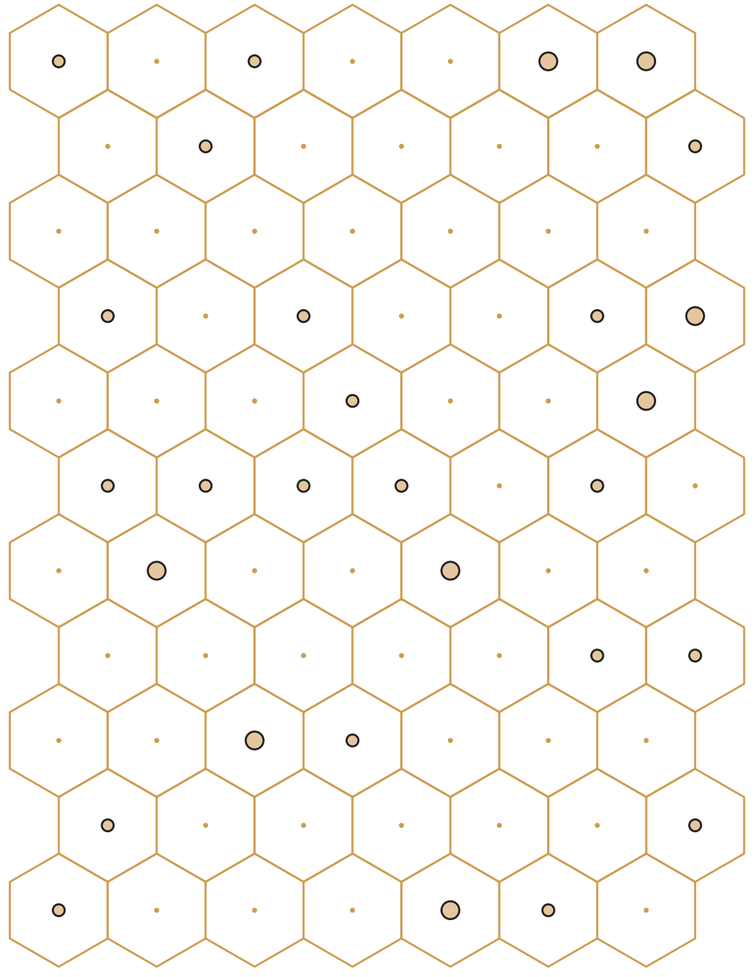

e.g. Heating Energy [KWh/m2]
e.g. Glare [%/year]
e.g. Building Volume [m3]

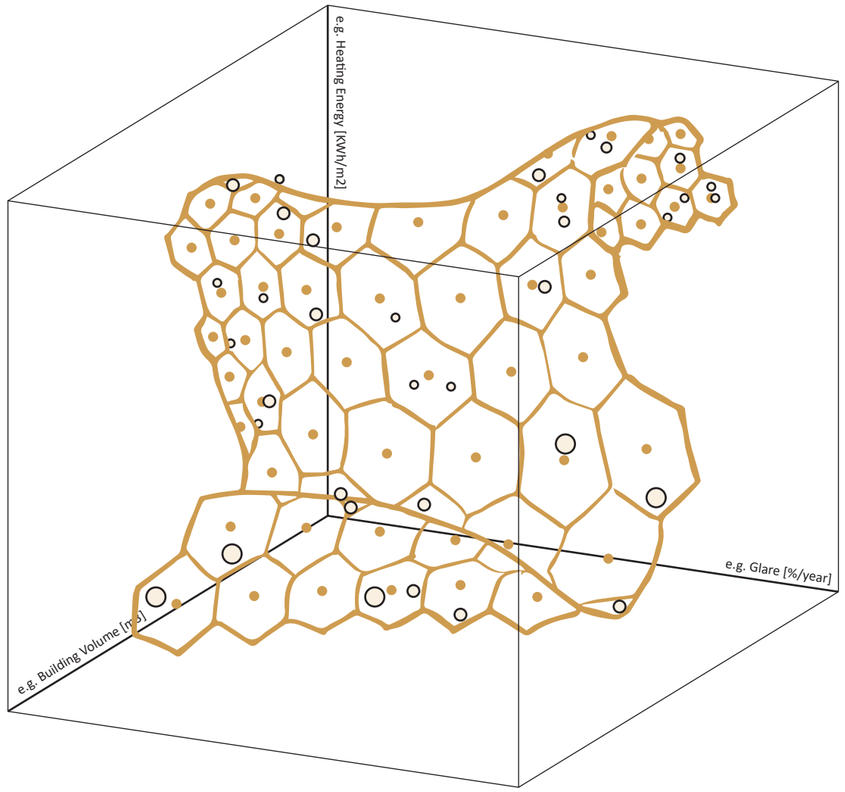

e.g. Heating Energy [KWh/m2]
e.g. Building Volume [m3]
e.g. Glare [%/year]

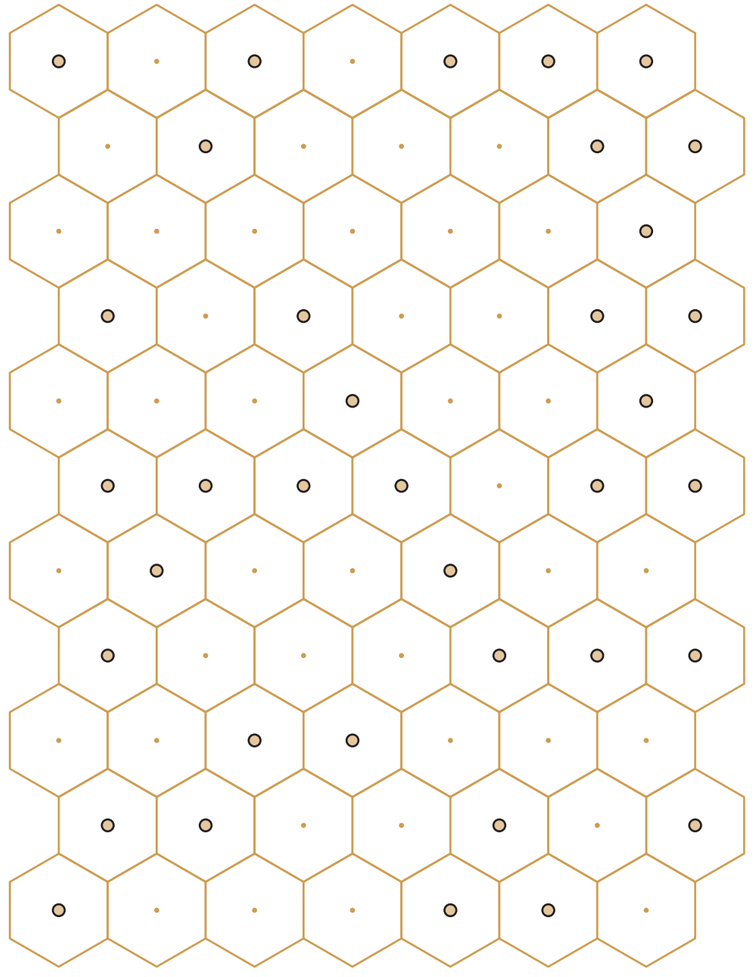

e.g. Heating Energy [KWh/m2]
e.g. Glare [%/year]
e.g. Building Volume [m3]

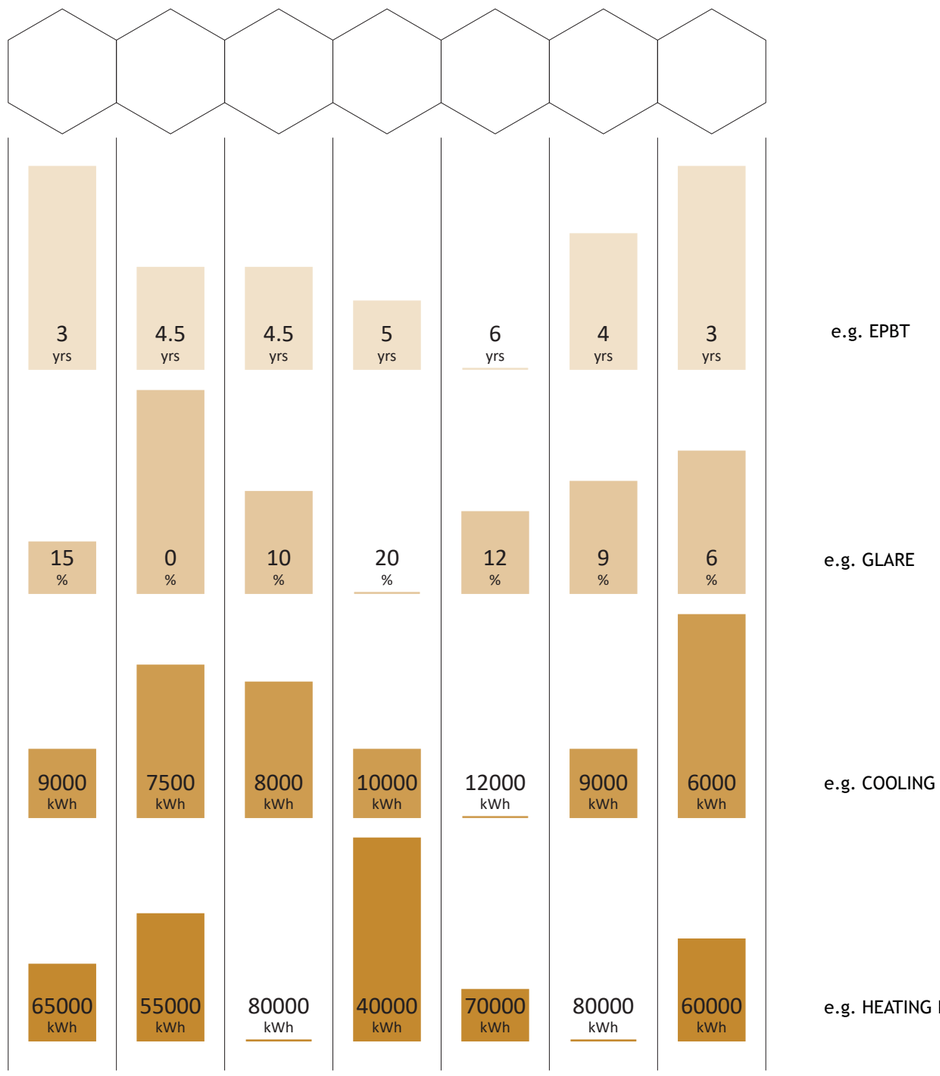


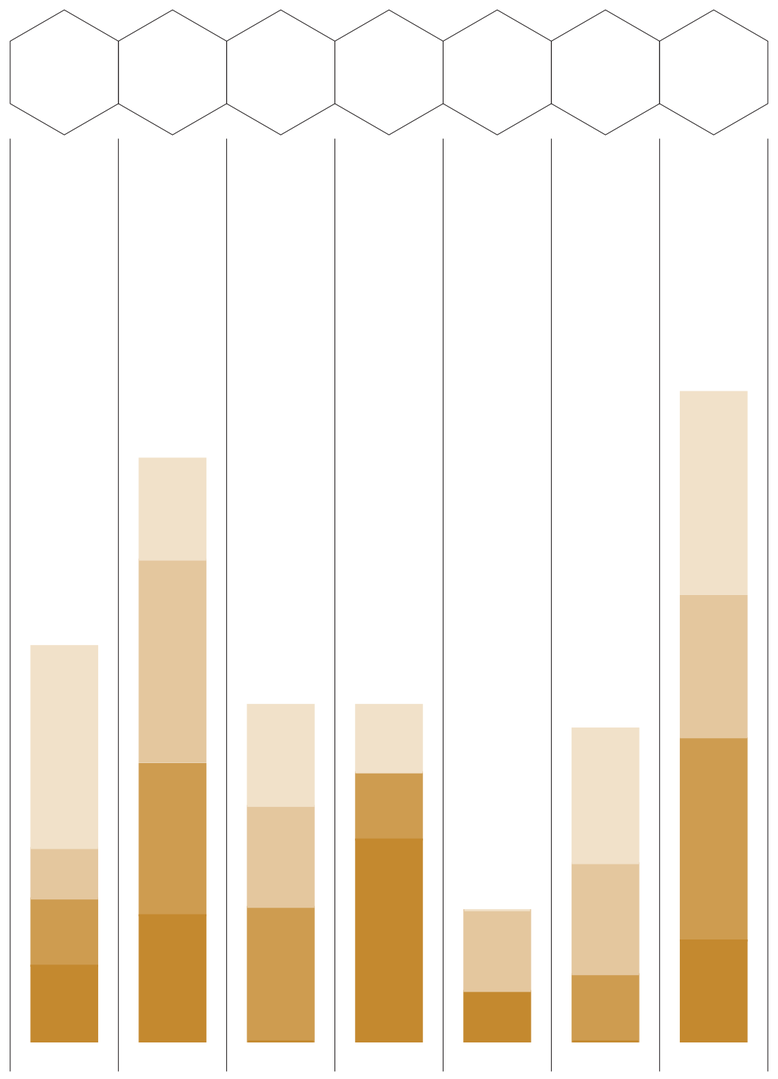

e.g. Heating Energy [KWh/m2]
e.g. Glare [%/year]
e.g. Building Volume [m3]

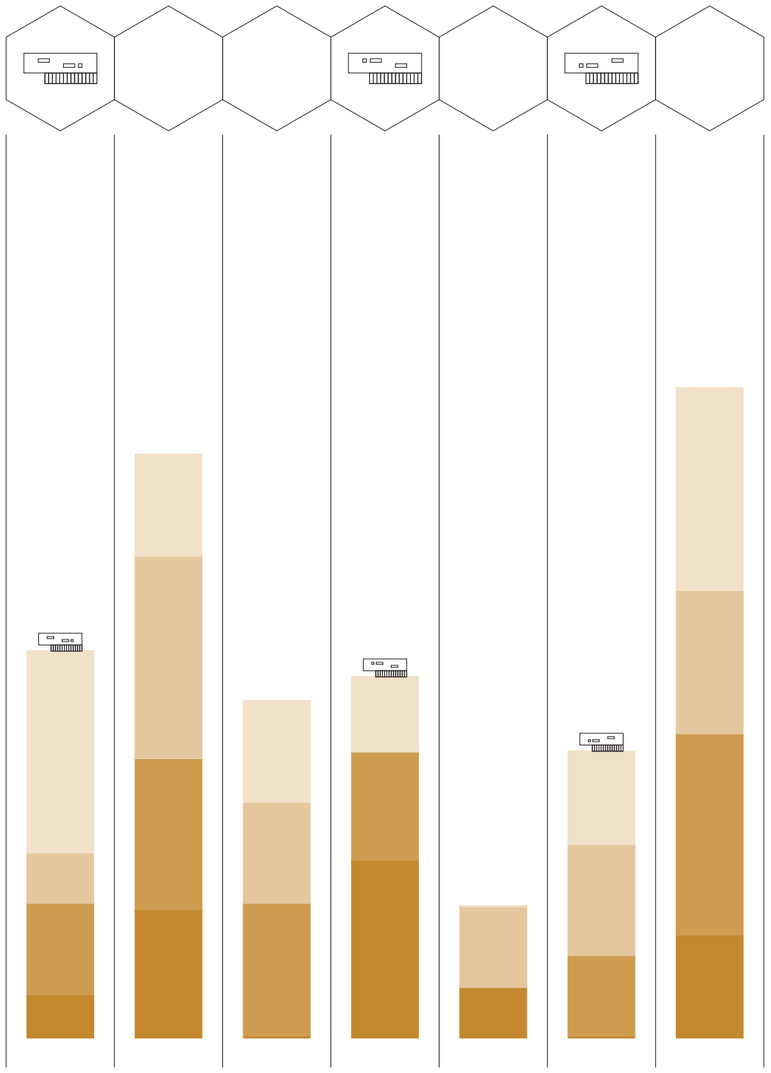


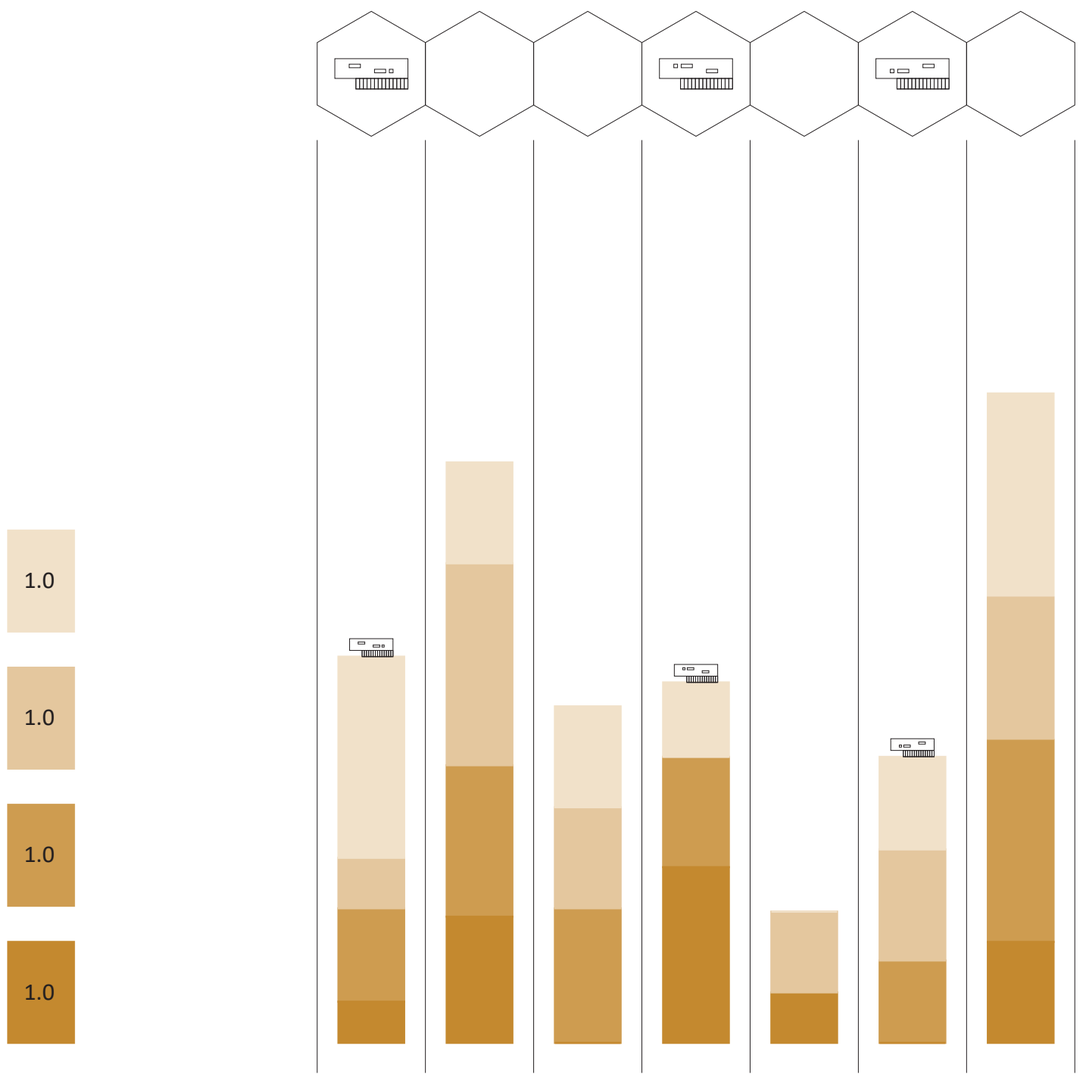

e.g. Heating Energy [KWh/m2]
e.g. Glare [%/year]
e.g. Building Volume [m3]




3 yrs
4.5 yrs
4.5 yrs
5 yrs
6 yrs
4 yrs
3 yrs
e.g. EPBT
15 %
0 %
10 %
20 %
12 %
9 %
6 %
e.g. GLARE
9000 kWh
7500 kWh
8000 kWh
10000 kWh
12000 kWh
9000 kWh
6000 kWh
e.g. COOLING ENERGY
65000 kWh
55000 kWh
80000 kWh
40000 kWh
70000 kWh
80000 kWh
60000 kWh
e.g. HEATING ENERGY



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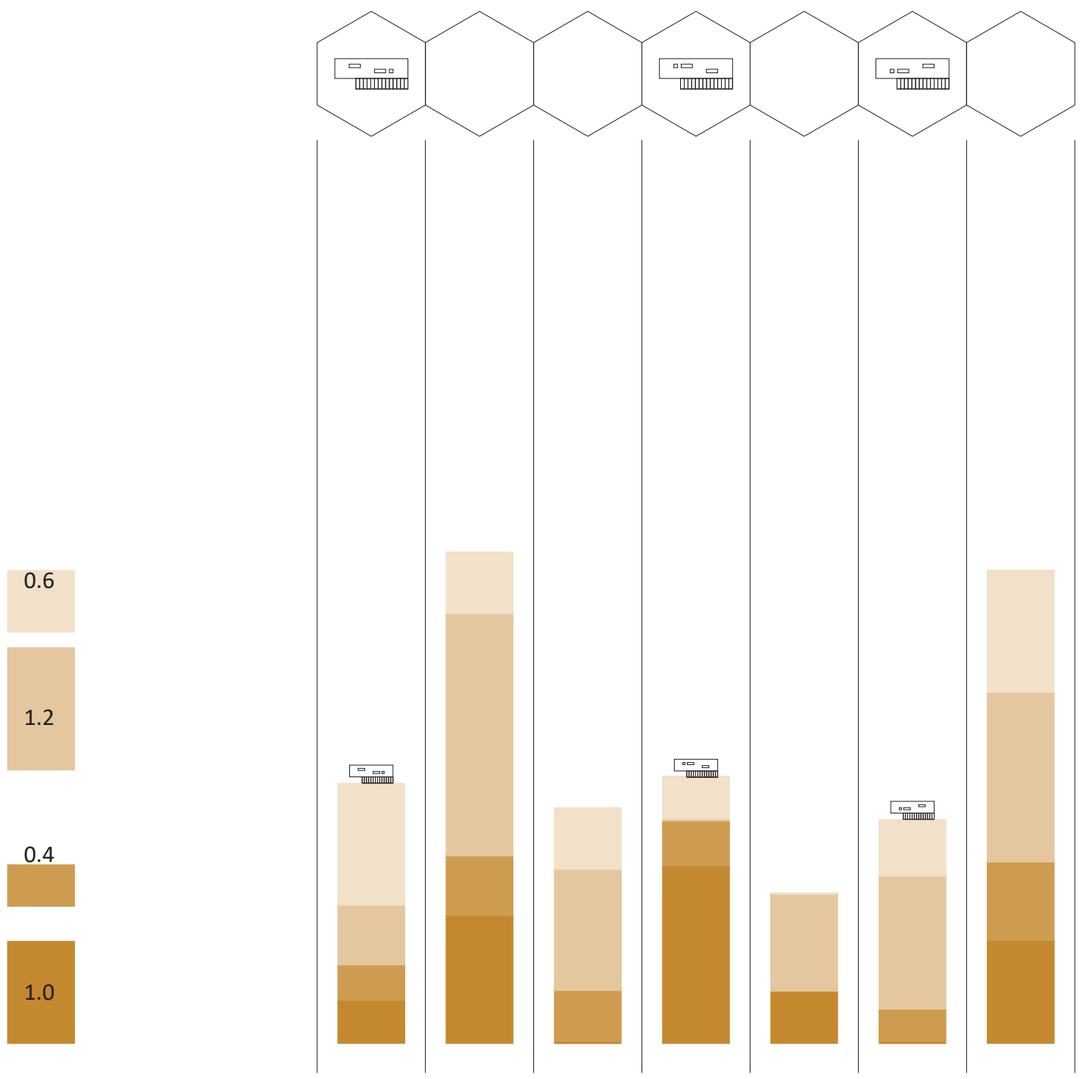
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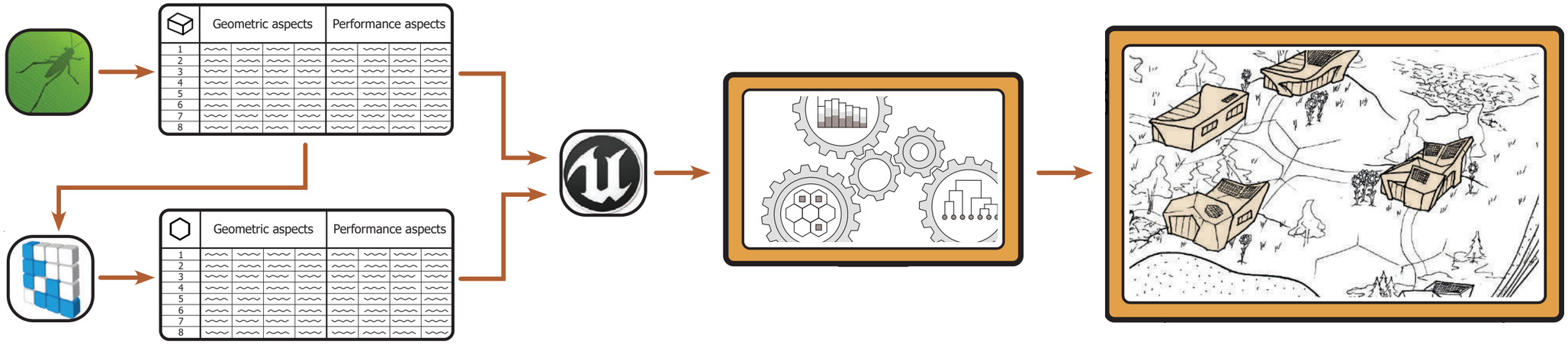
Geometric aspects
Performance aspects
1
2
3
4
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8
Geometric aspects
Performance aspects
1
2
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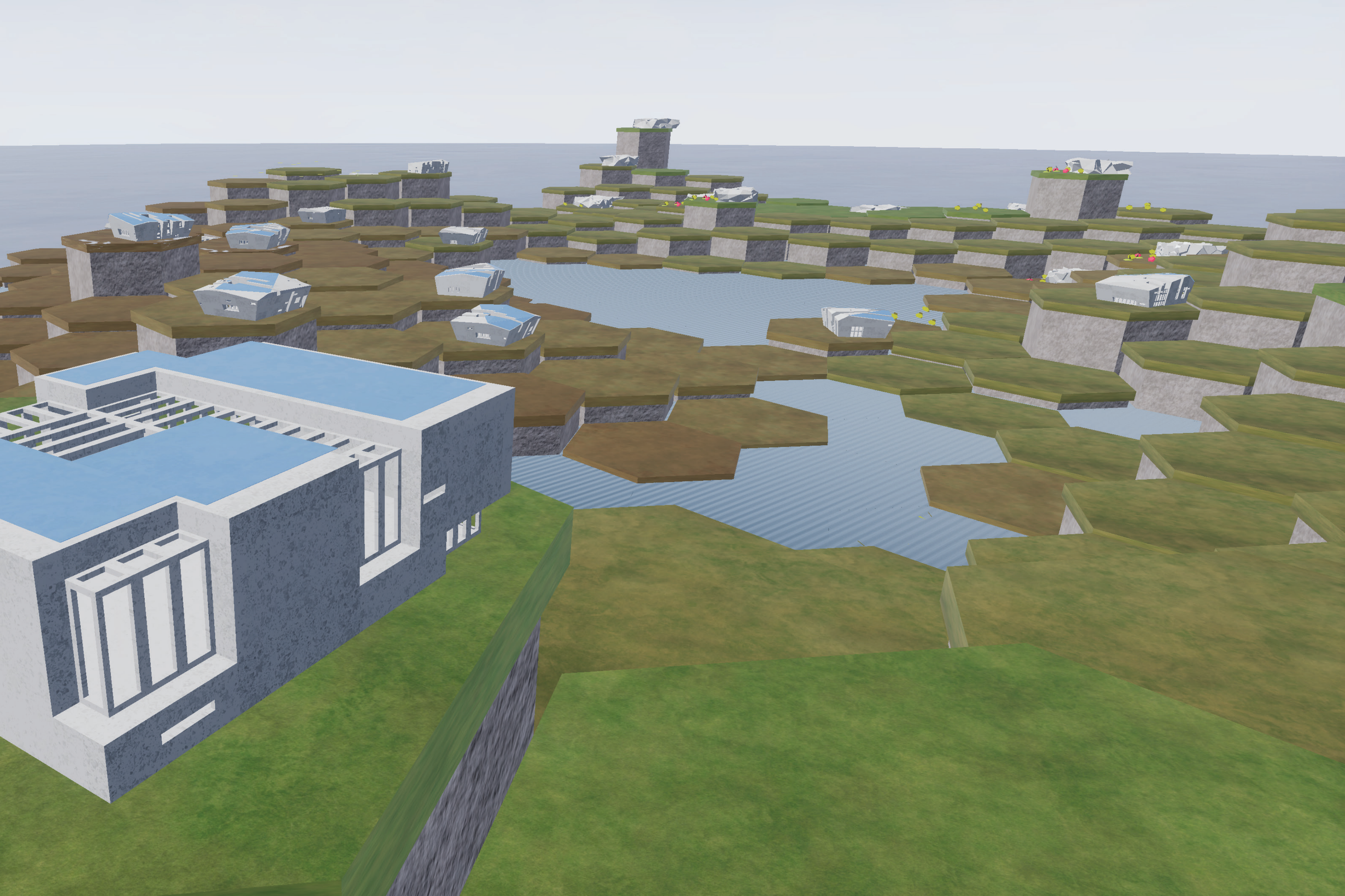
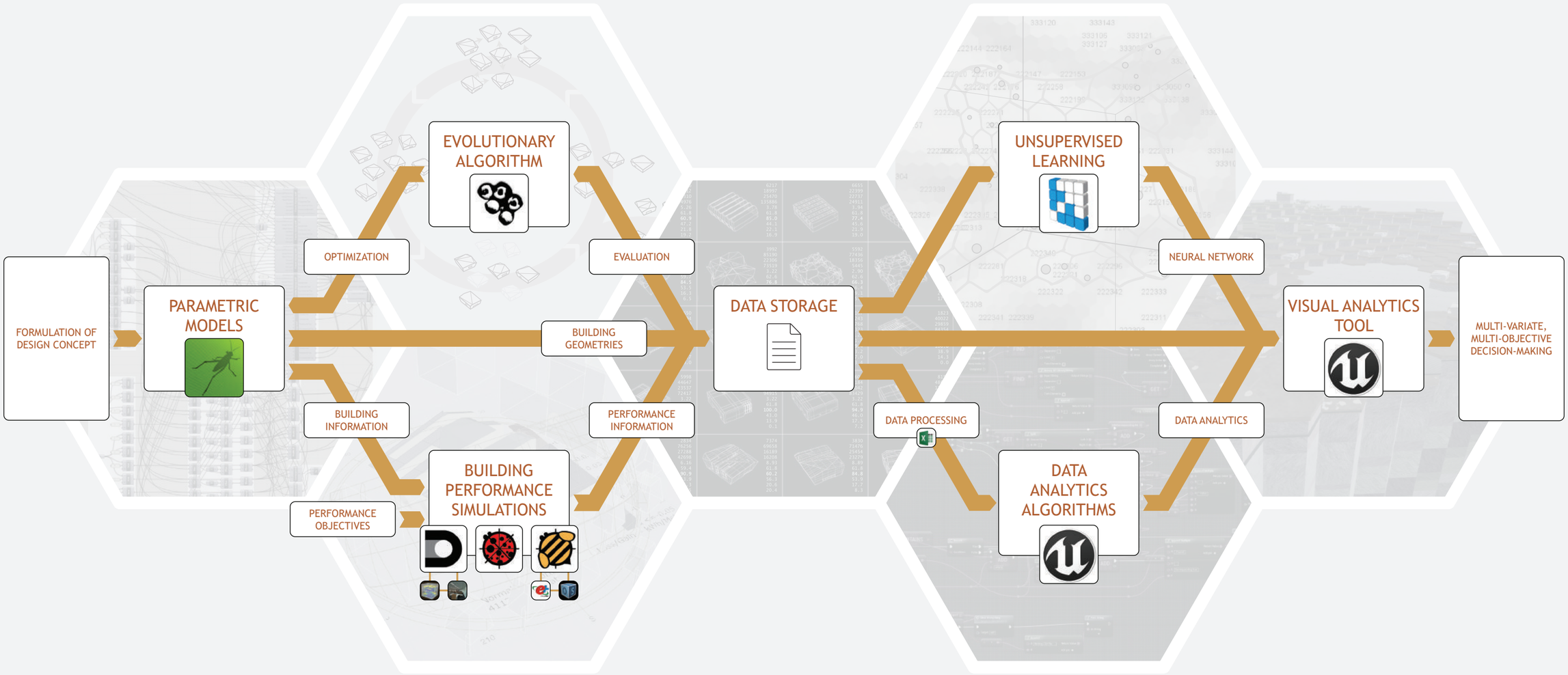
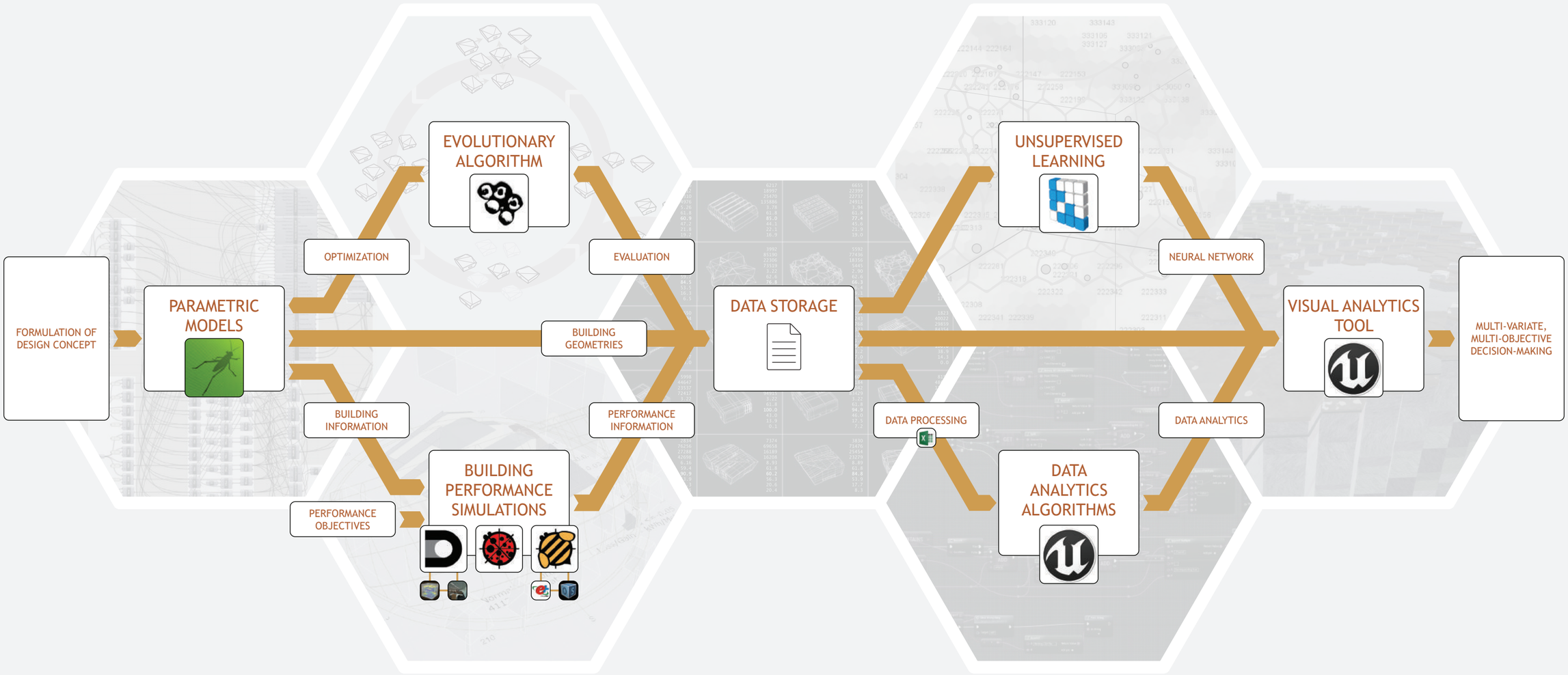



FORMULATION OF DESIGN CONCEPT
PARAMETRIC MODELS
OPTIMIZATION
EVOLUTIONARY ALGORITHM
BUILDING GEOMETRIES
BUILDING INFORMATION
PERFORMANCE OBJECTIVES
BUILDING PERFORMANCE SIMULATIONS
EVALUATION
PERFORMANCE INFORMATION
DATA STORAGE
DATA PROCESSING
DATA ANALYTICS ALGORITHMS
UNSUPERVISED LEARNING
NEURAL NETWORK
DATA ANALYTICS
VISUAL ANALYTICS TOOL
MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING



SUITABLE COMPUTATIONAL DESIGN SYSTEM

DOES USE OF A DATA-DRIVEN DESIGN APPROACH RESULT IN BETTER-PERFORMING DESIGNS?

EFFECTIVE VISUAL ANALYTICS SYSTEM

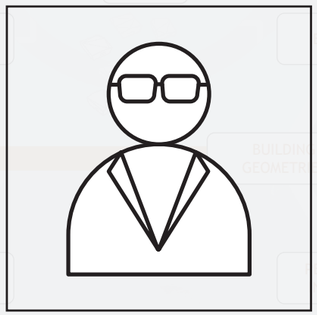
DOES THE VISUAL ANALYTICS TOOL ENABLE INTUITIVE DESIGN EXPLORATION?

SUITABLE COMPUTATIONAL DESIGN SYSTEM

DOES USE OF A DATA-DRIVEN DESIGN APPROACH RESULT IN BETTER-PERFORMING DESIGNS?

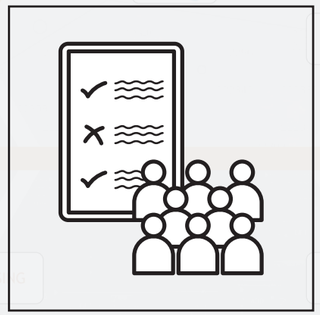
EFFECTIVE VISUAL ANALYTICS SYSTEM

DOES THE VISUAL ANALYTICS TOOL ENABLE INTUITIVE DESIGN EXPLORATION?



PERSONAL EXPERIENCE

PEER REVIEW



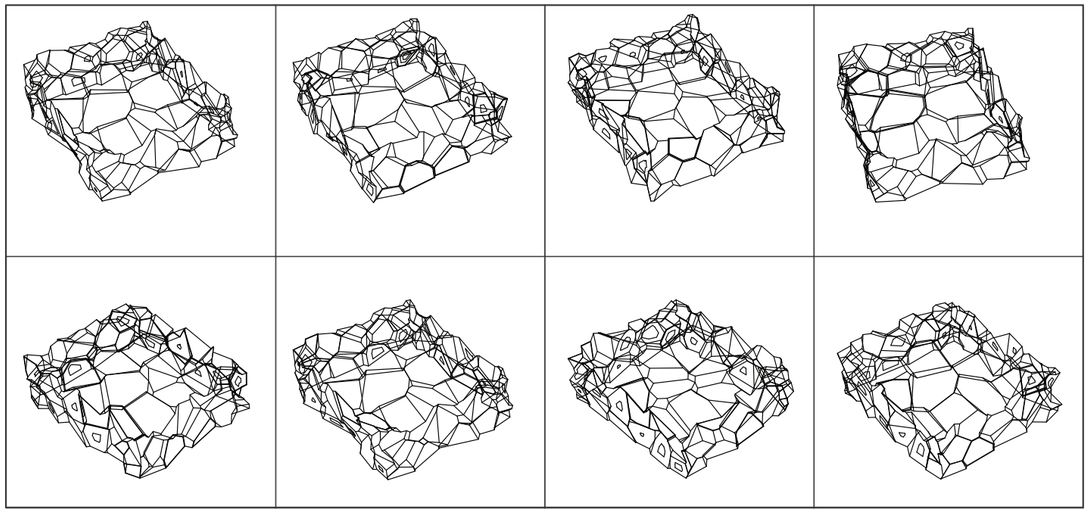
QUESTIONNAIRE

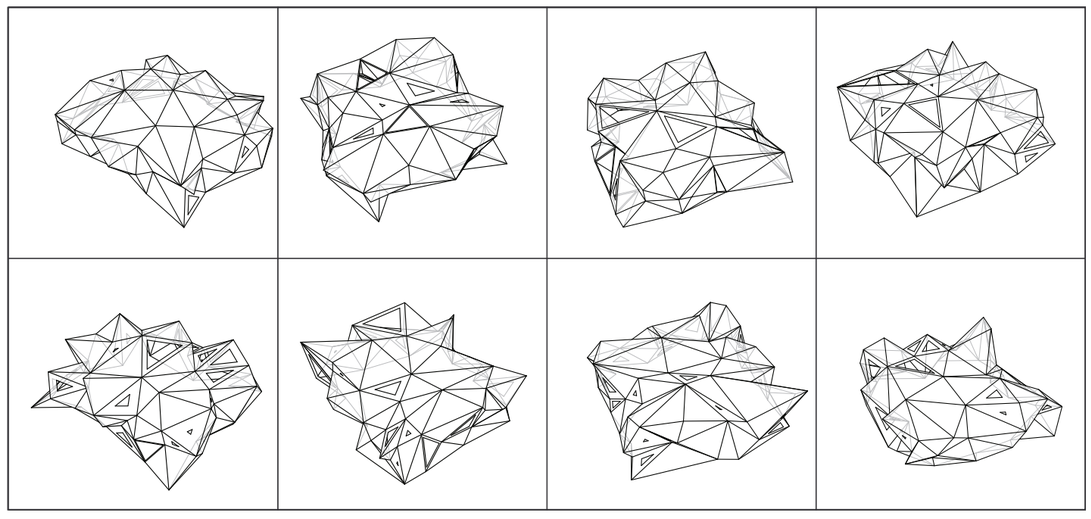
SUITABLE COMPUTATIONAL DESIGN SYSTEM

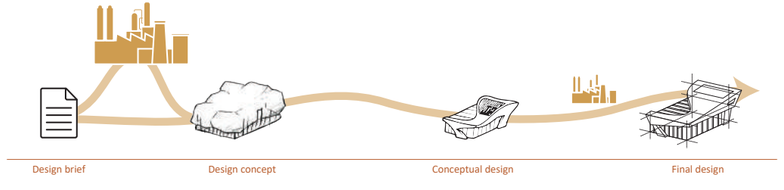
DOES USE OF A DATA-DRIVEN DESIGN APPROACH RESULT IN BETTER-PERFORMING DESIGNS?

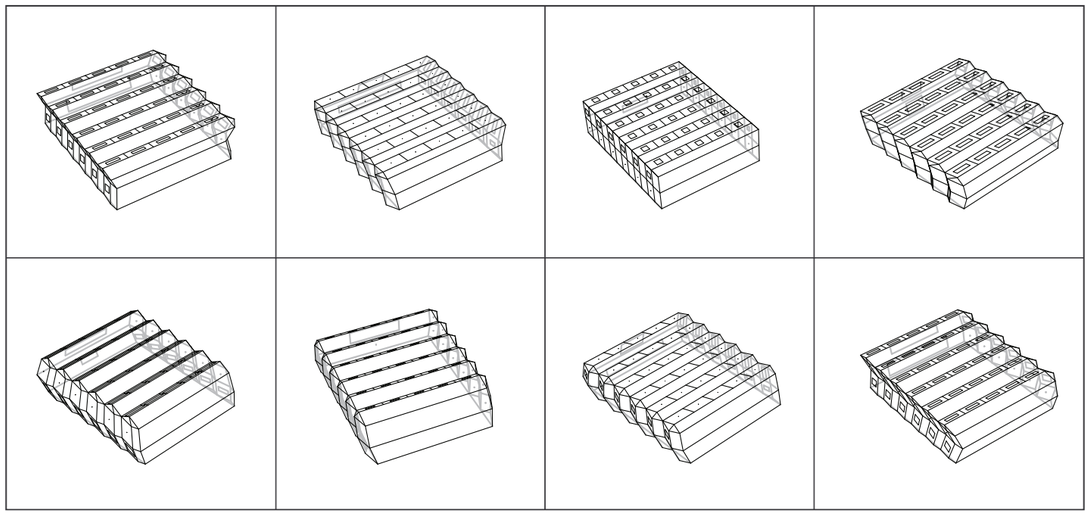
EFFECTIVE VISUAL ANALYTICS SYSTEM

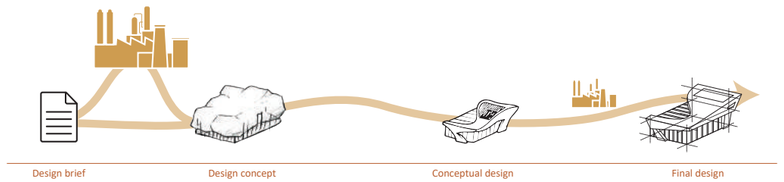
DOES THE VISUAL ANALYTICS TOOL ENABLE INTUITIVE DESIGN EXPLORATION?






Design brief
Design concept
Conceptual design
Final design




Design brief
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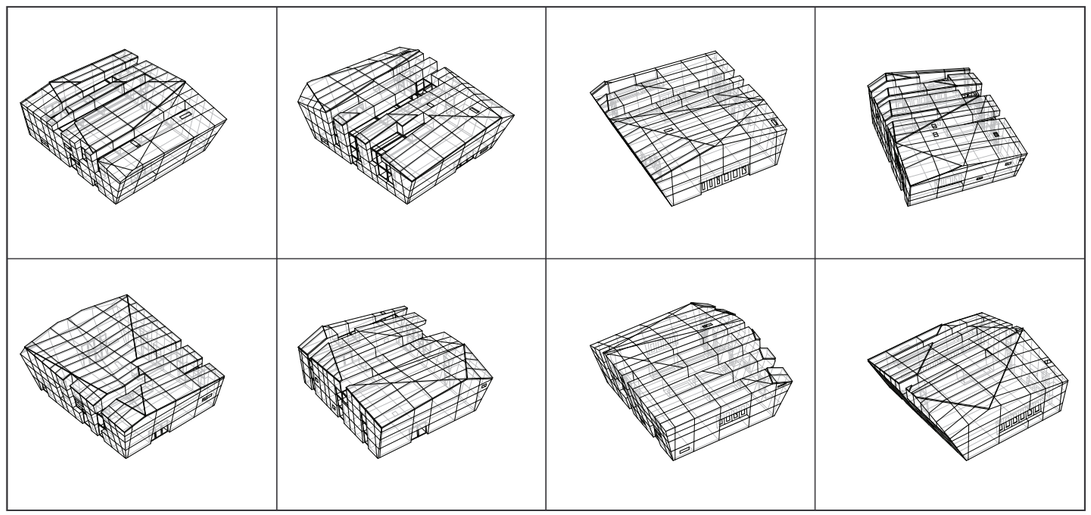

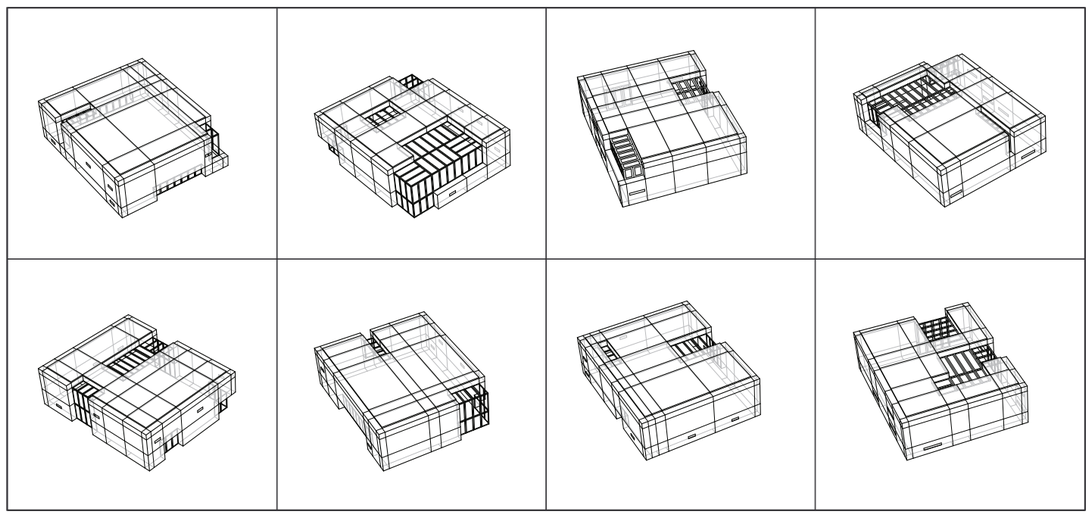

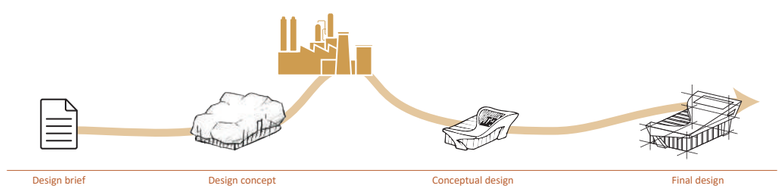
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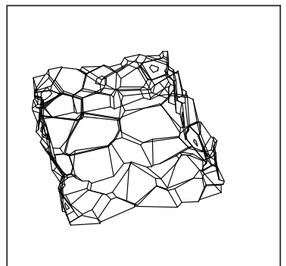
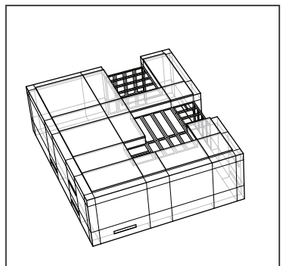
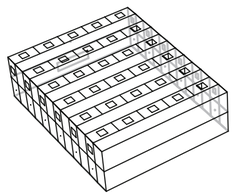


x 5

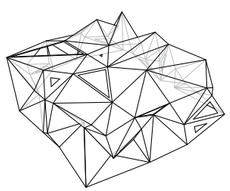


x 60



x 50

x 3



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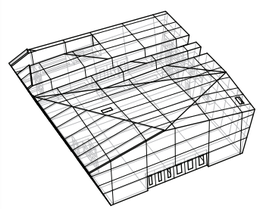


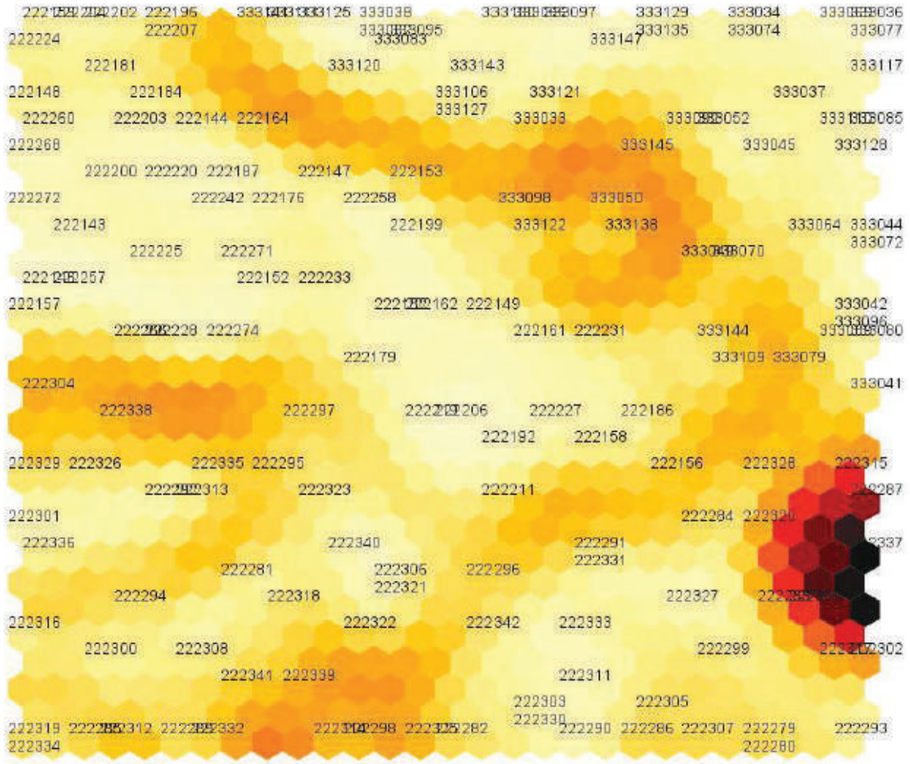
x 60

SUITABILITY OF C.D.S. THROUGHOUT DESIGN PROCESS

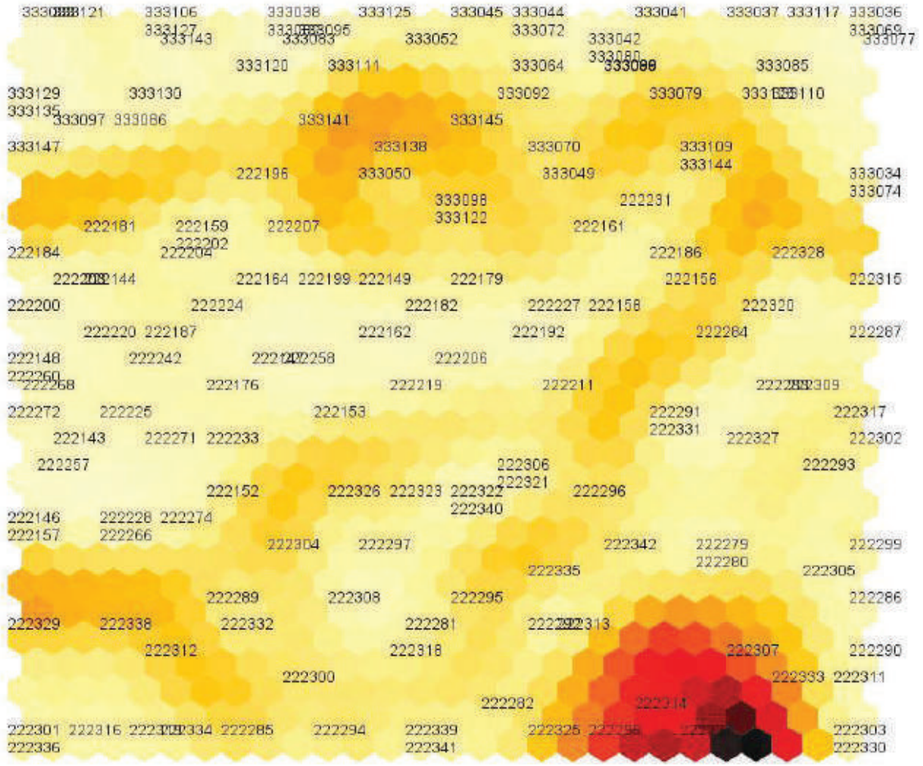
	DESIGN DECISIONS OF DEFAULT DATASET	ALTERNATIVE DESIGN DECISIONS
WALL INSULATION THICKNESS	140 mm	100 mm
WINDOW TYPE	Hr++ glazing	Translucent glazing
SETPOINT TEMPERATURES	21 °C - 27 °C	19 °C - 25 °C
SETBACK TEMPERATURES	13 °C - 35 °C	17 °C - 32 °C
OCCUPANCY SCHEDULE	17 hrs/day	9 hrs/day

SUITABILITY OF C.D.S. THROUGHOUT DESIGN PROCESS

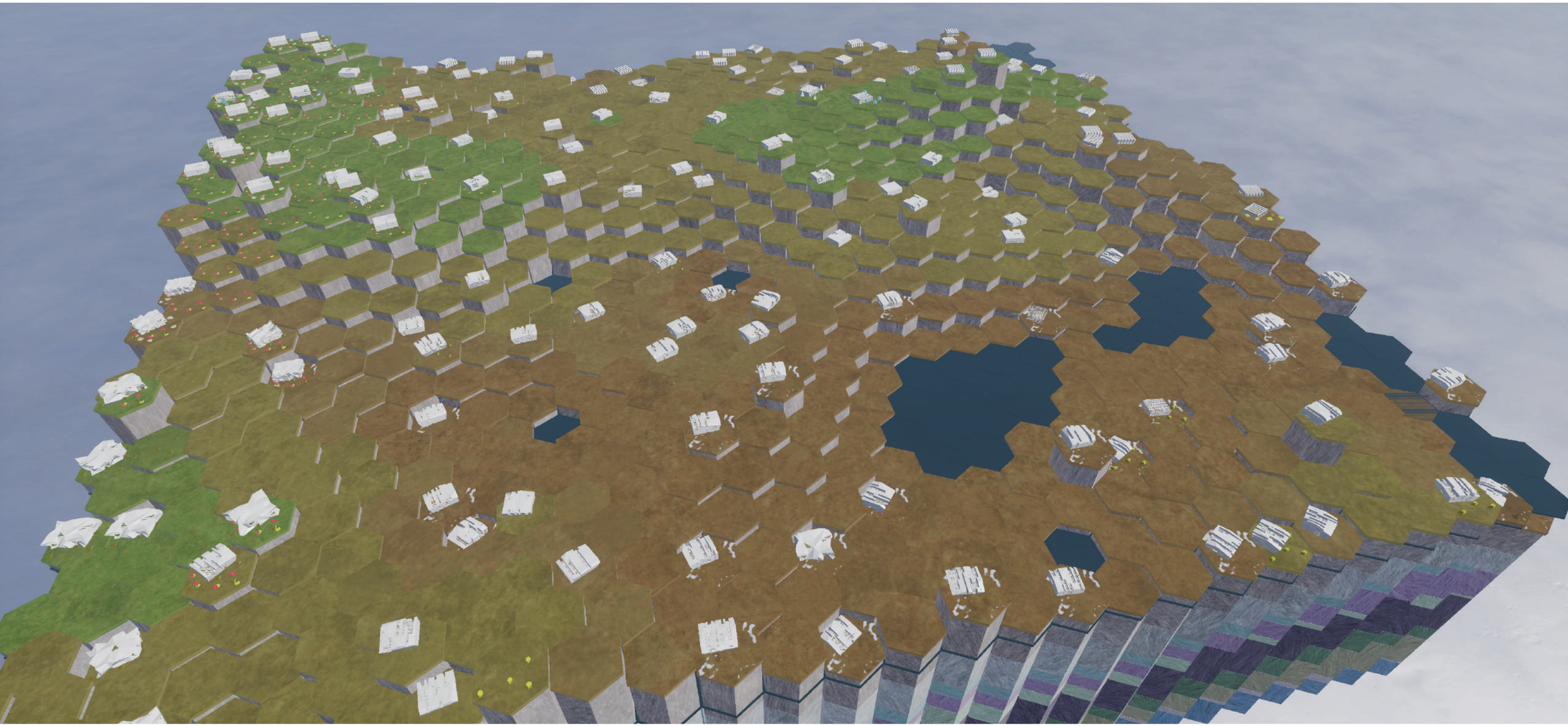
WALL INSULATION THICKNESS	Large differences in performances, little correlation, little predictability; regeneration required
WINDOW TYPE	Correlation between changes in design alternatives' performances; comparative assessment possible
SETPOINT TEMPERATURES	Correlation between changes in design alternatives' performances; comparative assessment possible
SETBACK TEMPERATURES	No significant changes; the dataset can be used as is
OCCUPANCY SCHEDULE	Correlation between changes in design alternatives' performances; comparative assessment possible



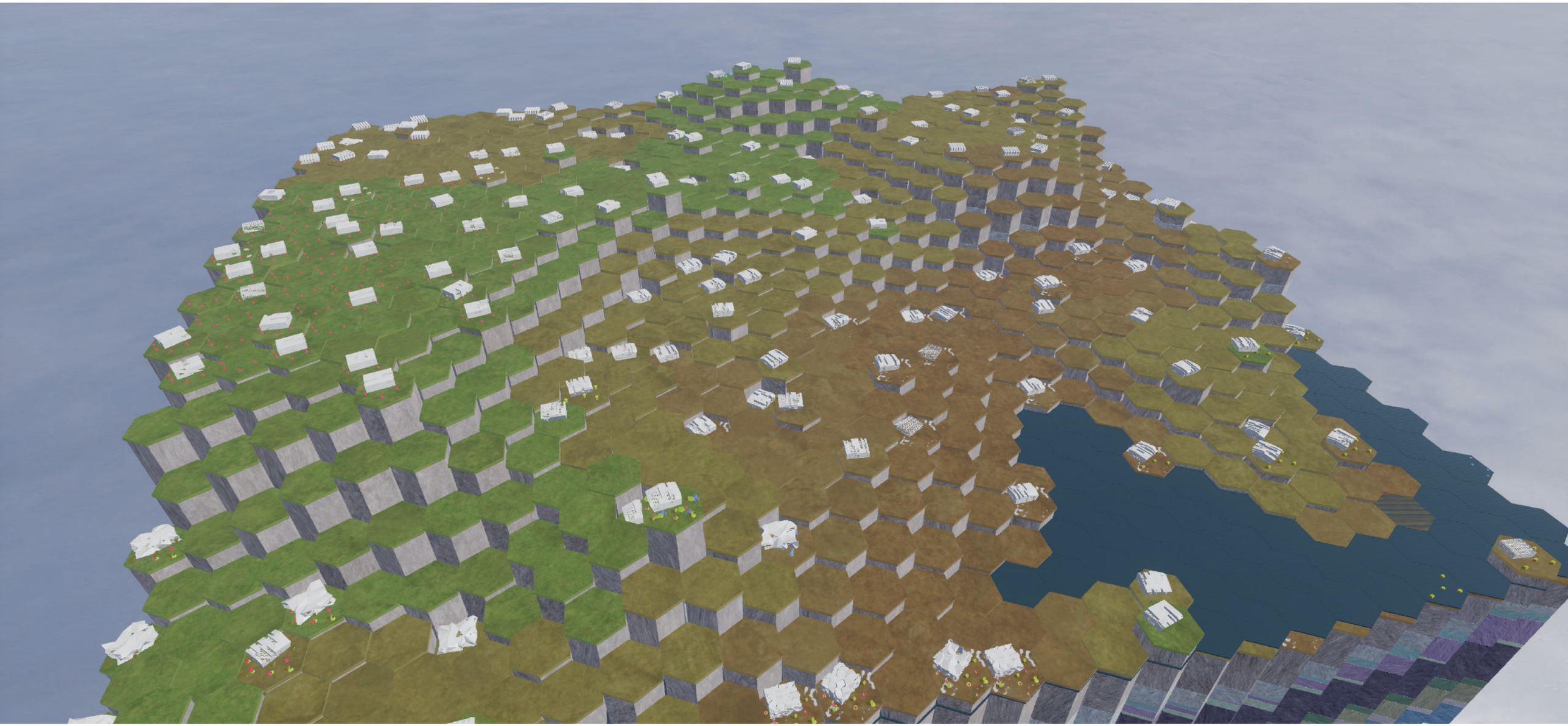
17 HRS/DAY SCHEDULE



9 HRS/DAY SCHEDULE



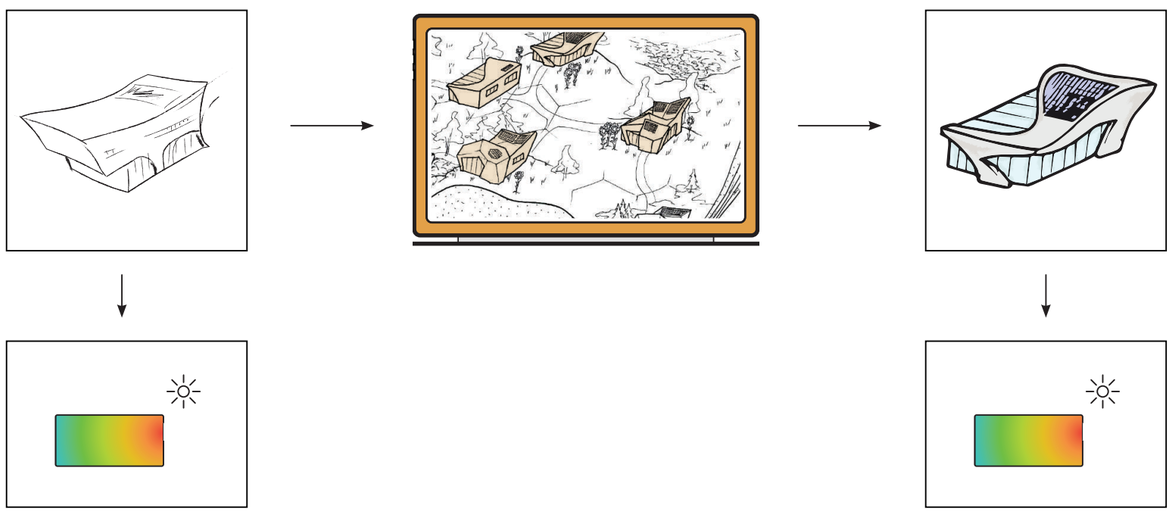
17 HRS/DAY SCHEDULE



9 HRS/DAY SCHEDULE

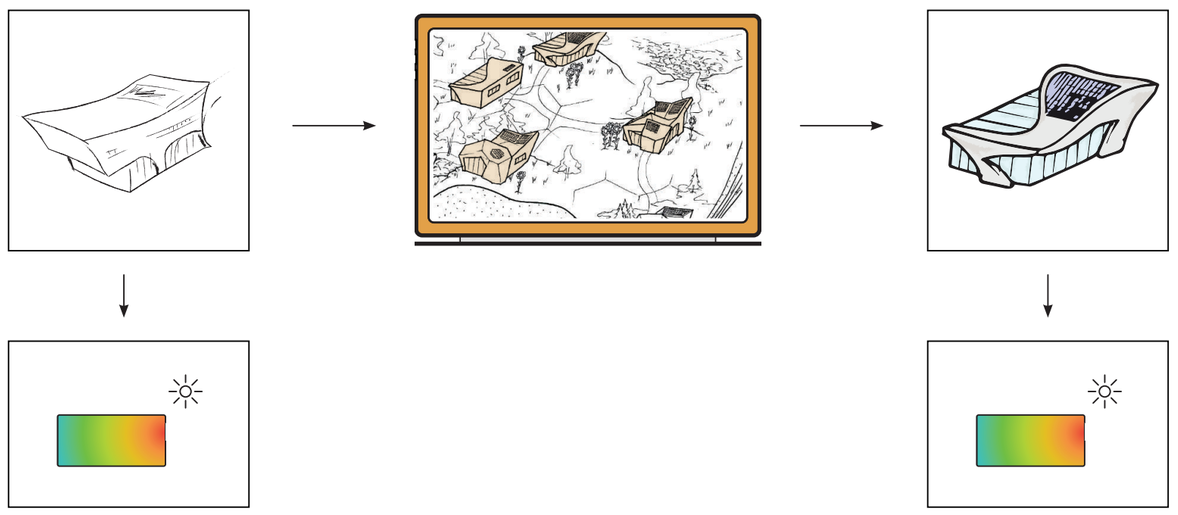
VALIDATION

SUITABLE COMPUTATIONAL DESIGN SYSTEM



VALIDATION

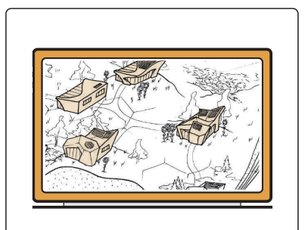
SUITABLE COMPUTATIONAL DESIGN SYSTEM

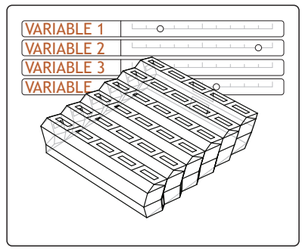


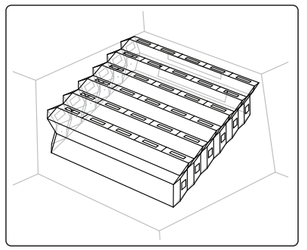
Cooling energy (kWh/y)	9126	6437	-29.5 %	6299	-31.0 %
Heating energy (kWh/y)	49576	50461	+1.8 %	58035	+17.1 %
Lighting energy (kWh/y)	29154	28925	-0.8 %	28925	-0.8 %
PV energy gain (kWh/y)	20958	52147	148.8 %	52147	148.8 %
PV energy payback time (yrs)	2.92	3.22	+10.3 %	3.22	+10.3 %
Glare (%/y)	63.3	0.0	-100 %	0.0	-100.0 %
Lighting uniformity (%/y)	42.8	42.5	-0.7 %	42.6	-0.5 %
Thermal comfort sports players (%/y)	52.6	54.2	+3.0 %	54.5	+3.6 %
Thermal comfort spectators (%/y)	24.7	20.4	-17.4 %	20.5	-17.0 %
Temperature criteria (%/y)	30.6	20.0	-34.6 %	19.6	-35.9 %

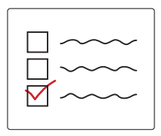
DESIGNS COURTESY OF L. POL

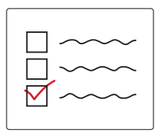
VALIDATION

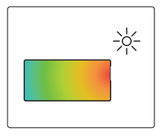


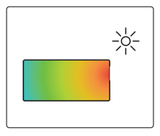






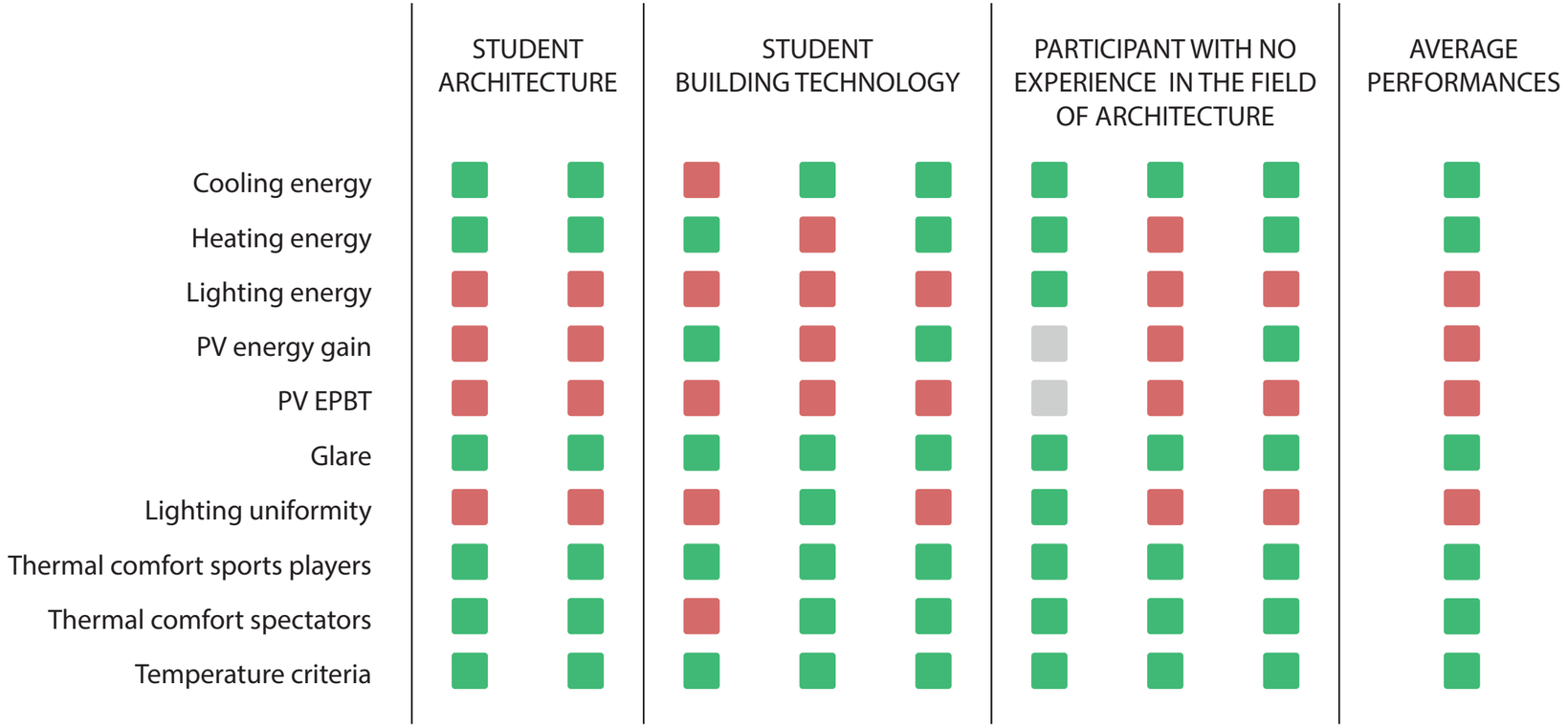






VALIDATION

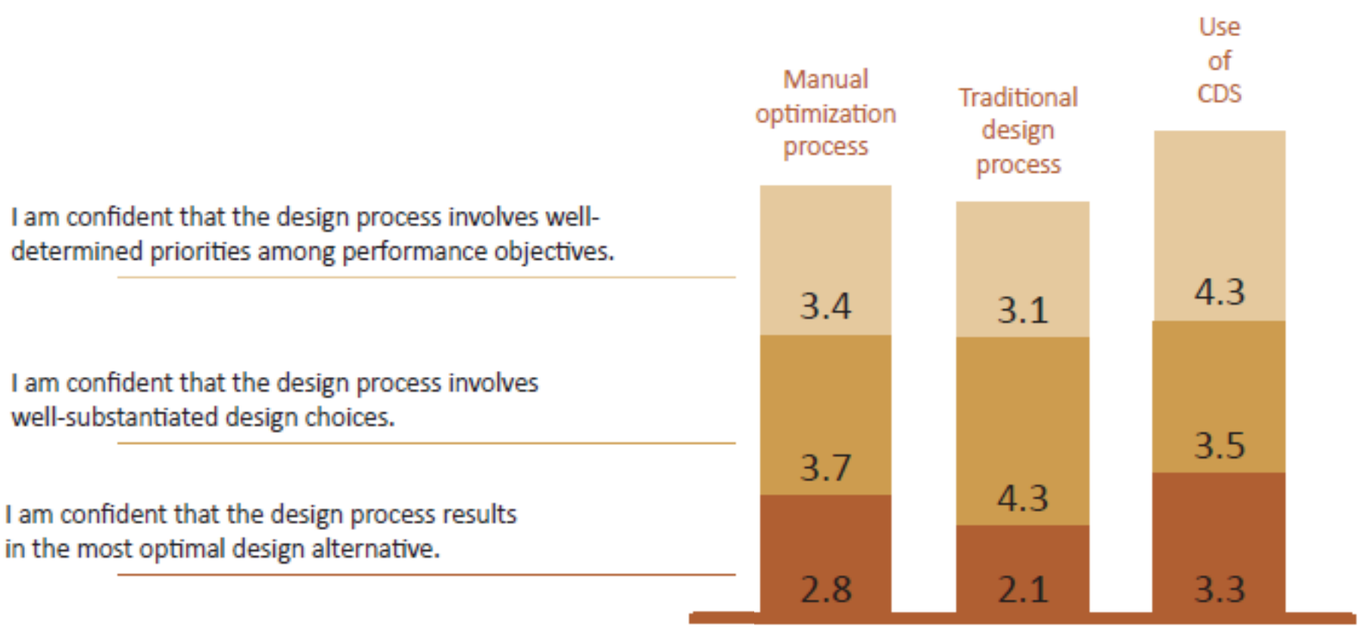
SUITABLE COMPUTATIONAL DESIGN SYSTEM



Performances of designs selected in the visual analytics tool relative to ‘manually optimized’ designs. Green marks a relative improvement in performances, red marks a decline

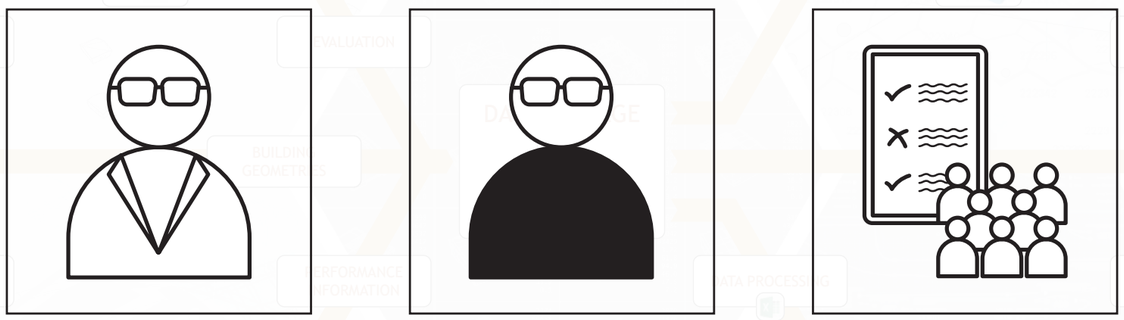
VALIDATION

SUITABLE COMPUTATIONAL DESIGN SYSTEM



Presented ratings correspond to degree to which participants agree to the statement (1 - Strongly disagree, 5 - Strongly agree)

VALIDATION



PERSONAL EXPERIENCE

PEER REVIEW

QUESTIONNAIRE

SUITABLE COMPUTATIONAL DESIGN SYSTEM

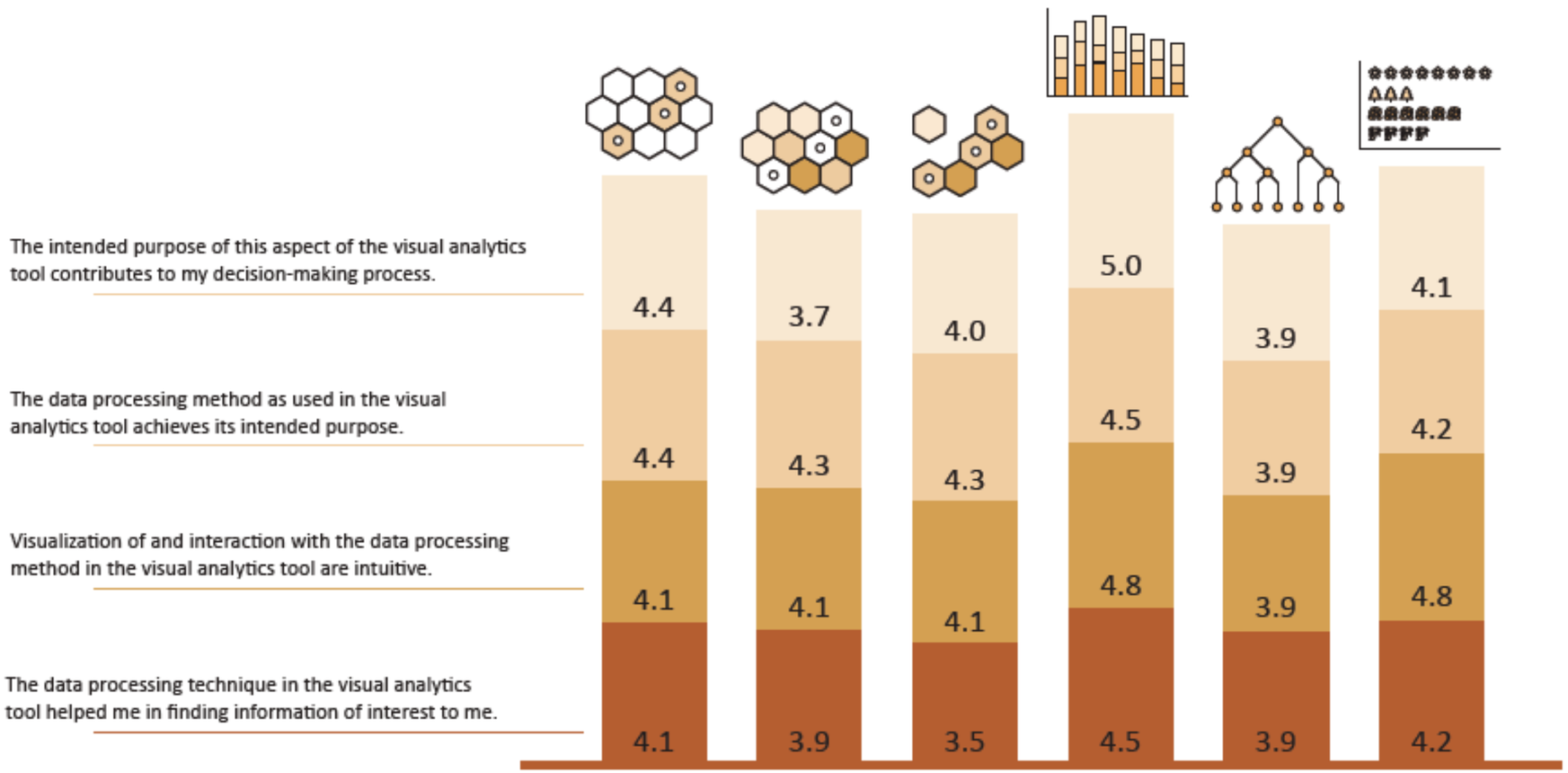
DOES USE OF A DATA-DRIVEN DESIGN APPROACH RESULT IN BETTER-PERFORMING DESIGNS?

EFFECTIVE VISUAL ANALYTICS SYSTEM

DOES THE VISUAL ANALYTICS TOOL ENABLE INTUITIVE DESIGN EXPLORATION?

VALIDATION

EFFECTIVE VISUAL ANALYTICS SYSTEM

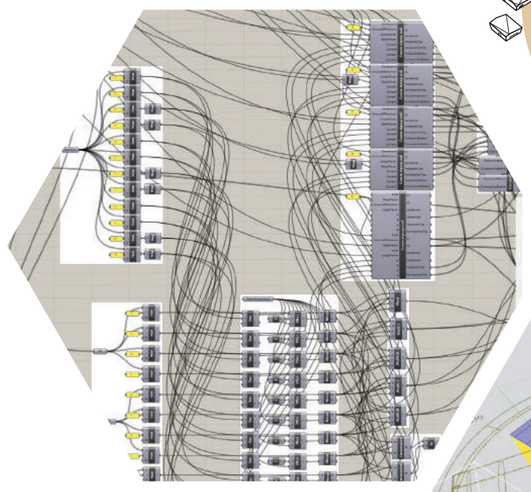


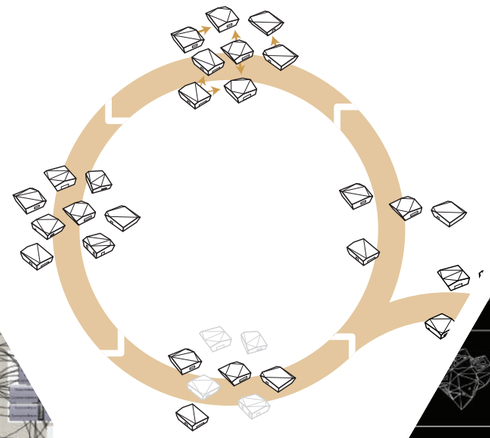
Presented ratings correspond to degree to which participants agree to the statement (1 - Strongly disagree, 5 - Strongly agree)

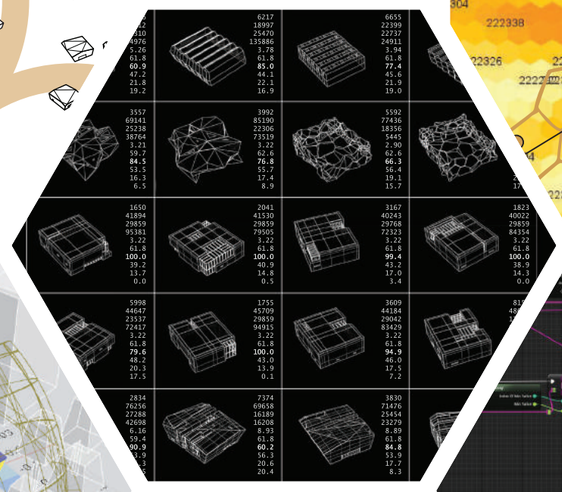
EFFECTIVE VISUAL ANALYTICS SYSTEM

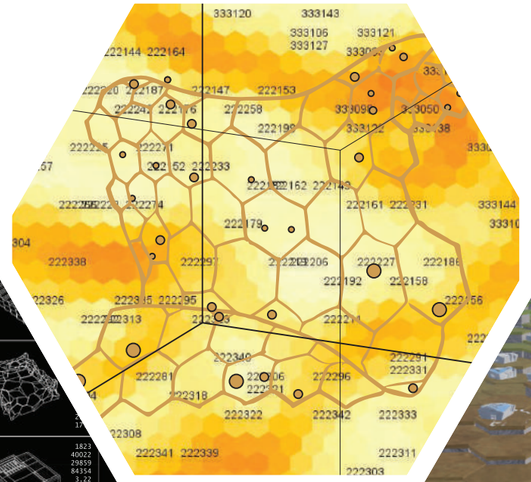
The visual analytics tool has the potential to improve visualization of the performances of design alternatives, compared to traditional design processes.	4.9
The visual analytics tool has the potential to improve substantiation of decision-making in the design process, compared to traditional design processes.	4.4
The visual analytics tool has the potential to facilitate exploration of a larger amount of design alternatives, compared to traditional design processes.	4.8
The visual analytics tool has the potential to lead to a better understending of building performances, compared to traditional design processes.	4.5
Use of the visual analytics tool encourages me to create more sustainable and/or better-performing designs, compared to traditional design processes.	3.6
Use of the visual analytics tool has the potential to result in better-performing architecture, compared to traditional design processes.	4.4
I would consider using an Iterative Design System to generate a data set of design alternatives in a design project.	4.3
I would consider using the visual analytics tool in a design project to visualize a data set of design alternatives.	4.4

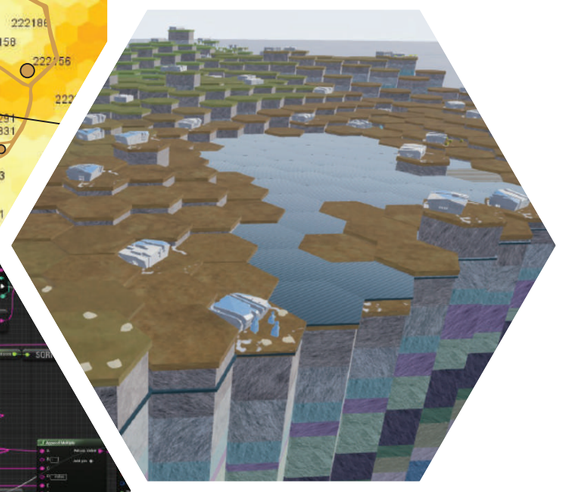
SUMMARY OF FINDINGS

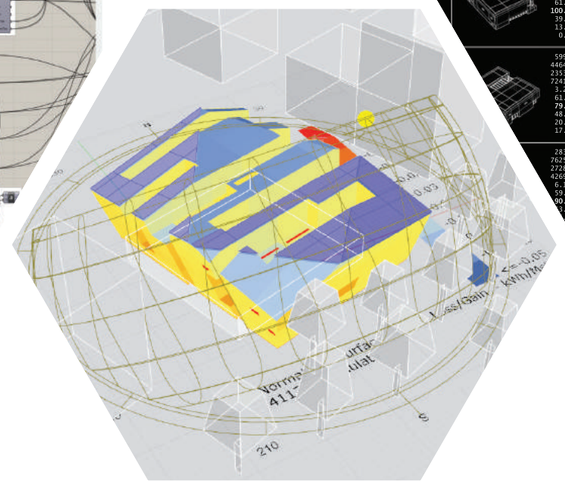


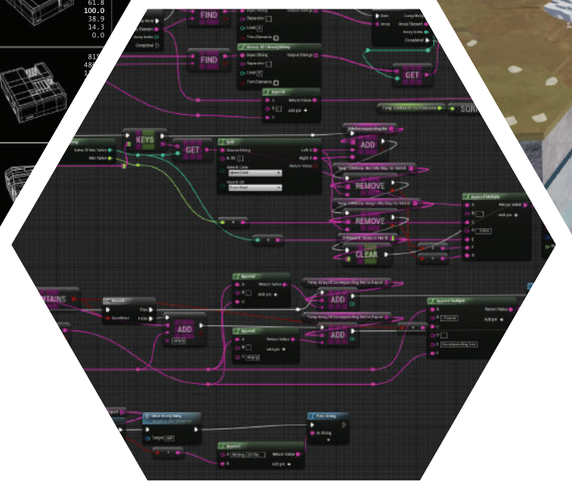








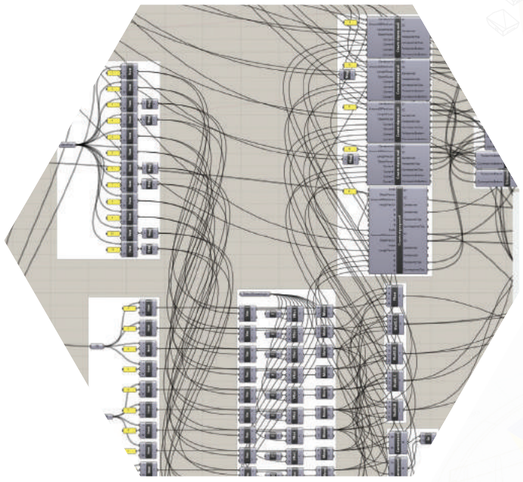




SUMMARY OF FINDINGS

CONCLUSION:
THE DESIGN PROCESS BEST CONTRIBUTES FROM THE USE OF MULTIPLE PARAMETRIC MODELS THAT ARE BASED ON ARCHITECTURAL CONCEPTS

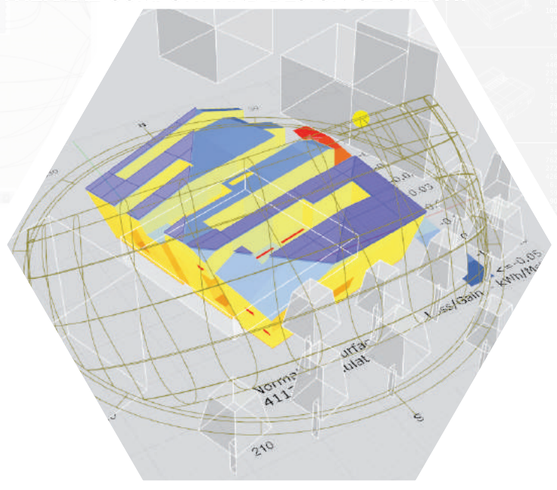
LIMITATION:
THE AMOUNT OF PARAMETERS SHOULD BE MINIMIZED TO ACHIEVE OPTIMIZATION



SUMMARY OF FINDINGS

CONCLUSION:
NEARLY HALF OF DESIGN ALTERNATIVES GENERATED WITH THE ITERATIVE DESIGN SYSTEM ARE (NEARLY) ZERO-ENERGY BUILDINGS

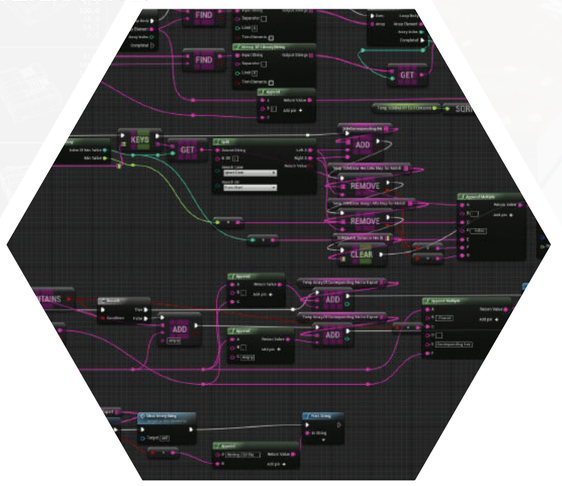
LIMITATION:
THERMAL COMFORT PERFORMANCES CONTRIBUTE LITTLE TO THE DECISION-MAKING PROCESS, BECAUSE THERE IS NO CAUSATION BETWEEN THERMAL COMFORT AND DESIGN GEOMETRY



SUMMARY OF FINDINGS

CONCLUSION:
THE DATA ANALYTICS TECHNIQUES IMPLEMENTED IN THE COMPUTATIONAL DESIGN SYSTEM TOGETHER SUBSTANTIATE MULTI-VARIATE, MULTI-OBJECTIVE DECISION-MAKING OF LARGE SETS OF DESIGN ALTERNATIVES

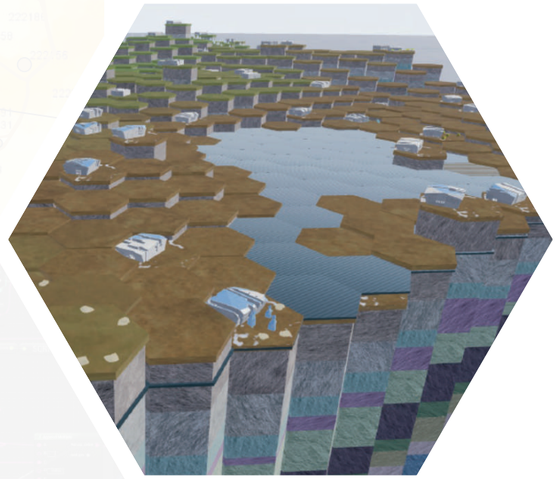
LIMITATION:
CORRELATION BETWEEN GEOMETRY VARIABLES AND PERFORMANCES IS HARD TO DEFINE, LIKELY BECAUSE OF GREAT DIFFERENCES BETWEEN DESIGN ALTERNATIVES



SUMMARY OF FINDINGS

CONCLUSION:
USE OF A GAME-LIKE, 3D DATA ENVIORNMENT ENABLES INTUITIVE EXPLORATION OF A LARGE, HIGH-DIMENSIONAL DATA SET

LIMITATION:
PRESENTATION OF GEOMETRY INFORMATION MAY BE FURTHER INTEGRATED IN THE VISUAL ANALYTICS SYSTEM



CONCLUSIONS

OPTIMIZATION
OF MULTI-VARIATE, MULTI-OBJECTIVE DESIGN ASSIGNMENTS

EXPLORATION
OF HIGH-DIMENSIONAL DATA

DESIGN VISUALIZATION

CONCLUSIONS

OPTIMIZATION
OF MULTI-VARIATE, MULTI-OBJECTIVE DESIGN ASSIGNMENTS

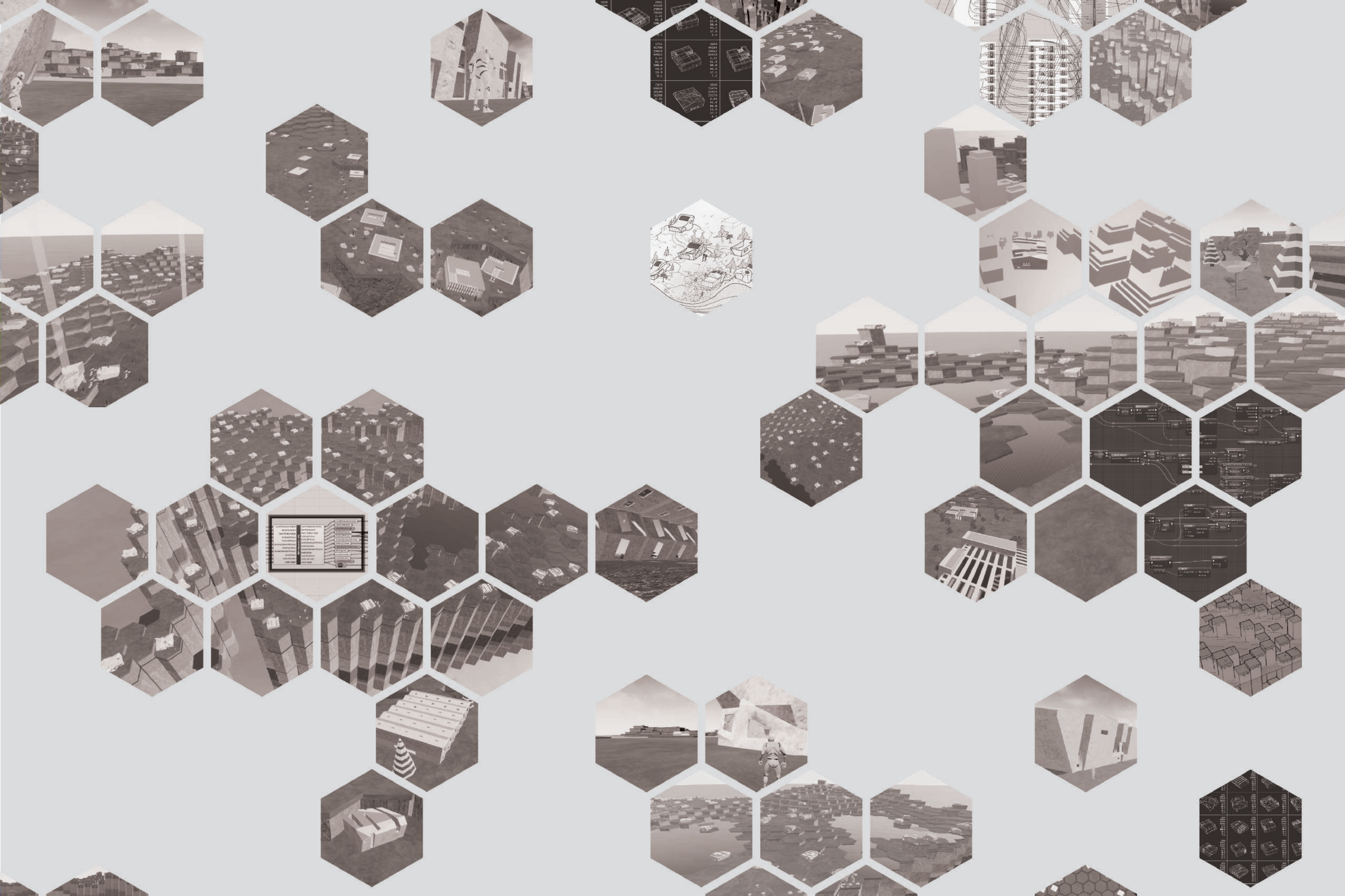
DOCUMENTATION
E.G. USE AS FRAME OF REFERENCE

EXPLORATION
OF HIGH-DIMENSIONAL DATA

COMMUNICATION
E.G. FACILITATING DISCUSSION OF DESIGN ALTERNATIVES WITH CLIENTS

DESIGN VISUALIZATION

EDUCATION
A.O.. INCREASED AWARENESS OF ENERGY PERFORMANCES



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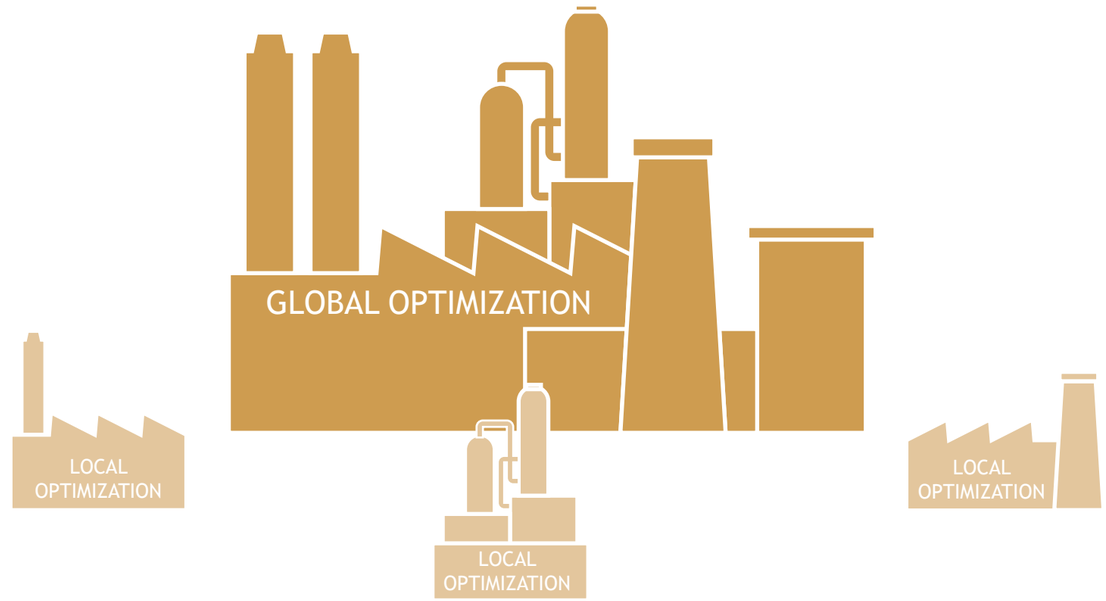
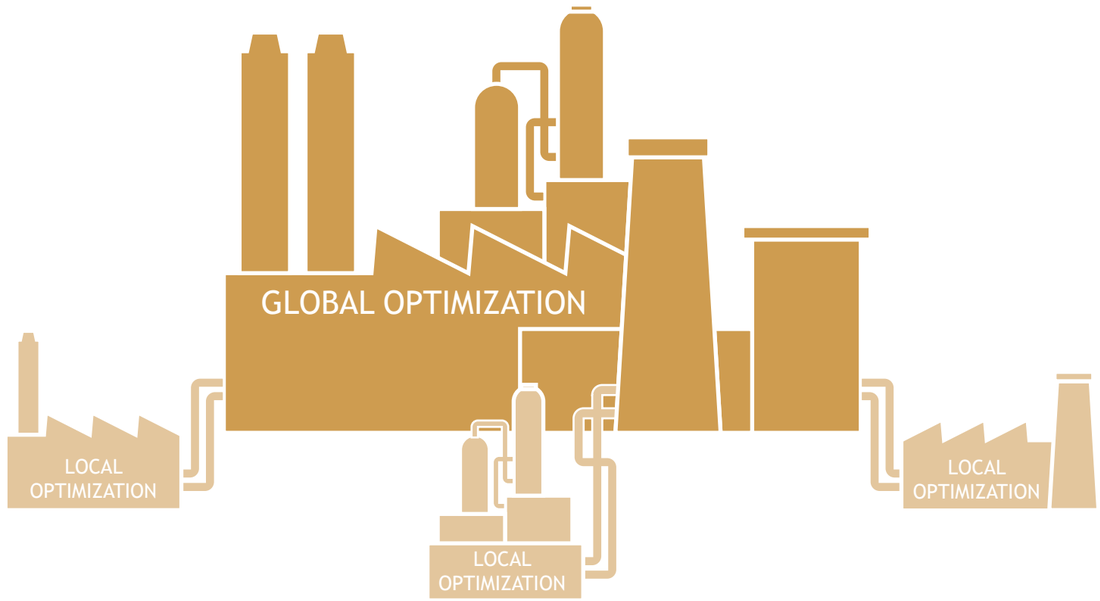
GLOBAL OPTIMIZATION


GLOBAL OPTIMIZATION
LOCAL OPTIMIZATION
LOCAL OPTIMIZATION
LOCAL OPTIMIZATION


GLOBAL OPTIMIZATION
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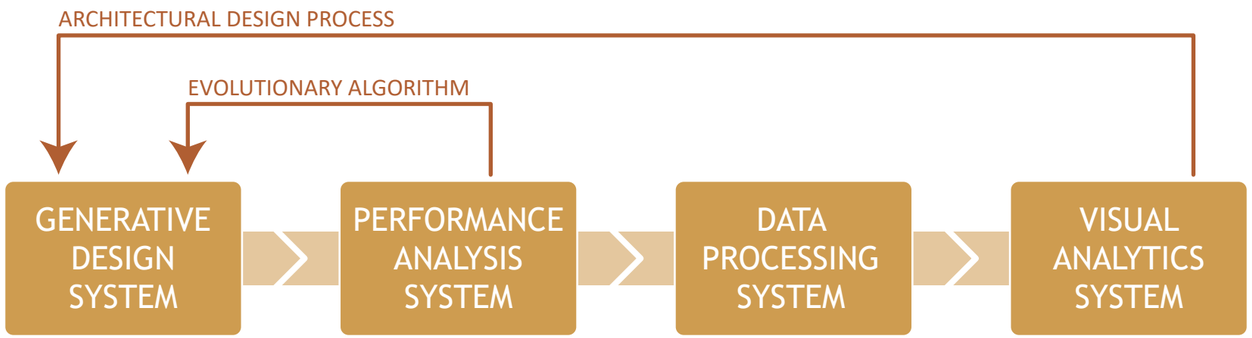
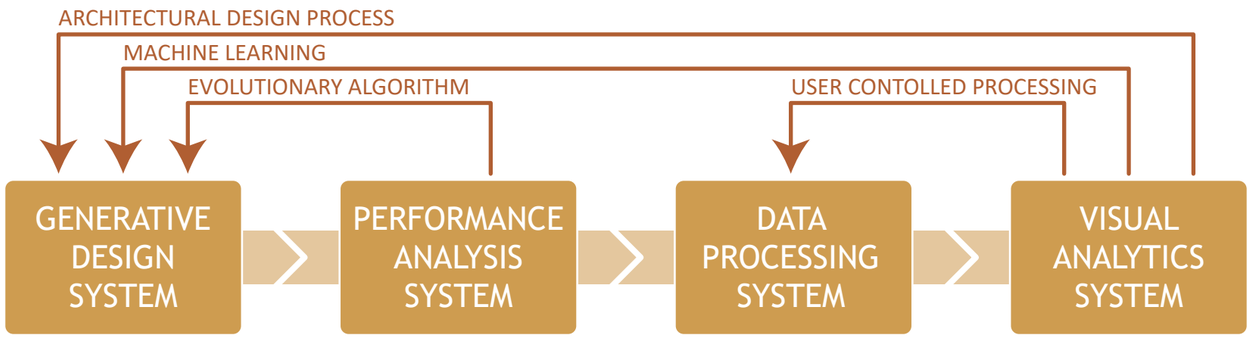
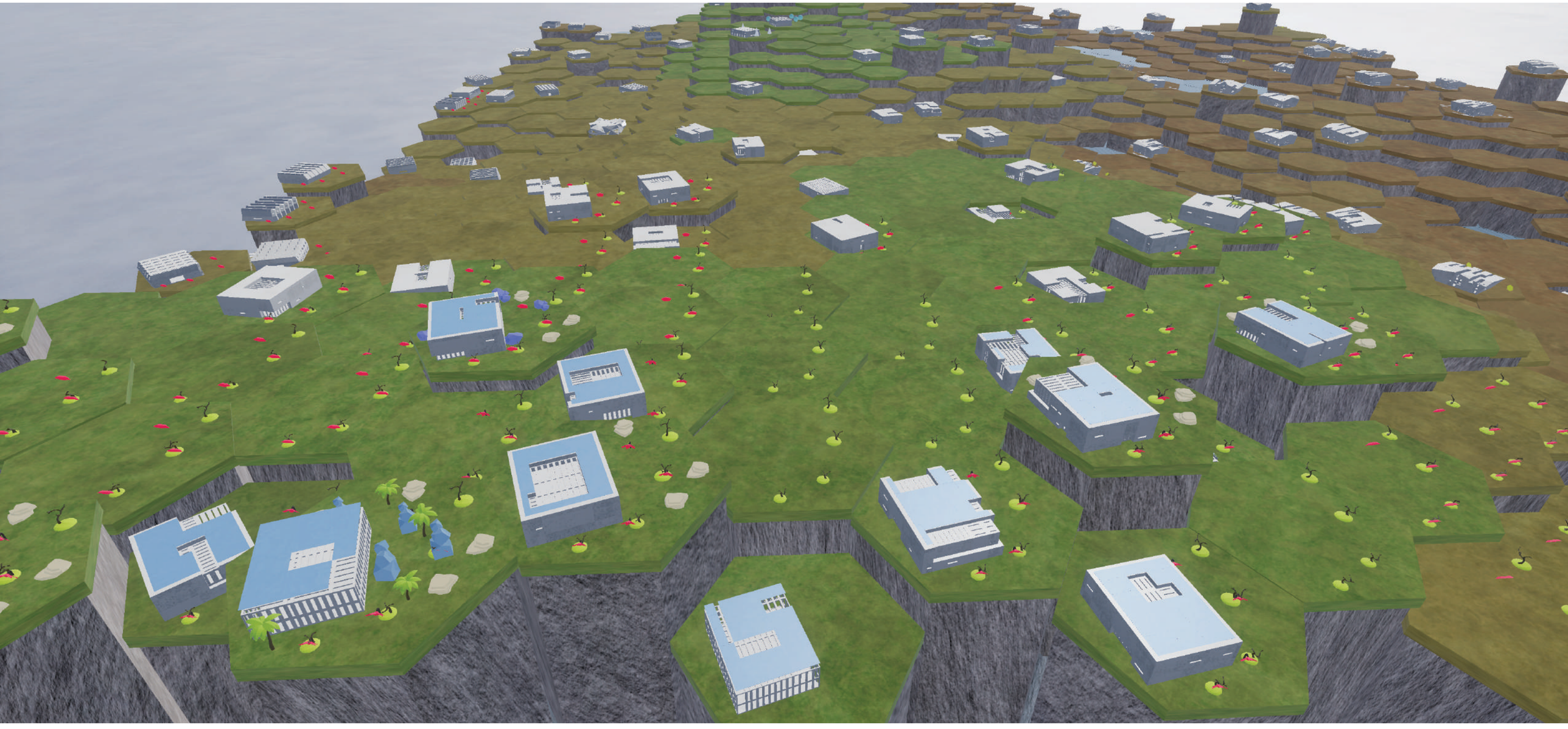
LOCAL OPTIMIZATION

RECOMMENDATIONS



RECOMMENDATIONS





17 HRS/DAY SCHEDULE