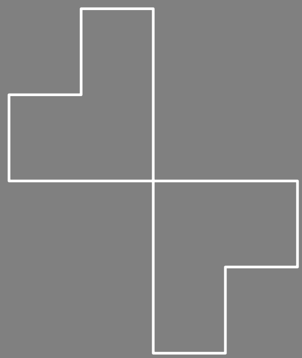
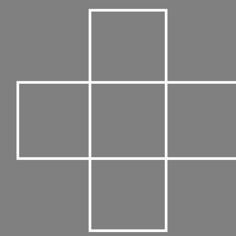
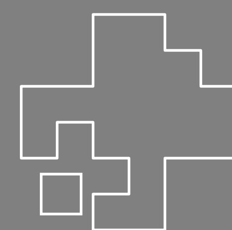
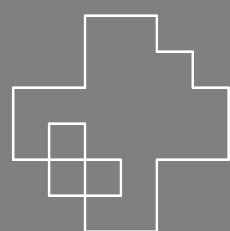
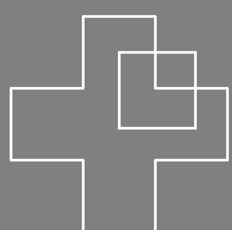


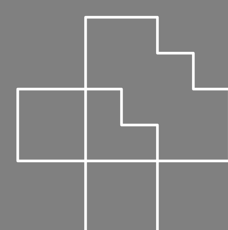


Shape Grammars









history of computation

1930s	formal theories of computation (Turing, Godel, Church, etc)
1940s	first computer *neural nets (McCulloch and Pitts)* production systems (Post)
1950s	*parallel computation (von Neuman)* *cellular automata (Ulam, von Neuman)* generative grammars (Chomsky)
1960s	*evolutionary computation* pattern grammars (Fu)
1970s	shape grammars (Stiny, Gips)
1980s	*artificial life (Langton), self-organizing systems*

innovative, creative, productive, synthetic

explanatory, descriptive, interpretive, analytic

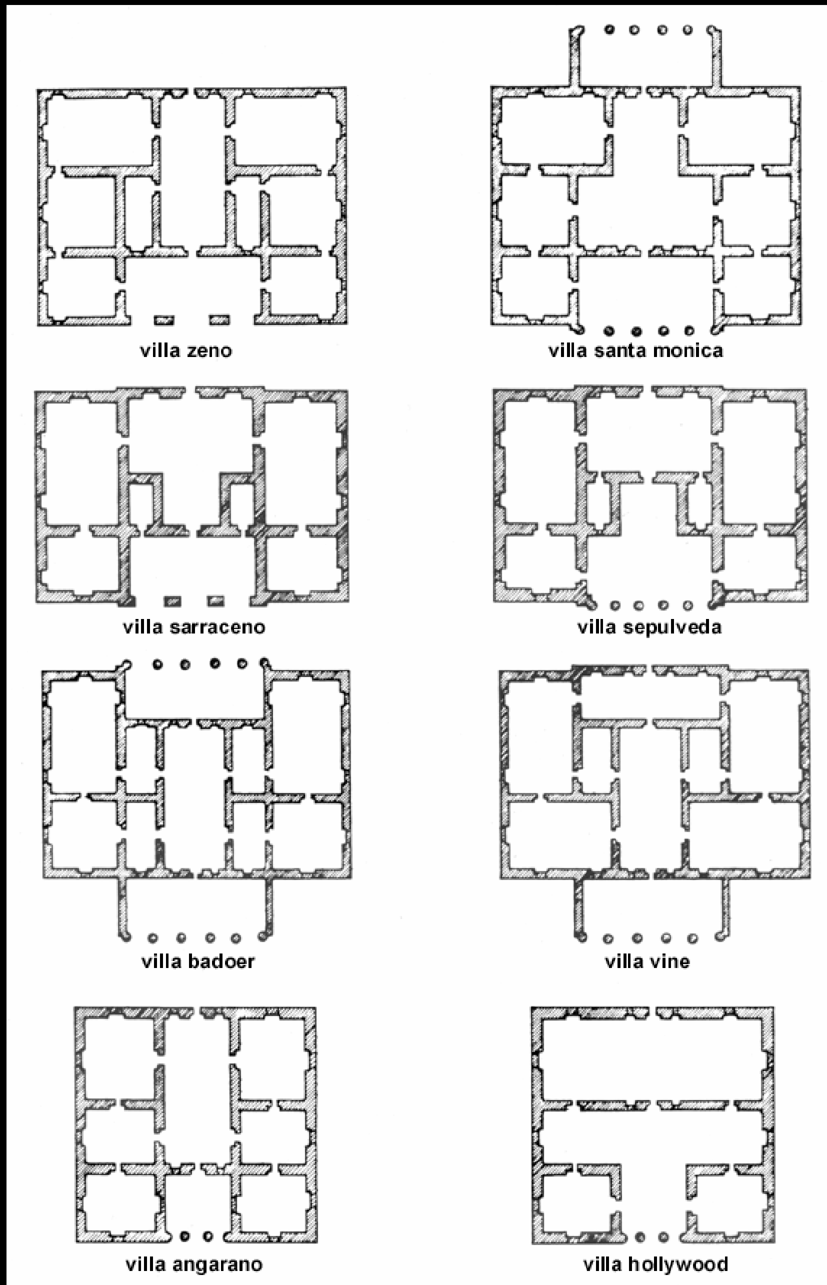
shape grammars

productive	produce designs
explanatory	rules describe structure of designs dynamic (not static) description spatial (not textual) description

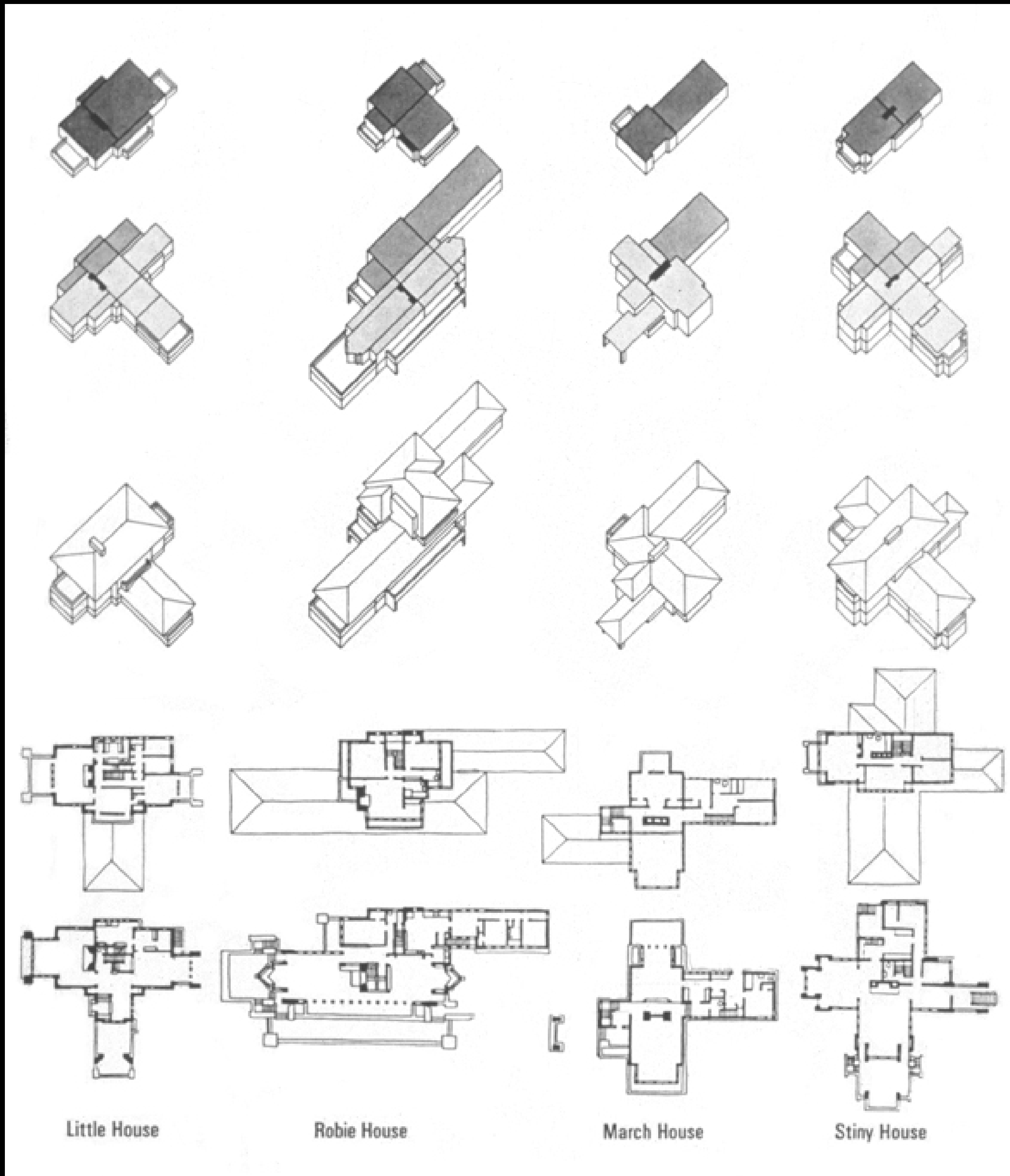
shape grammar applications

analysis

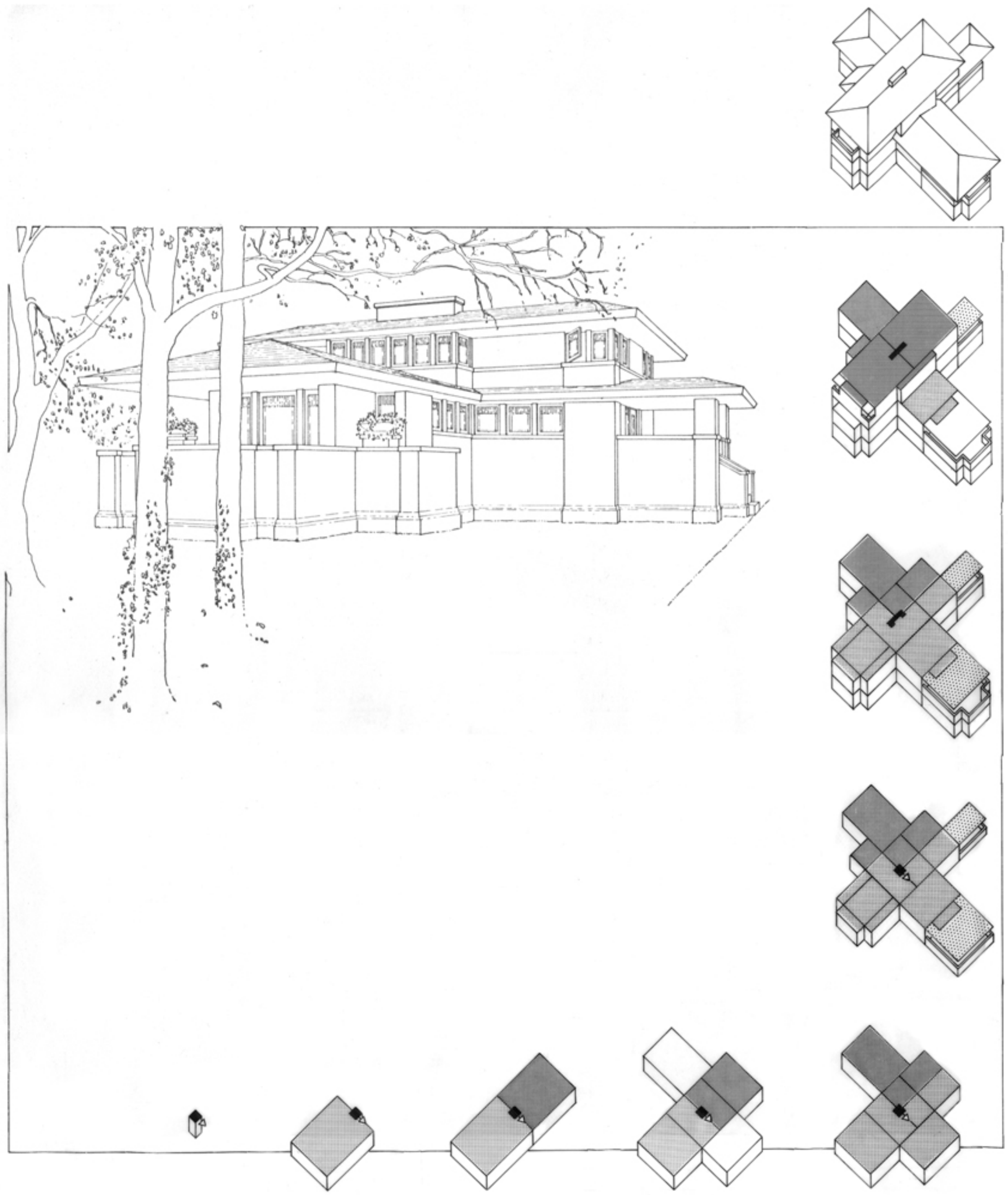
synthesis



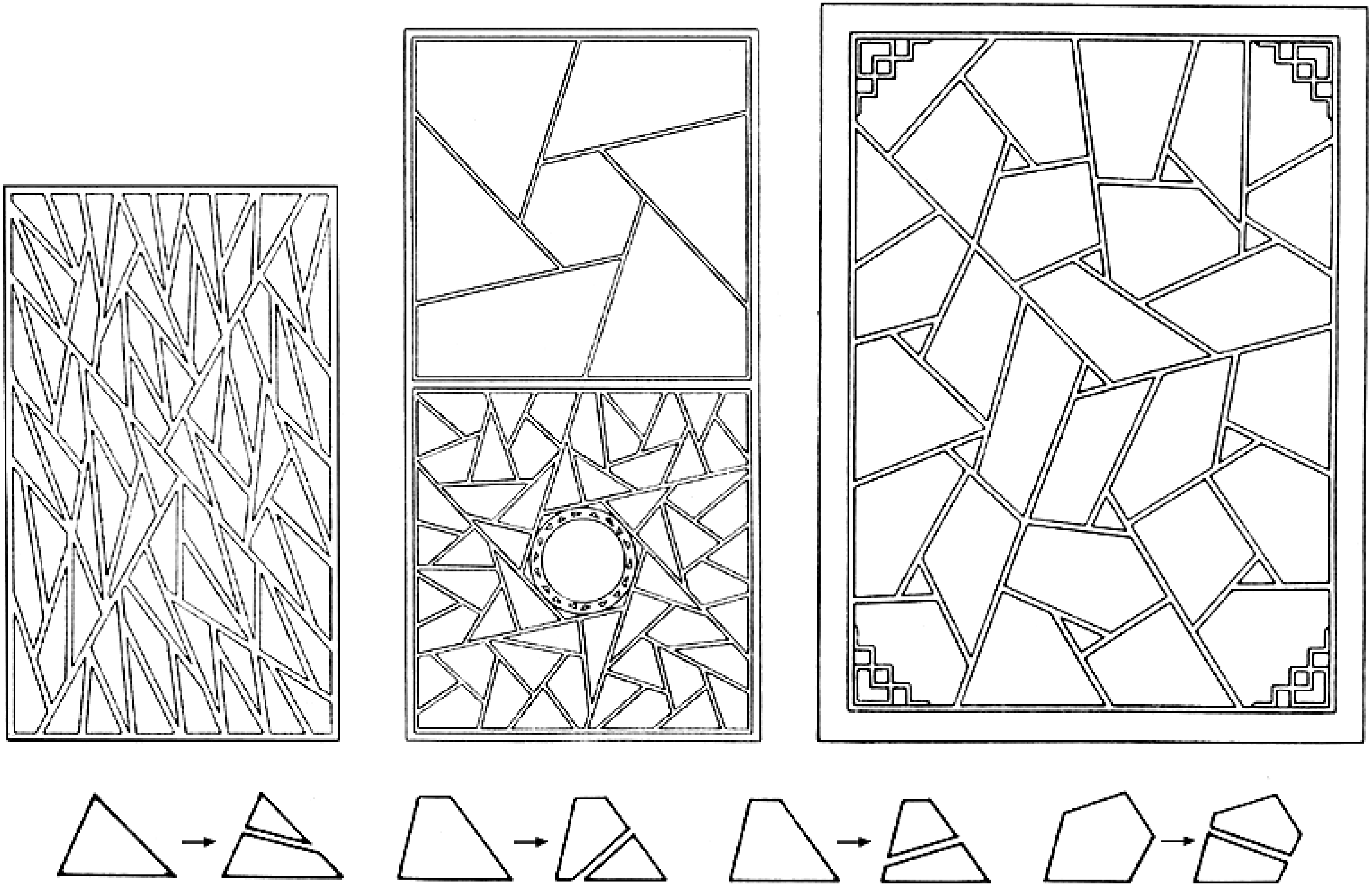
Palladian villas
(Stiny and Mitchell, 1978)



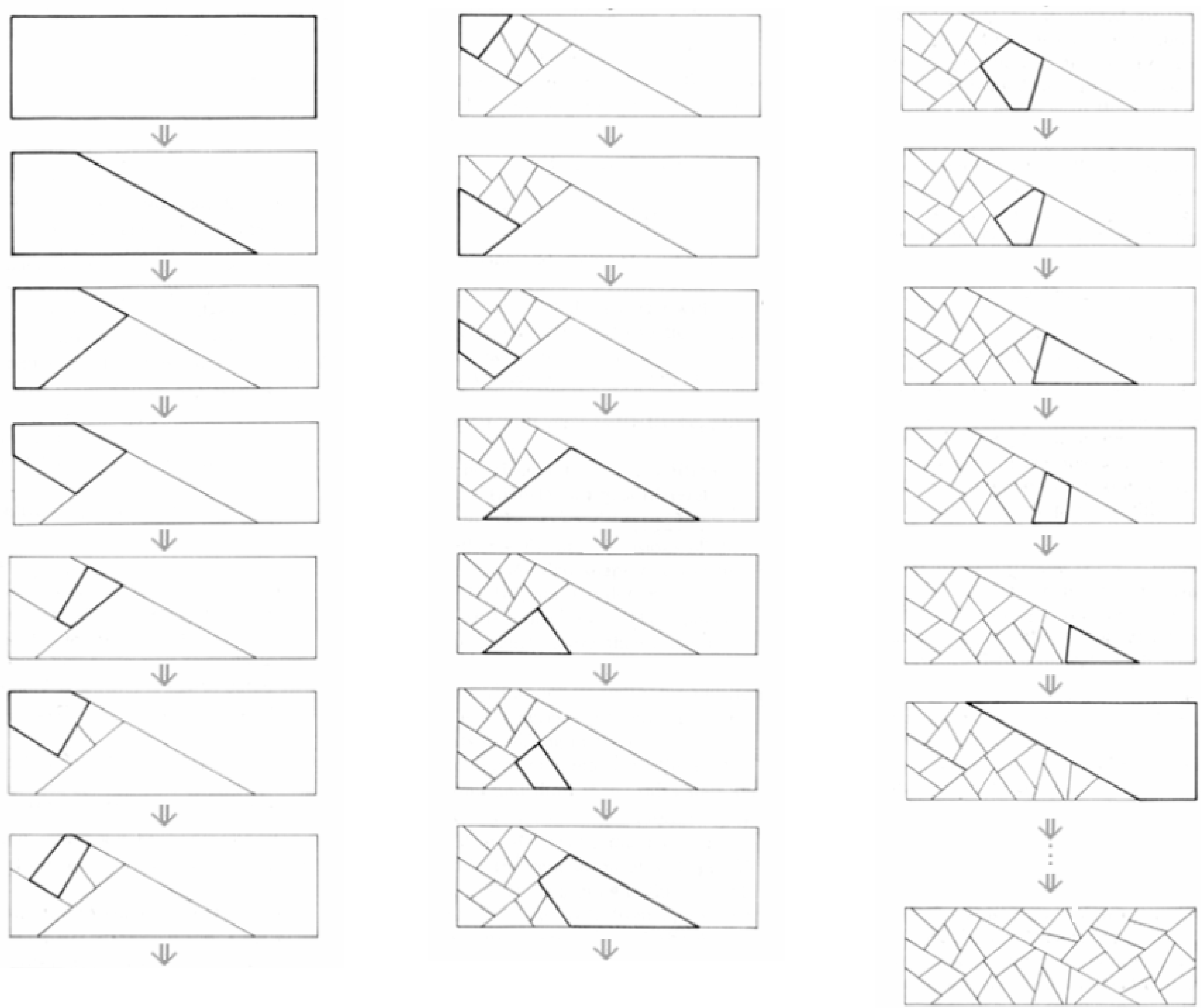
Frank Lloyd Wright prairie houses
(Koning and Eizenberg, 1981)



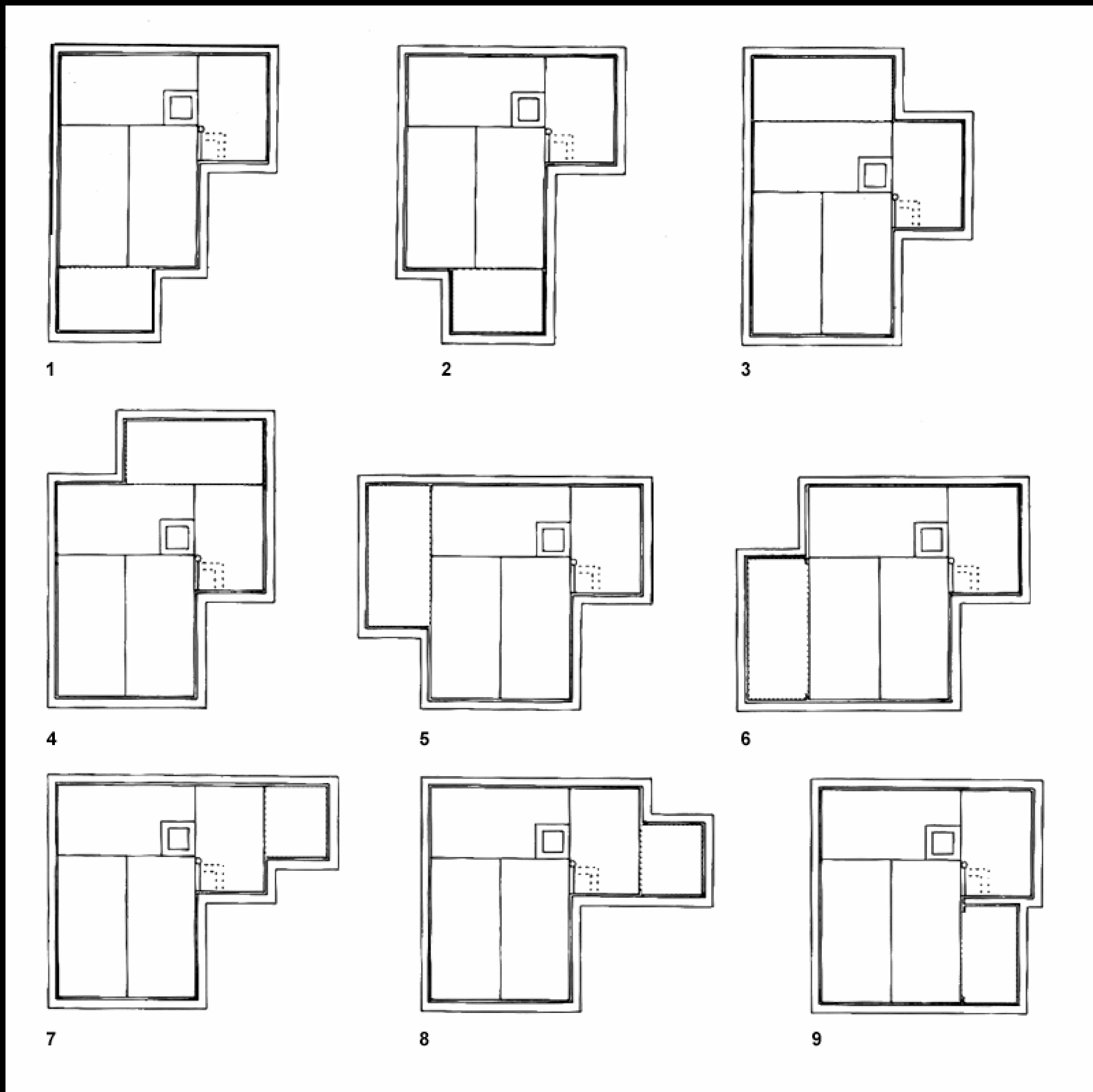
shape grammar derivation of
Frank Lloyd Wright prairie houses
(from Koning and Eizenberg, 1981)



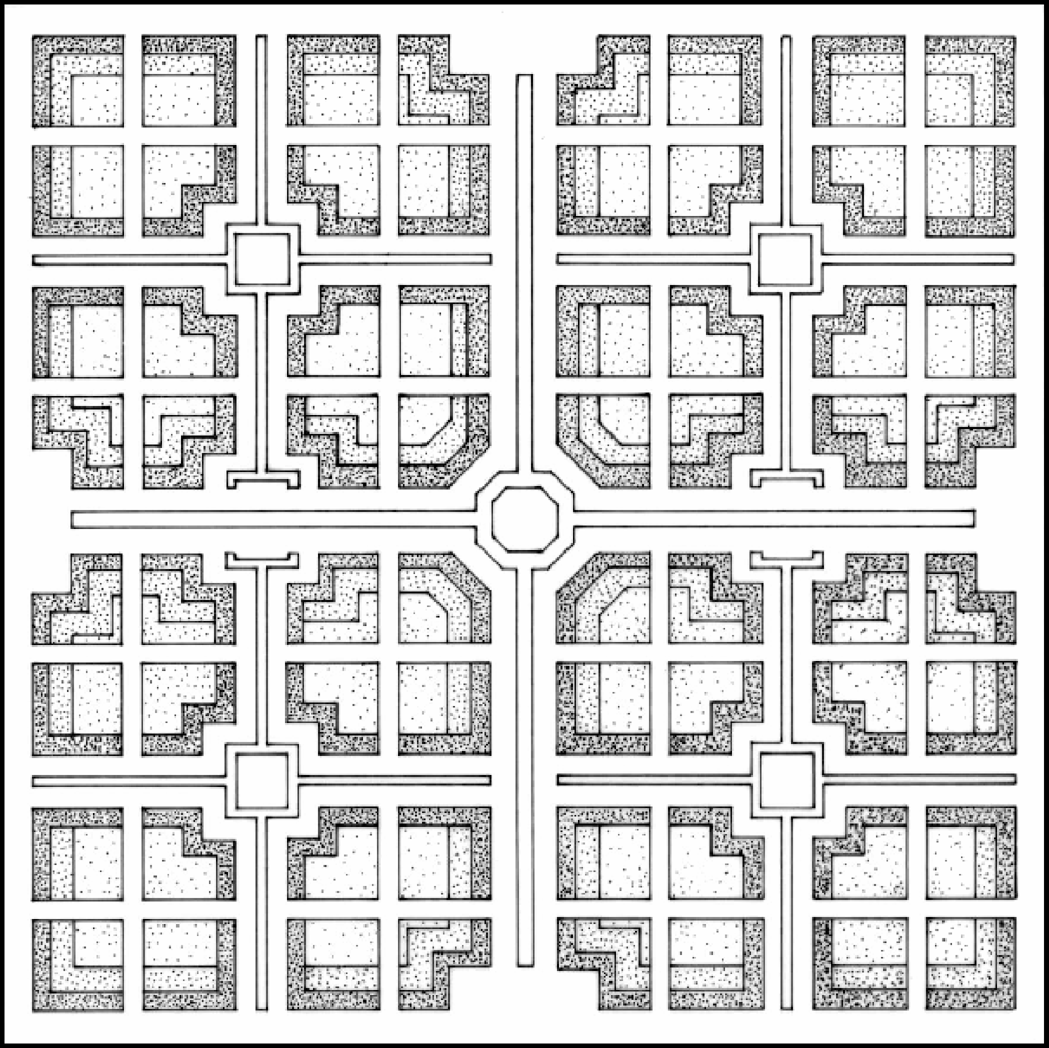
Chinese ice-ray shape grammar (Stiny, 1977)



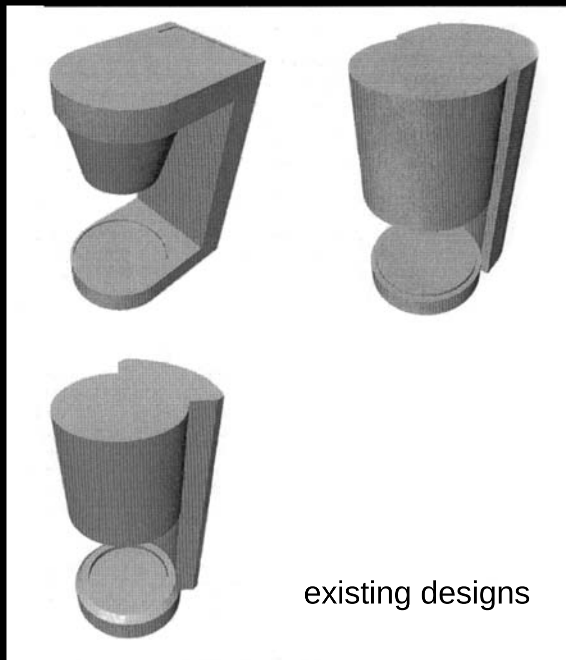
derivation of an ice-ray design



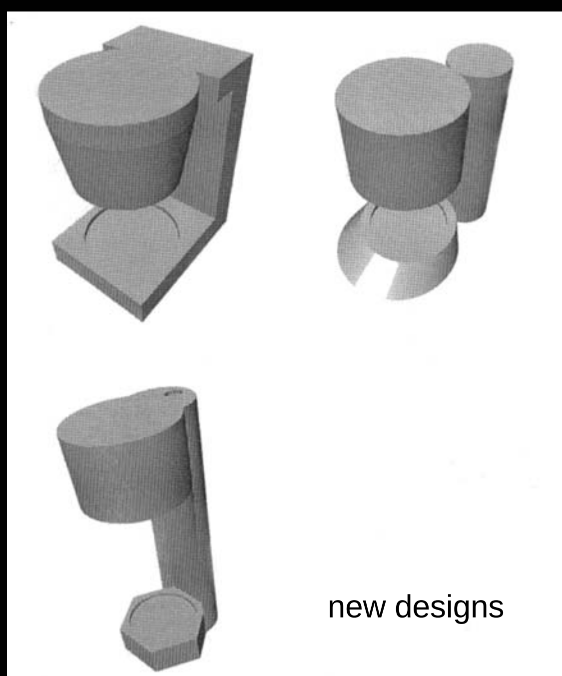
Japanese tearooms
(Knight, 1981)



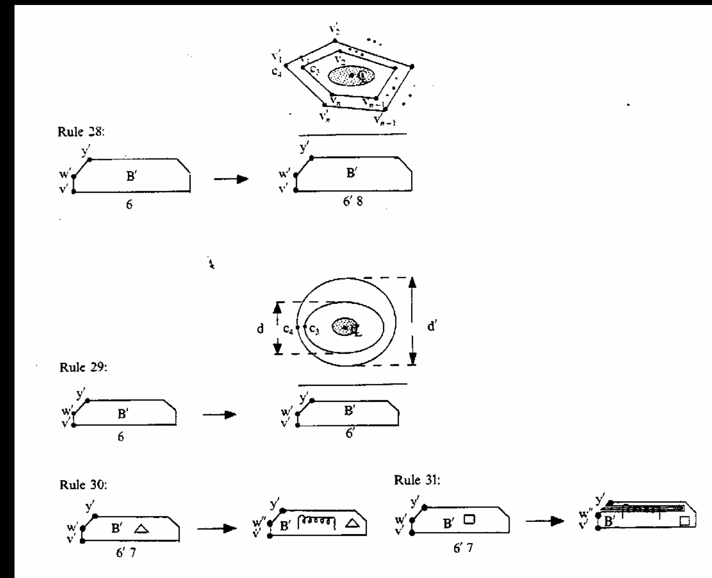
Mughul gardens
(Stiny and Mitchell, 1980)



existing designs



new designs



sample shape rules for base unit
(top and side views)

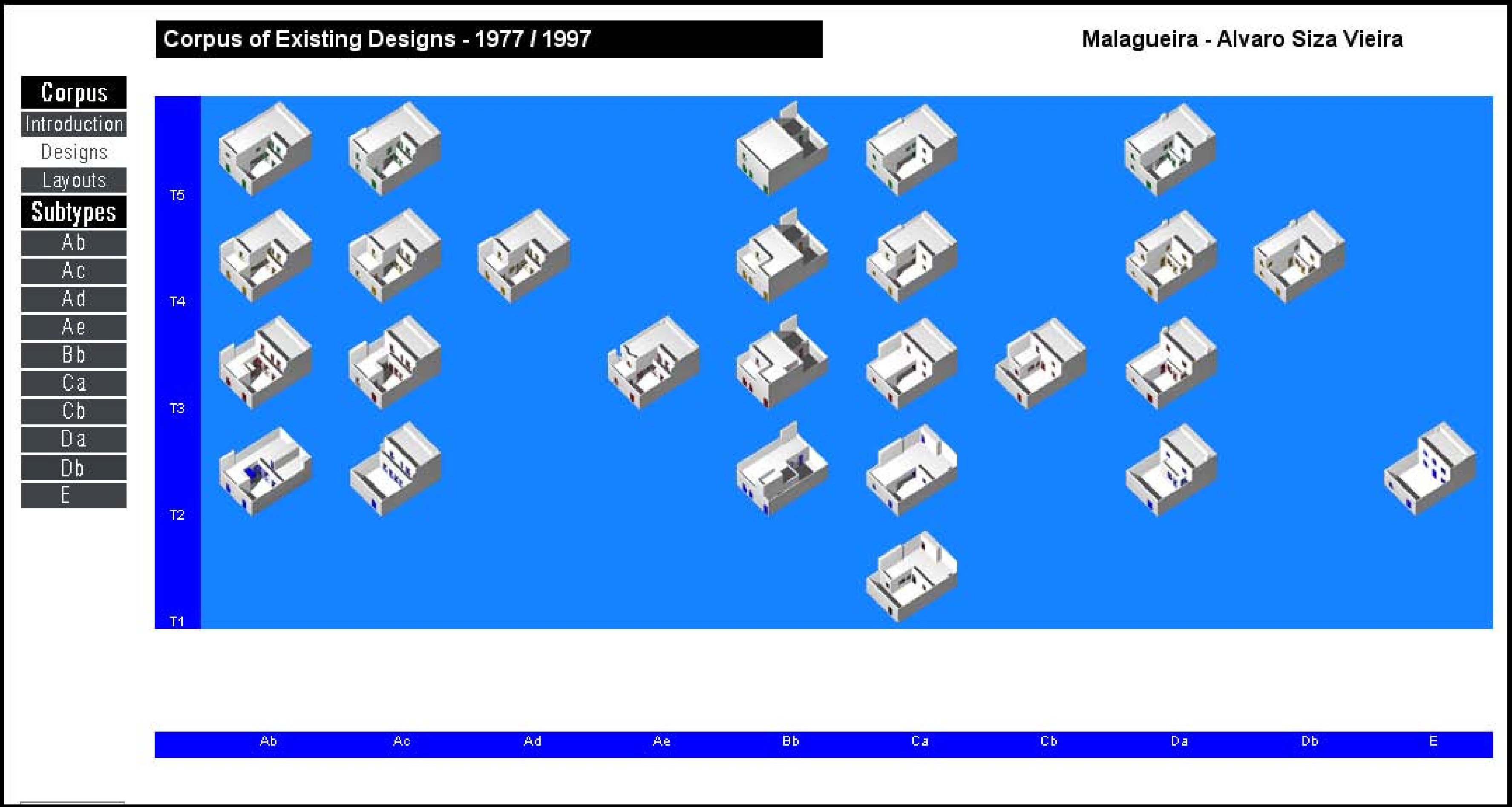
material cost = (\$0.84/kg) x (0.00091 kg/1000 mm3) x (part volume)

tooling cost = total tooling cost/useful tool life based on the number of parts produced by that tool

base area: $A' = \Sigma A'_k + A'_n - \pi d^2_{plate}/4$

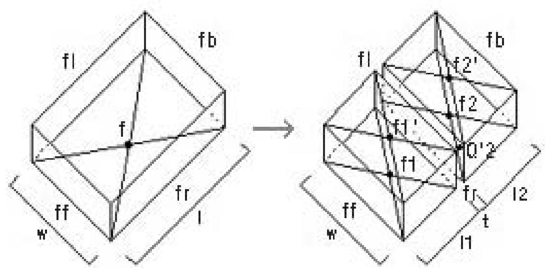
sample cost expressions

coffee-maker shape grammar
(Agarwal and Cagan, 1998)



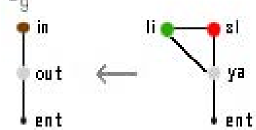
Malagueira housing designs of Alvaro Siza (Jose Duarte)

Rule 9: dissecting the outside zone

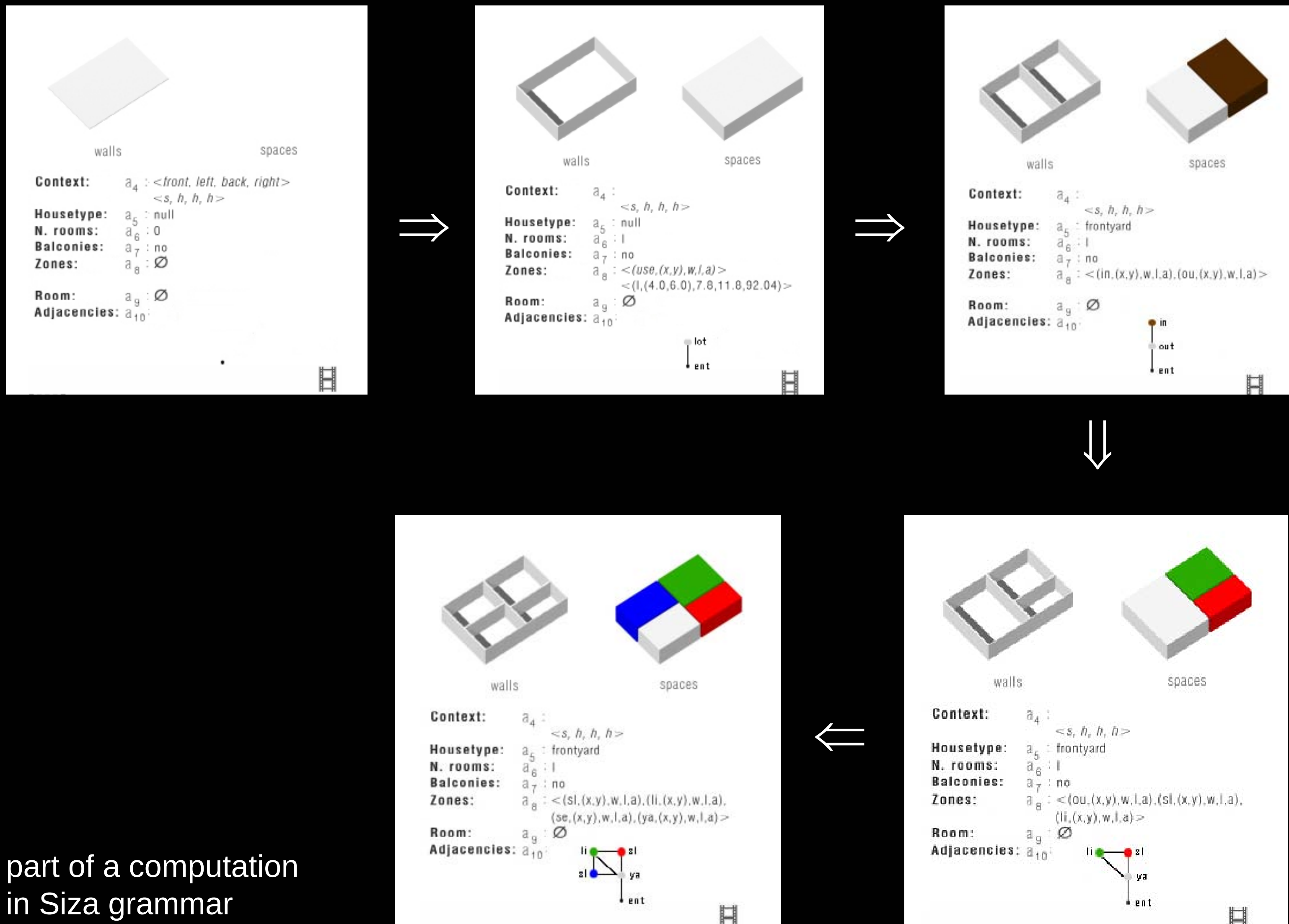


R9: $<F_1;\ f_b,\ f_r,\ f_f,\ li;\ o;\ Z> \longrightarrow$
$<F_1;\ f_b,\ f_r,\ f_f,\ f_l;\ ya,\ sl;\ Z\ -\ \{ya, sl\}>$

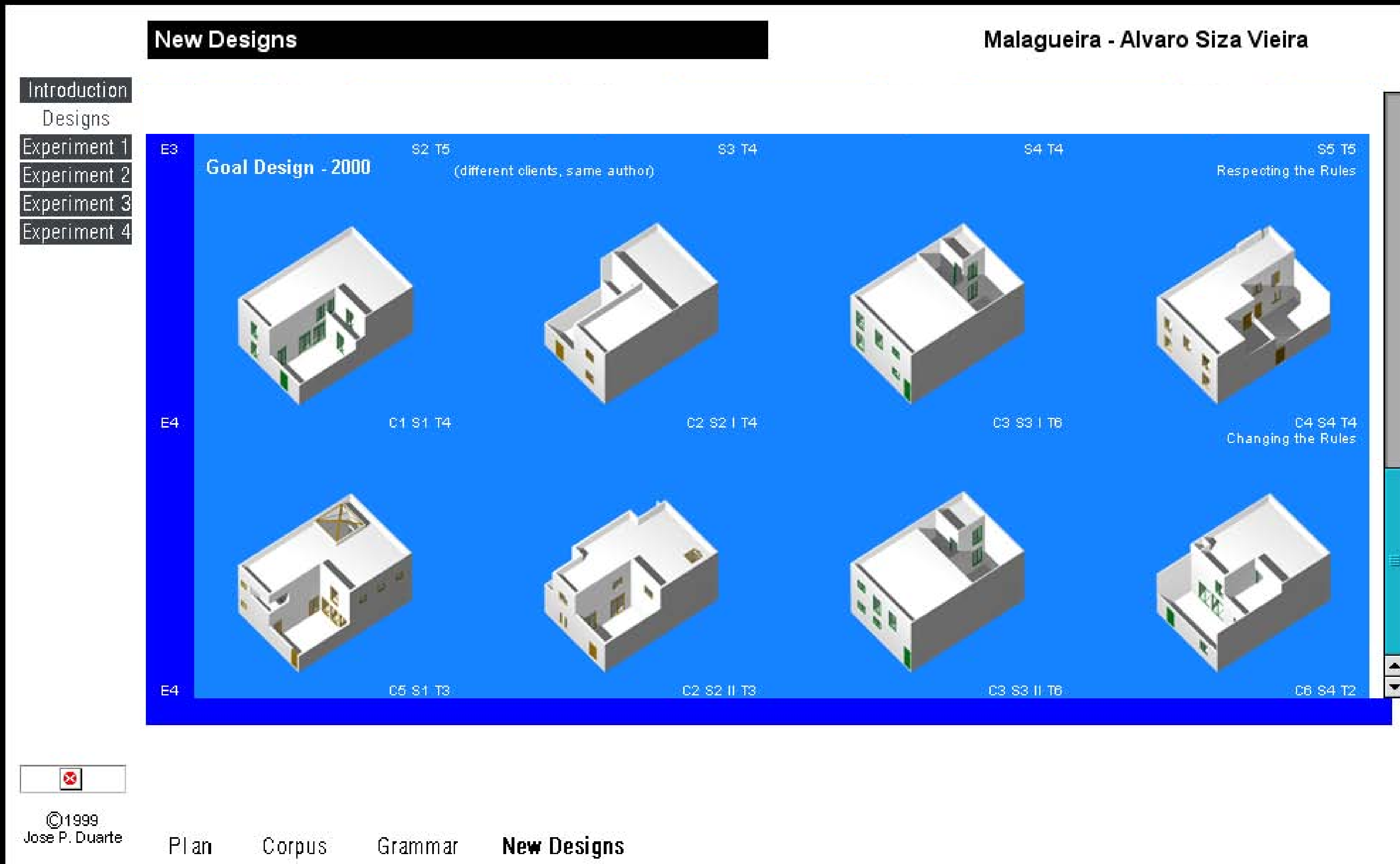
Context: g_4 : $a_4 \leftarrow a_4$
Housetype: g_5 : $a_5 \leftarrow a_5$
N. rooms: g_6 : $a_6 \leftarrow a_6$
Balconies: g_7 : $a_7 \leftarrow a_7$
Zones: g_8 : $a_8 \leftarrow a_8$ <-(in, (x,y), w, l, a),
+(li, (x,y), w, l, a),
+(sl, (x,y), w, l, a),
Room: g_9 : $a_9 \leftarrow a_9$
Adjacencies: g_{10} :



rule from Siza grammar



part of a computation
in Siza grammar

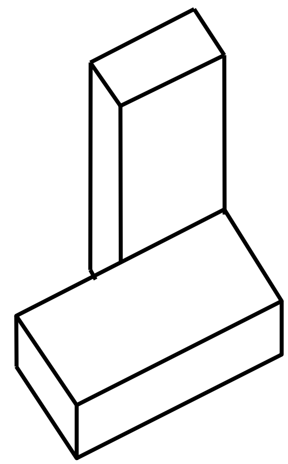


new Malagueira houses

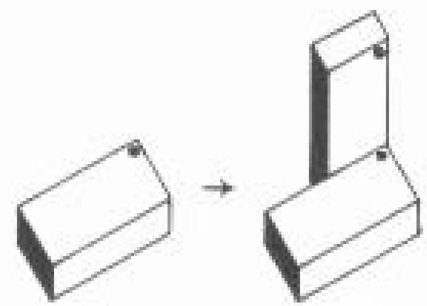
shape grammar applications

analysis

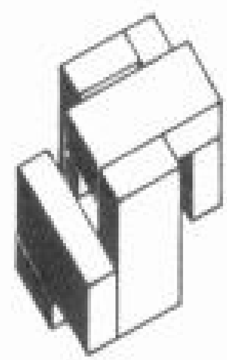
> synthesis



spatial relation

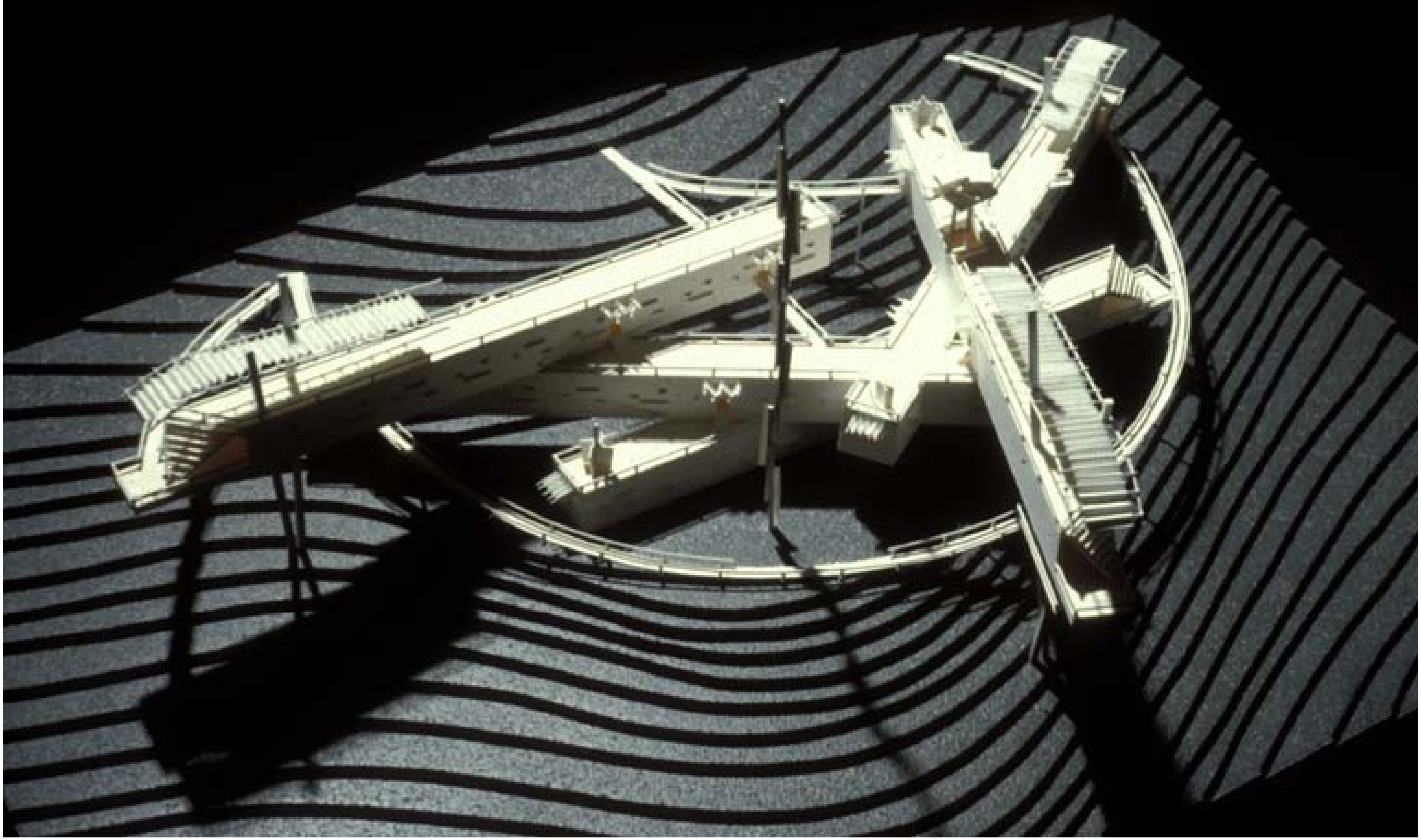


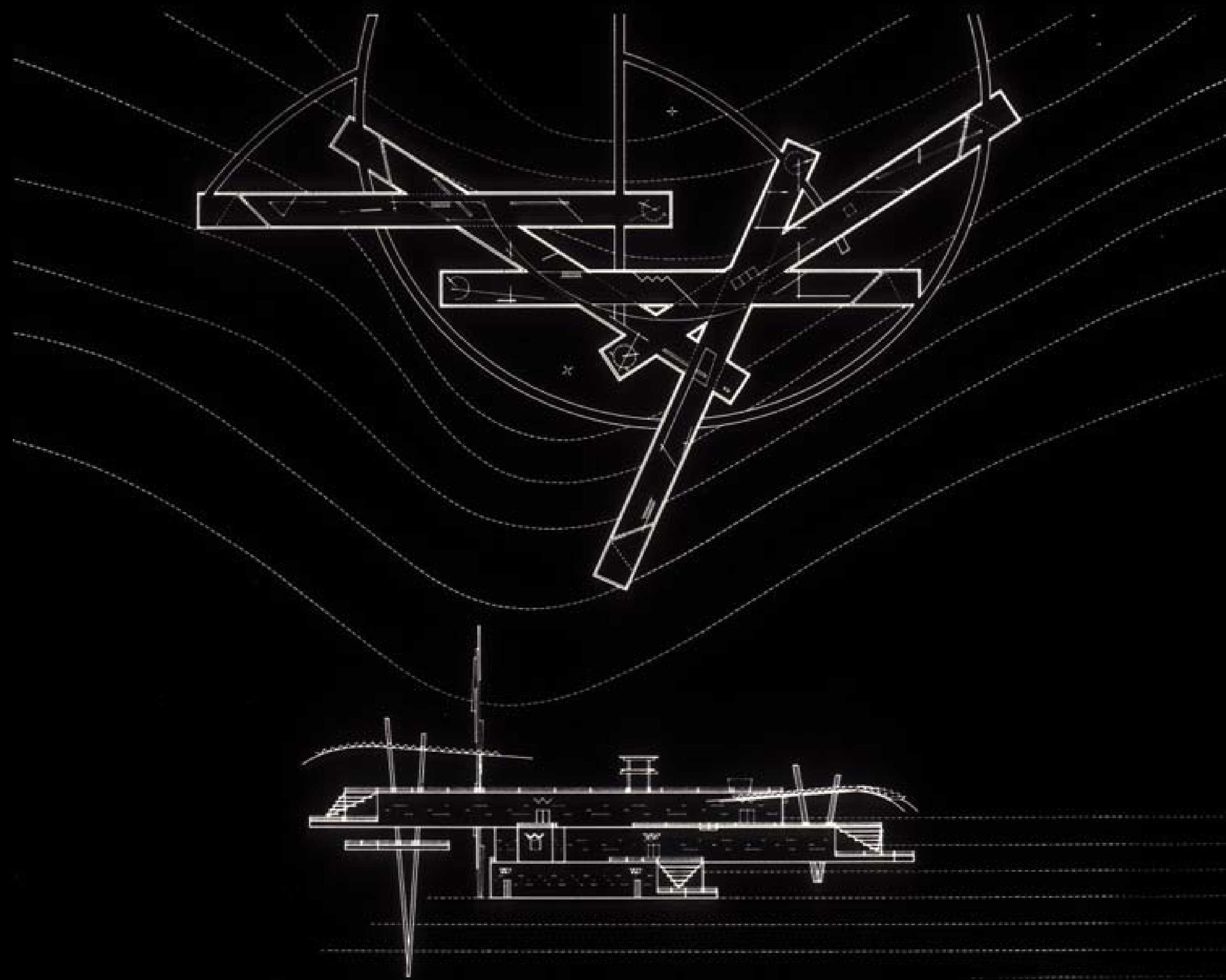
rule



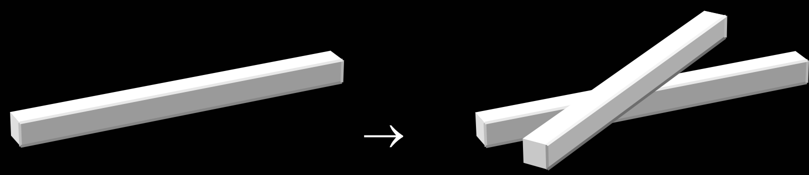
design

historical museum, San Gimignano, Italy (Randy Brown)

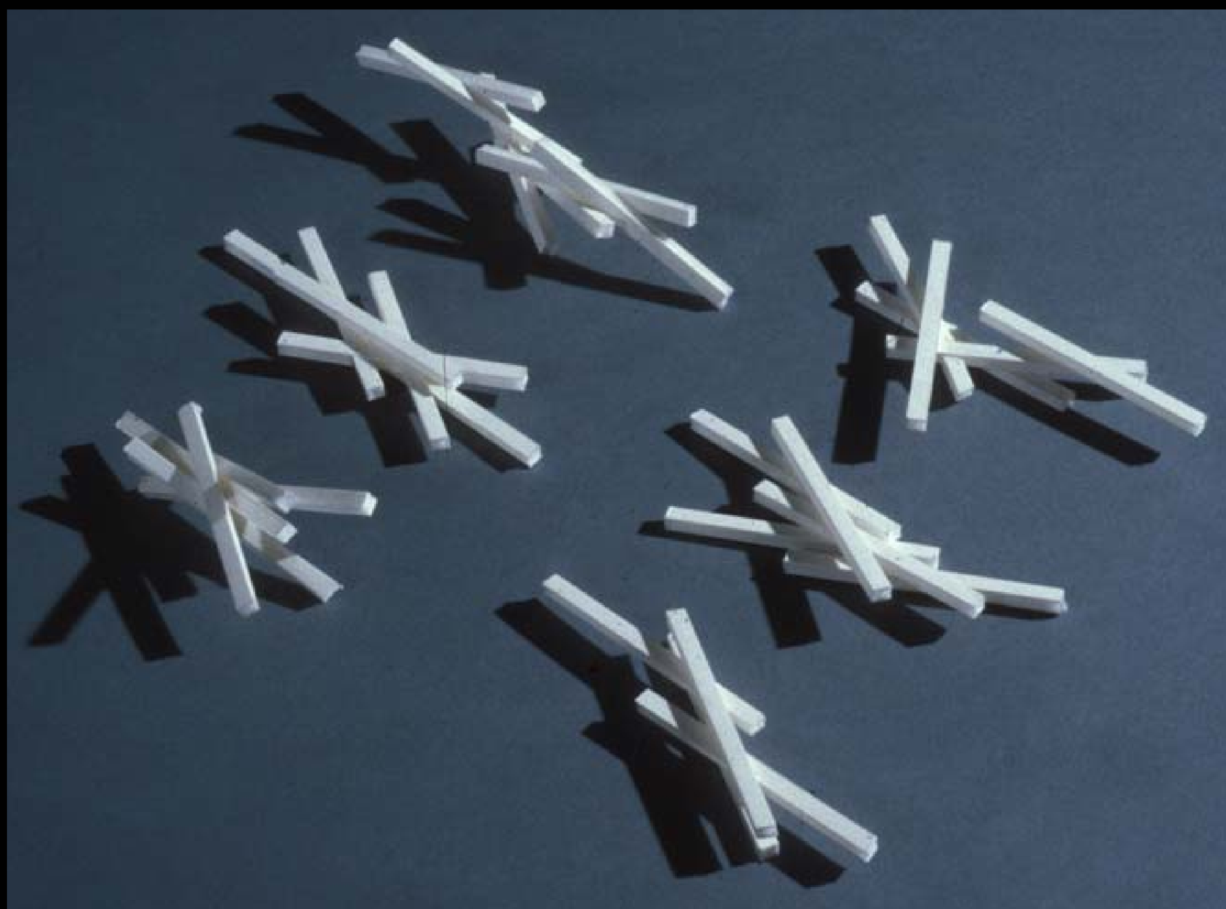




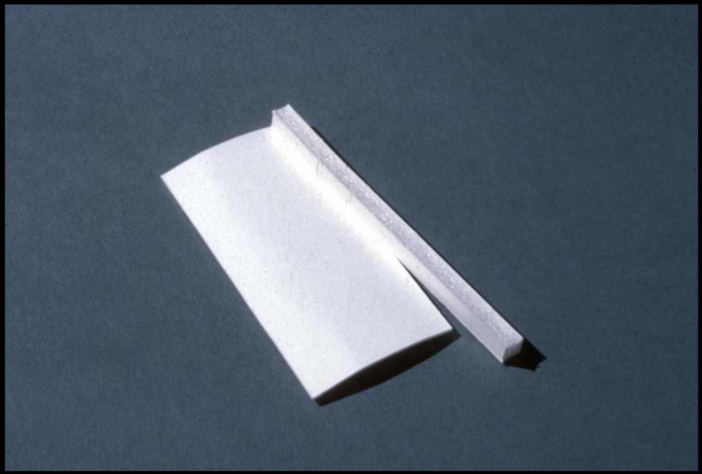
historical museum, San Gimignano, Italy (Randy Brown)



underlying rule

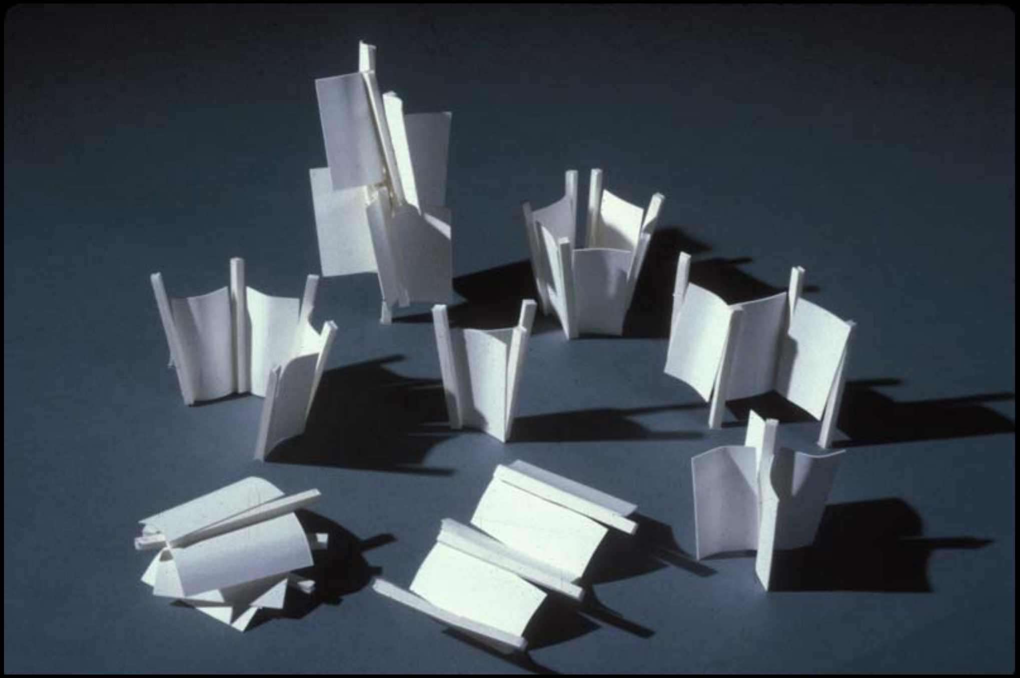


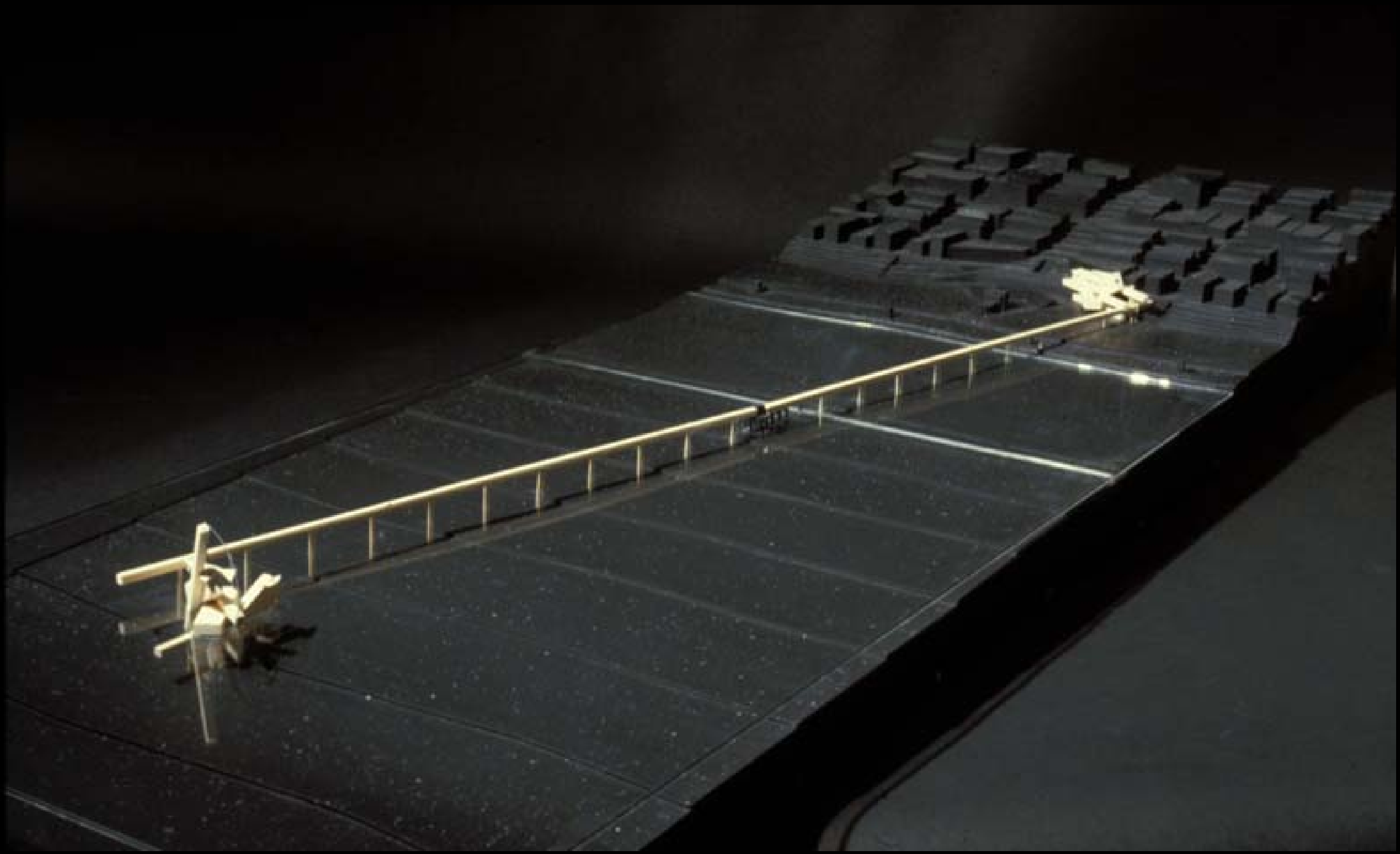
massing studies



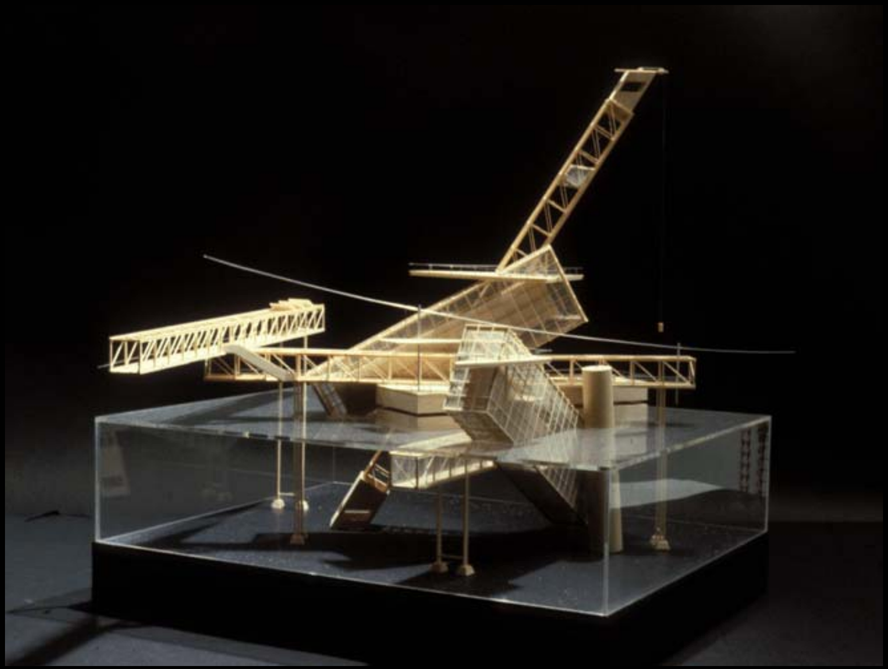
spatial relation

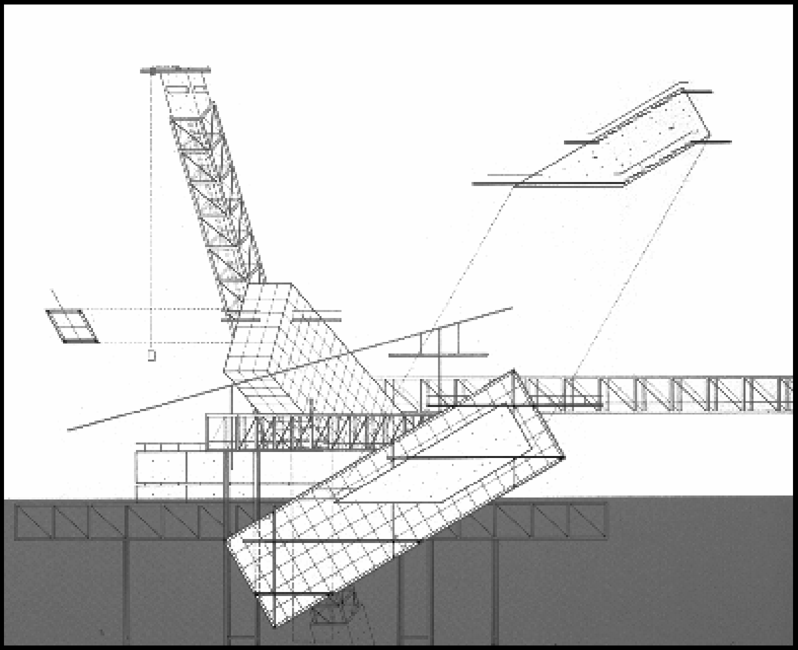
generated designs



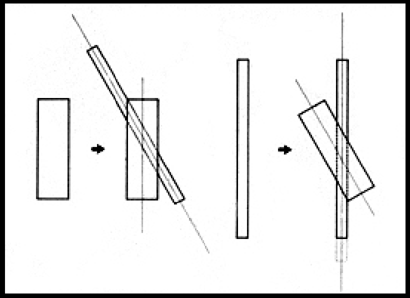


pier, ocean observatory and education facility, Manhattan Beach, CA
(Randy Brown)

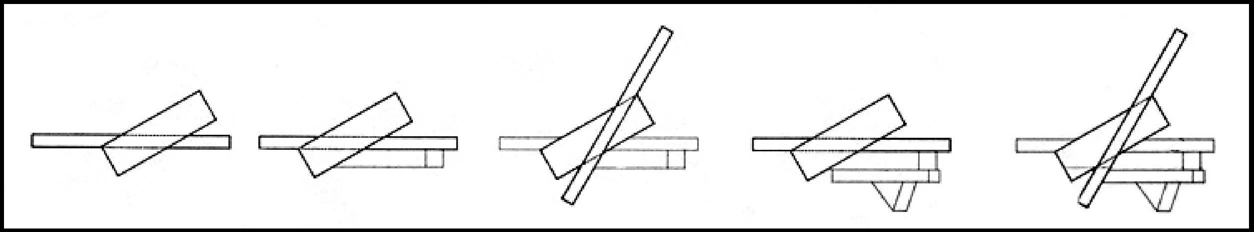




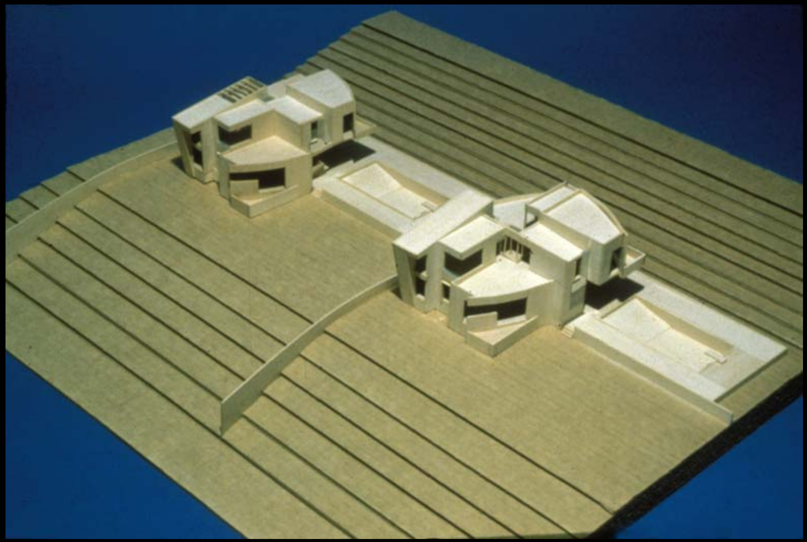
ocean building



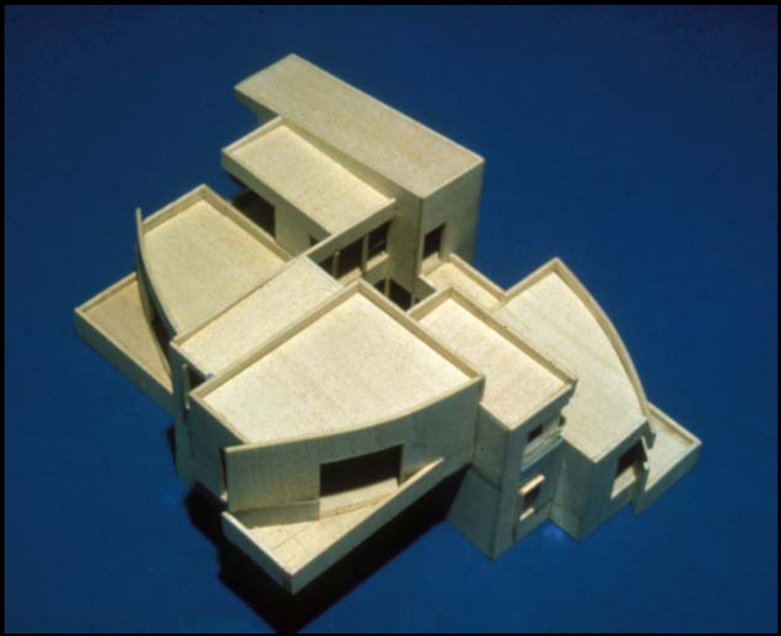
rules

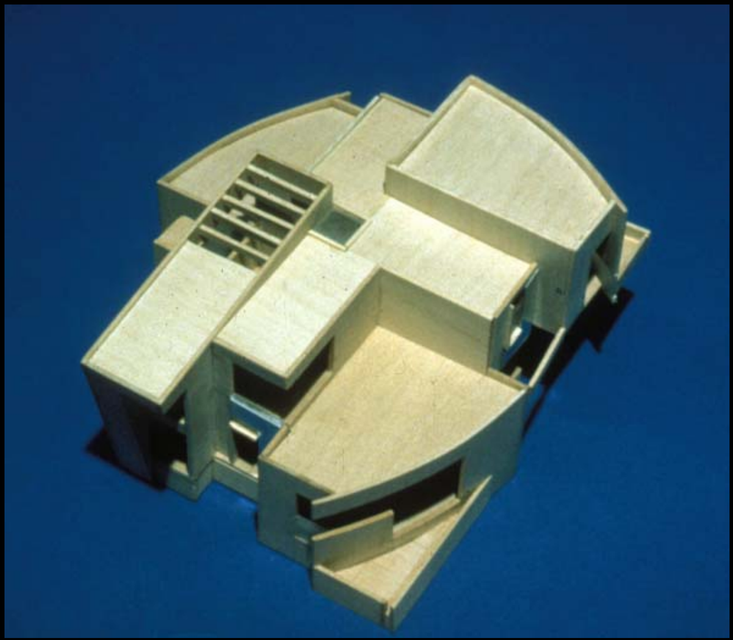


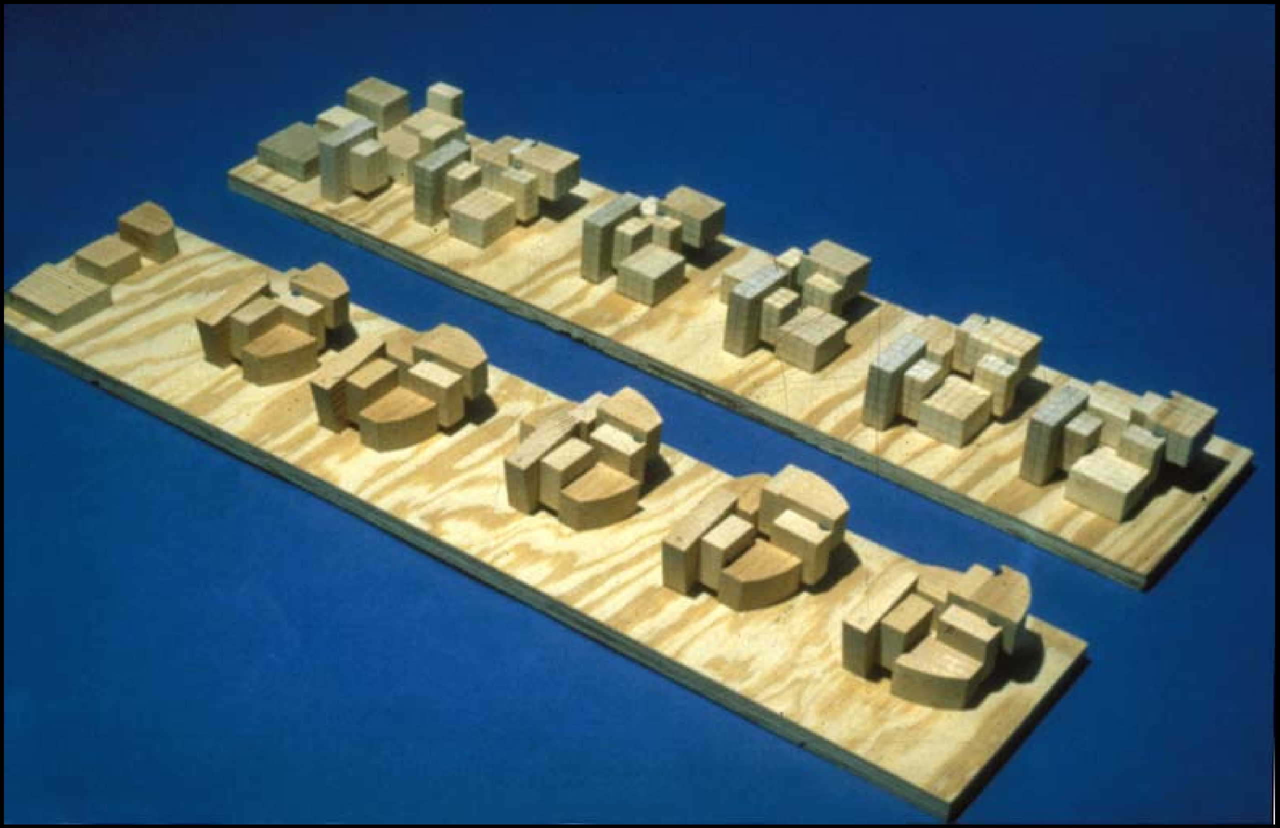
derivation



courtyard houses, Malibu, CA
(Jin-Ho Park)

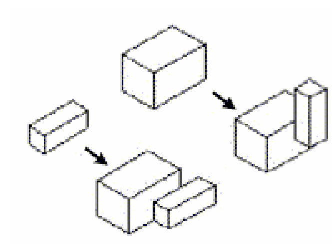




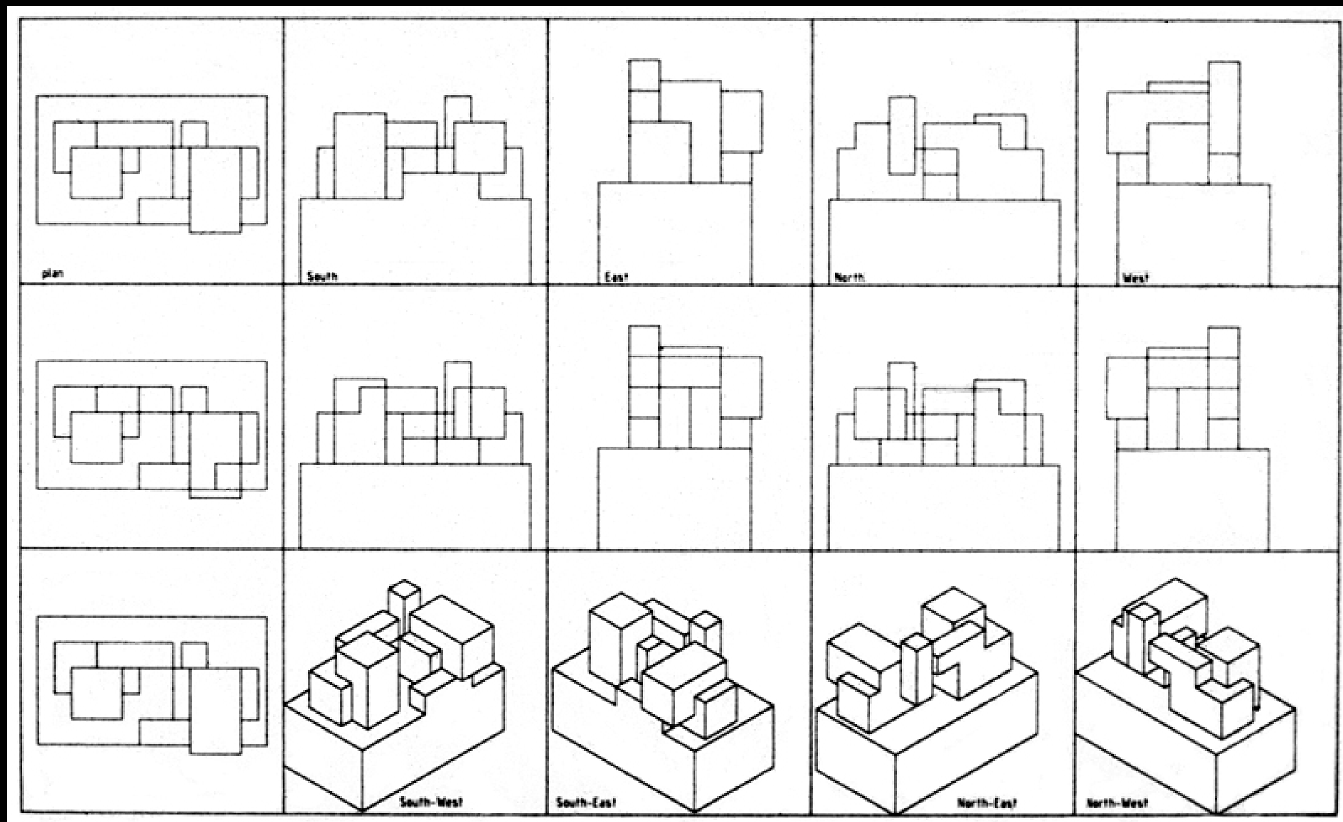


courtyard house possibilities

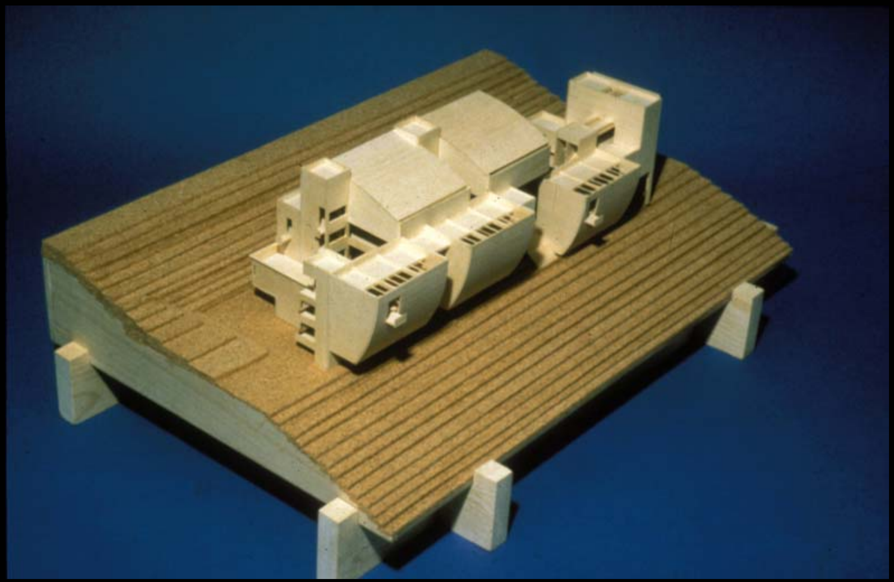
apartment house complex
(Murat Sanal)



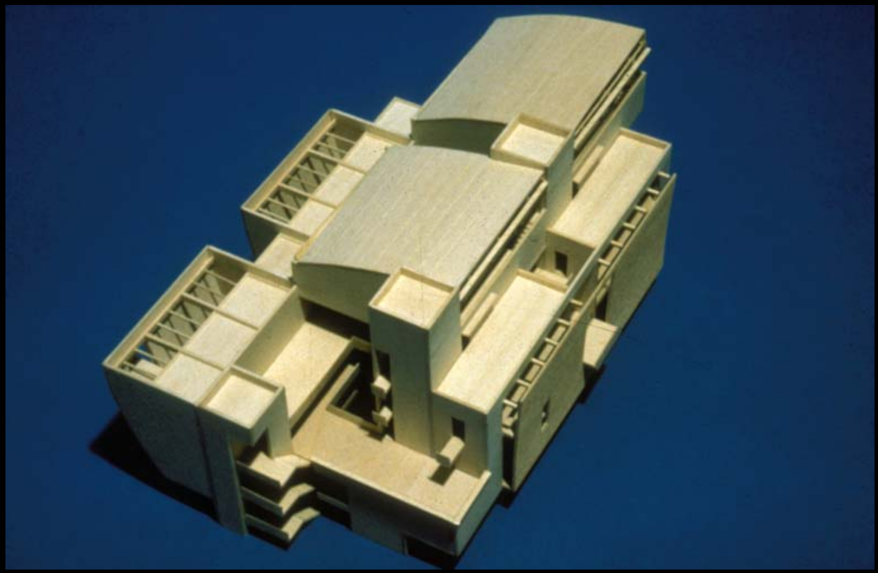
underlying shape rules

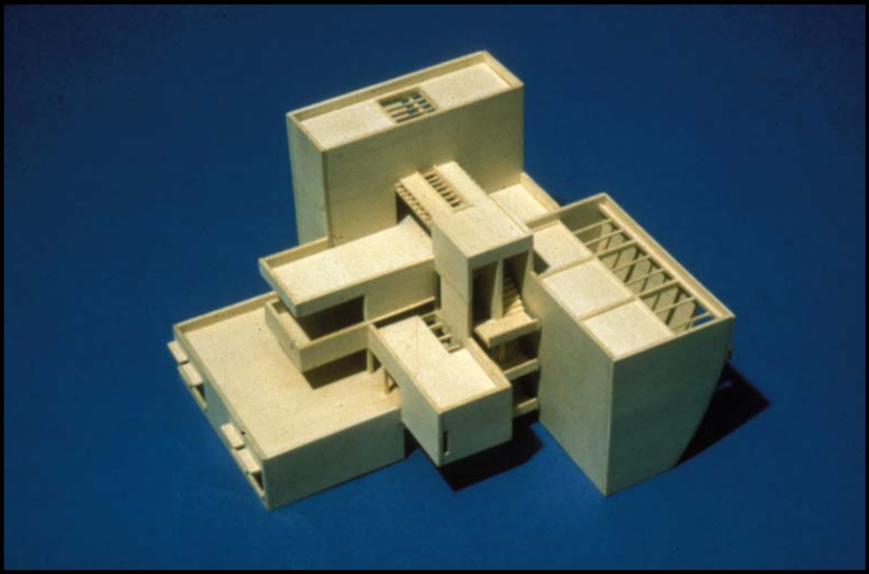

plan
South
East
North
West
South-West
South-East
North-East
North-West

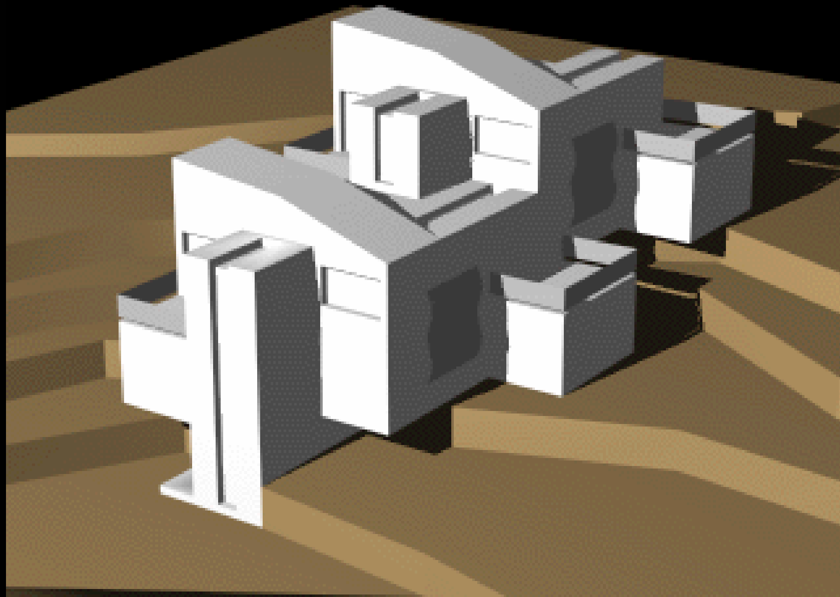
variations

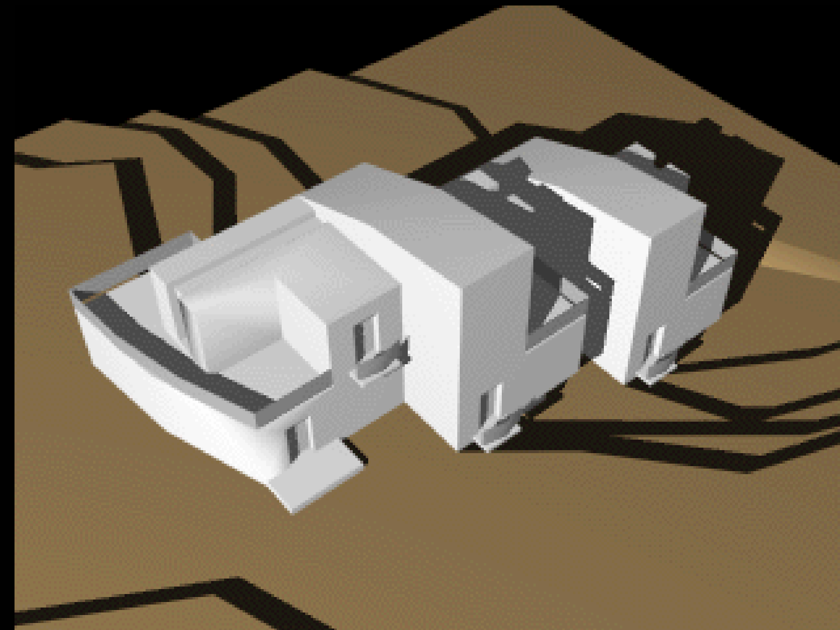


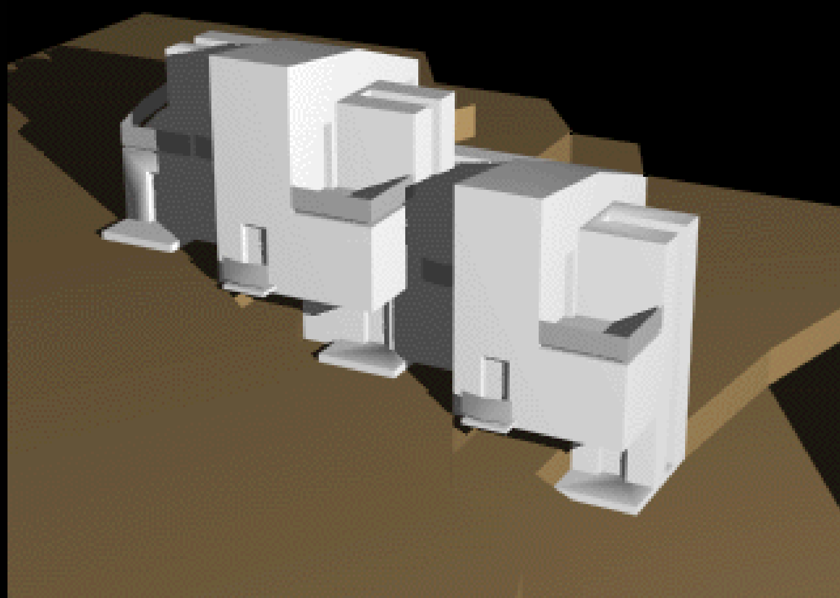
cultural history museum, Los Angeles
(Jin-Ho Park)

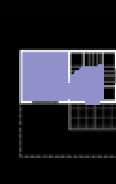




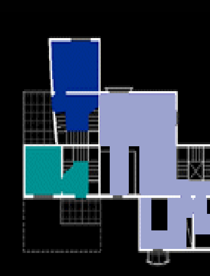








1st floor

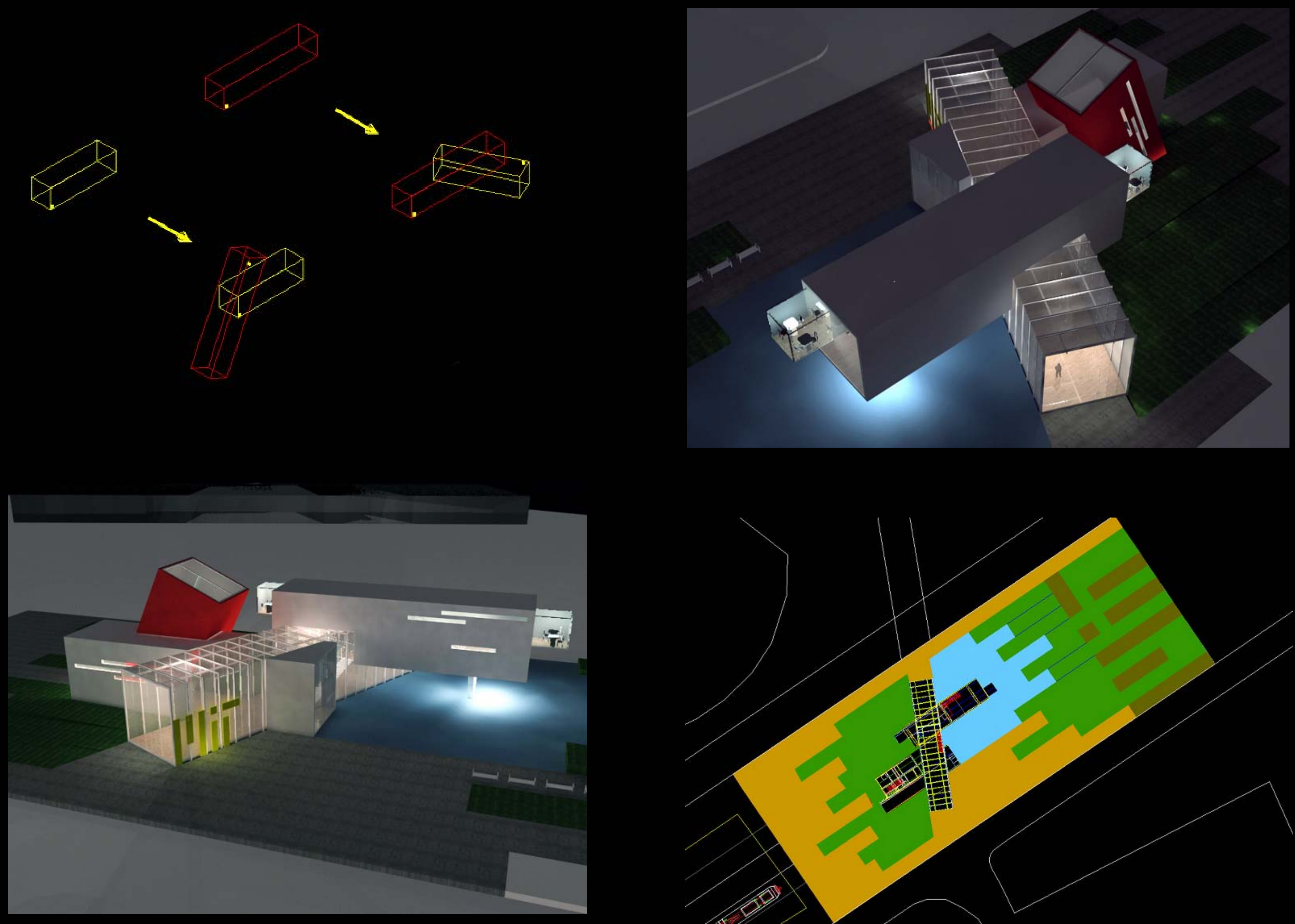


2nd floor

3rd floor

4th floor

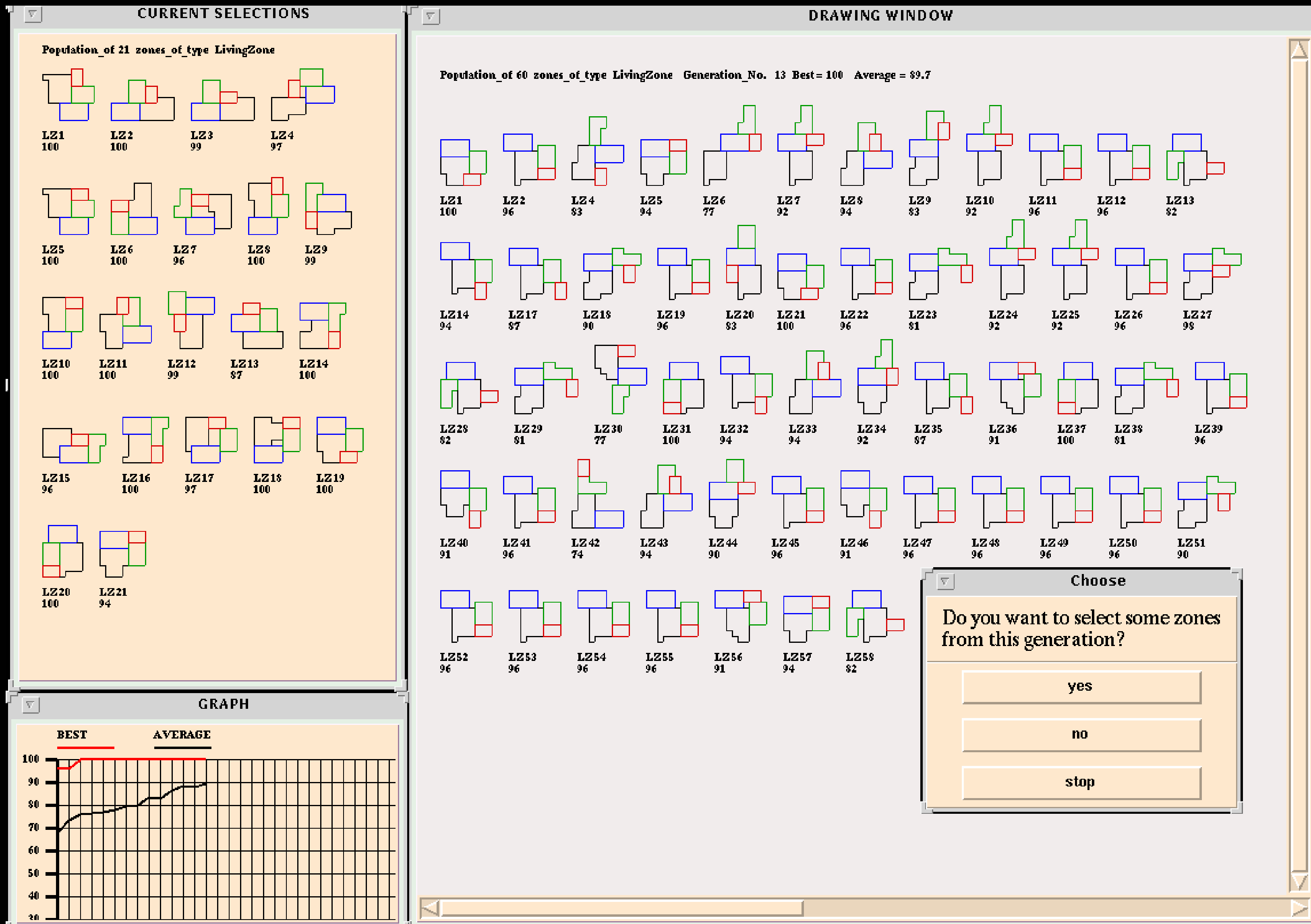
hillside townhouses (Gabriela Celani)



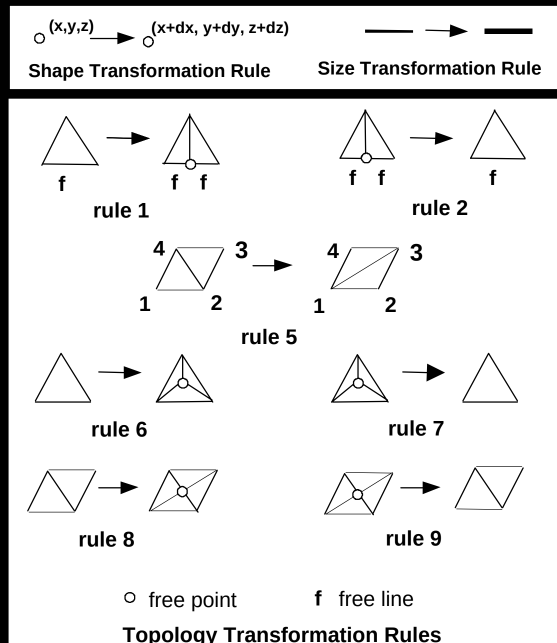
subway station, MIT campus (Gane, Gichuhi,Tian)

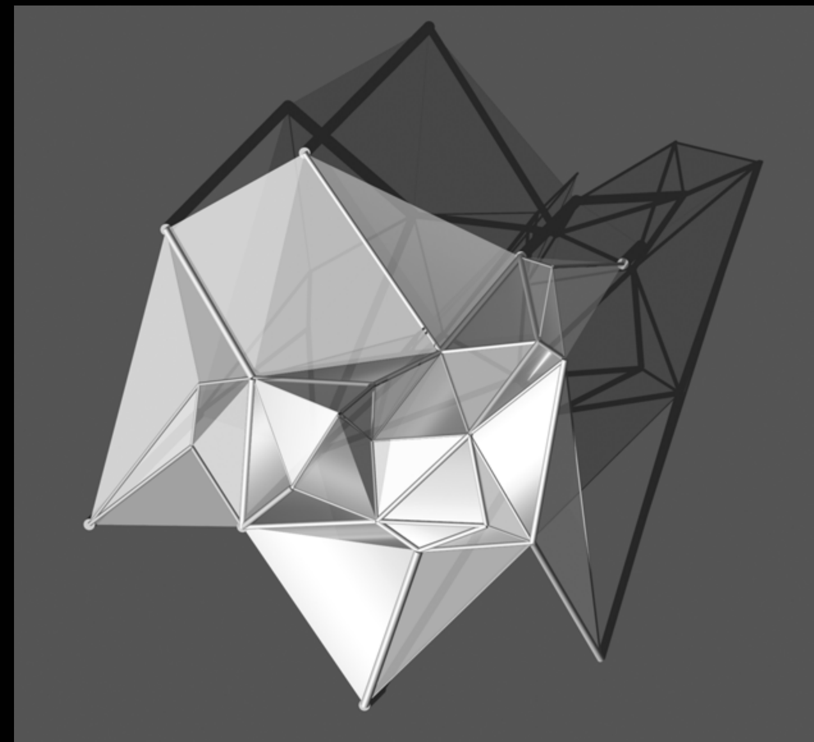
history of computation

1930s	formal theories of computation (Turing, Godel, Church, etc)
1940s	first computer
	> *neural nets (McCulloch and Pitts)*
	production systems (Post)
1950s	> *parallel computation (von Neuman)*
	> *cellular automata (Ulam, von Neuman)*
	generative grammars (Chomsky)
1960s	> *evolutionary computation*
	pattern grammars (Fu)
1970s	shape grammars (Stiny, Gips)
1980s	> *artificial life (Langton), self-organizing systems*



evolutionary design of houses (from Rosenman and Gero,1999) rules





generated pavilion design (top view)

Specifications (Syntax)	Constraints (Semantics)
• material properties • number of supports and locations • symmetry • joint angles	• stress • Euler buckling • displacement • geometric obstacles
Objectives (Semantics)	
• efficiency minimum mass • economy minimum number of distinct cross-sections minimum number of distinct lengths • utility maximum enclosure space minimum surface area	• aesthetics uniformity metric = σ(member lengths)[1] golden ratio metric = $\sum_{numshapes} \left\| -\frac{b}{a} \right\| + \left\| -\frac{b}{c} \right\| + \left\| -\frac{a}{b} \right\|^2$

performance criteria
(fitness functions)

EifForm (Shea, 1997)

One of the interesting things about the … programs that evolved in my experiment is that I do not understand how they work.

I have carefully examined their instruction sequences, but I do not understand them.

I have no simpler explanation of how the programs work than the instruction sequences themselves. It may be that the programs are not understandable.

Simulated evolution is a good way to create novel structures, but it is an inefficient way to tune an existing design.

Its weaknesses as well as its strengths stem from evolution's inherent blindness to the 'why' of a design . . .

Evolution chooses variations blindly, without taking into account how the changes will affect the outcome.

Daniel Hillis

Sims's computer-generated images give us an example of unintelligible emergence . . .Sims himself cannot always explain the changes he sees appearing on the screen before him, even though he can access the mini-program responsible for any image he cares to investigate. . .

Often he cannot even 'genetically engineer' the underlying LISP expression so as to get a particular visual effect.

Margaret Boden

stages of shape grammar development

shapes

↓

spatial relations

↓

rules

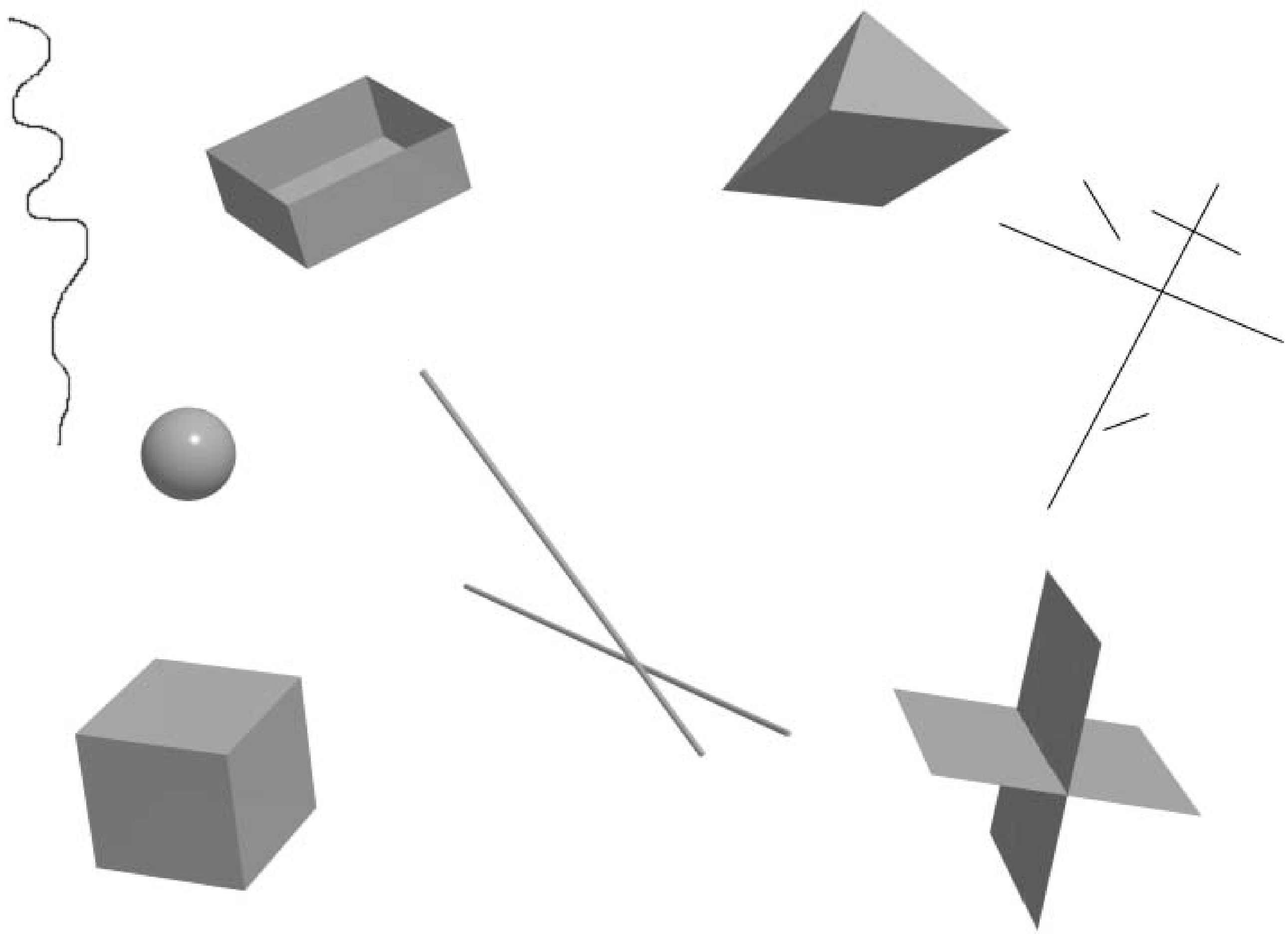
↓

shape grammar

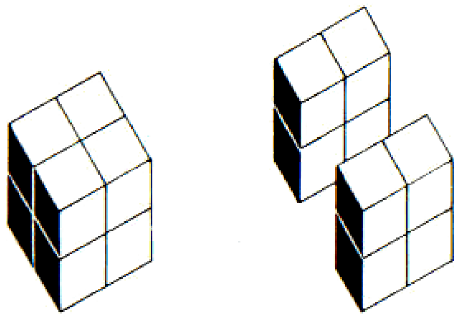
↓

designs

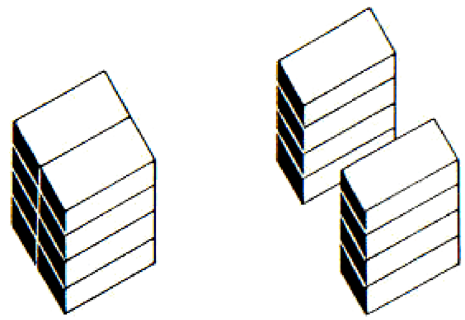
shapes



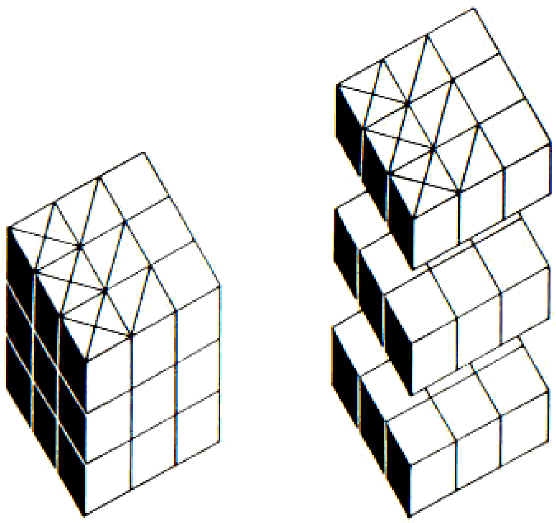
Froebel building gifts



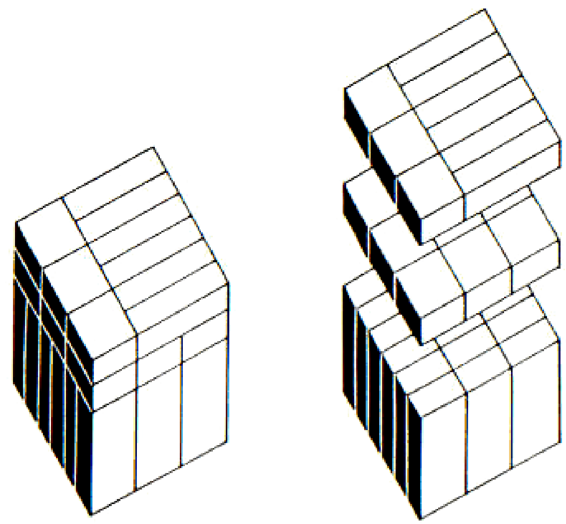
Gift 3



Gift 4



Gift 5

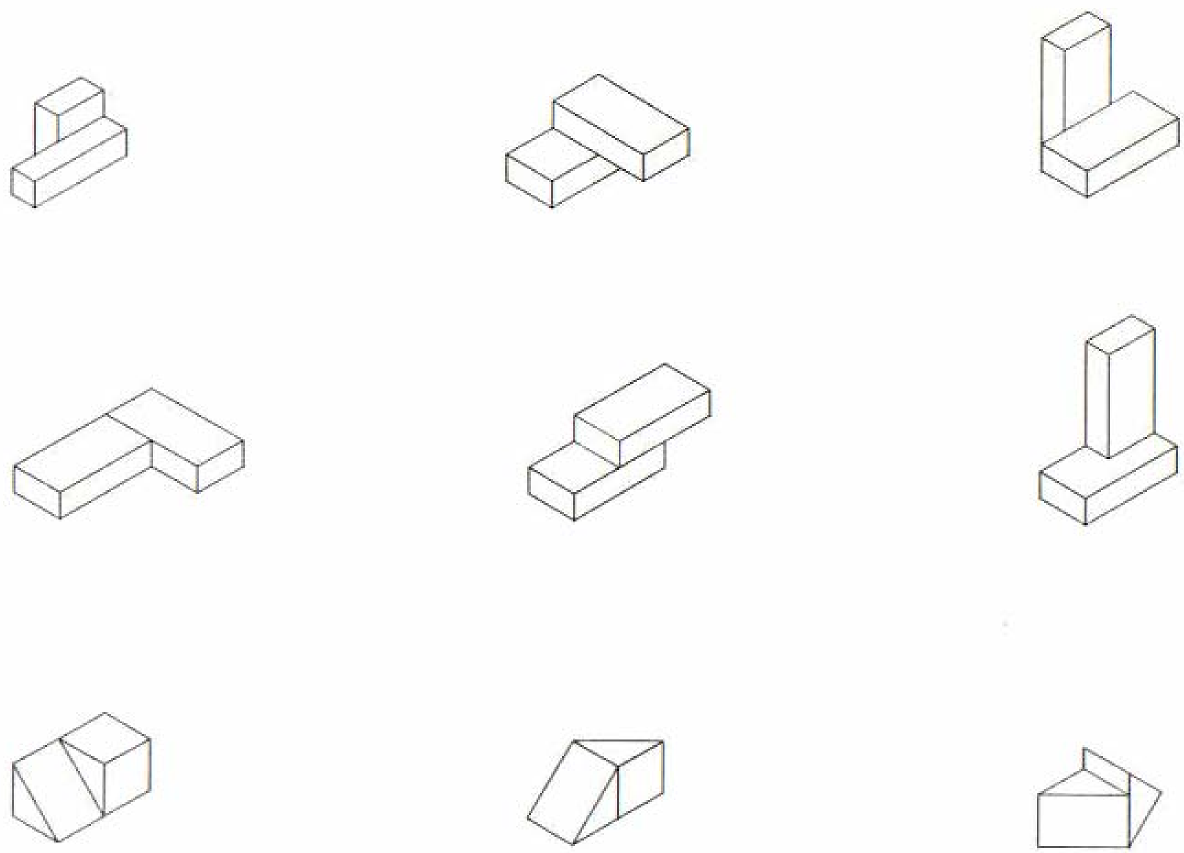


Gift 6

spatial relations

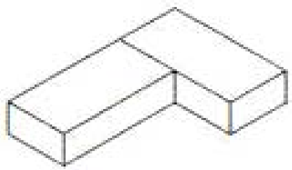
arrangements of shapes

spatial relations

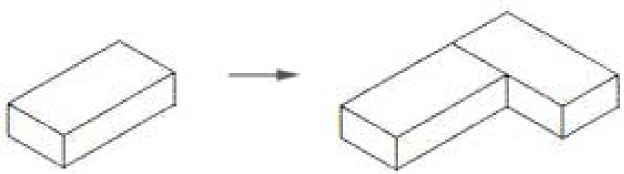


shape rules

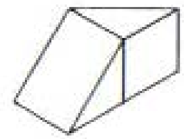
shapes:	A, B
spatial relation:	$A + B$
rules:	$A \rightarrow A + B$
	$B \rightarrow A + B$



spatial relation

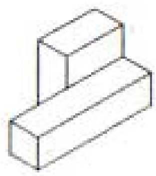


rule

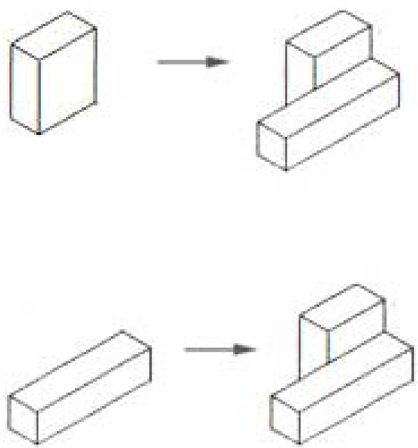


spatial relation

rule



spatial relation



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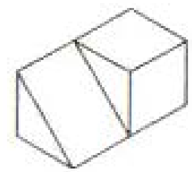

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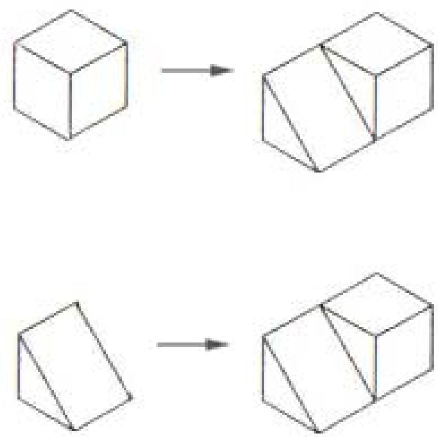

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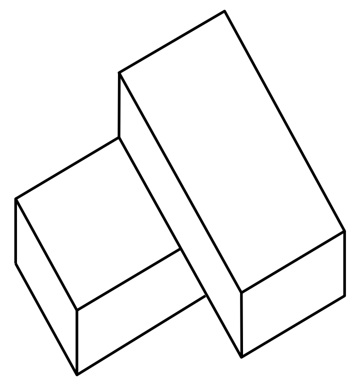
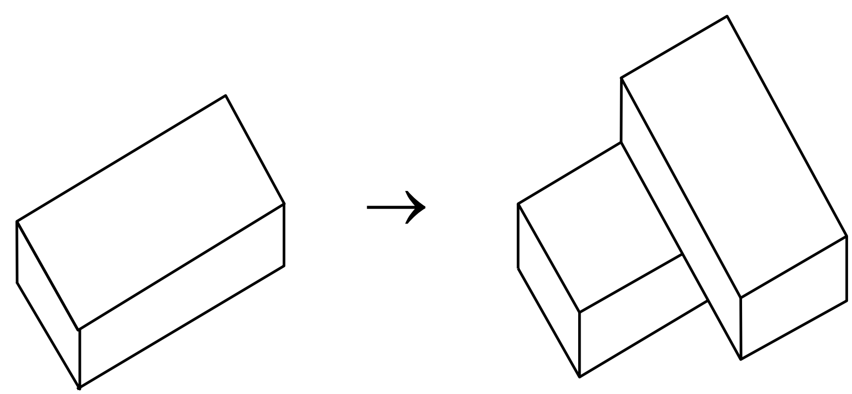


spatial relation A + B between two oblongs



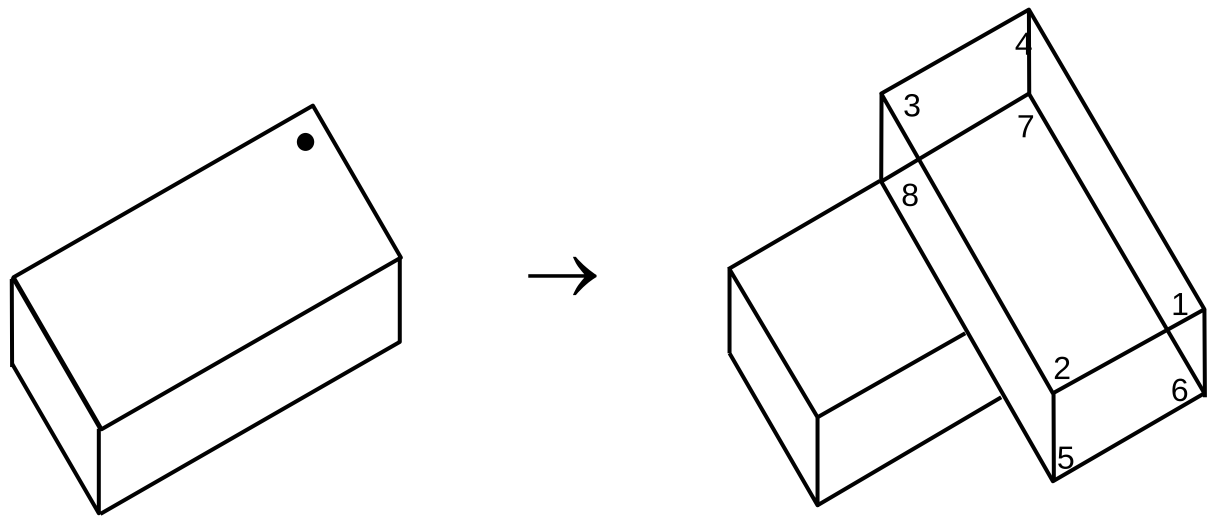
addition rule A → A + B based on the spatial relation

applying a rule

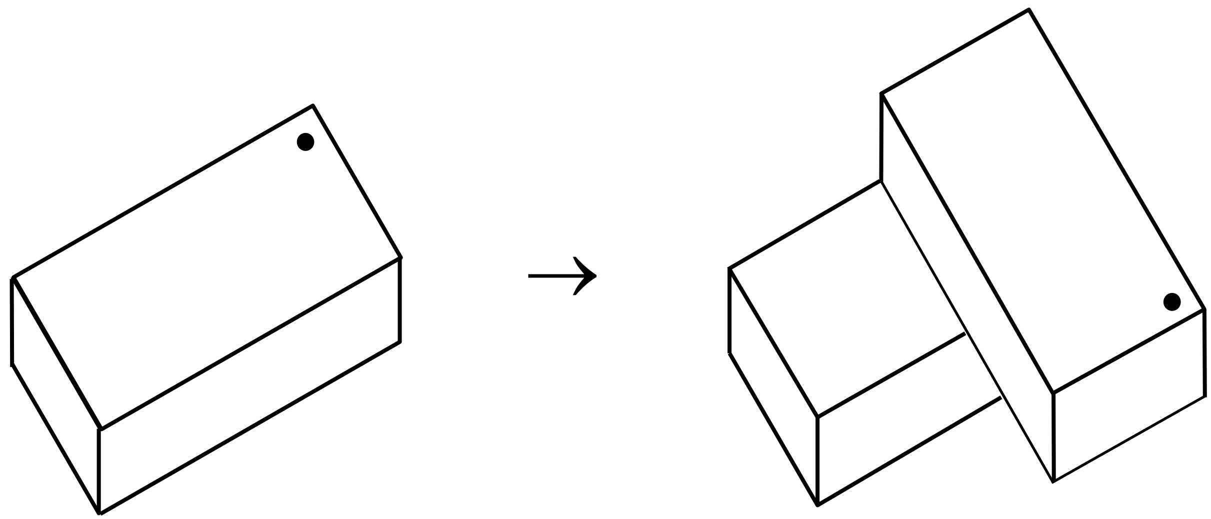
$A \rightarrow A + B$

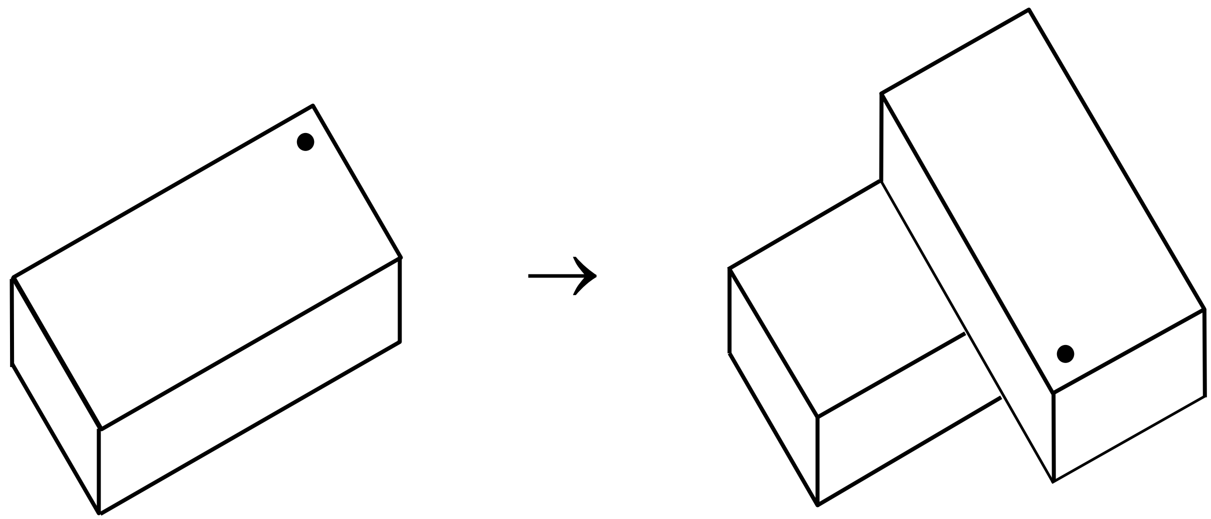
match the shape A
with a shape in a design

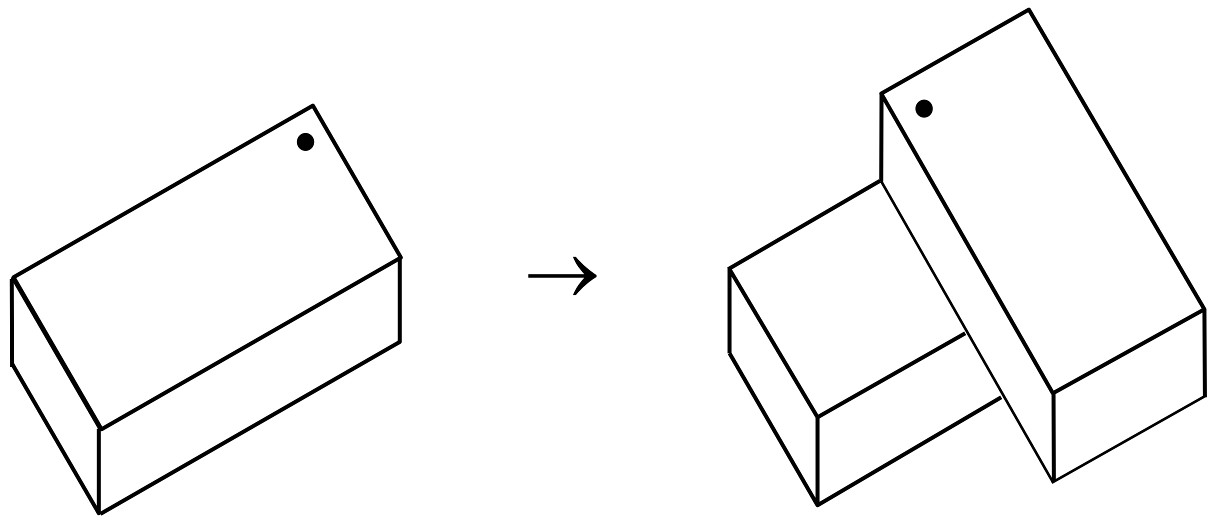
add the shape B to the design
to create the spatial relation A+B

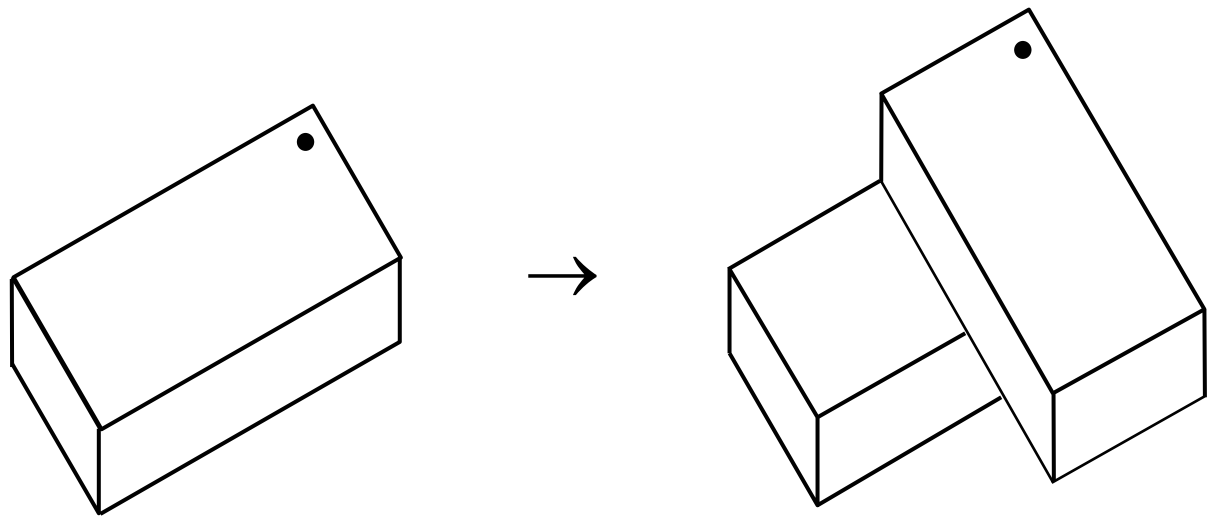


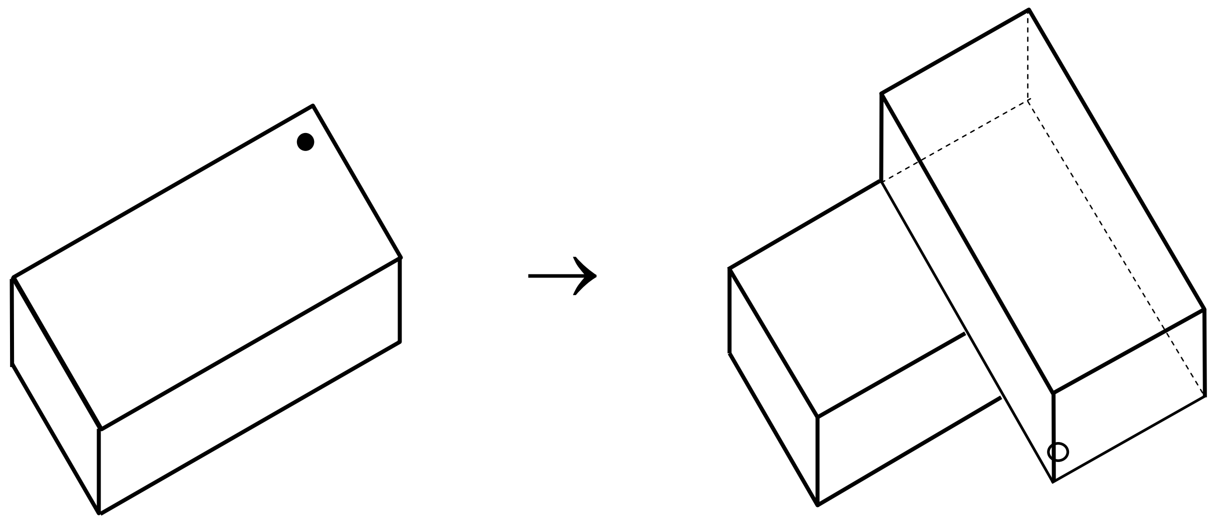
different labelings of the rule A $\rightarrow$ A + B

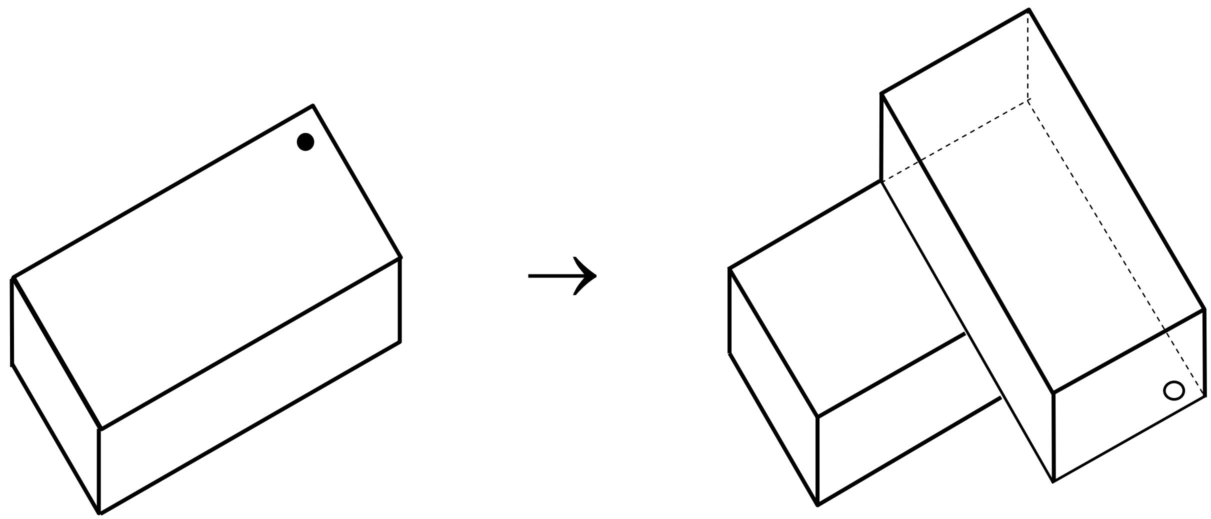


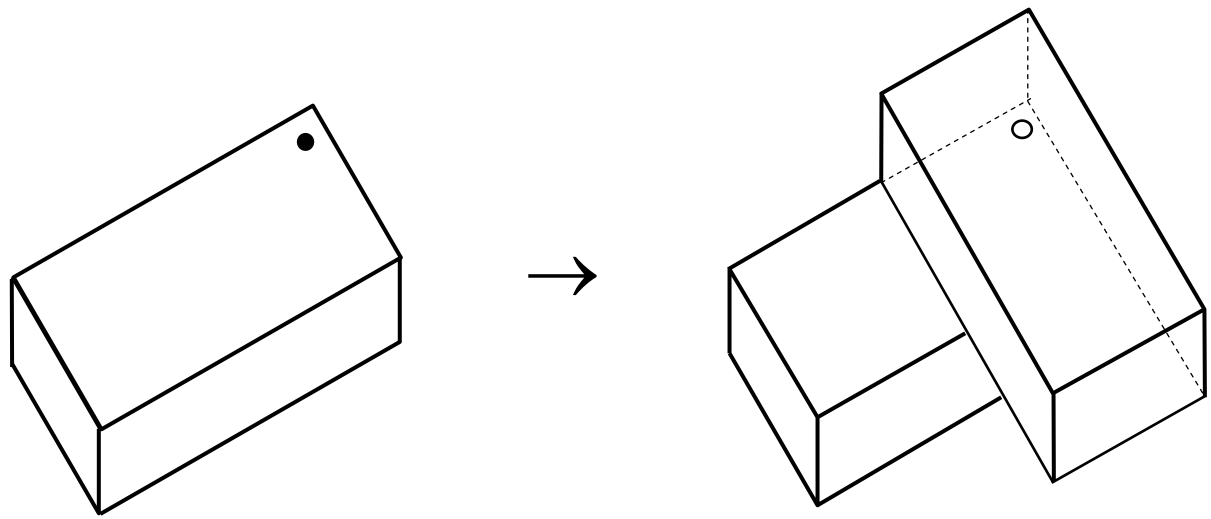


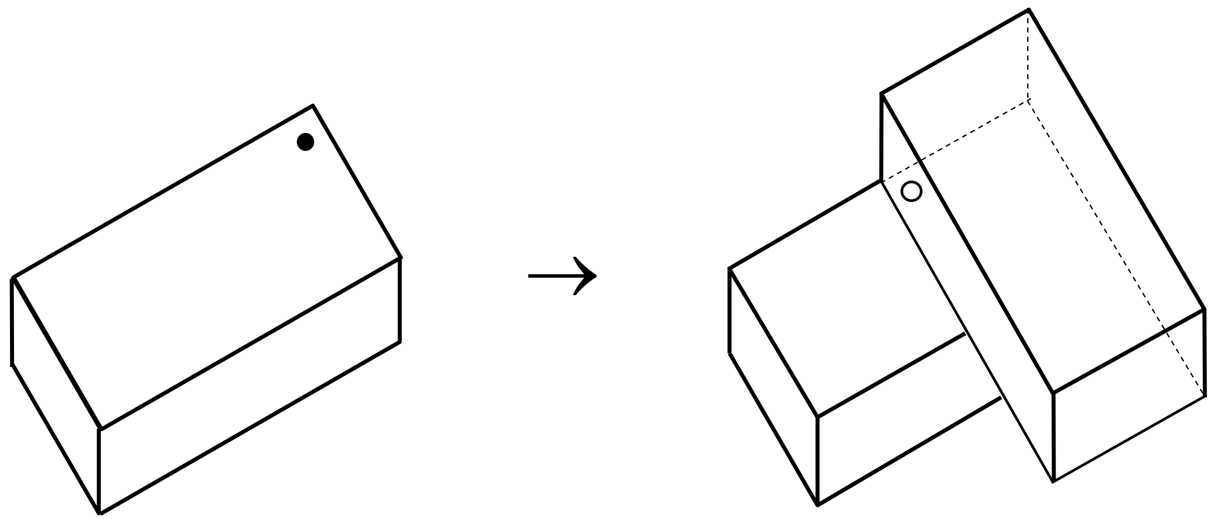


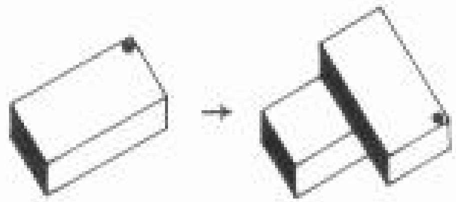












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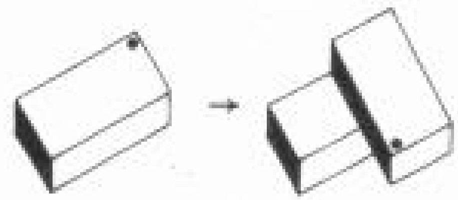

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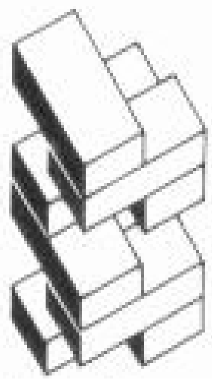

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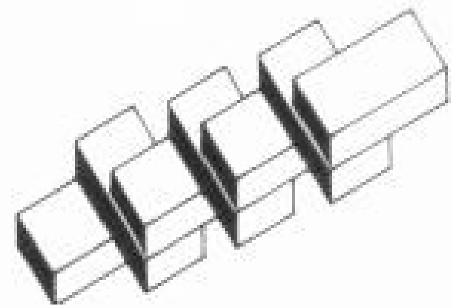

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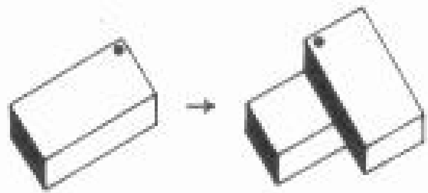

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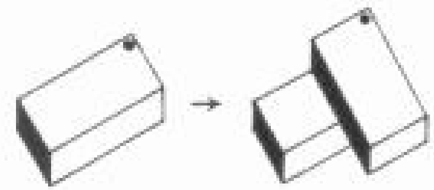

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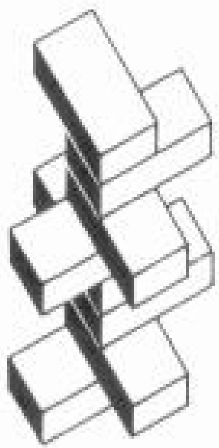

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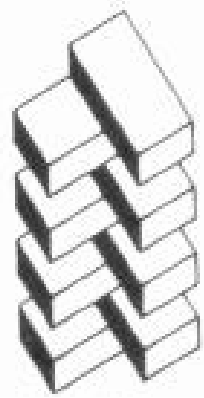

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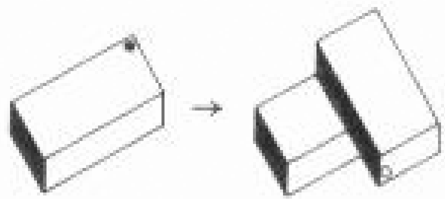

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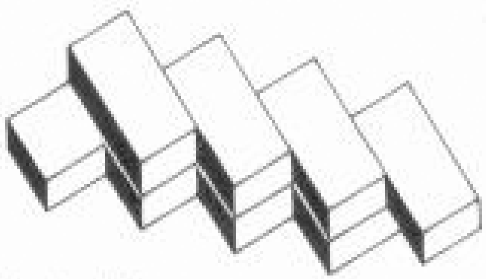

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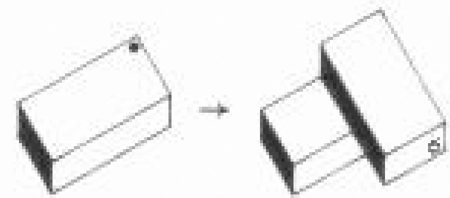

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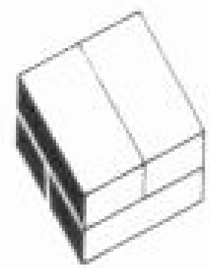

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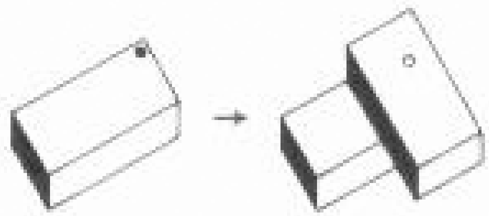

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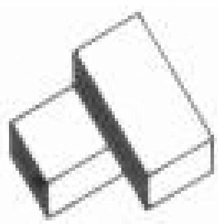

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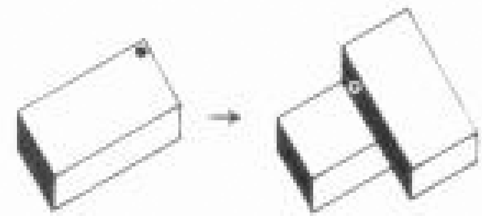

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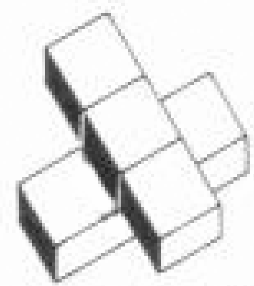

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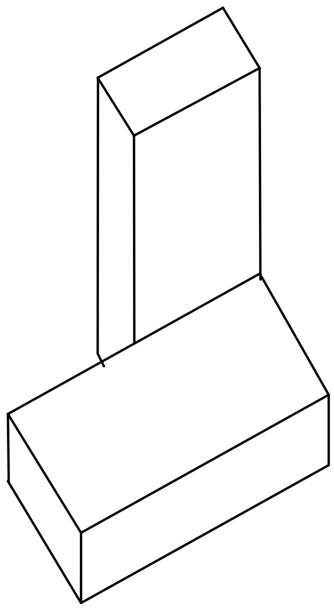
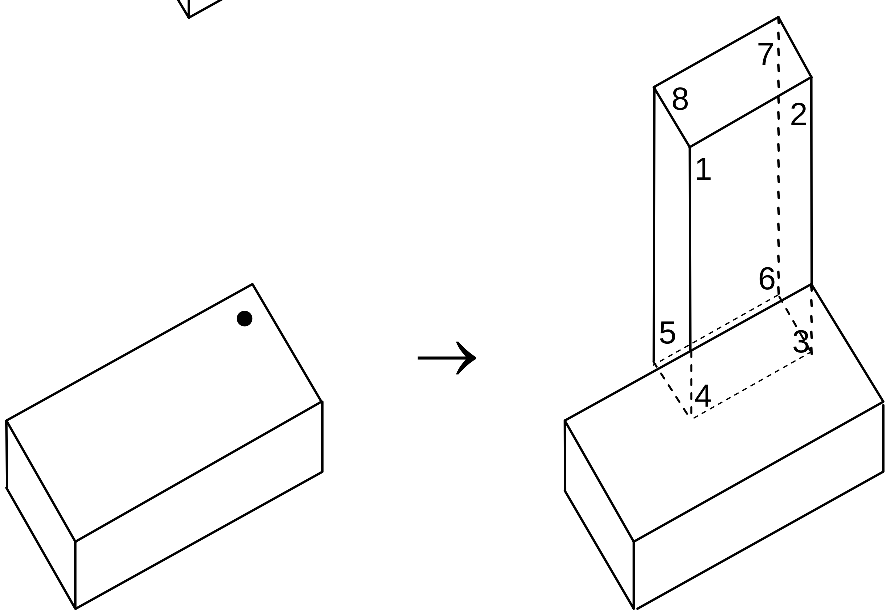
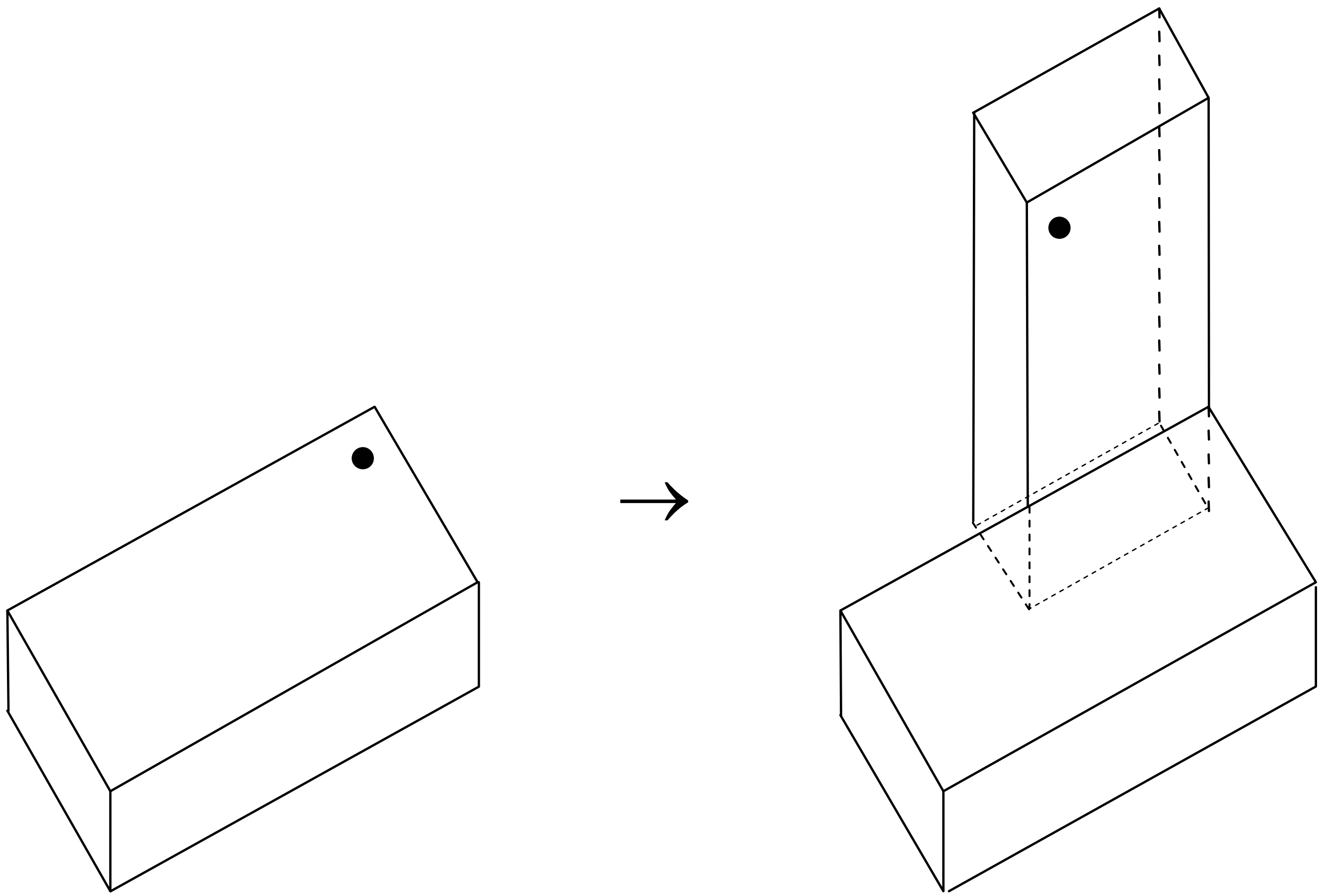
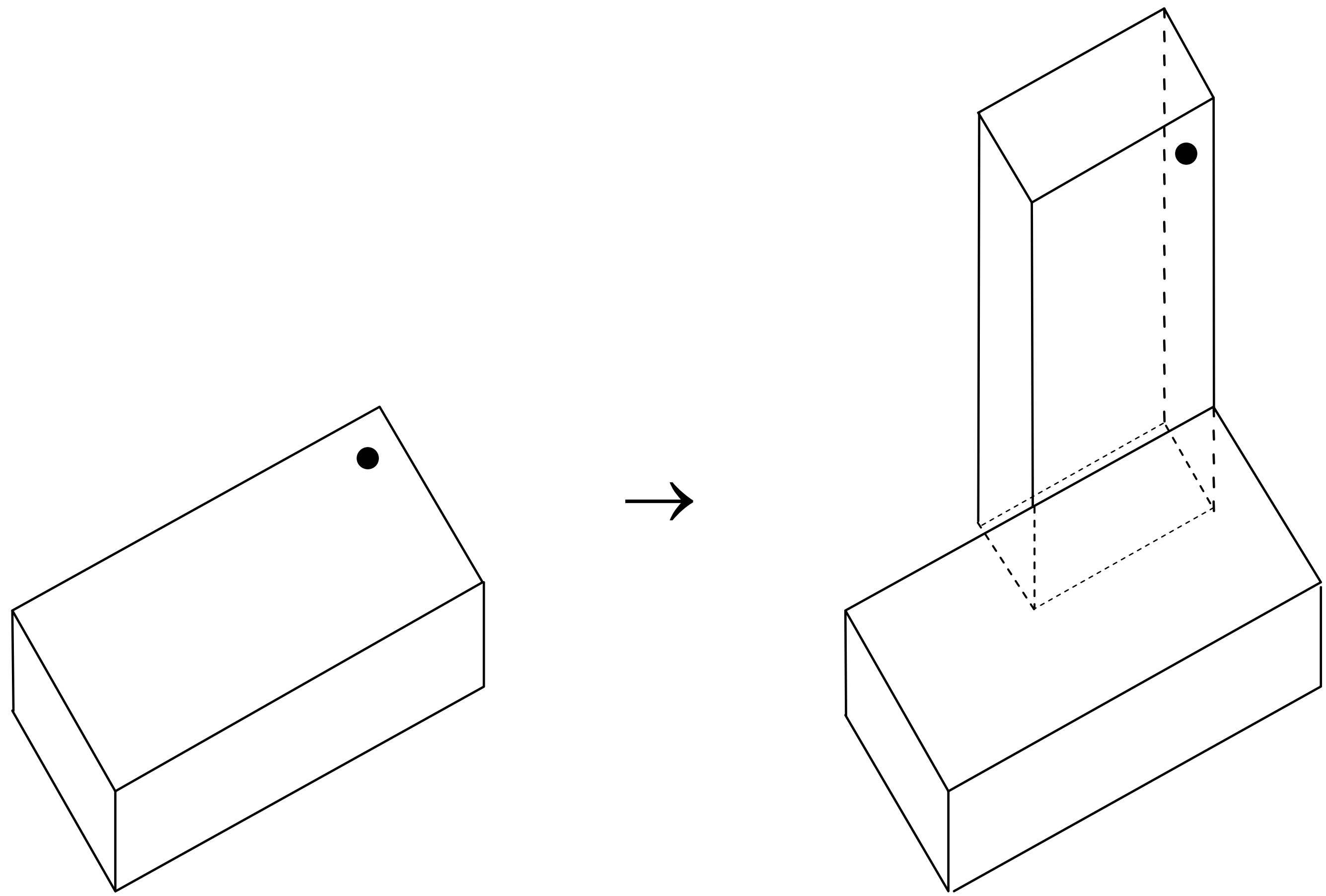


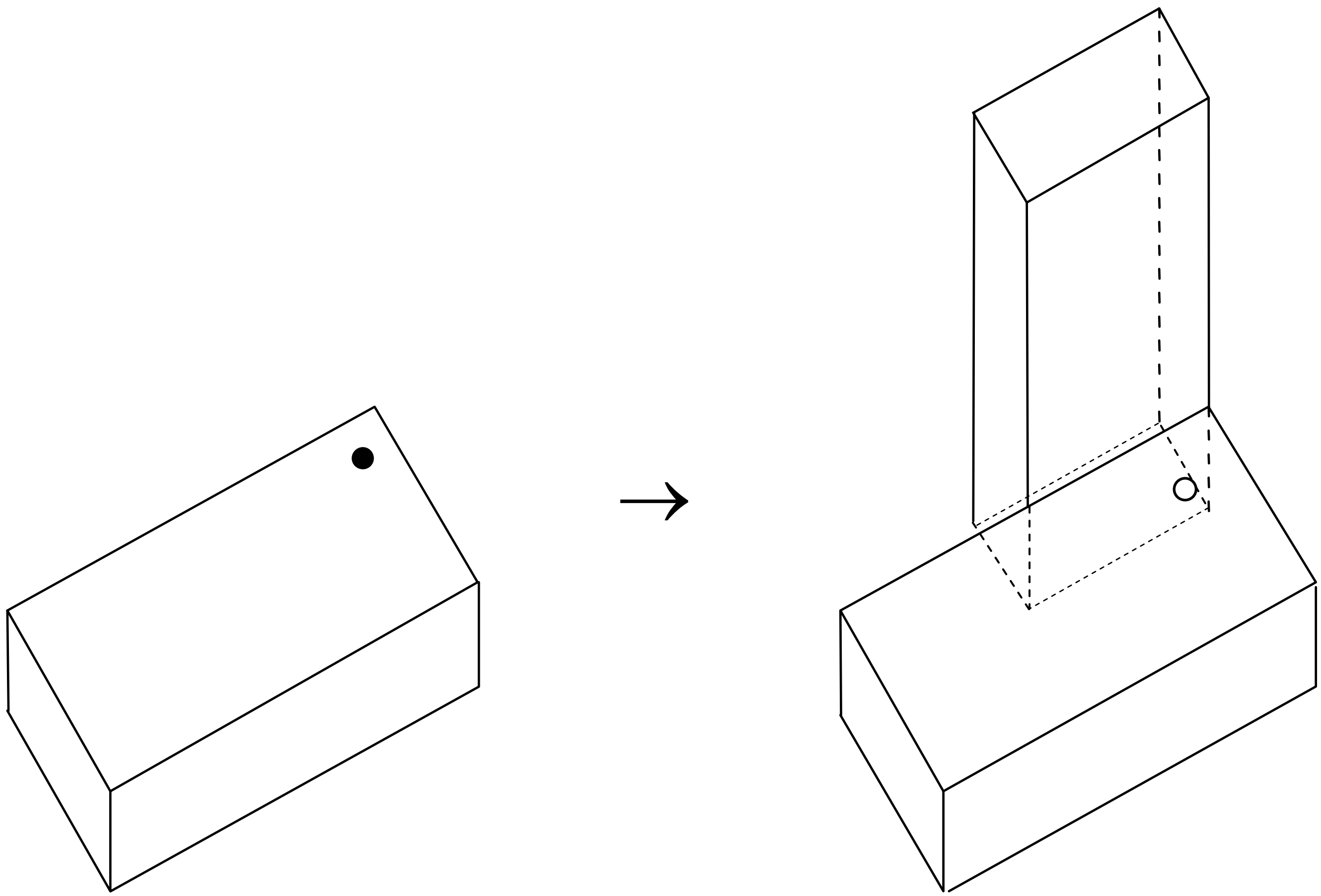
spatial relation A + B between two oblongs

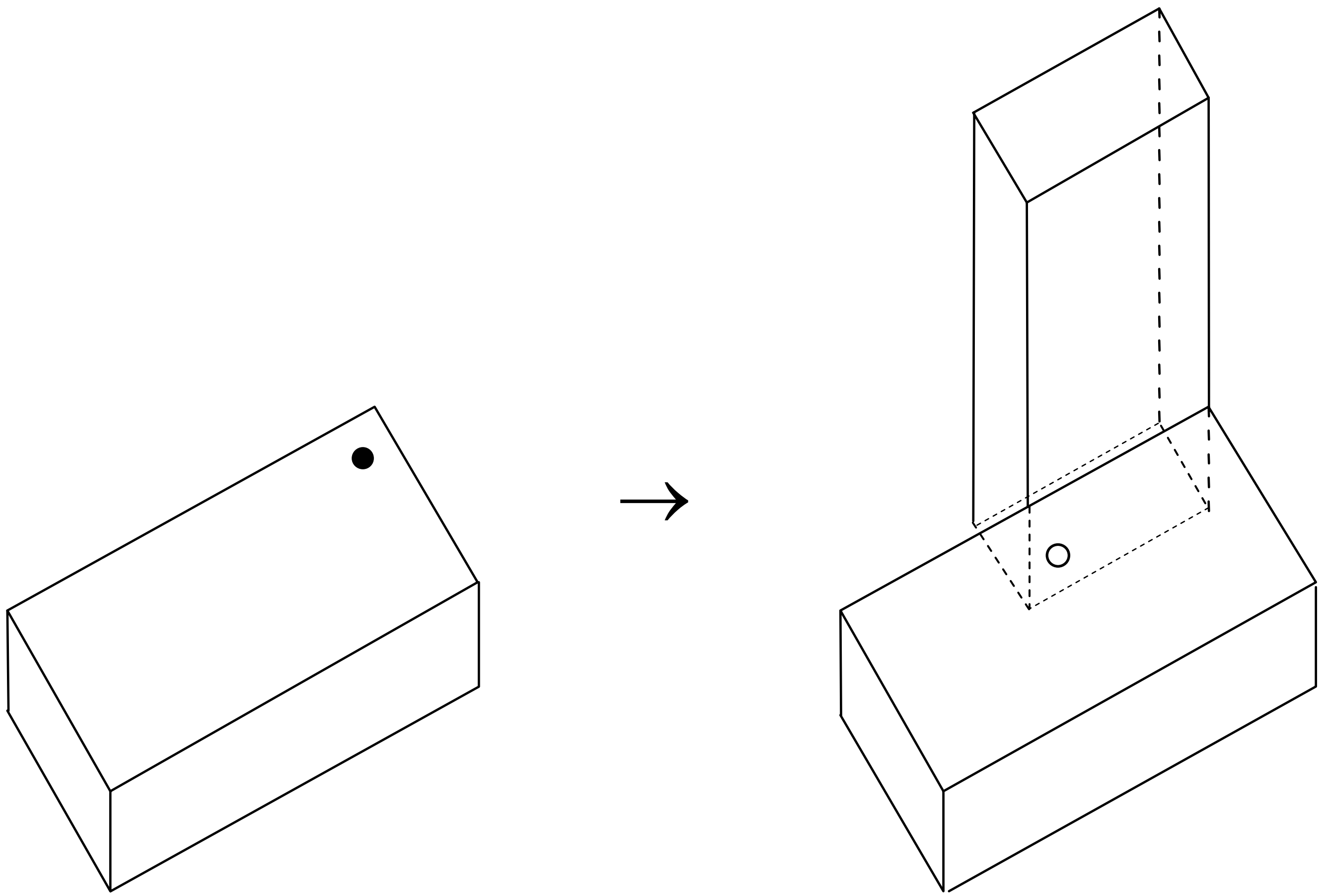


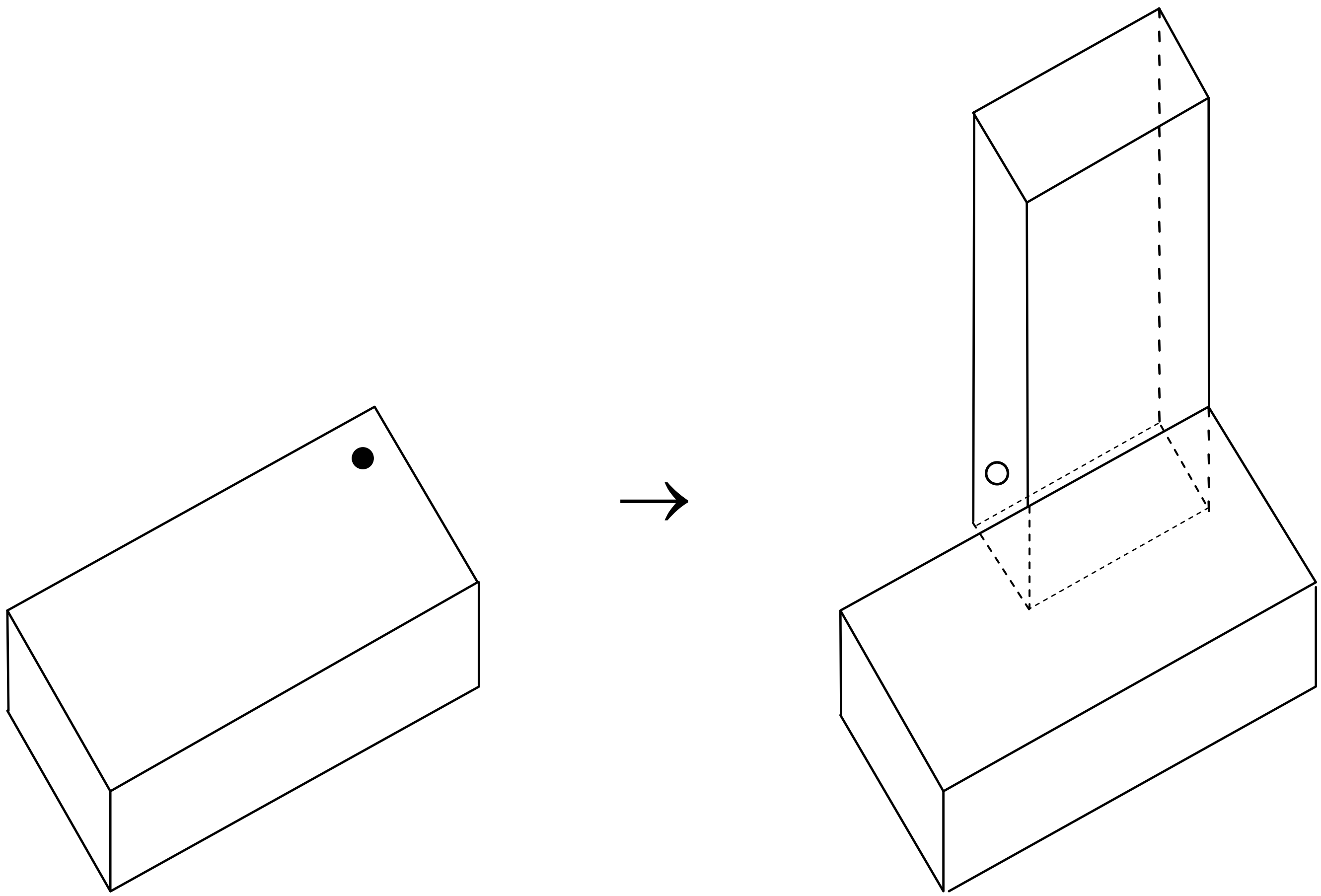
different labelings of the rule A $\rightarrow$ A + B

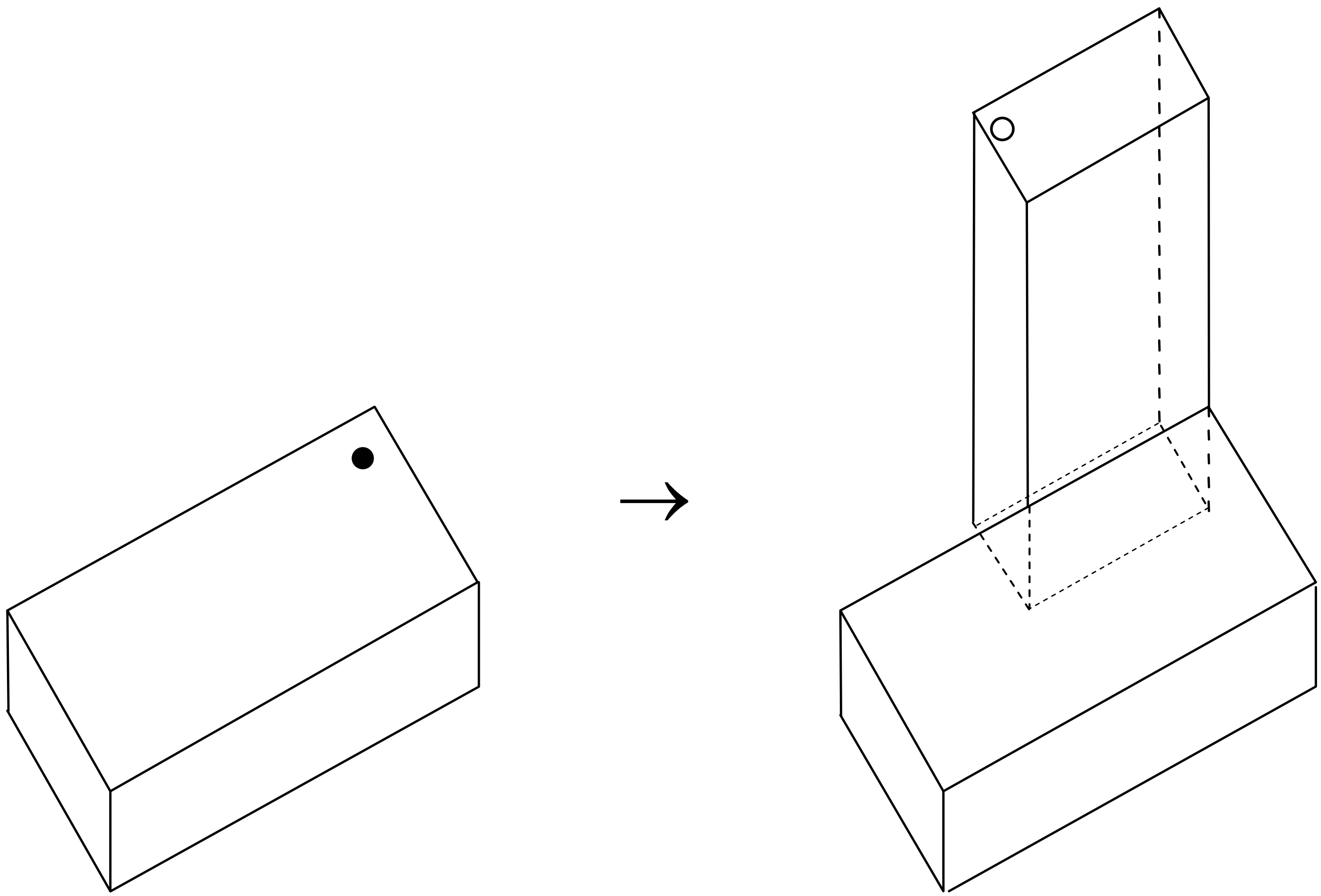


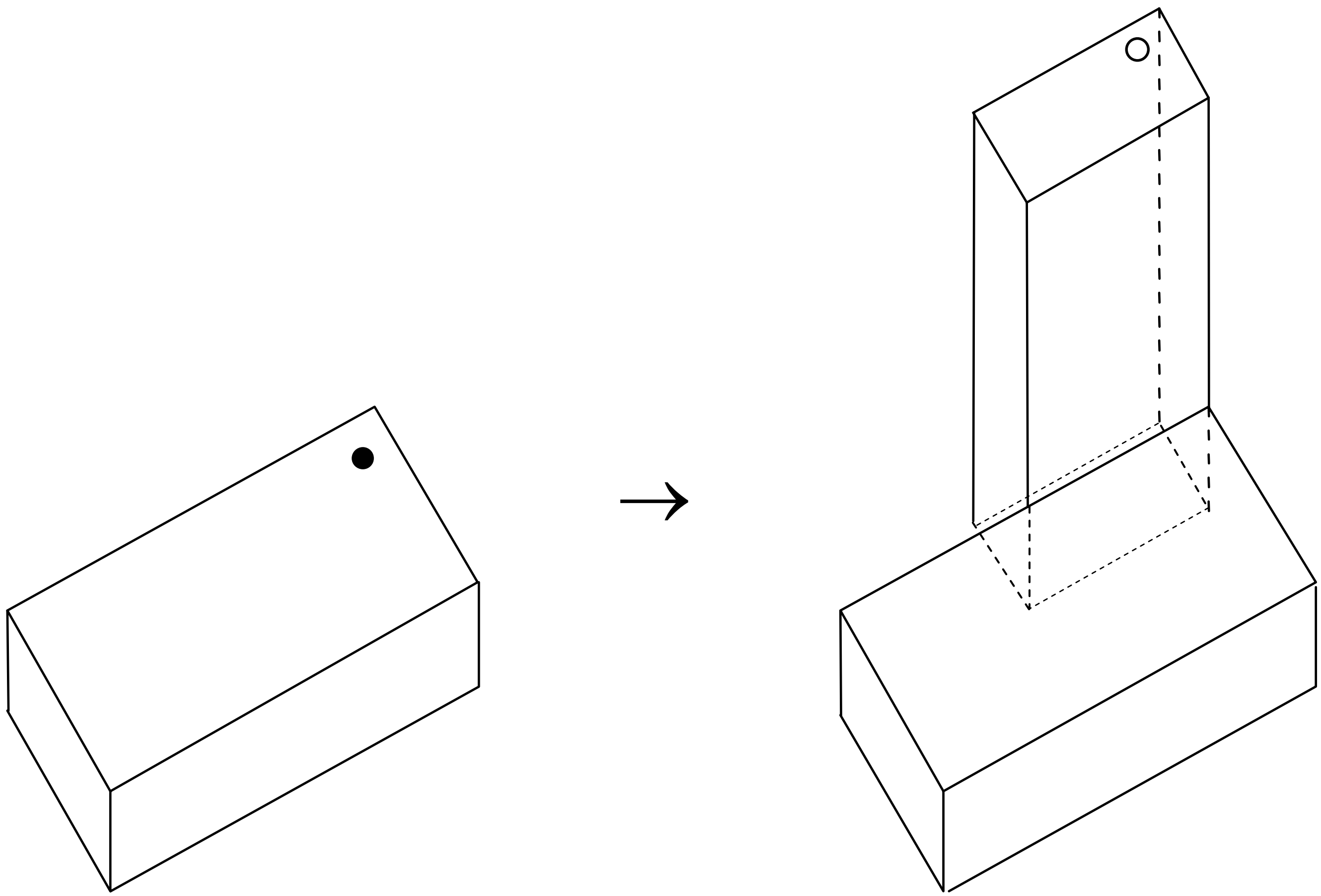


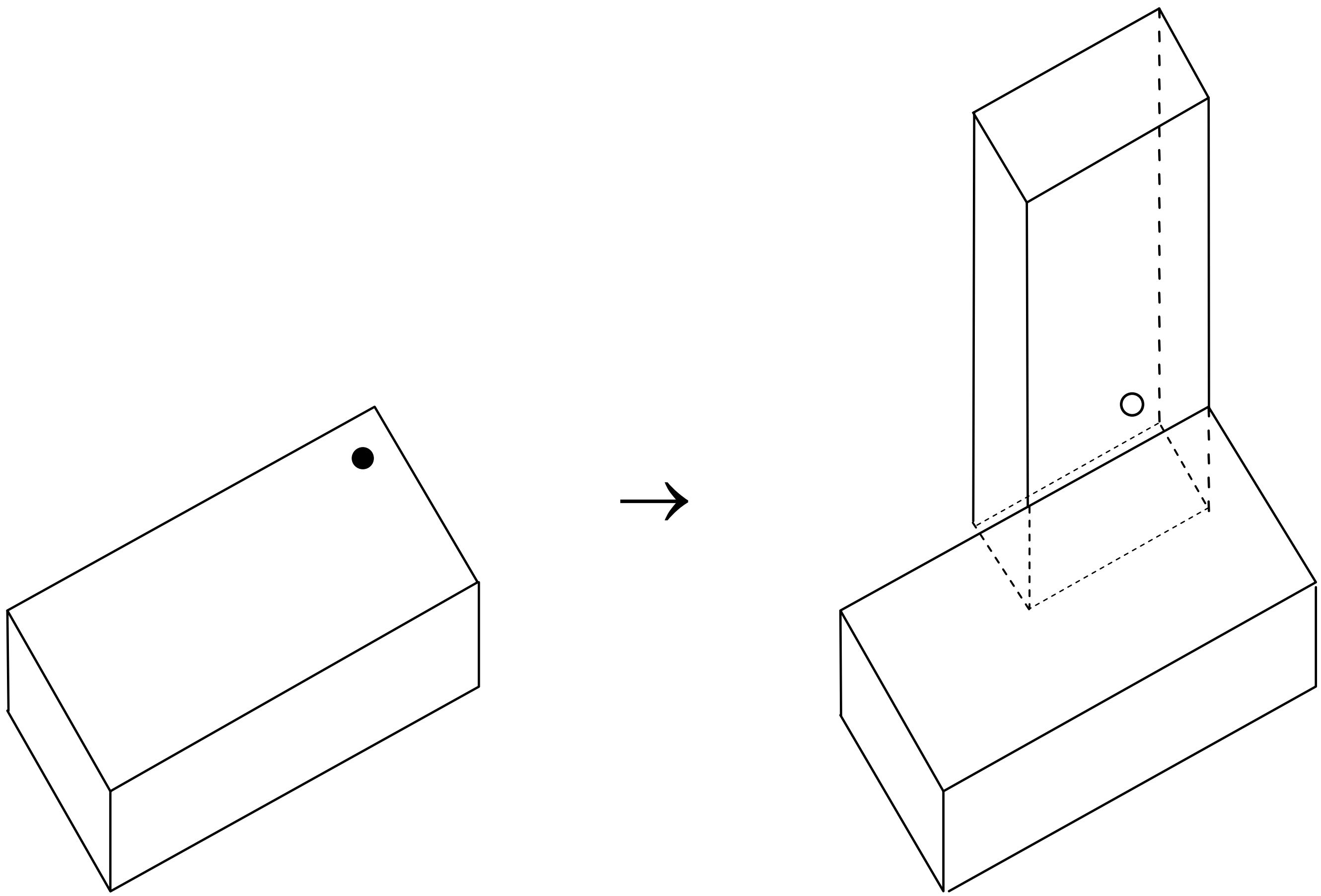


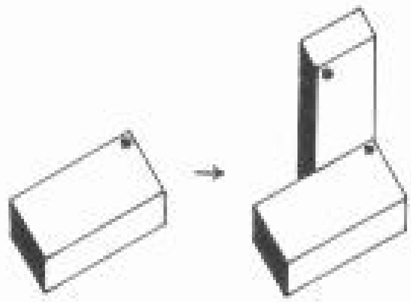












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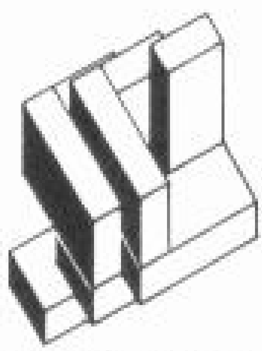

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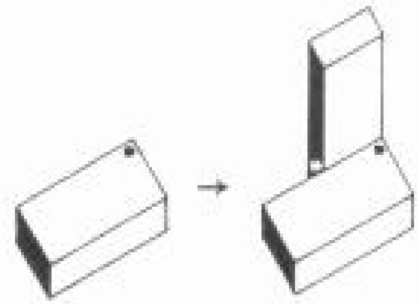

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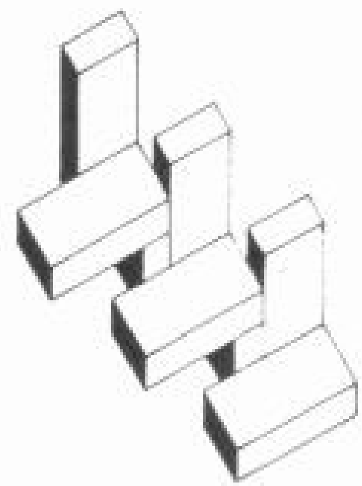

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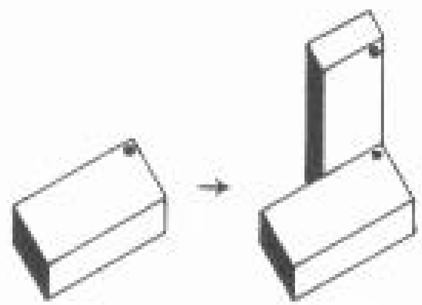

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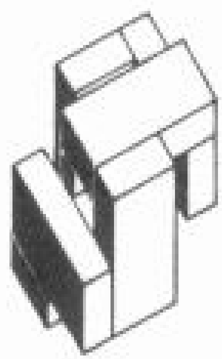

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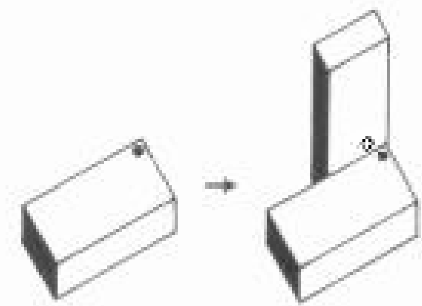

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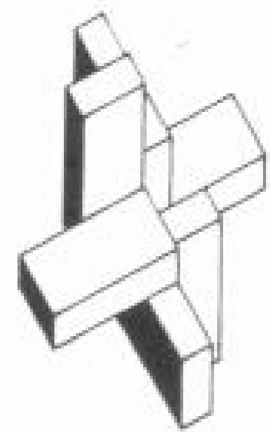

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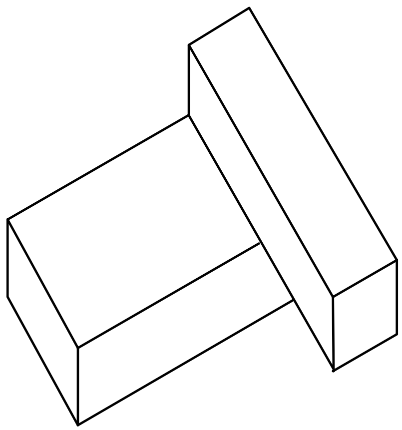
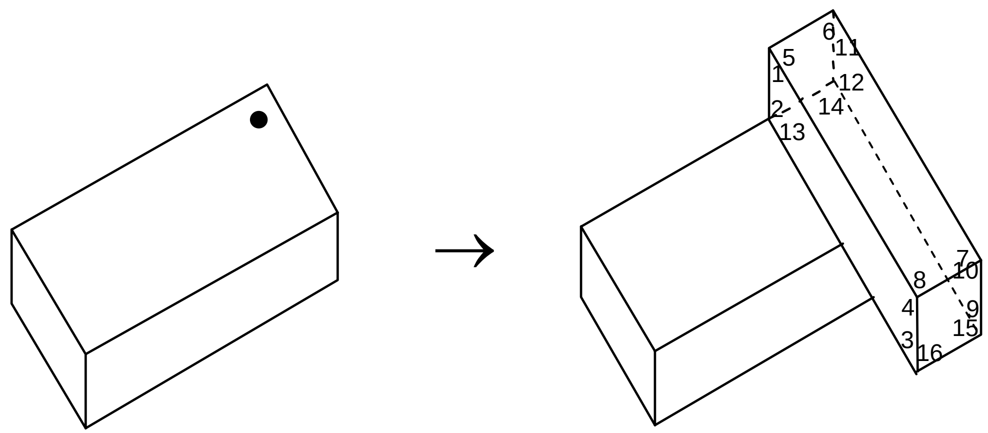
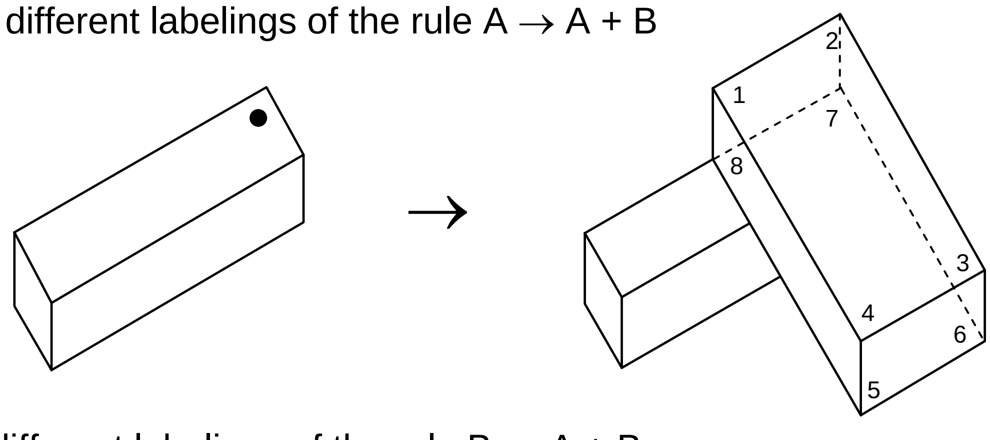


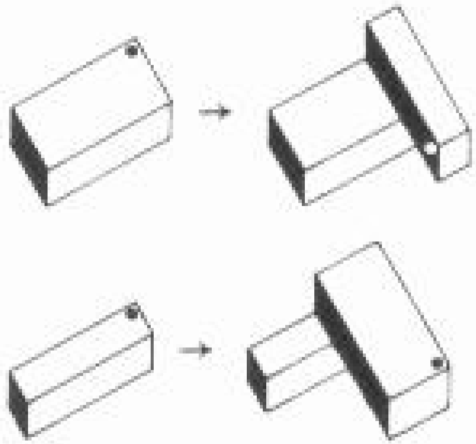
spatial relation A + B between two oblongs



different labelings of the rule A $\rightarrow$ A + B



different labelings of the rule B $\rightarrow$ A + B



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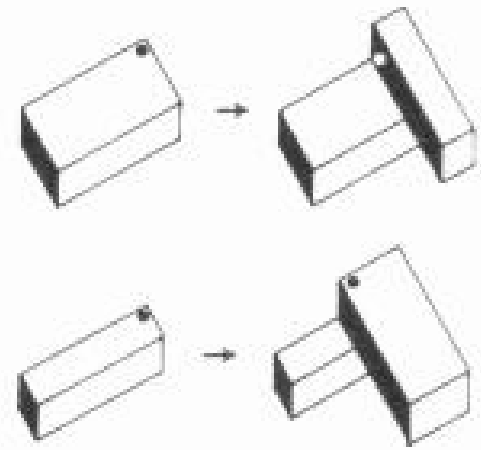

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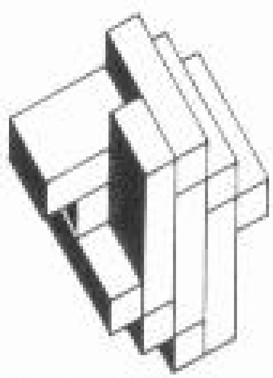

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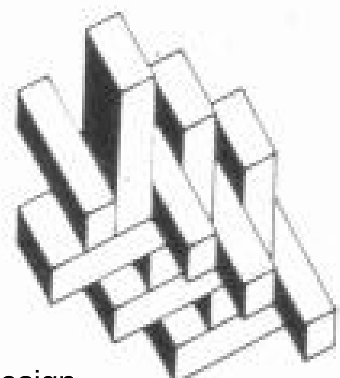

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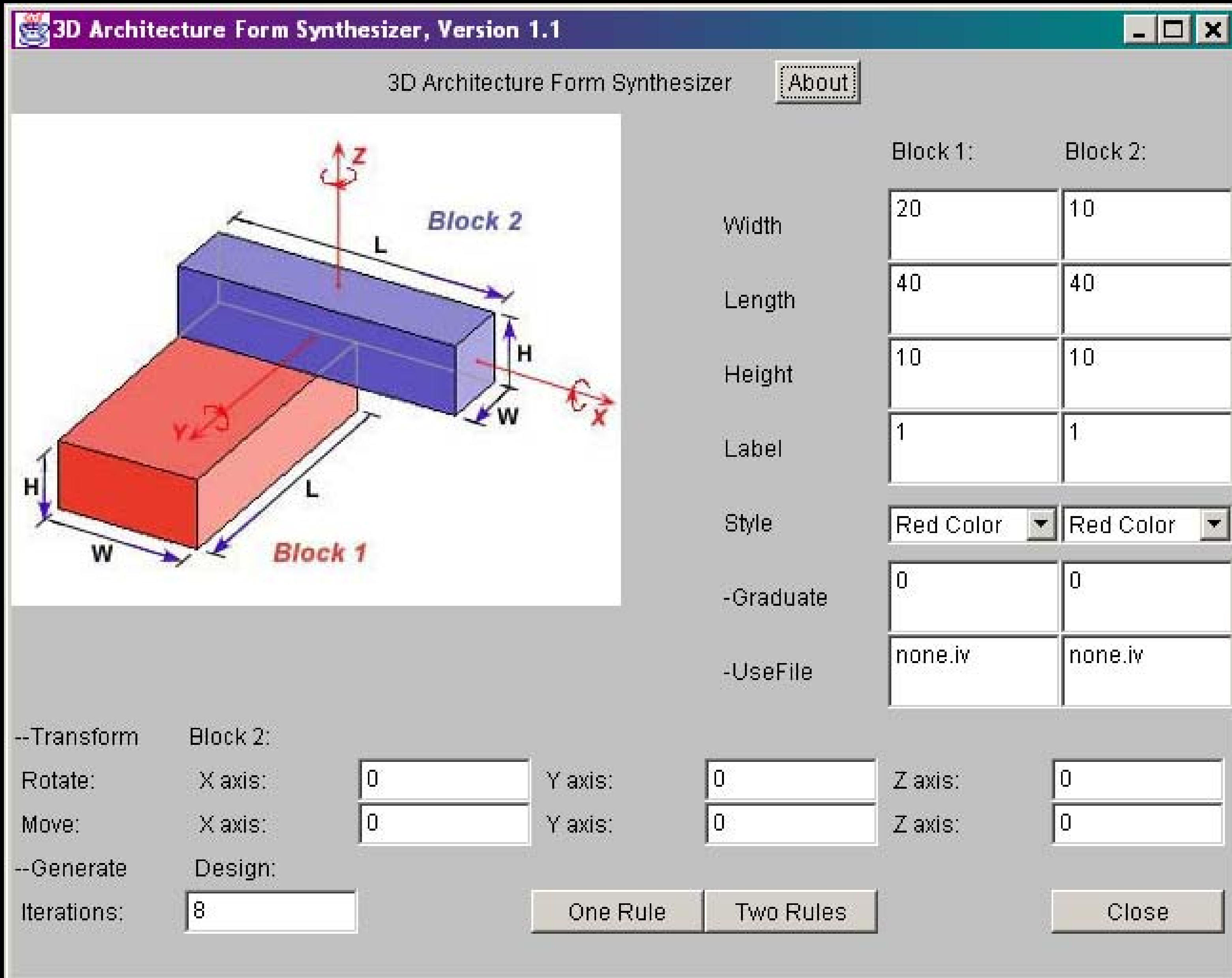
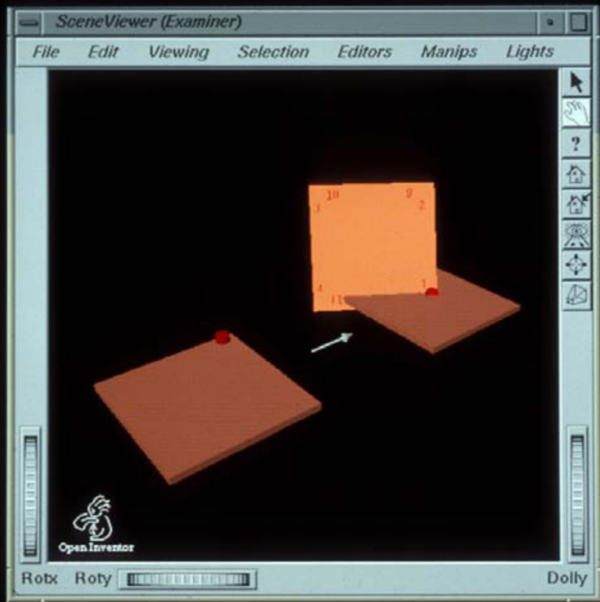
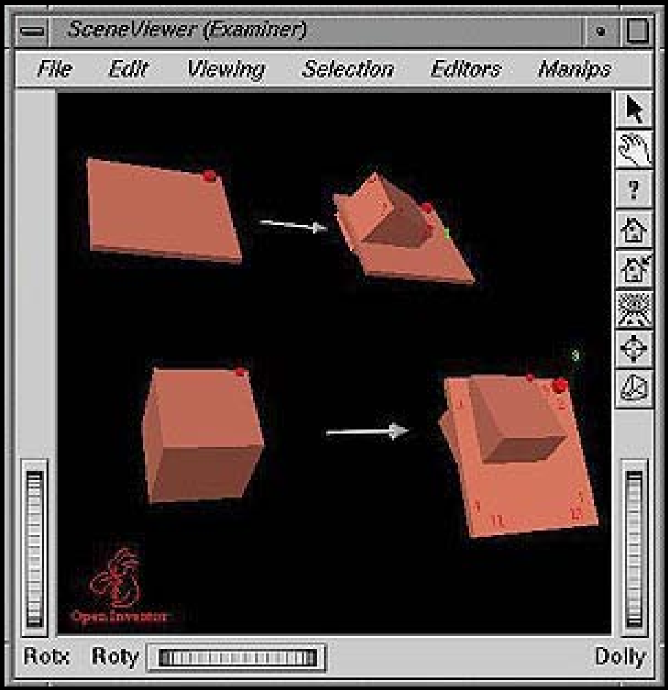
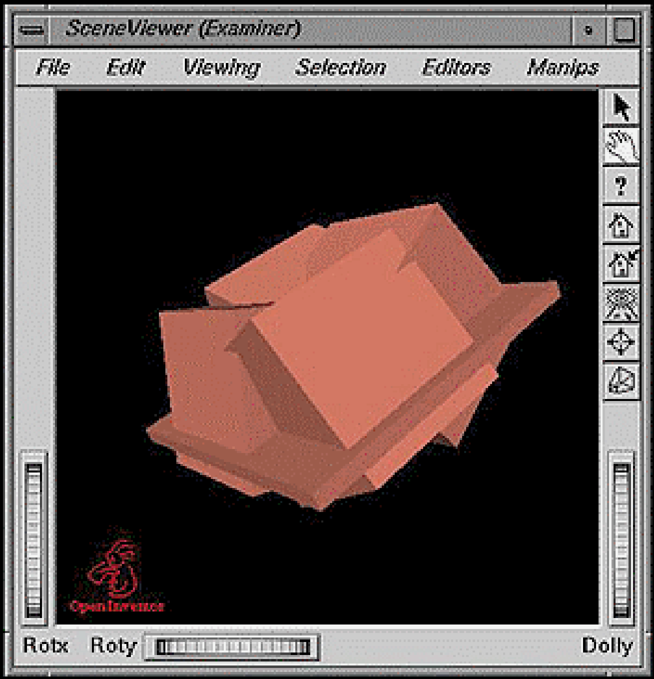


3D architecture form synthesizer (Yufei Wang) rule



designs





rule

designs