Maximum Power Design

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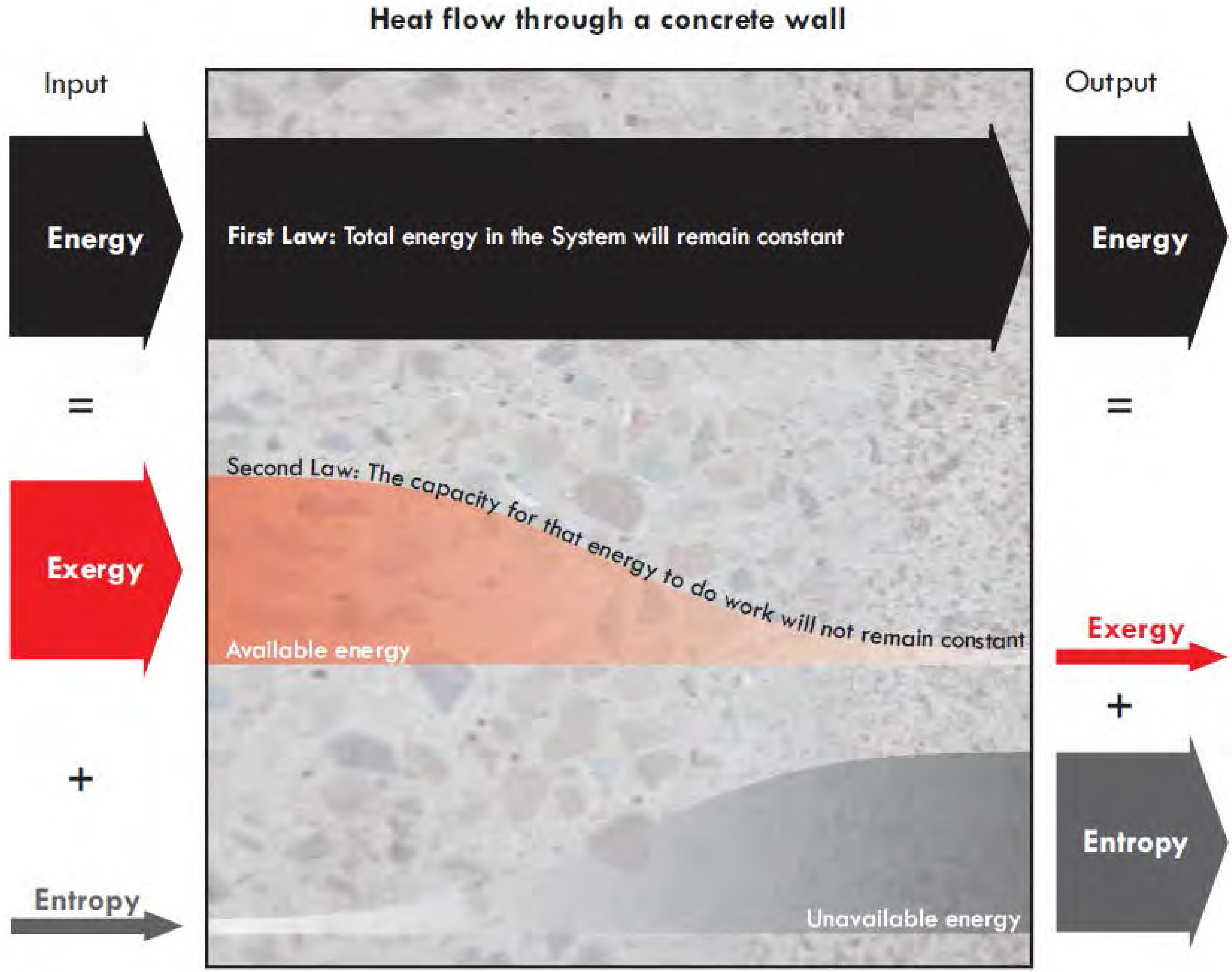
Workshop D Architecture & Space
Swiss-US Energy Innovation Days | Zurich

ENERGY AND URBAN SYSTEMS

ENERGY AND URBAN SYSTEMS

EXERGY AND URBAN SYSTEMS



Energy, Exergy, Entropy
Energy cannot be made more efficient, it is constant.
Exergy and entropy are variable, however.

The Energy Efficiency Fallacy

First Law of Thermodynamics:

Energy is transferred at 100% efficiency.

(you cannot try to conserve energy or make it effiecent)

Second Law of Thermodynamics:

Energy's capacity to do work will not be conserved.

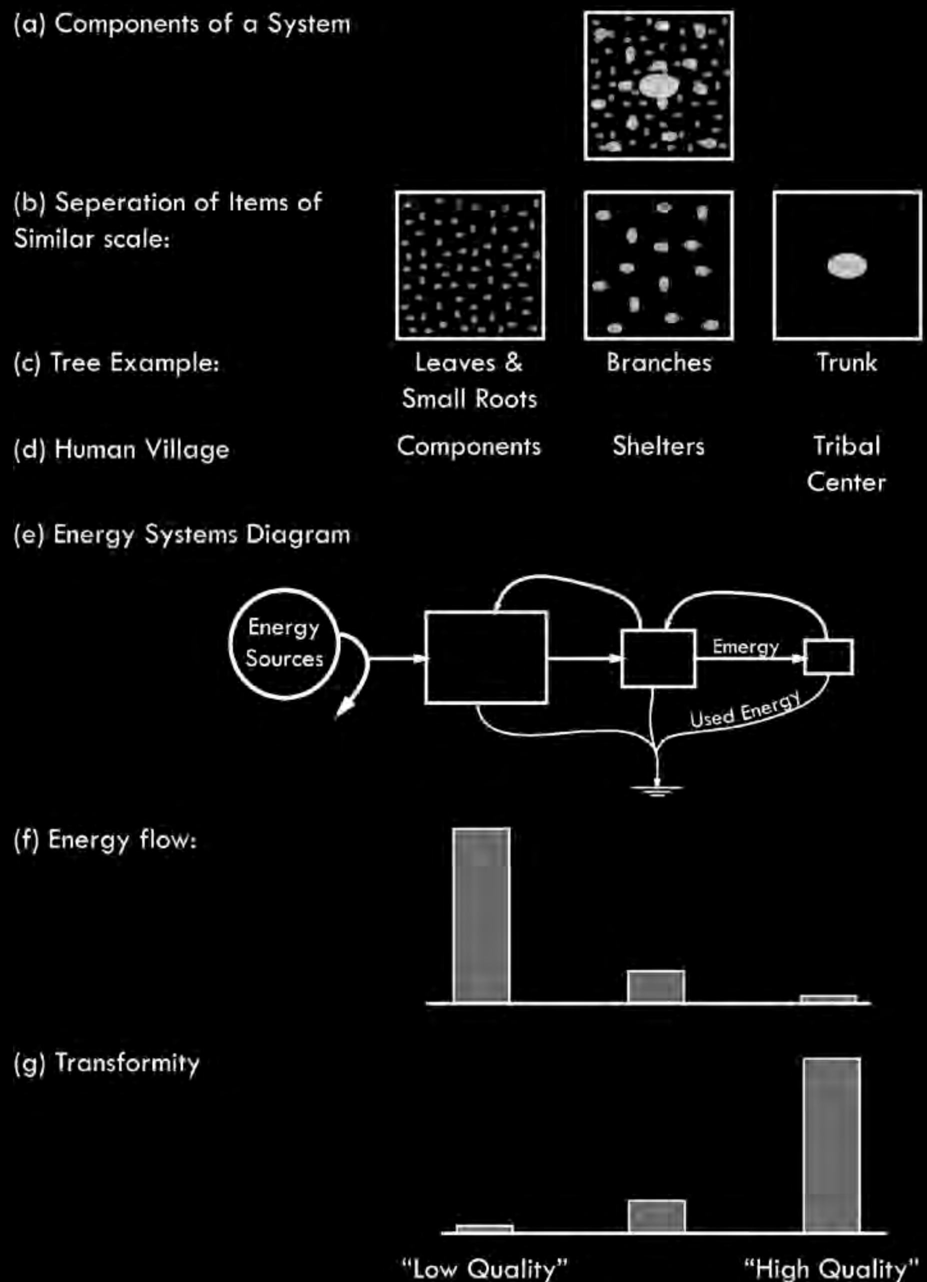
(thus we must design entropy/exergy relationships)

EMERGY AND URBAN SYSTEMS

“the available energy of one kind previously used up directly and indirectly to make a product or service.”

“the exergy of one kind previously used up directly and indirectly to make a product or service.”

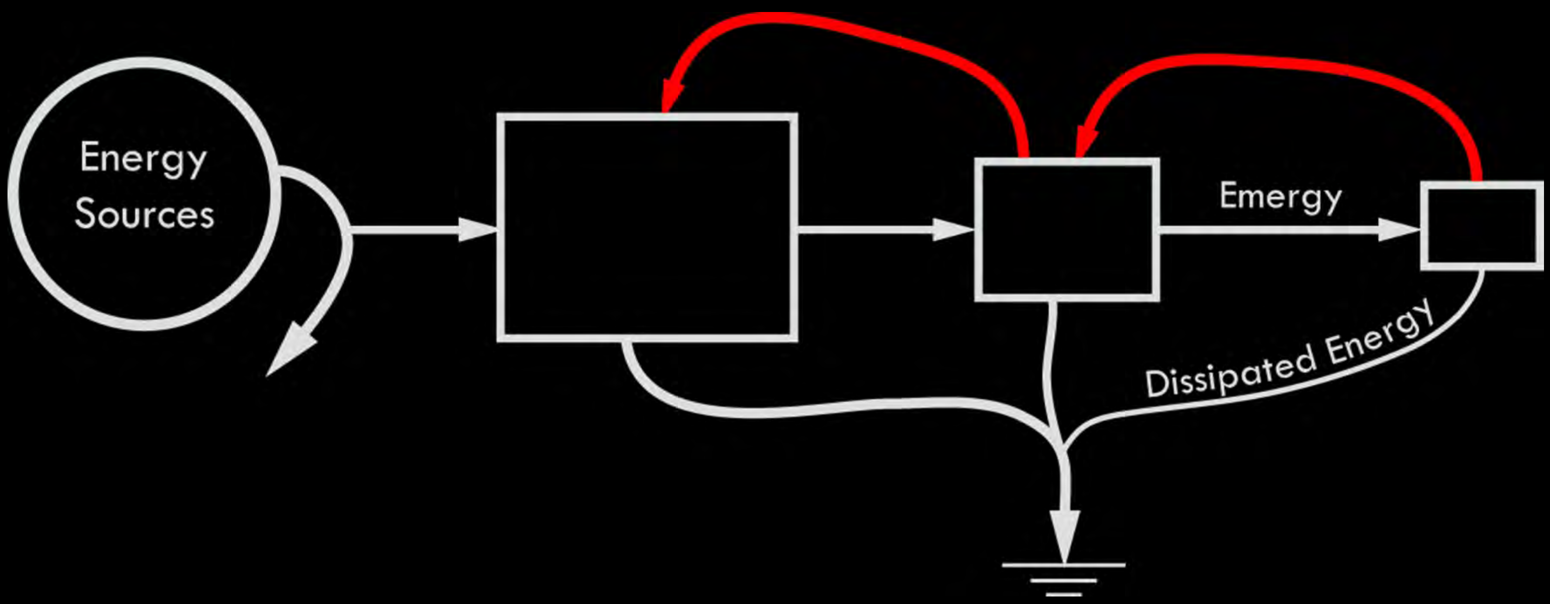
Howard T. Odum's Energy Hierarchy



HIERARCHY OF ENERGY

Typical Solar Transformaties	solar emjoules per joule (sej/J)
Sunlight	1
Wind kinetic energy	623
Unconsolidated organic matter	4,420
Geopotenital energy in dispersed rain	8,888
Chemical energy in dispsred rain	15,423
Geopotential energy in rivers	23,564
Chemical energy in rivers	41,000
Mechanical energy, waves, tides	17,000-29,000
Consolidated fuels	18,000-58,000
Food, greens, grains, staples	24,000-200,000
Protein foods	1,000,000-4,000,000
Human services	80,000-5,000,000,000
Information	10,000-10,000,000,000,000

FEEDBACK REINFORCEMENT



"…a *maximum power design* develops in which each scale is symbiotically connected by feedback loops with the next."

“Generally, when a system is optimal, its components are themselves run in a suboptimal way.

-ecosystem scientist James J. Kay

“Generally, when a system is optimal, its components are themselves run in a suboptimal way.

One cannot assume that imposing efficiency on every component in a system will lead to the most efficient system overall.”

-ecosystem scientist James J. Kay

maximum power design

“during self organization, system designs develop and prevail that maximize power intake, energy transformation, and those uses that reinforce production”

-Howard T. Odum

MAXIMUM POWER DESIGN

NOT

ZERO-ENERGY DESIGN

or efficient buildings

or optimized buildings

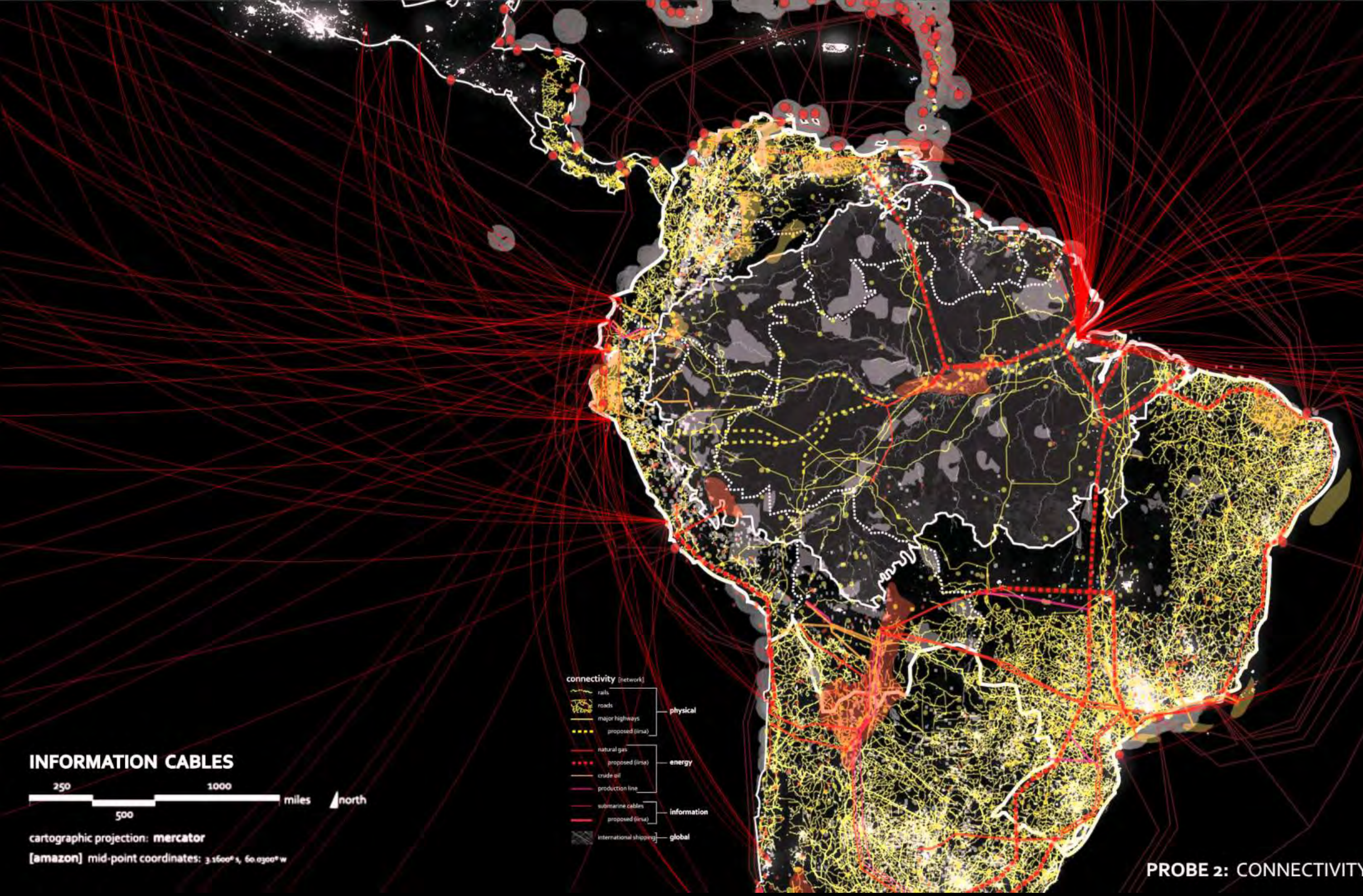
or conservation of energy…etc

ENERGY, EXERGY, EMERGY AND URBAN SYSTEMS

ENERGY, EXERGY, EMERGY AND URBAN SYSTEMS

154
139
123
107
91

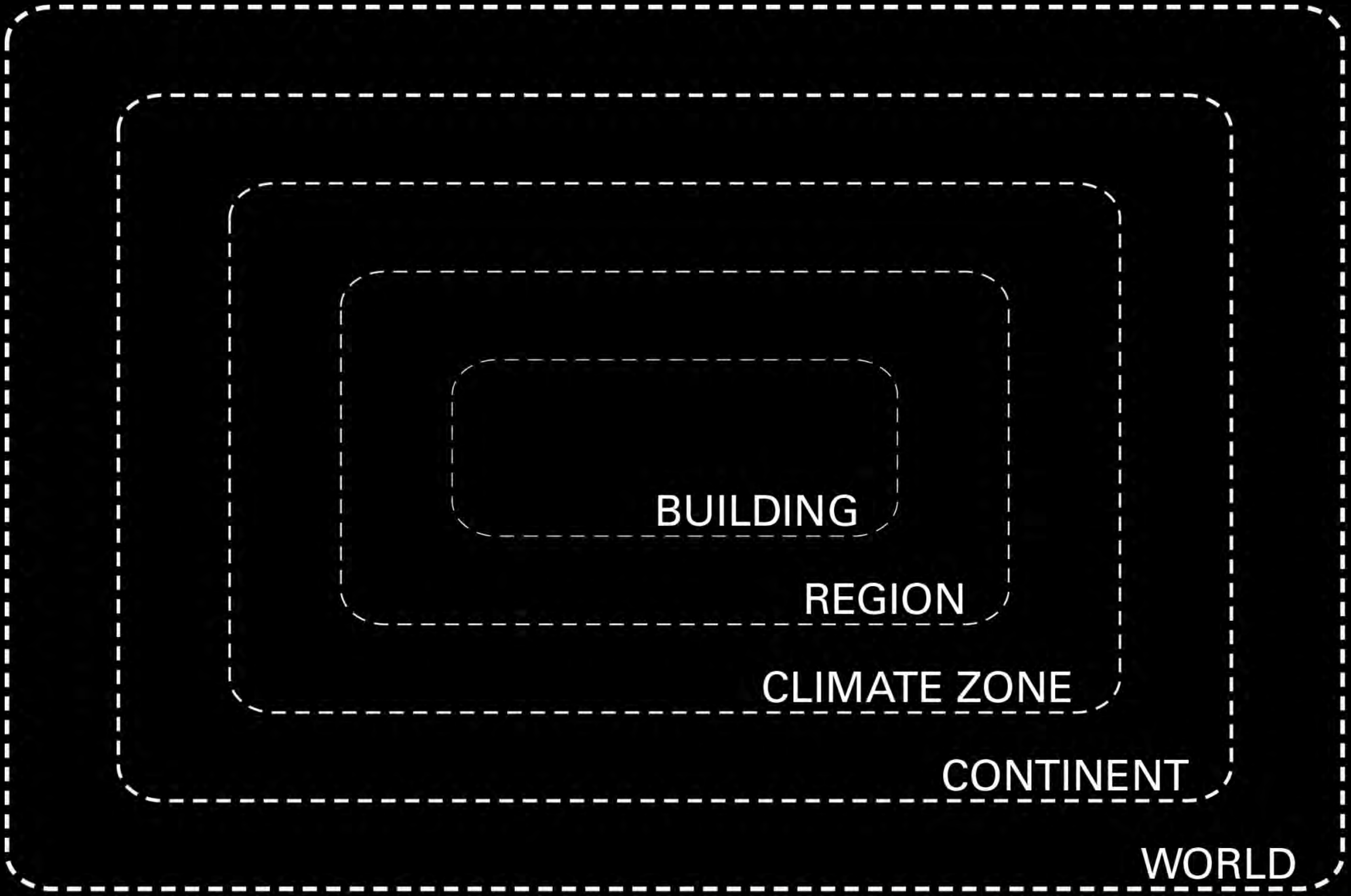
ENERGY, EXERGY, EMERGY AND URBANIZATION



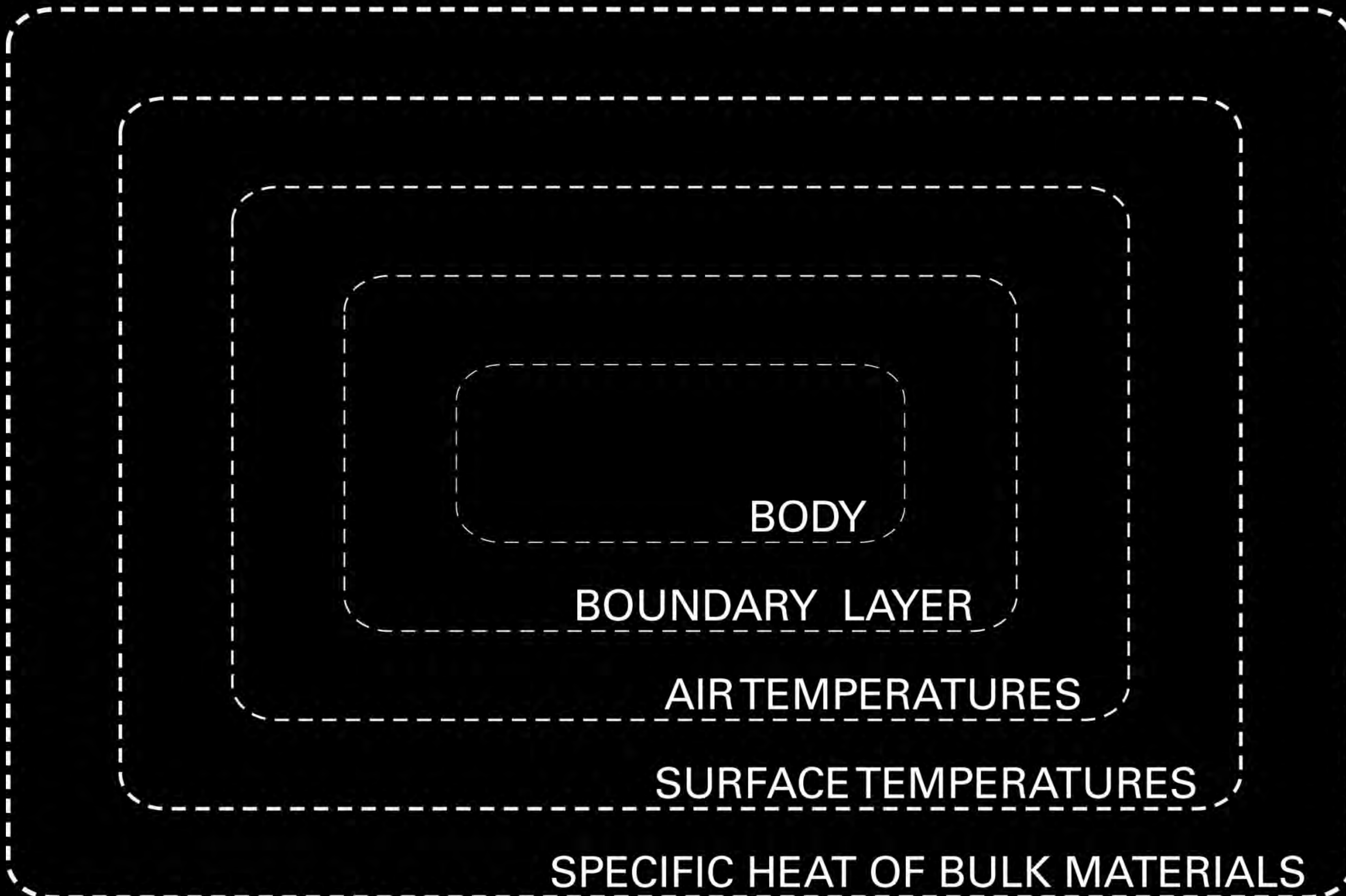
Neil Brenner, Urban Theory Lab, Harvard GSD

ENERGY, EXERGY, EMERGY AND URBANIZATION

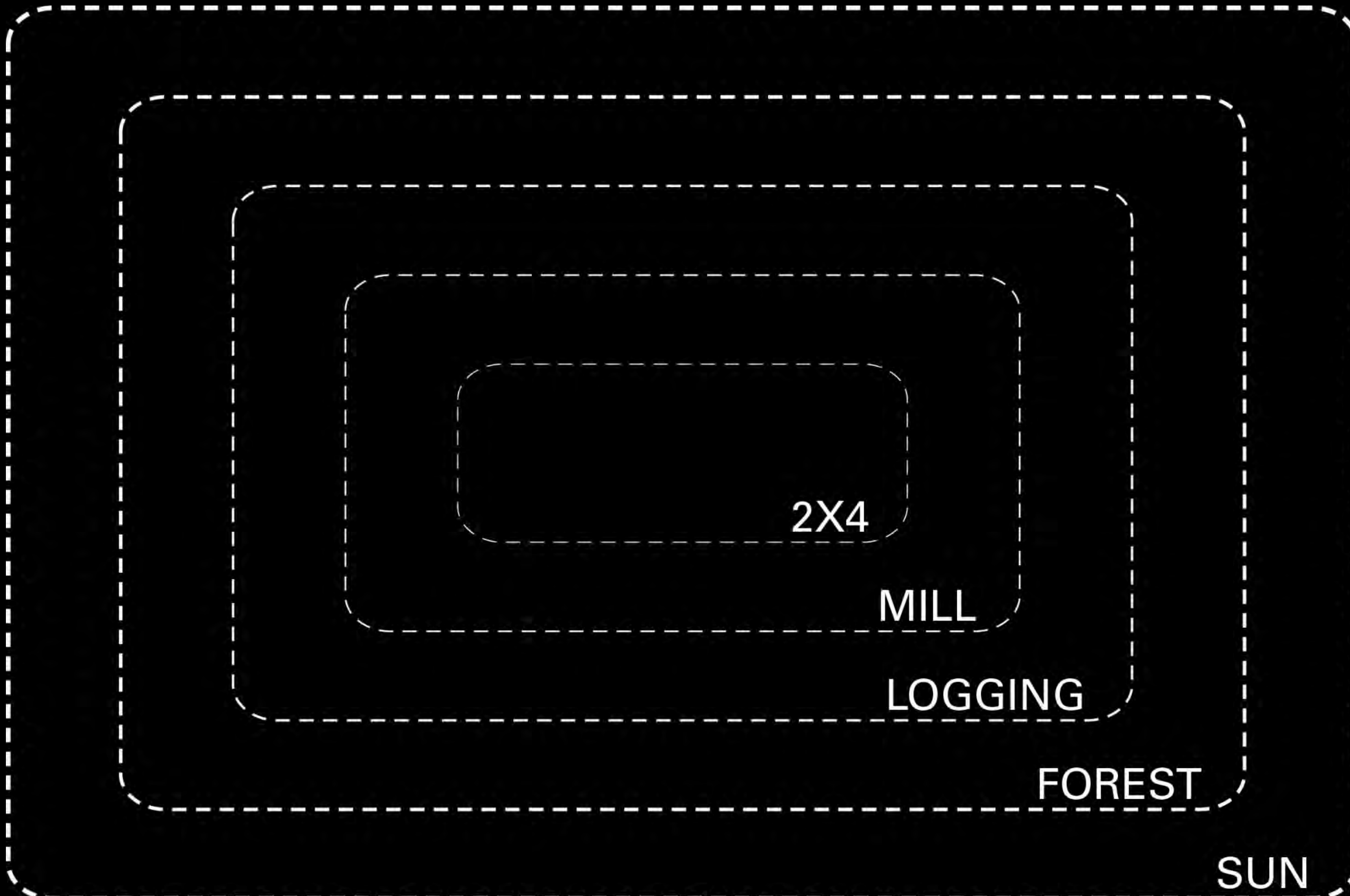
System Boundaries



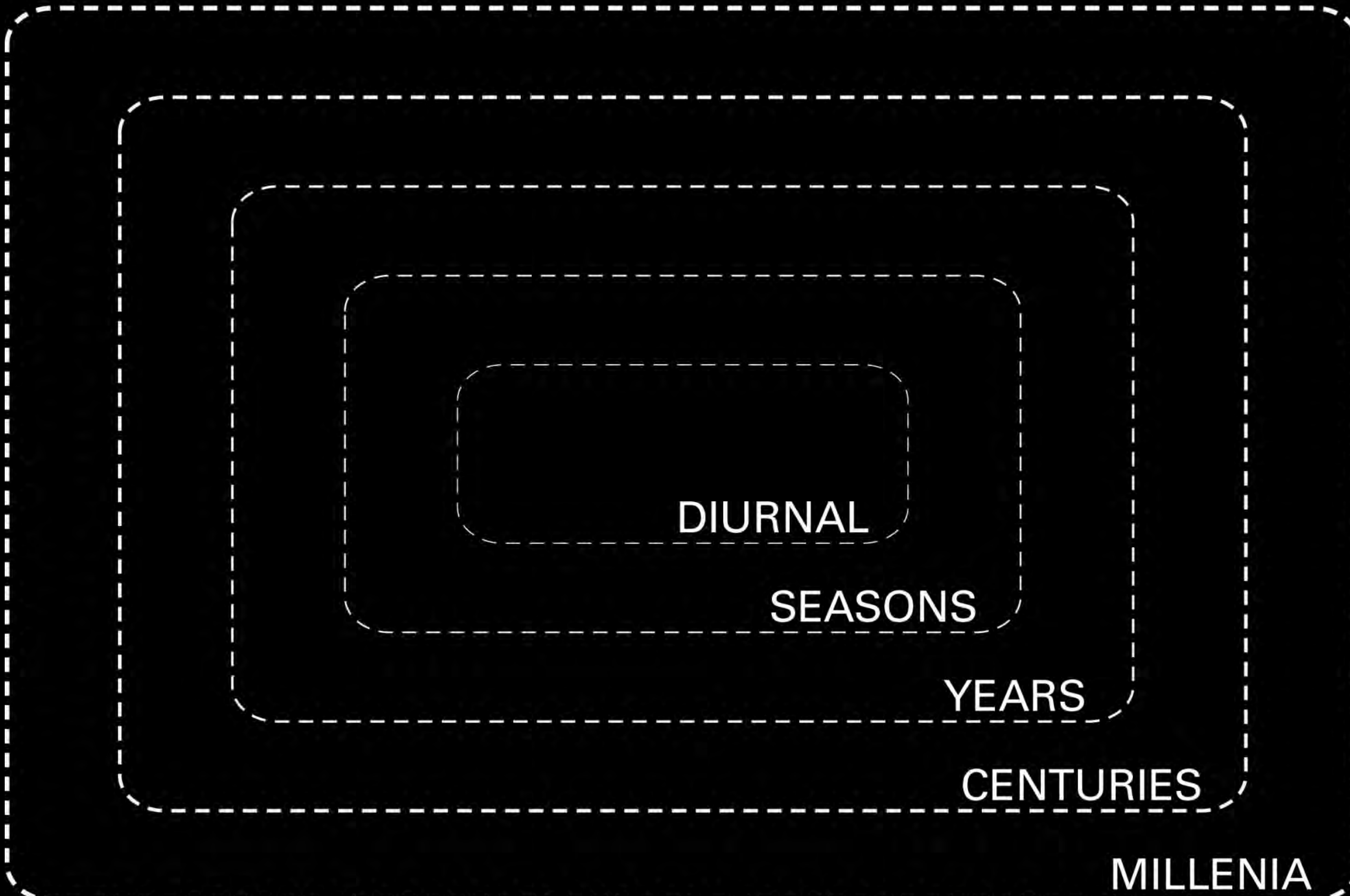
A BUILDING ON EARTH



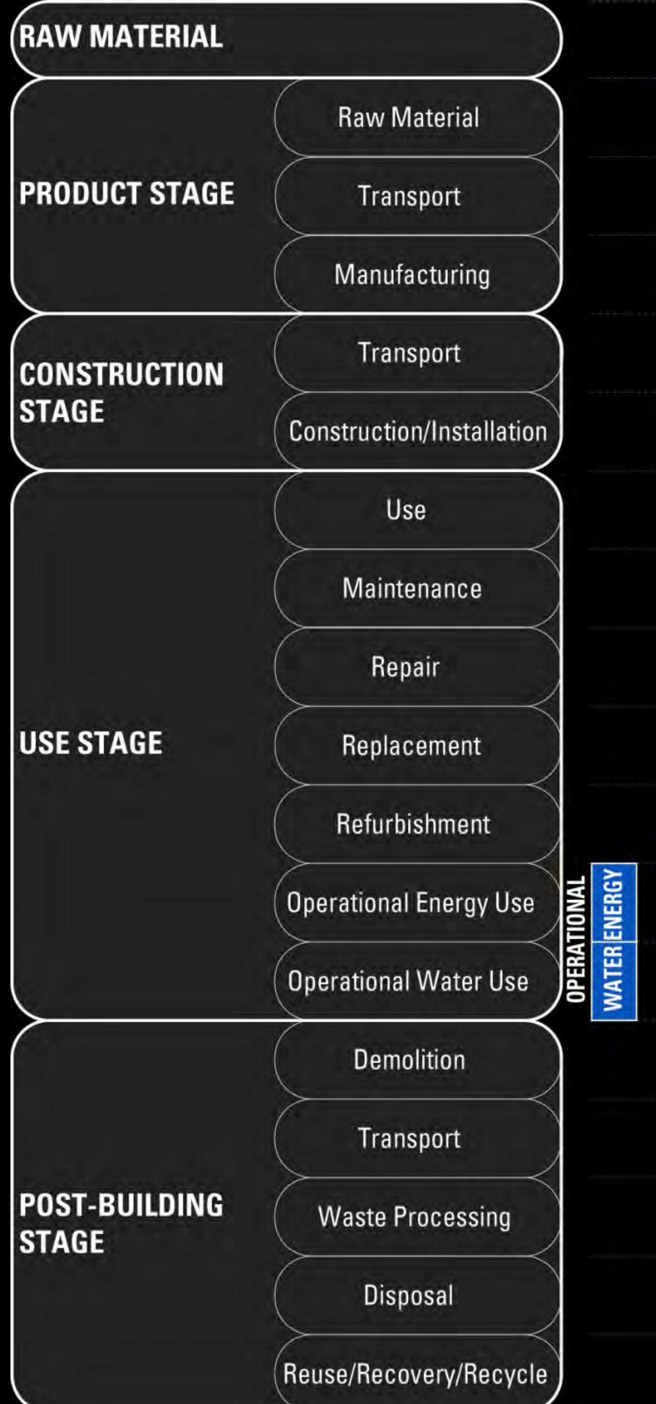
A BODY IN A ROOM

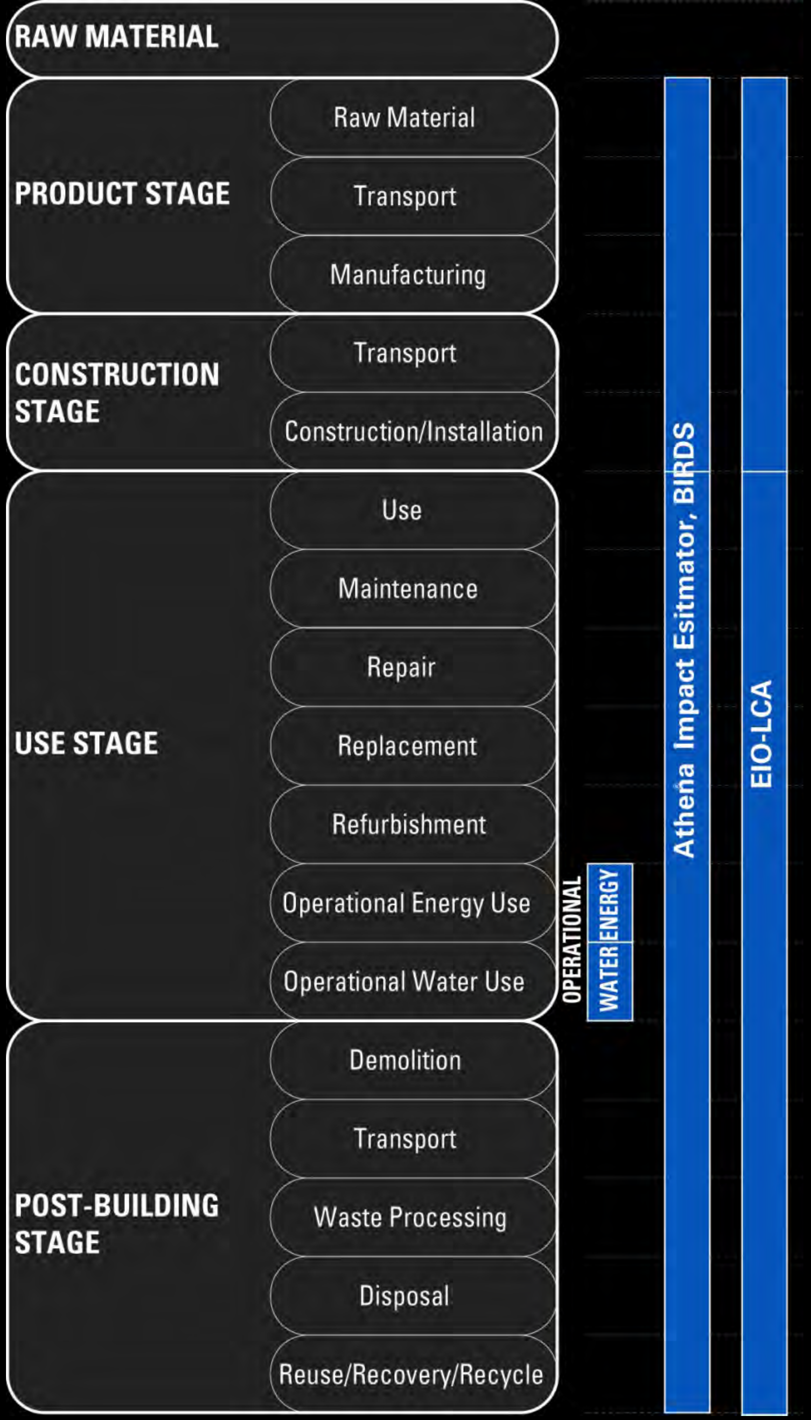


LUMBER



EVOLUTION OF CIVILIZATION


RAW MATERIAL
PRODUCT STAGE
Raw Material
Transport
Manufacturing
CONSTRUCTION STAGE
Transport
Construction/Installation
USE STAGE
Use
Maintenance
Repair
Replacement
Refurbishment
Operational Energy Use
Operational Water Use
OPERATIONAL
ENERGY
WATER
POST-BUILDING STAGE
Demolition
Transport
Waste Processing
Disposal
Reuse/Recovery/Recycle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PRODUCT STAGE
Raw Material
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Manufacturing
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Construction/Installation
USE STAGE
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Replacement
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Demolition
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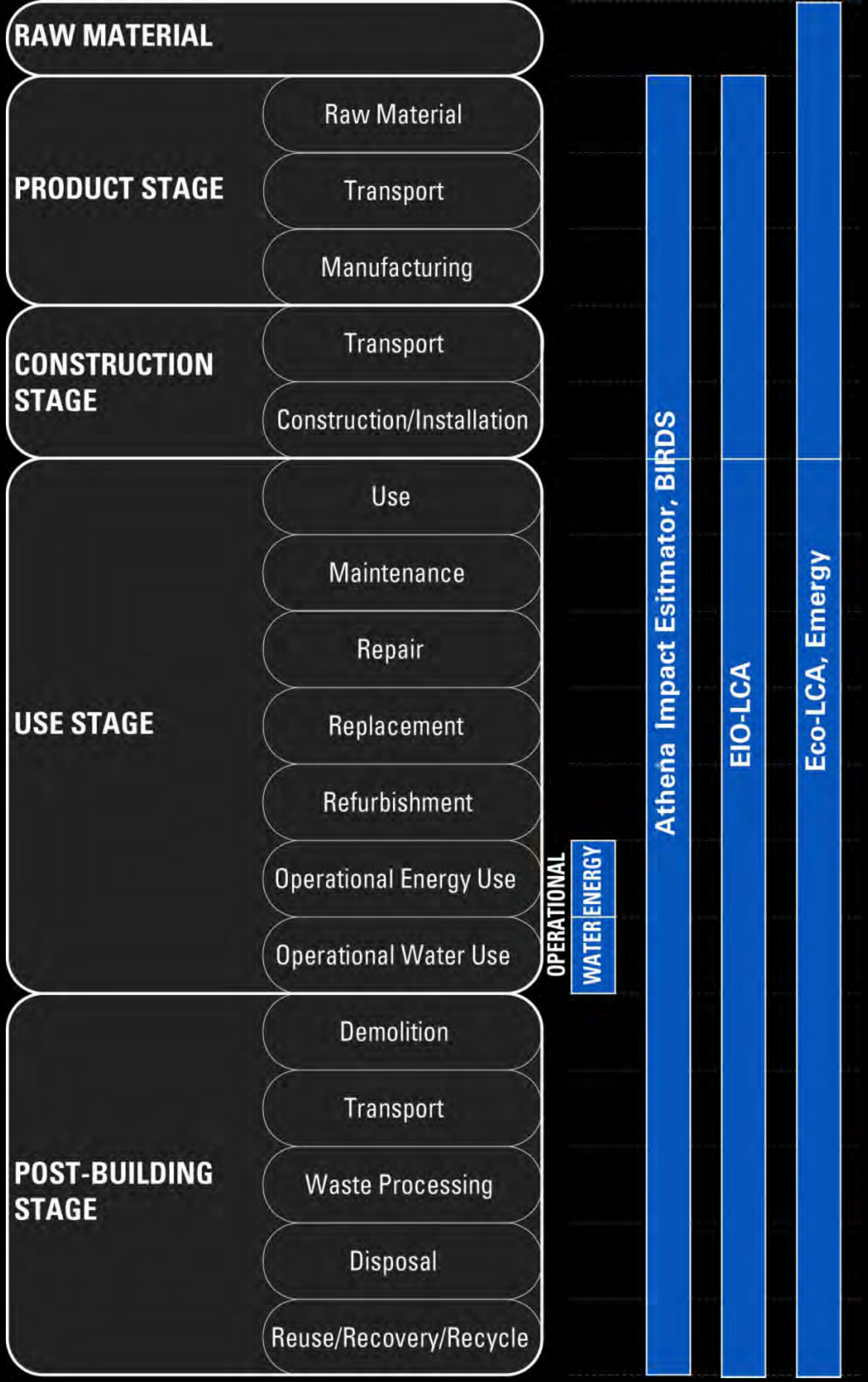
OPERATIONAL
WATER
ENERGY
Athena Impact Esitmator, BIRDS
EIO-LCA


RAW MATERIAL
PRODUCT STAGE
Raw Material
Transport
Manufacturing
CONSTRUCTION STAGE
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Construction/Installation
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Replacement
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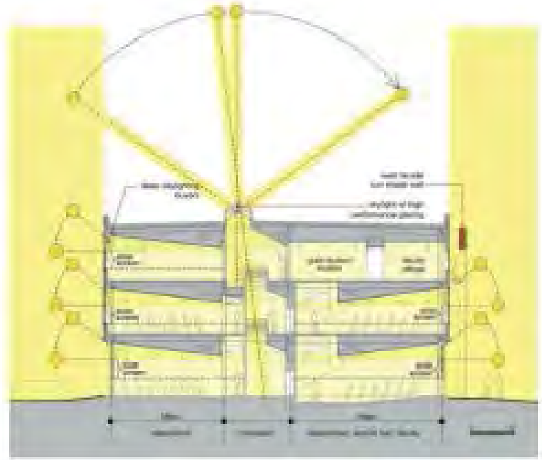
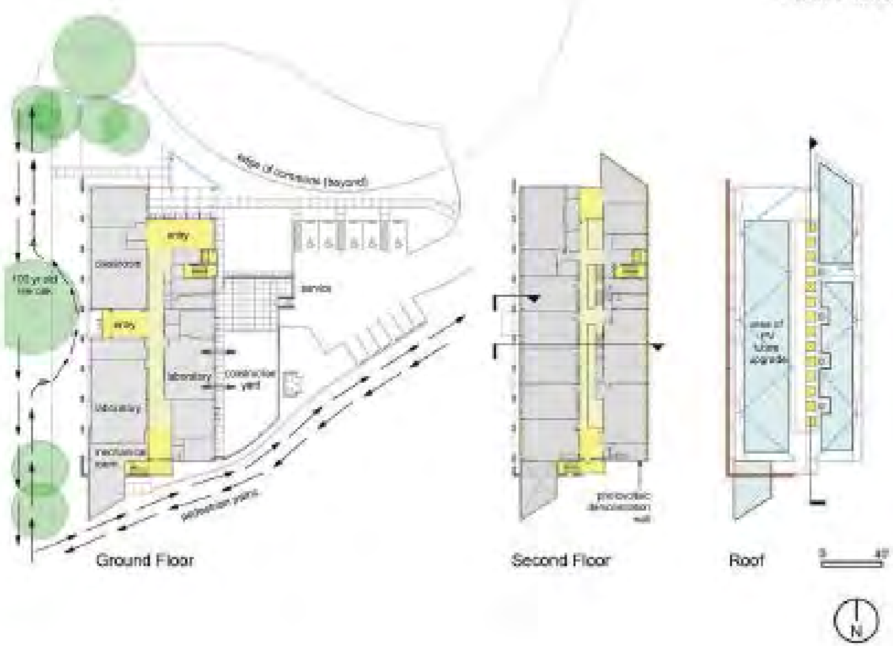
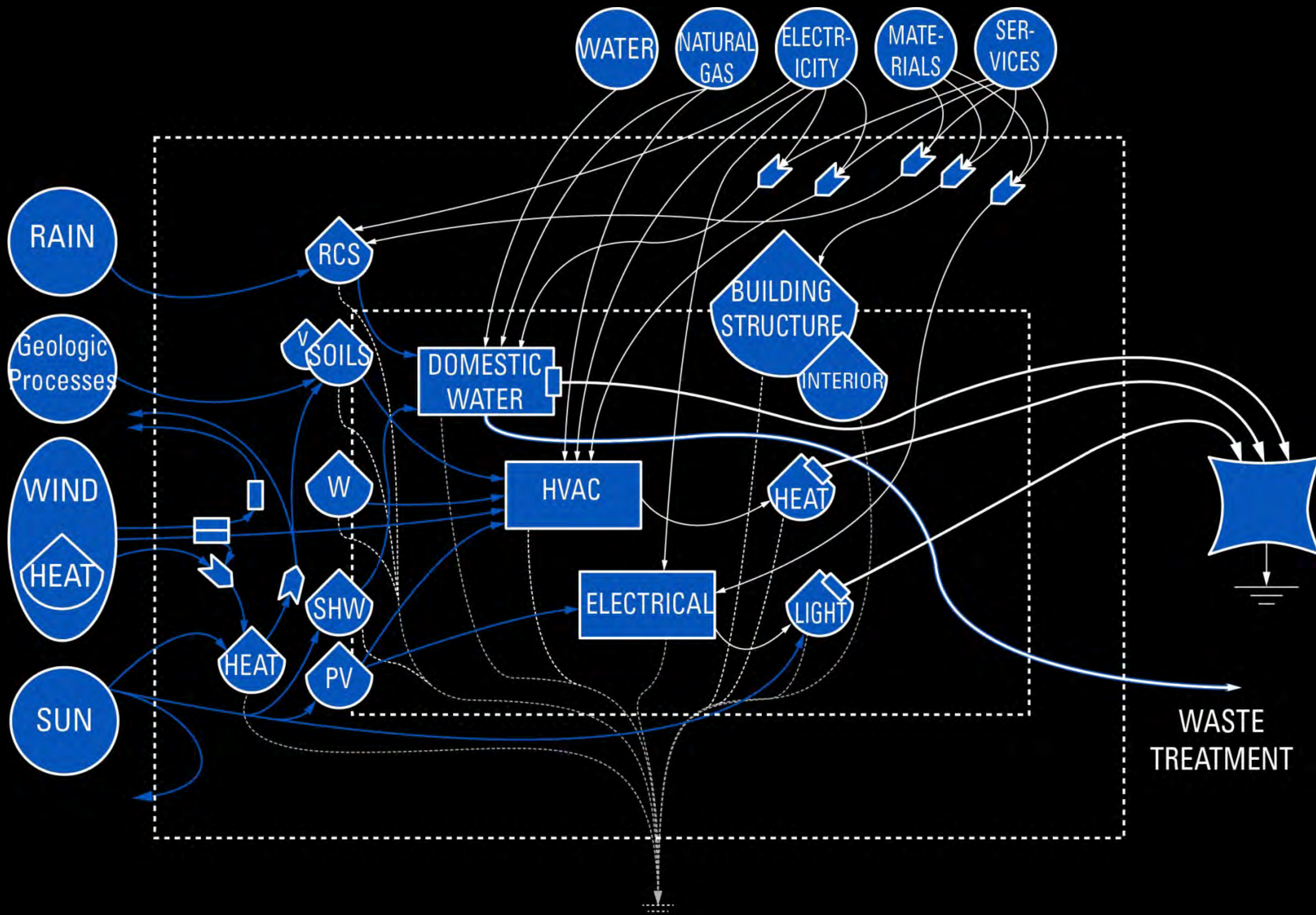
Waste Processing
Disposal
Reuse/Recovery/Recycle
OPERATIONAL
WATER
ENERGY
Athena Impact Esitmator, BIRDS
EIO-LCA
Eco-LCA, Emergy



Floor Plans


entry
classroom
entry
laboratory
laboratory
construction yard
service
Ground Floor
Second Floor
Roof
0
40'
N


WATER
NATURAL GAS
ELECTR-ICITY
MATE-RIALS
SER-VICES
RAIN
Geologic Processes
WIND
HEAT
SUN
RCS
V
SOILS
W
SHW
HEAT
PV
DOMESTIC WATER
HVAC
ELECTRICAL
BUILDING STRUCTURE
INTERIOR
HEAT
LIGHT
WASTE TREATMENT

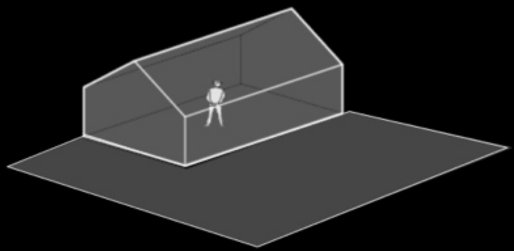
Source Note	Items	Data (units/yr)	Unit	Unit Solar Emergy (sej/unit)	Solar Emergy (sej/yr)	Solar Emergy (sej/building lifetime)
RENEWABLE INPUTS (R)						
1	Sunlight	4.08E+13	J	1.00E+00	4.08E+13	3.06E+15
2	Rain (chemical potential)	1.82E+10	J	1.81E+04	3.30E+14	2.47E+16
3	Wind (kinetic energy)	1.63E+11	J	1.47E+03	2.39E+14	1.79E+16
	Total Renewable Inputs (R)					**4.57E+16**
NON-RENEWABLE STORAGES USED (N)						
4	Net topsoil loss	3.11E+07	J	1.24E+05	3.86E+12	2.89E+14
	Total Non-Renewable Storages Used					**2.89E+14**
PURCHASED INPUTS (F)						
5	Electricity	1.64E+12	J	4.16E+04	6.82E+16	5.11E+18
6	Chilled water	4.03E+12	J	3.99E+04	1.61E+17	1.21E+19
7	Steam	7.85E+11	J	4.89E+04	3.84E+16	2.88E+18
8	Water	7.24E+09	J	2.61E+04	1.89E+14	1.42E+16
9	Material Transport	2.48E+03	gal	6.58E+04	1.63E+08	1.63E+08
10	Construction Materials (except PV system)	1.80E+10	g	4.08E+09		7.32E+19
11	Construction Materials (PV system)	1.31E+01	m^2	6.40E+14		8.38E+15
12	Construction Materials: Maintenance and Replacements (except PV system)	1.37E+09	g	3.31E+09		4.53E+18
13	Construction Materials: Maintenance and Replacements (PV system)	2.62E+01	m^2	6.40E+14		1.68E+16
14	Construction Activities					3.69E+18
	Total Purchased Inputs					**1.02E+20**

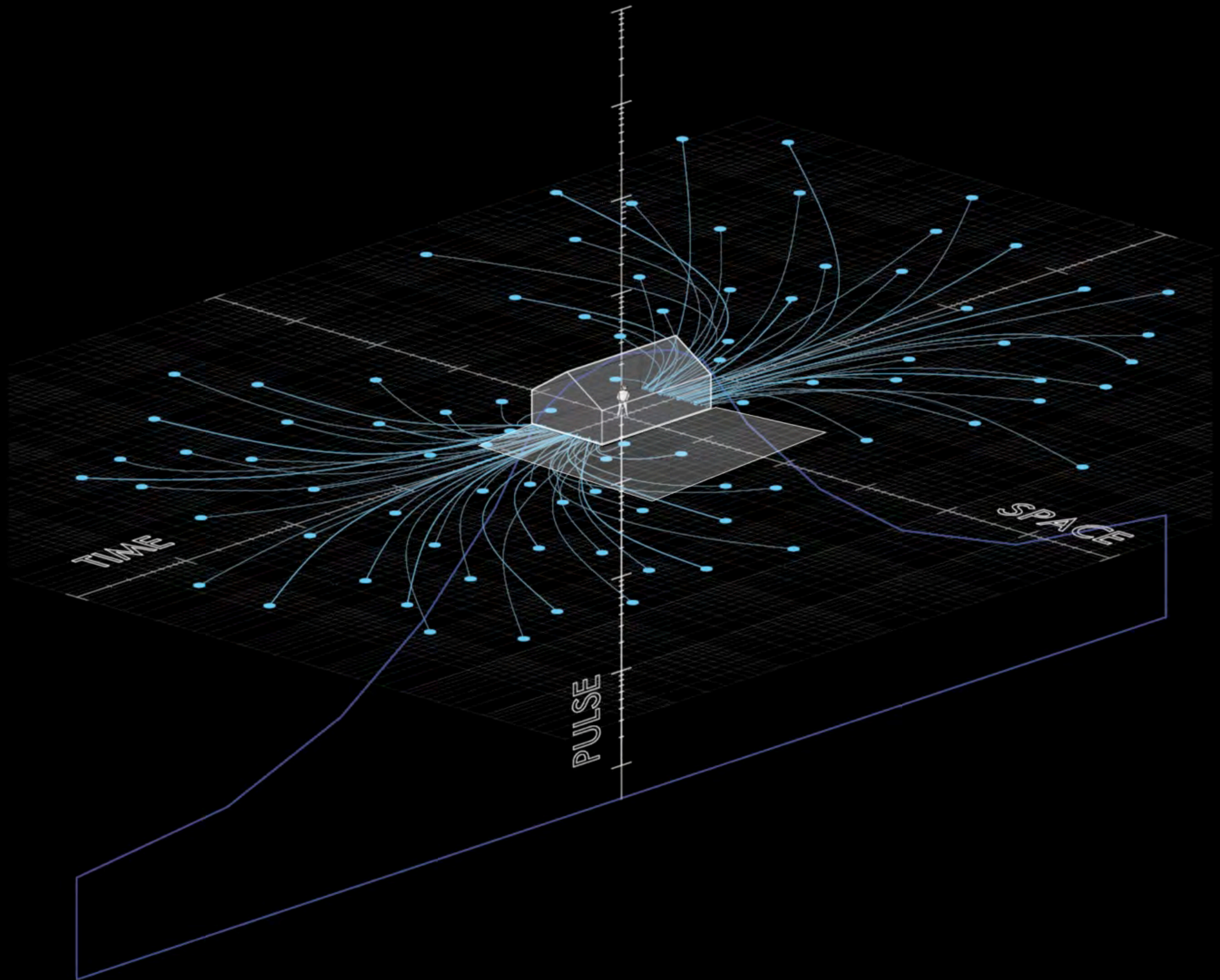
Rinker Hierarchy of Energy	
Construction Materials (except PV system)	7.32E+19
Chilled Water	1.21E+19
Electricity	5.11E+18
Replacements (except PV system)	4.53E+18
Construction Acitvities	3.69E+18
Steam	2.88E+18
Rain	2.47E+16
Wind	1.79E+16
Replacements (PV system)	1.68E+16
Water	1.42E+16
Construction Materials (PV system)	8.38E+15
Sunlight	3.06E+15
Net Top Soild Loss	2.89E+14
Material Transport	1.63E+08
	1.02E+20

	Operational	Construction & Maintenance
Construction Materials (except PV system)		7.32E+19
Replacements (except PV system)		4.53E+18
Construction Acitvities		3.69E+18
Material Transport		1.63E+08
Net Top Soild Loss		2.89E+14
Construction Materials (PV system)		8.38E+15
Replacements (PV system)		1.68E+16
Chilled Water	1.21E+19	
Electricity	5.11E+18	
Steam	2.88E+18	
Rain	2.47E+16	
Wind	1.79E+16	
Water	1.42E+16	
Sunlight	3.06E+15	
	2.01E+19	**8.14E+19**
	19.83%	**80.17%**
	(of 1.02E+20 total building emergy)	

BUILDING MANUFACTURER: 49%
BUILDING MAINTENANCE: 35%
BUILDING OPERATION: 15%

Ricardo Maria Pulselli, Eudgenio Simoncini, and Nadia Marchettini, "Energy and emergy based coast-benefit evaluation of building envelopes relative to geographical location and climate," *Building and Environments* 44 (2009), p. 922.

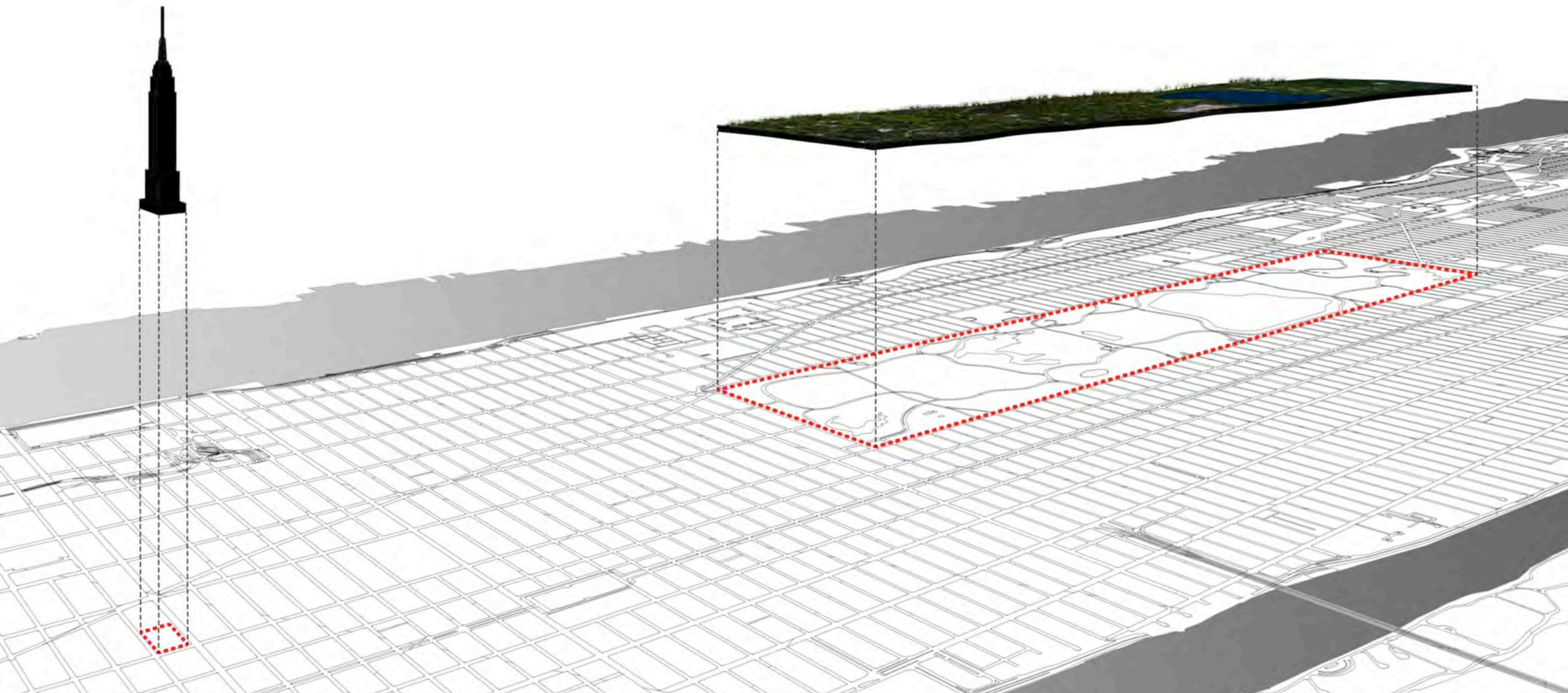


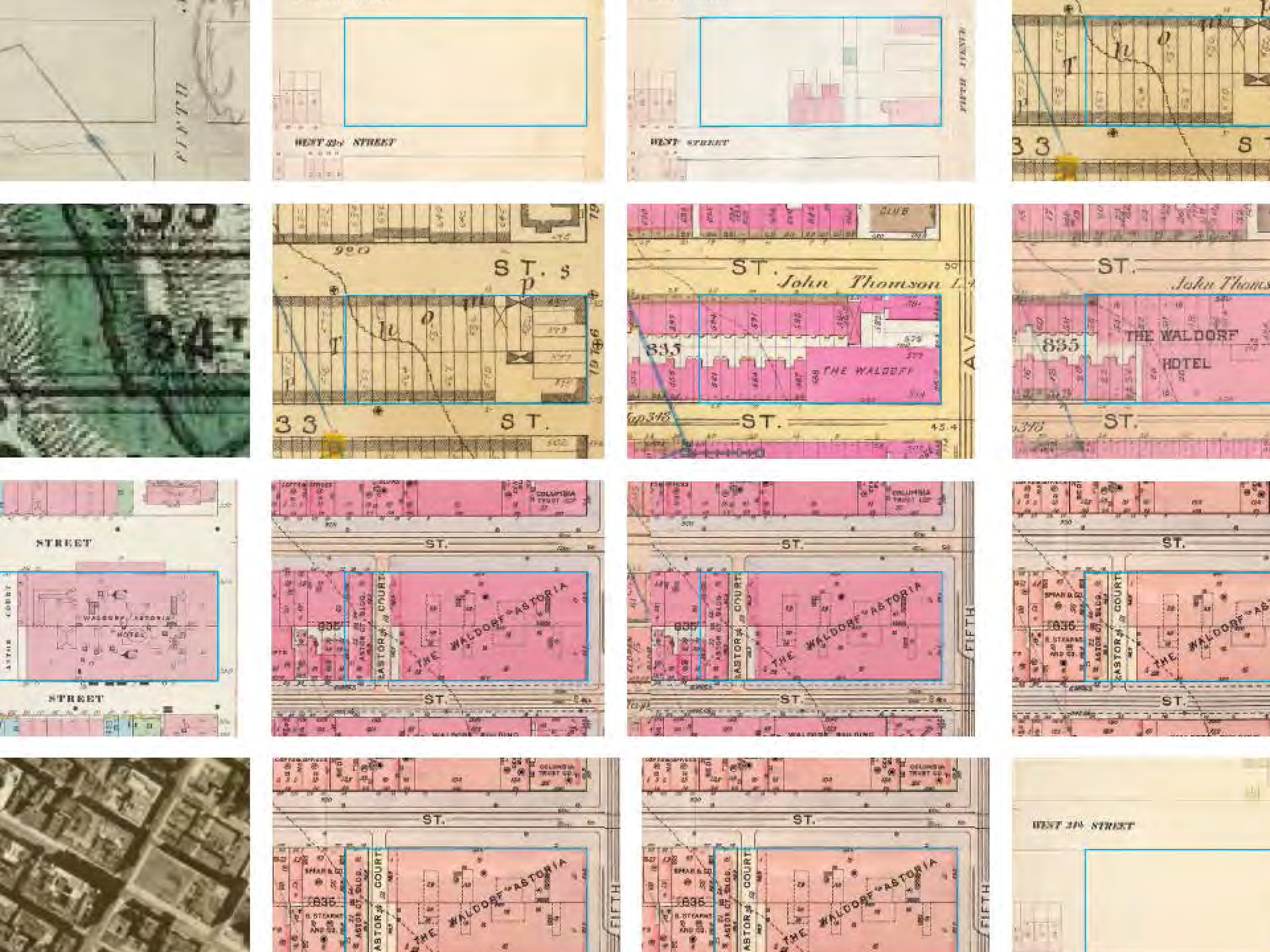

TIME
SPACE
PULSE

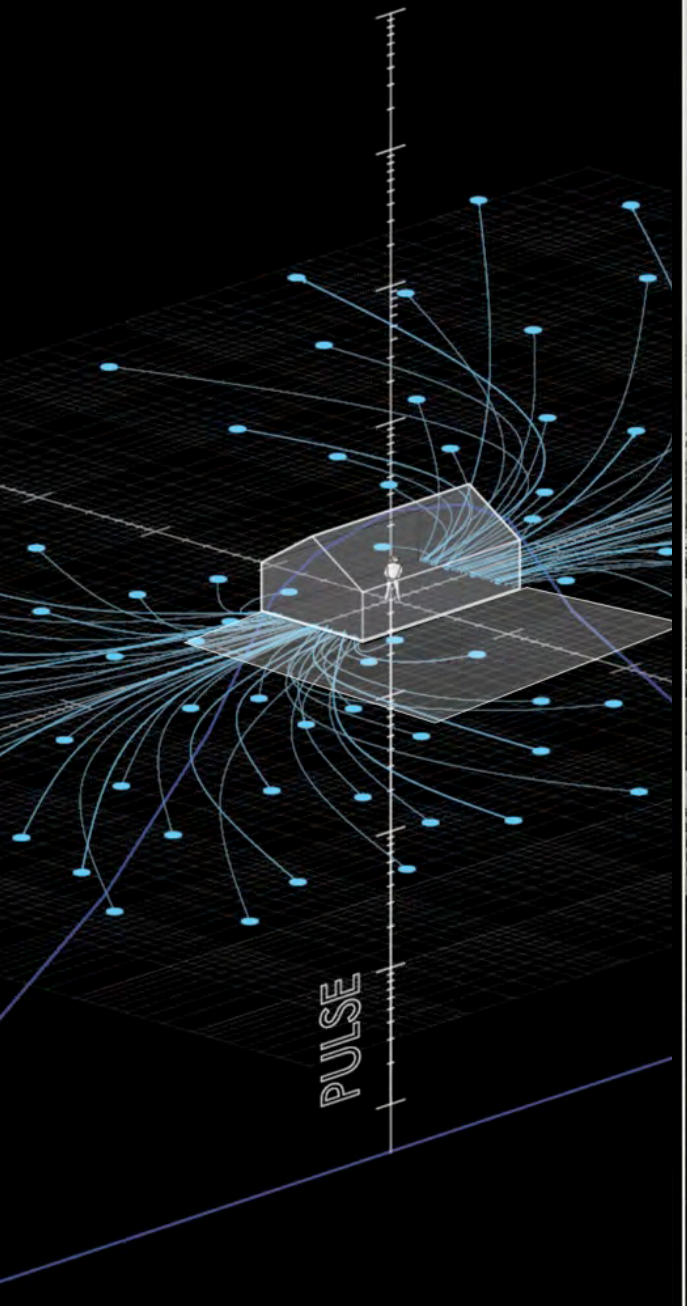
PLOT

THE MATTER OF URBANIZATION

Central Park & Empire State Building




WEST 33d STREET
WEST STREET
FIFTH AVENUE
33 ST.
John Thomson
THE WALDORF
835
THE WALDORF HOTEL
STREET
WALDORF ASTORIA HOTEL
ST.
COLUMBIA TRUST CO.
THE WALDORF-ASTORIA
ASTOR COURT
FIFTH
WALDORF BUILDING
SPEAR & CO.
WEST 33d STREET


PULSE

DAILY JOB ACTIVITY

Perhaps, the best way to get a cross section of the varied activities of the many men employed on a building operation of this size is to glance at the job diary.

Each day a diary is compiled, which corresponds to the log of a ship. This diary is required to give a record of the number of men employed and a digest of the activities of the various trades and groups.

Our records show that Thursday, August 14th,1930, was the day upon which the greatest number of men were employed - namely, 3,439 of whom 1928 were working for the Builders and 1511 for the various sub-contractors. But let the diary for that day tell its own story. It is a cross section of the job's activity at its busiest period.

STARRETT BROTHERS and EKEN
Incorporated

Building: Empire State   Date: Thursday, August 14, 1930

Location: 5th Ave., W. 33d & W.34th Sts.   Weather: Fair

Architect: Shreve, Lamb & Harmon   Temperature 68° 8 AM 72° 2 PM

Superintendent: John W.Bowser

DAILY CONSTRUCTION REPORT

No. Men   Remarks:

Starrett Brothers and Eken, Incorporated

Supervising Overhead:

1	Superintendent
1	Asst. Superintendent
1	Job Runner
2	Asst.Job Runners
1	Accountant
1	Purchasing Agent
1	Engineer
1	Asst.to Supt.
4	Stenographers
1	Plan Clerk
1	Telephone Operator
1	Office Boy
16	

16	Supervising Overhead
88	Operating "
104	

Operating Overhead:

1	Asst. Superintendent
1	Civil Engineer
7	Asst. Civil Engineers
1	Mechanical Inspector
1	Electrical "
1	Elevator "
1	Orn.Iron "
1	Caulking "
1	Inspector (General)
2	Expediters
1	Timekeeper
1	Asst. "
2	Cost Clerks
2	Clerks
1	Production Clerk
2	Distribution Clerks
27	Checkers
2	Storekeepers
31	Watchmen
1	Porter
1	Engineer (Quantities)
88	

1	Carpenter Foreman
2	" Deputies
10	" Pushers
269	Carpenters
10	Carpenter Apprentices
1	Lather Foreman
1	" Deputy
32	Lathers
326	

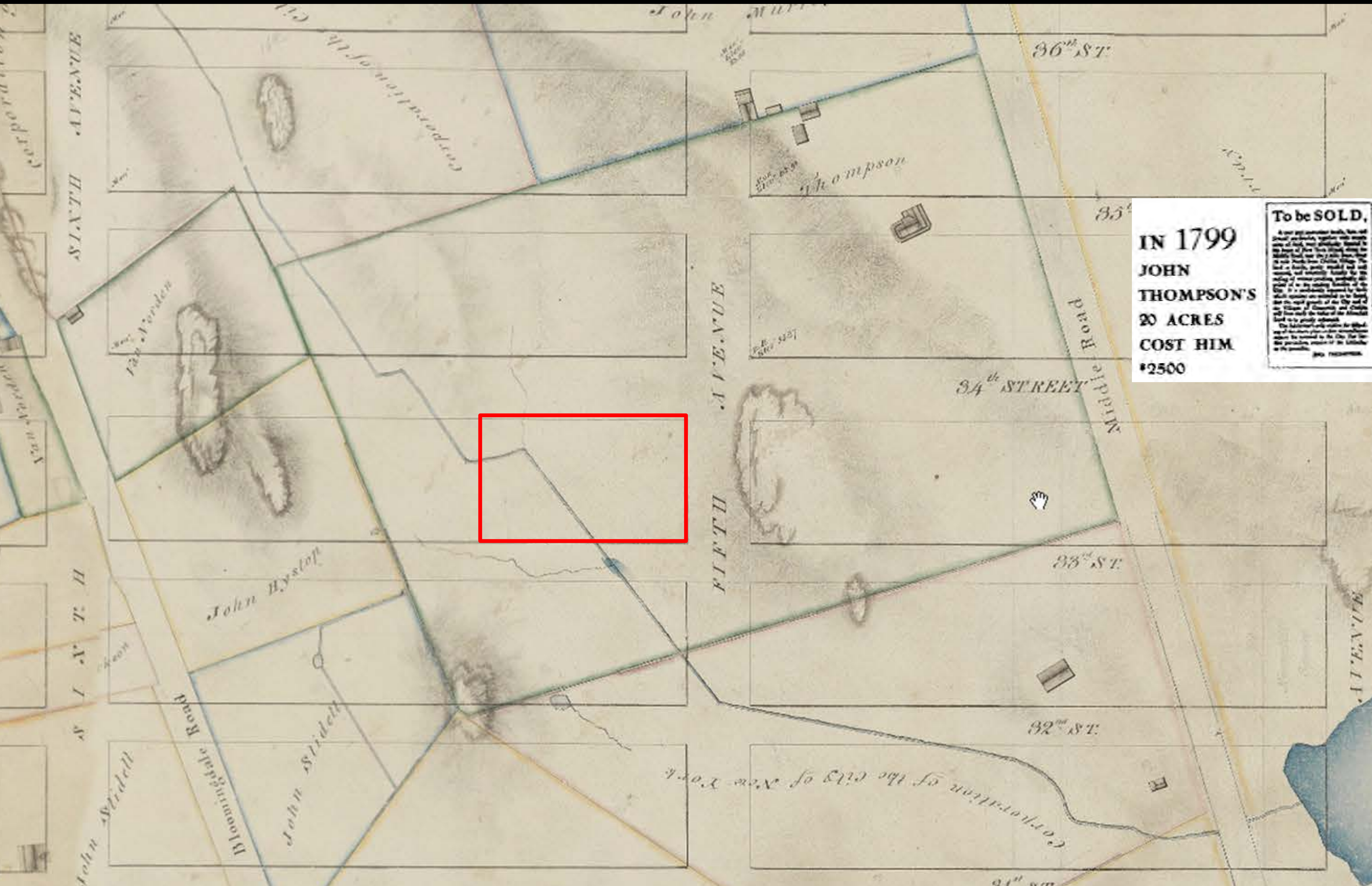
Carpenters: Continued on form work as follows: Making and placing floor arch forms on 54th and 55th flrs. - Making forms for beam sides, 1st bsmnt. - for beams and slab, Otis Elevator machine room, 21st flr. for column fireproofing - for underpinning under 5th Ave. sidewalk - for house pump and ejector foundations - for around electrical risers, and also making and placing forms at discontinued hoist shaft openings.


EMPIRE
STATE
BUILDING

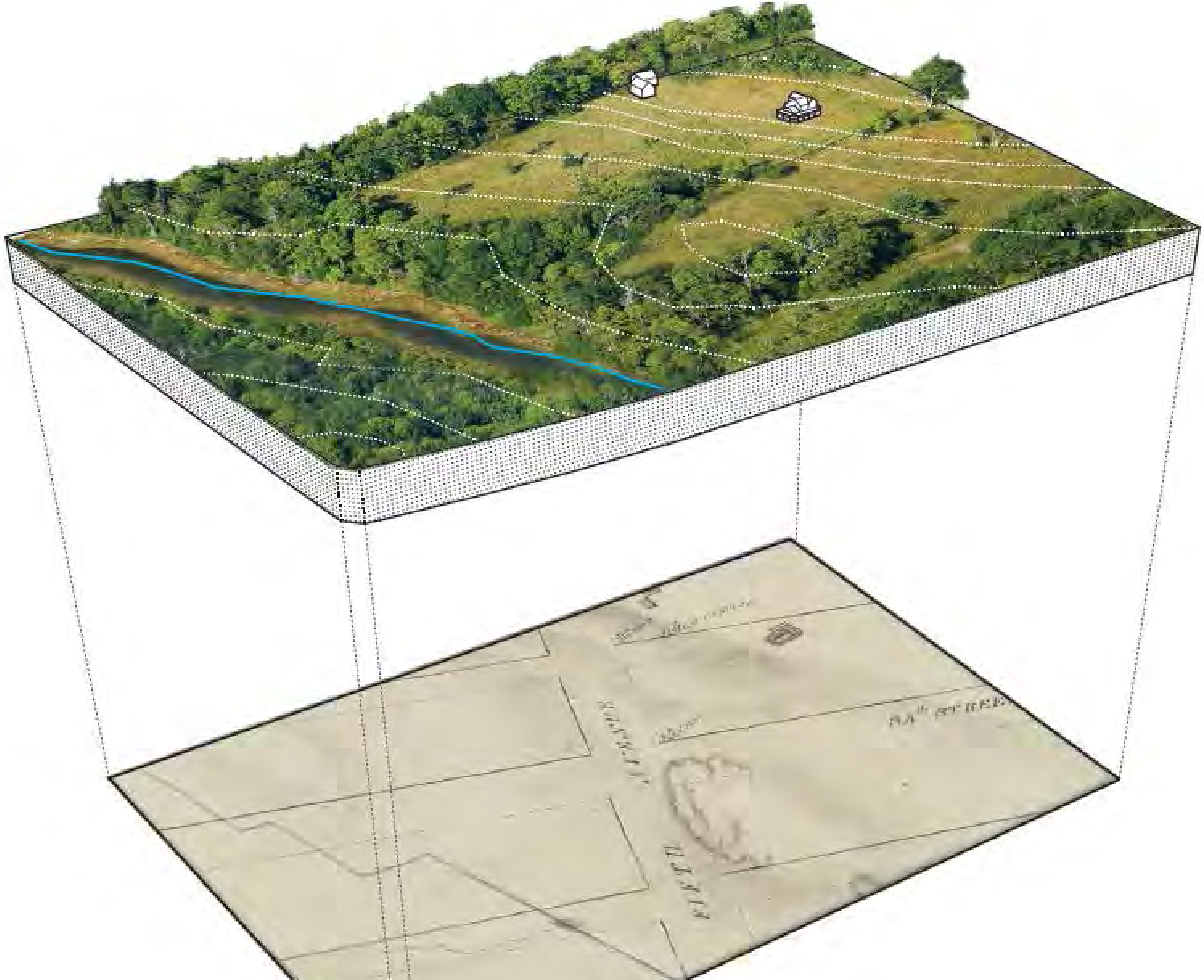
EMPIRE

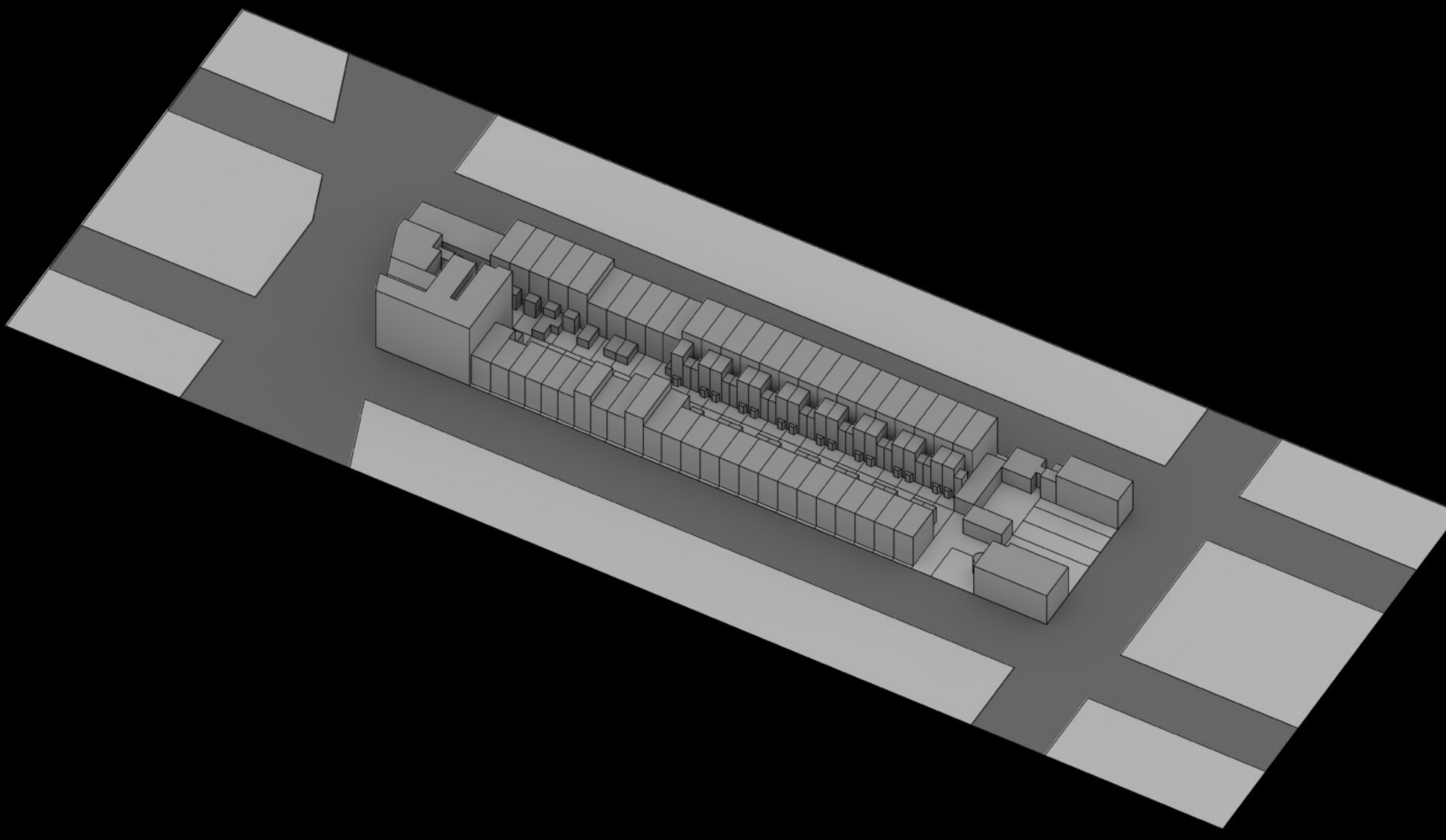
STATE

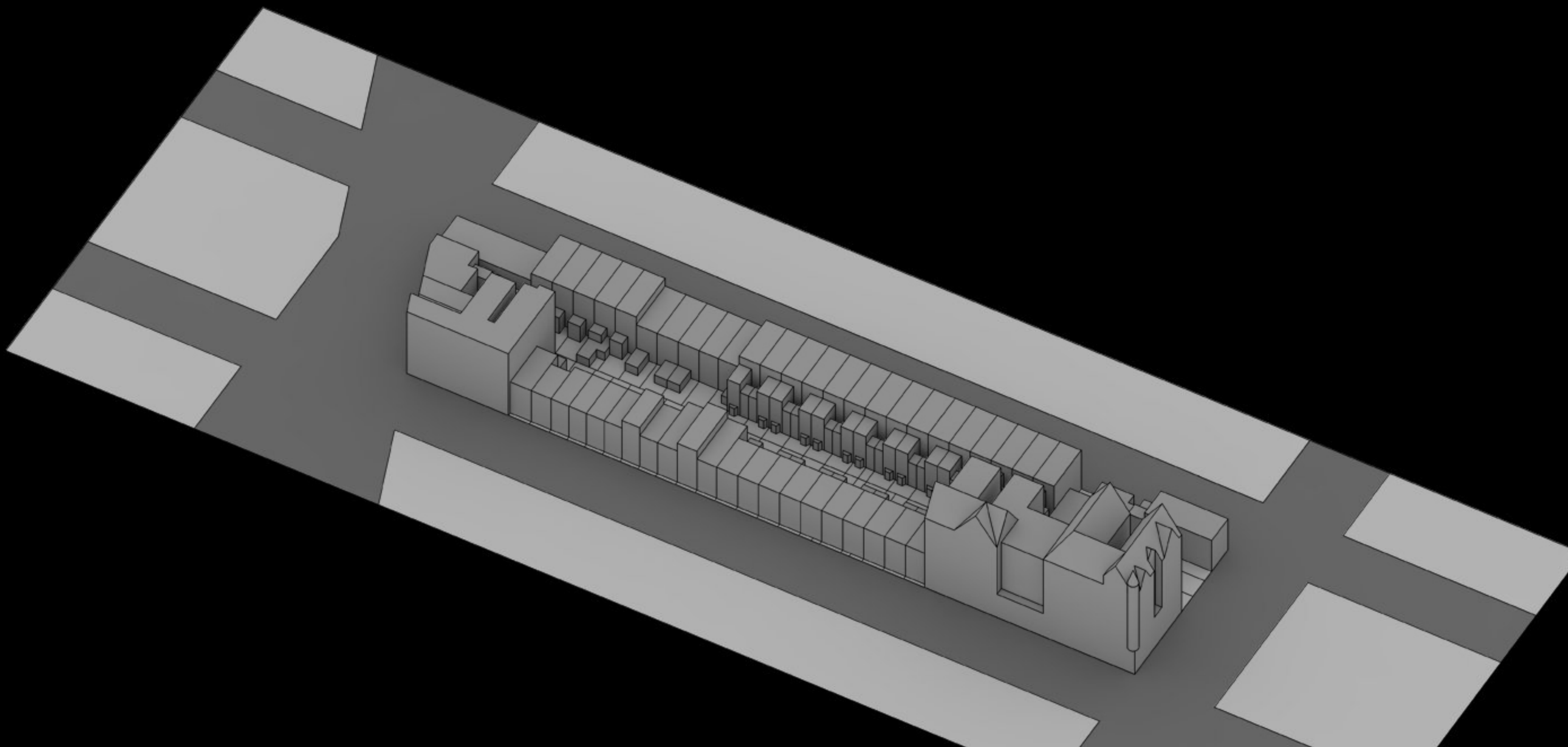
BUILDING

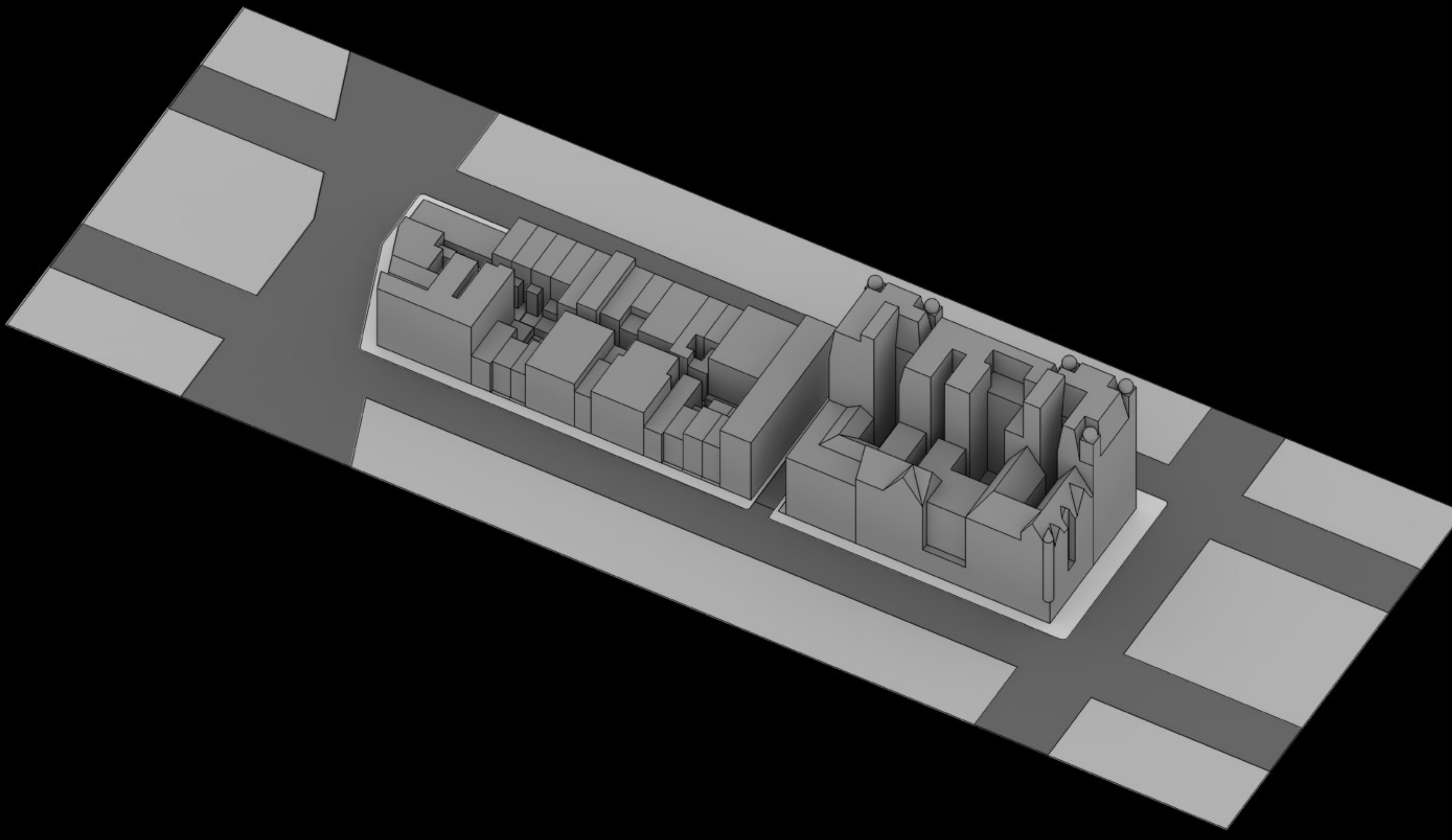


IN 1799
JOHN
THOMPSON'S
20 ACRES
COST HIM
$2500

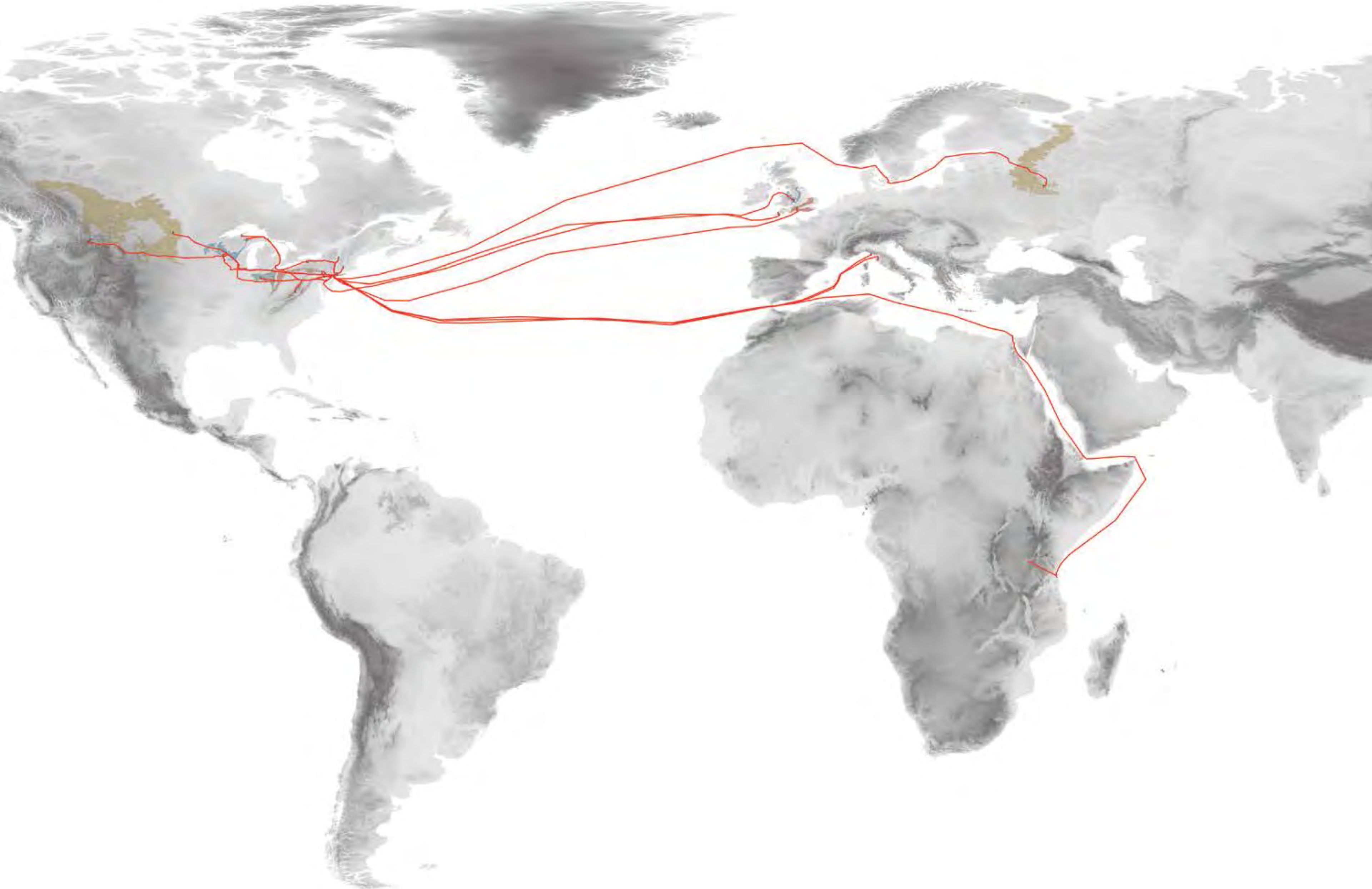


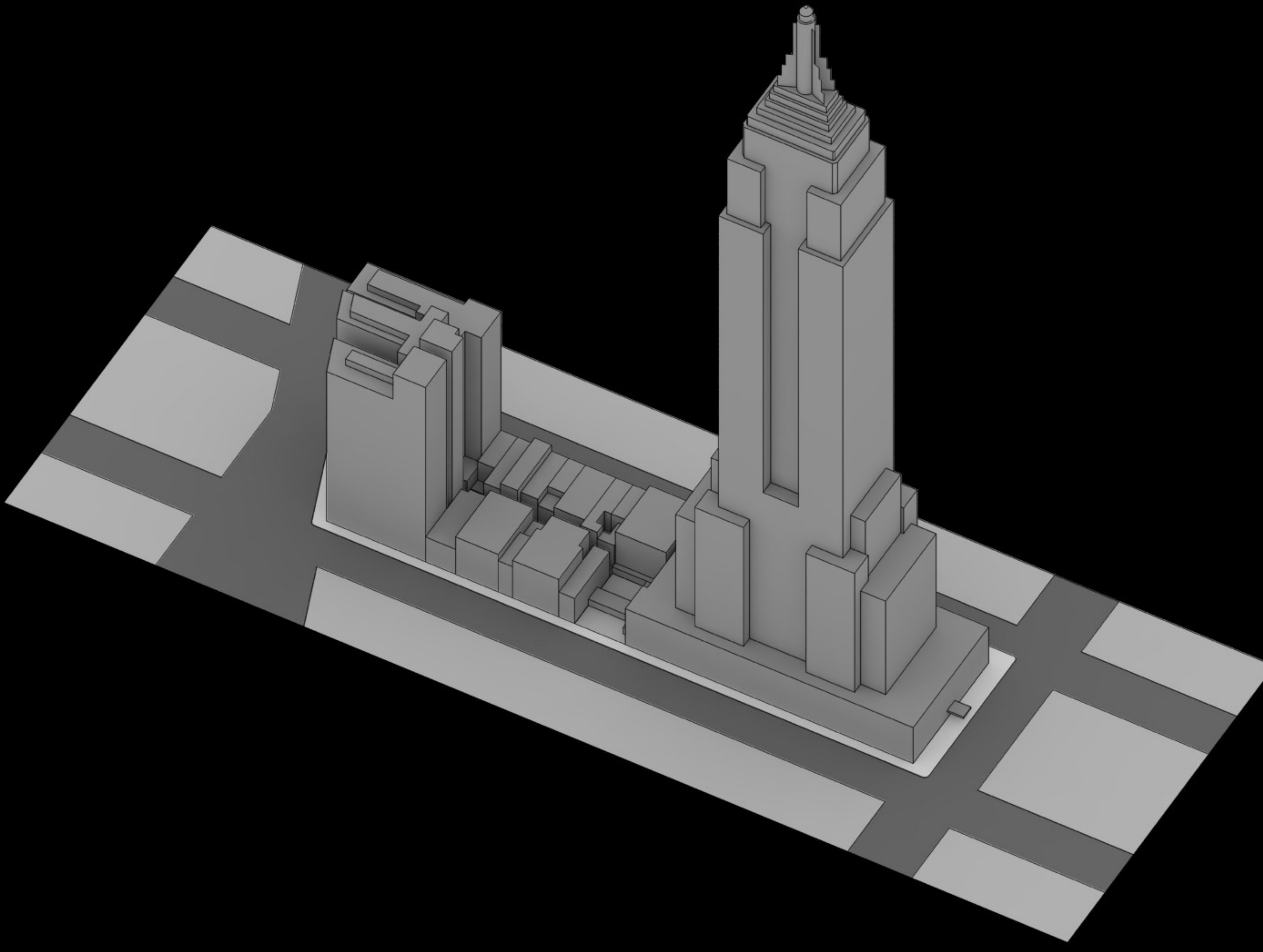




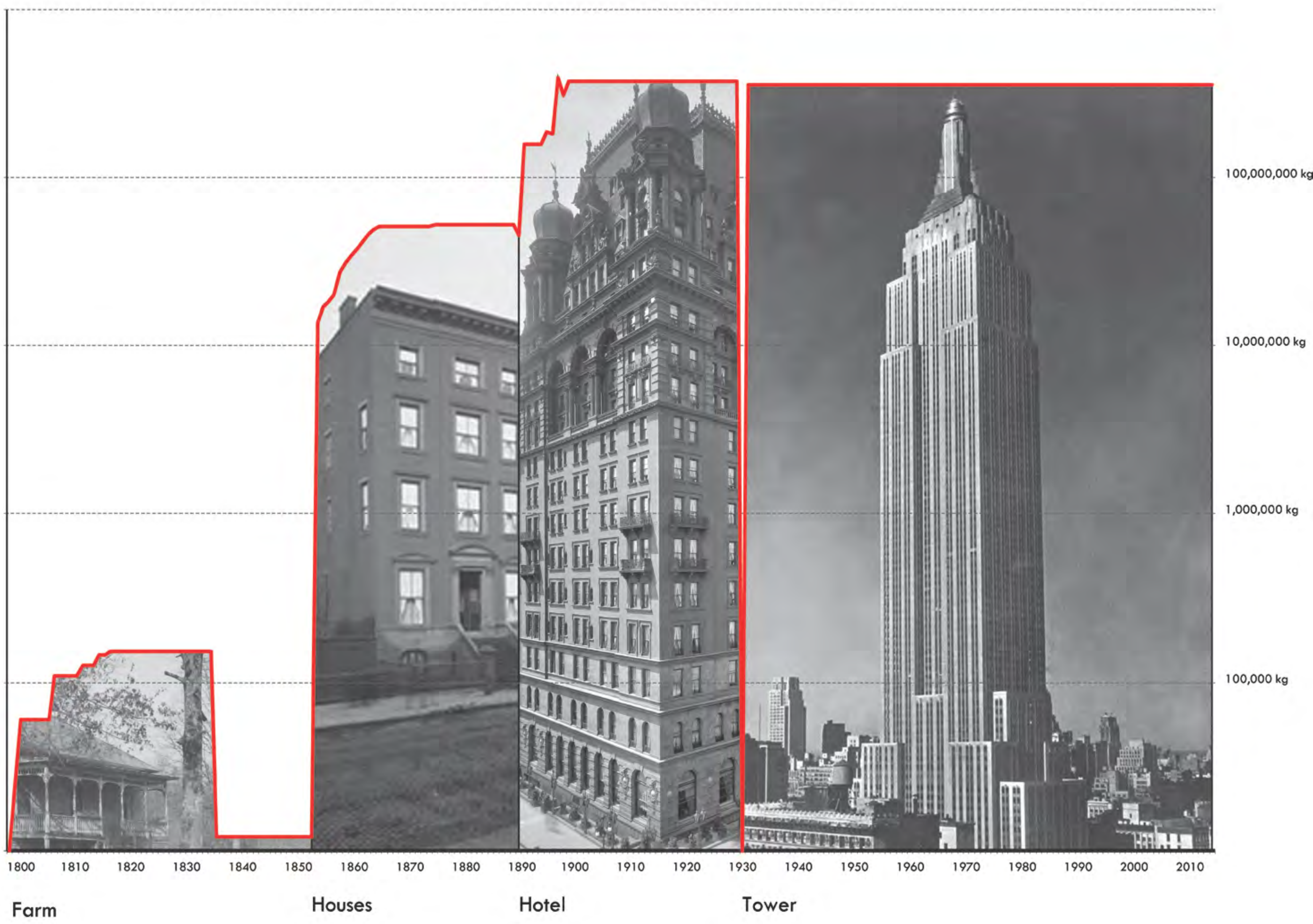


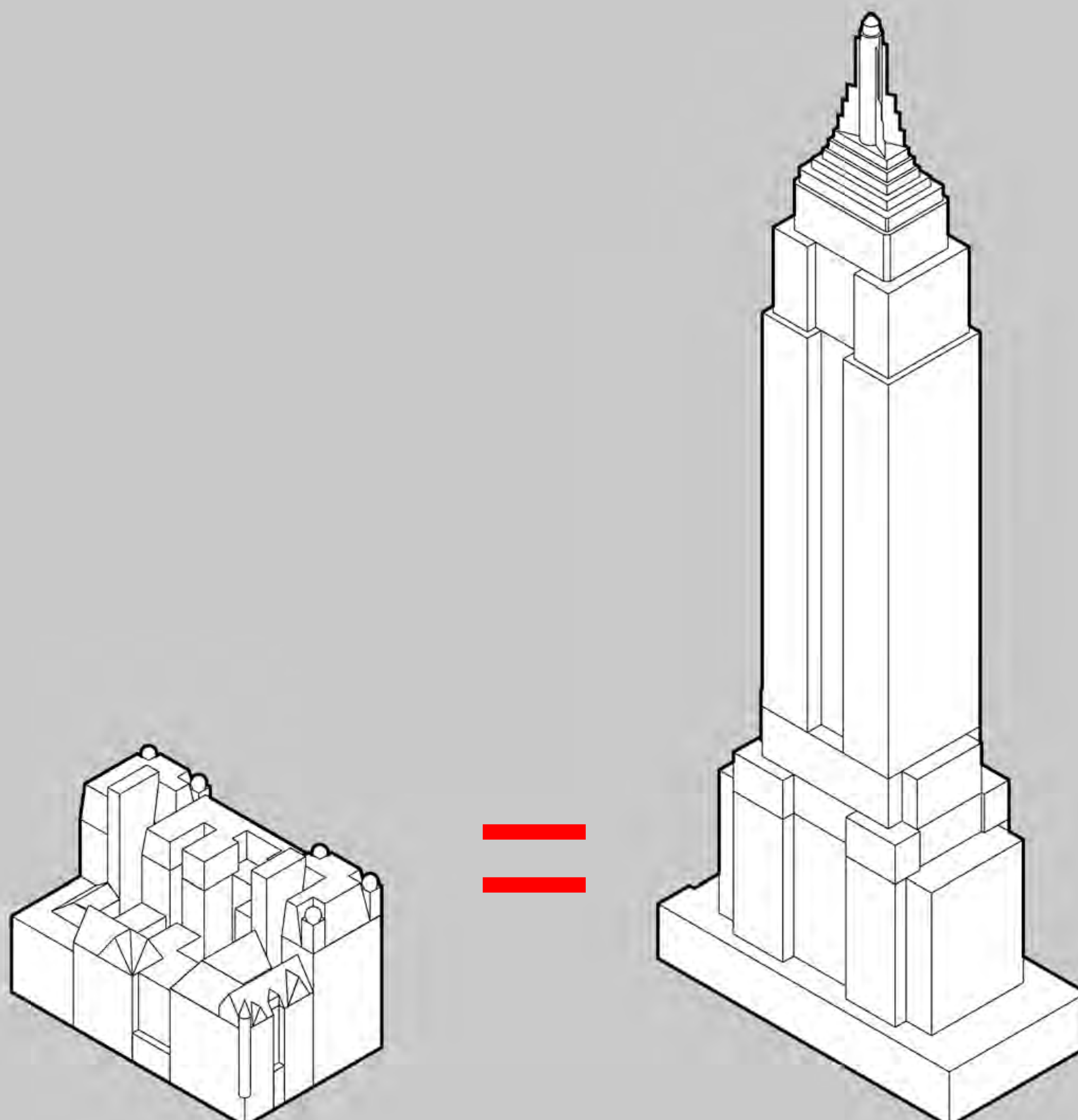
Waldorf-Astoria Hotel
1893-1929





Pulsation of Building Material (kg) Over Time





Emergy of different phases

Phase	Material (kg)	Emergy (sej)
1799-1850 Thompson's House	152,817	2.65957E+17
1850-1892 Houses	51,887,253	1.2499E+20
1892-1930 Waldorf Astoria	379,867,823	9.71873E+20
1930 Empire State Building	362,054,708	1.66369E+21

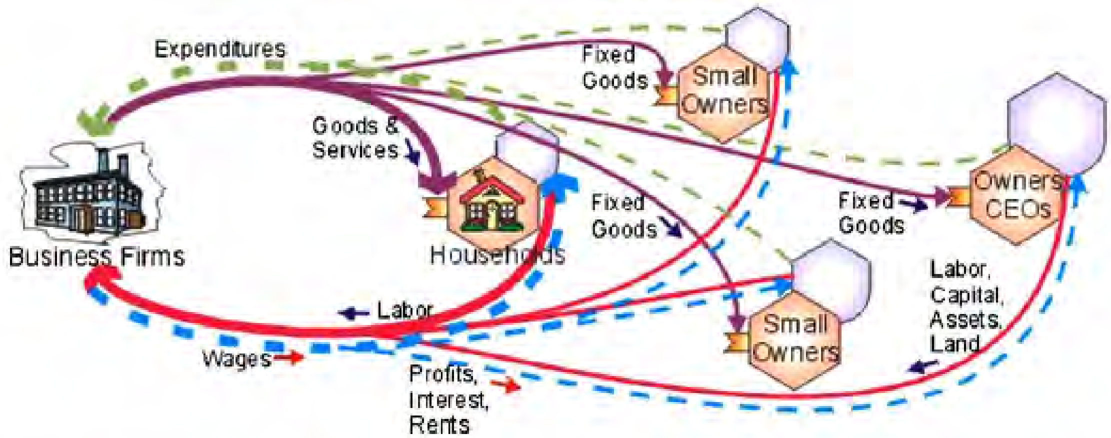


Fig. 2. A hierarchy of "households." A society is composed of family groups and their assets in households. Households can be placed into a web or hierarchy of production.

Thomas Abel, "Systems diagrams for visualizing macroeconomics," *Ecological Modelling*, Volume 178, Issues 1–2, 15 October 2004, Pages 189-194,

Emergy required for buildings	Phase
Solar energy required (directly and indirectly) to obtain a product; Global cost of production: the convergence of space, time and energy required for production	1799-1850 Thomson's House
	1850-1892 Houses
	1892-1930 Waldorf Astoria
	1930 Empire State Building

Exergy density of people in buildings	Phase
Energy that can be obtained when a system is brought to the thermodynamic equilibrium; Distance from equilibrium; level of organization, structure and information	1799-1850 Thomson's House
	1850-1892 Houses
	1892-1930 Waldorf Astoria
	1930 Empire State Building

Emergy/Exergy Ratio	Phase
Cost of production of a unit exergy; the reciprocal of the efficiency of a system in converting the energy cost of available inputs in actual organization	1799-1850 Thomson's House
	1850-1892 Houses
	1892-1930 Waldorf Astoria
	1930 Empire State Building

Phase	Material (kg)	Emergy (sej)	Years	Sej/year
1799-1850 Thomson's House	152,817	2.65957E+17	50	5.31914E+15
1850-1892 Houses	51,887,253	1.2499E+20	42	2.97594E+18
1892-1930 Waldorf Astoria	379,867,823	9.71873E+20	35	2.77678E+19
1930 Empire State Building	362,054,708	1.66369E+21	85	1.95728E+19

Phase	Material (kg)	Emergy (sej)	Years	Sej/year
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1930 Empire State Building	362,054,708	1.66369E+21	85	1.95728E+19

Phase	Number of People	Metabolic Energy	Years	Total Exergy
1799-1850 Thomson's House	6	3.82E+09	35	8.02E+19
1850-1892 Houses	292	3.82E+09	40	4.46E+21
1892-1930 Waldorf Astoria	3000	3.82E+09	35	4.01E+22
1930 Empire State Building	20000	3.82E+09	85	6.49E+23

Phase	Material (kg)	Emergy (sej)	Years	Sej/year
1799-1850 Thomson's House	152,817	2.65957E+17	50	5.31914E+15
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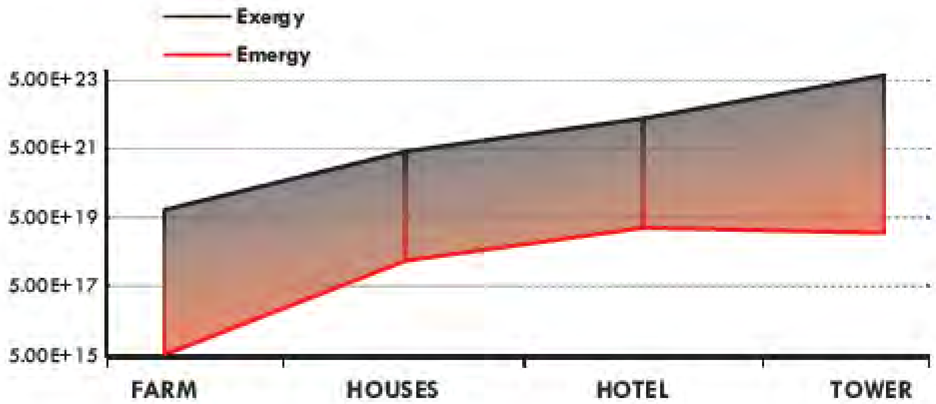
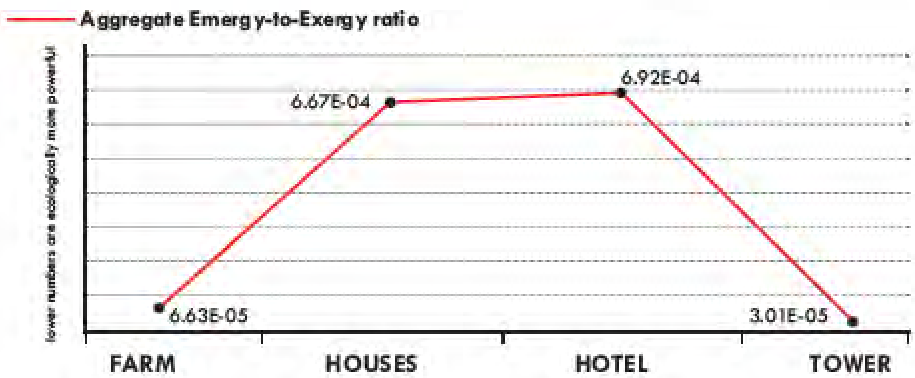
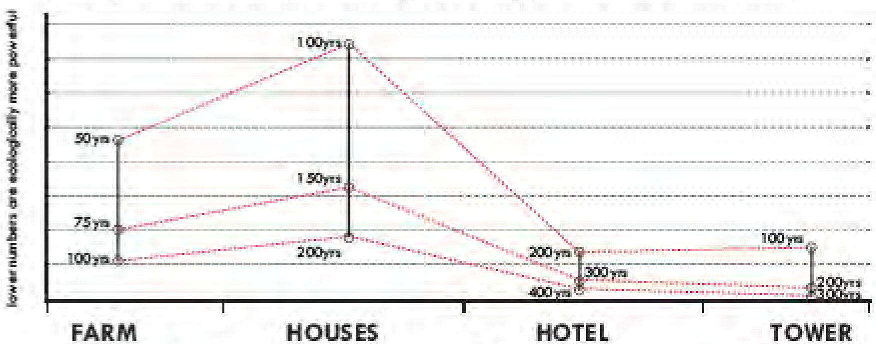
1892-1930 Waldorf Astoria	3000	3.82E+09	35	4.01E+22
1930 Empire State Building	20000	3.82E+09	85	6.49E+23

Phase	Emergy/Exergy ratio
1799-1850 Thomson's House	0.000066
1850-1892 Houses	0.000667
1892-1930 Waldorf Astoria	0.000692
1930 Empire State Building	0.000030

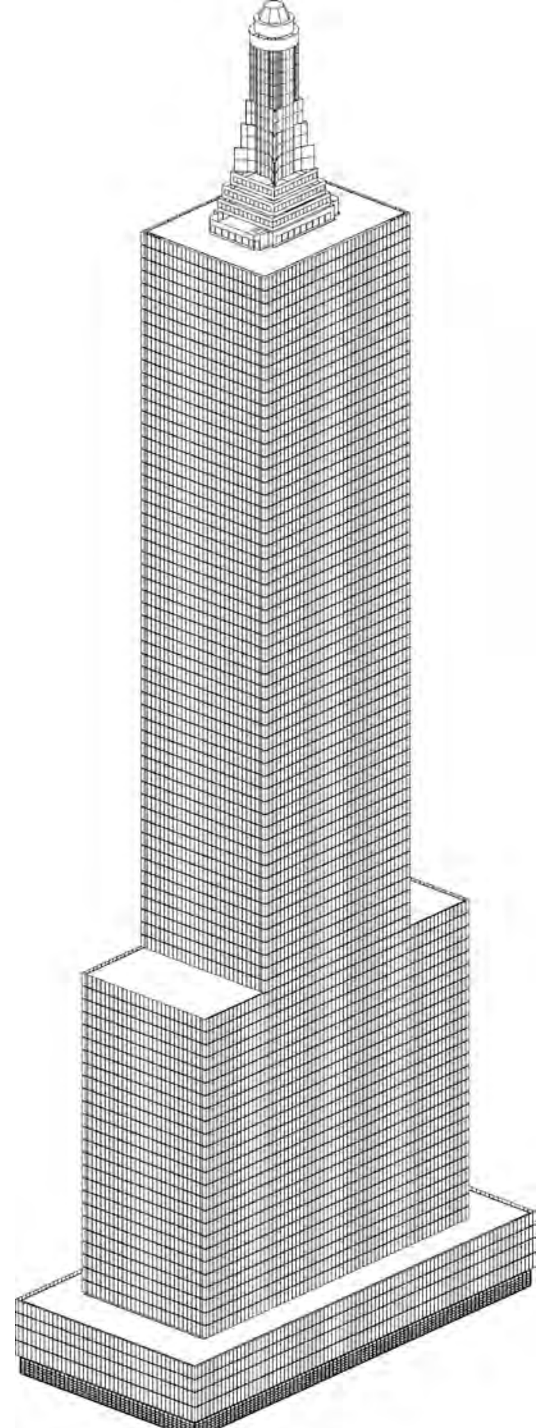


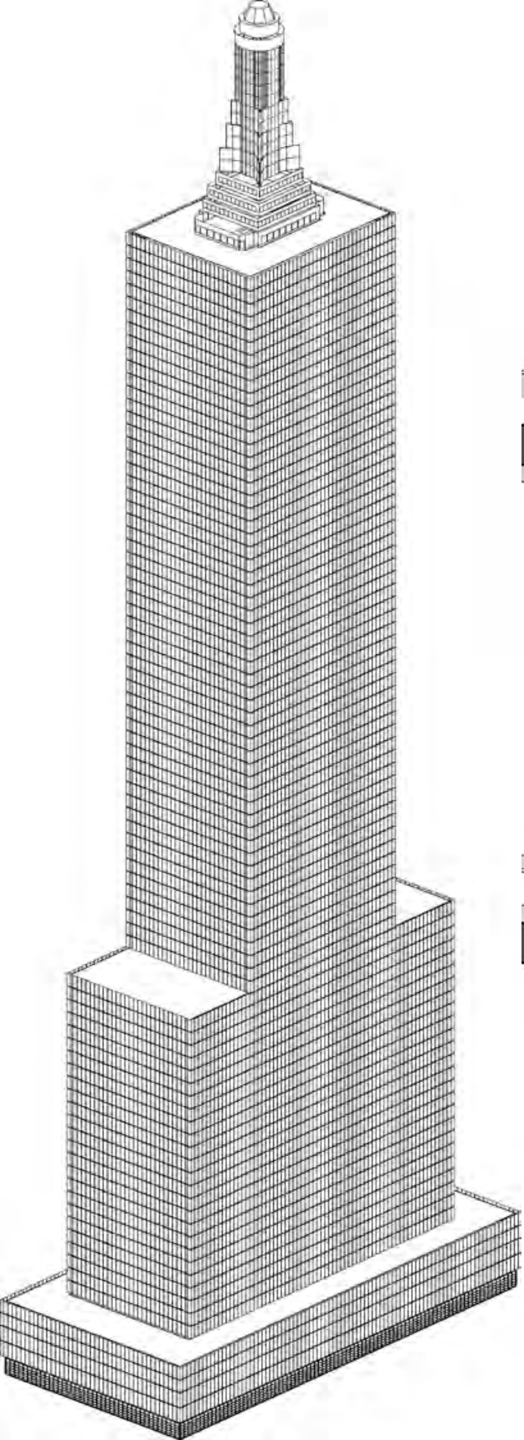


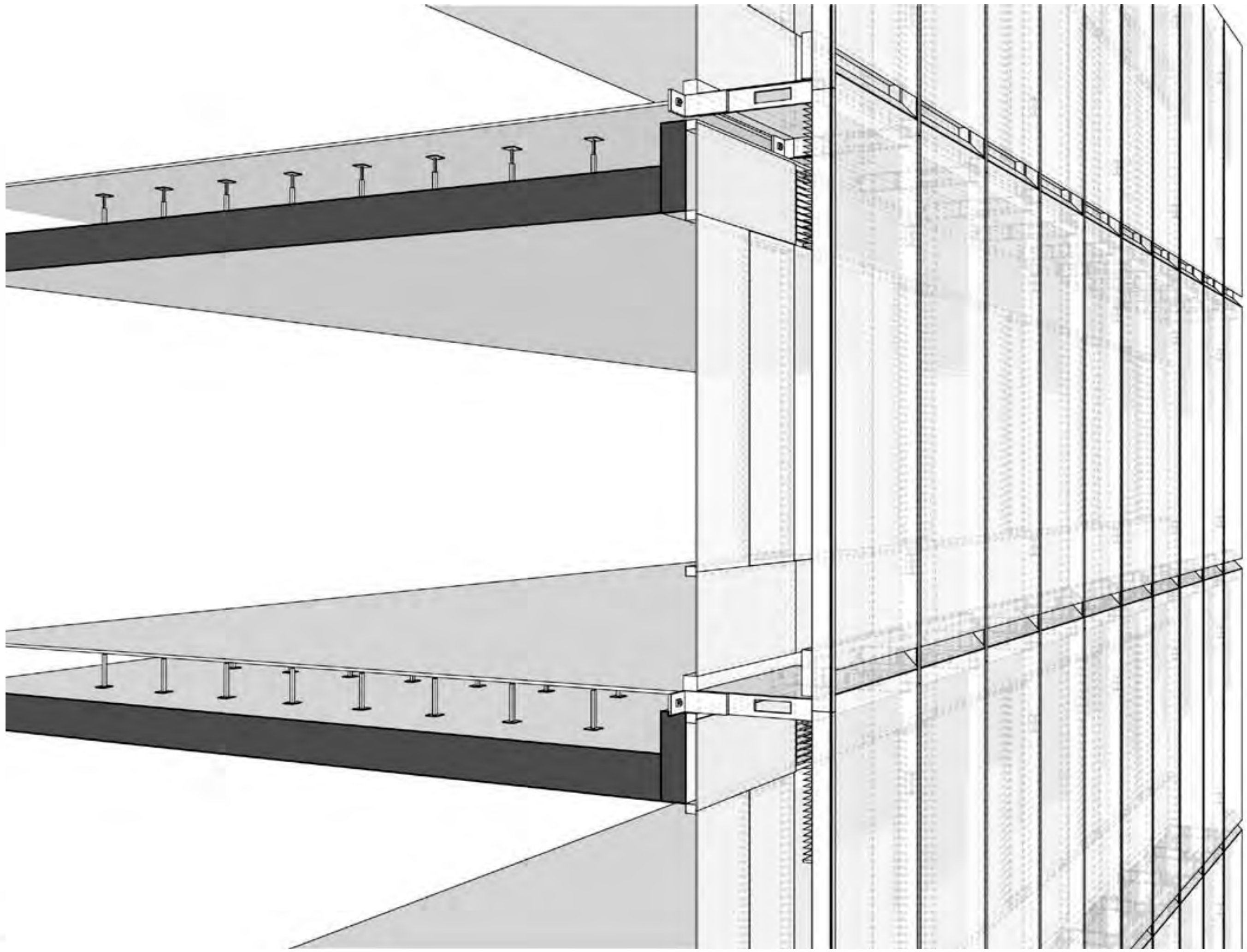
Relative Non-Obsolesence Emergy/Exergy Ratios
(building duration related to construction type durability rather than market obsolesence)



FARM	HOUSES	HOTEL	TOWER
50 years 6.95E-05	100 years 1.12E-04	200 years 2.11E-05	100 years 2.32E-05
75 years 3.09E-05	150 years 4.96E-05	300 years 9.39E-06	200 years 5.81E-06
100 years 1.74E-05	200 years 2.79E-05	400 years 2.58E-06	300 years 2.58E-06





	m³		kg	sej/kg	sej
Empire State Building	**volume**	**density**	**mass**	**Specific Emergy**	**Emergy**
cinder concrete			81,896,743	1.44E+12	1.18E+20
structural steel			41,977,943	5.35E+12	2.25E+20
concrete			22,288,403	1.44E+12	3.21E+19
red brick			22,096,222	2.22E+12	4.91E+19
limestone			16,238,808	1.00E+12	1.62E+19
			184,498,210		**4.40E+20**

	m³		kg	sej/kg	sej
New Tower	**volume**	**density**	**mass**	**Specific Emergy**	**Emergy**
Concrete	154211	2400	370,106,400	1.44E+12	5.33E+20
Rebar Steel	3084	7850	24,211,127	5.35E+12	1.30E+20
Welded Wire fabric	771	7850	6,052,782	5.35E+12	3.24E+19
Glass	682	2500	1,704,250	7.87E+12	1.34E+19
Aluminum	18908	2720	51,429,651	1.27E+13	6.53E+20
			453,504,210		**1.36E+21**
			246%		309%

What is your system boundary? Why?

Work on the correct order of magnitude.

Take care of power and the necessary "efficiencies" will take care of themselves.

Maximum Power Design

Kiel Moe
Harvard University Graduate School of Design

Workshop D Architecture & Space
Swiss-US Energy Innovation Days | Zurich