

Computational Design + Fabrication: 3D Fab

Jonathan Bachrach

EECS UC Berkeley

September 24, 2015

- News
- 3D Rationalization
- 3D CNC
- 3D Joinery
- 3D Validation
- Lab 2 Critique



- reading 4 out question due next tuesday
- lab out soon after class due next thursday – read tonight
- section tomorrow 11a-12p in jacobs 220
- bcourse on jacbobs type A 3d printing

- 2 extra rotations
- better surface finish
- more complex parts can be manufactured
- CAM determines poses, tools, tool paths



by shopbot 5 axis

Large 5 Axis CNC

4

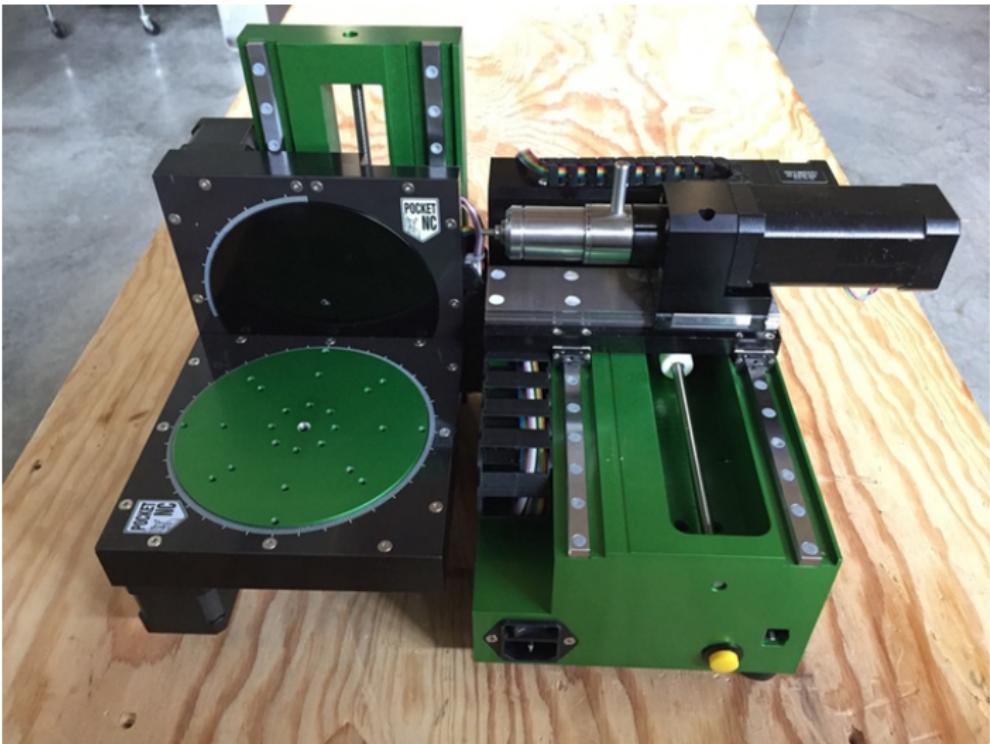


- A** Advanced 5-Axis Control
- B** Best-In-Class Chip Management
- C** High Accuracy Components
- D** Rigid Construction
- E** Advanced spindle technology

by hurco 5 axis

Desktop 5 Axis CNC

5



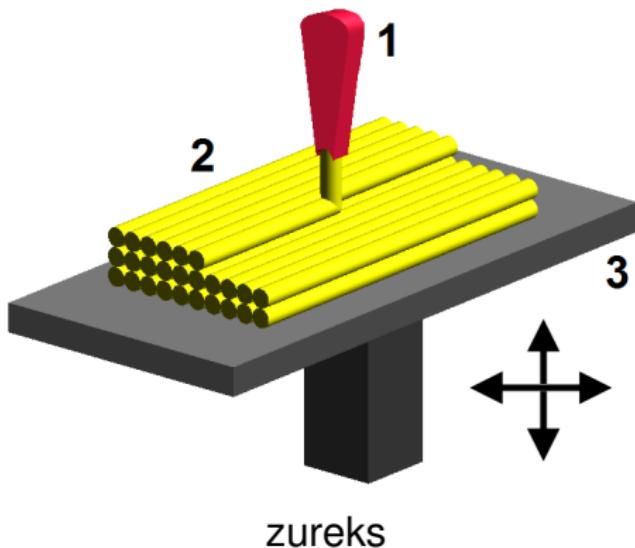
by pocket nc

- extrusion
- light polymerised
- powder bed
- laminated
- wire

Extrusion 3DP

7

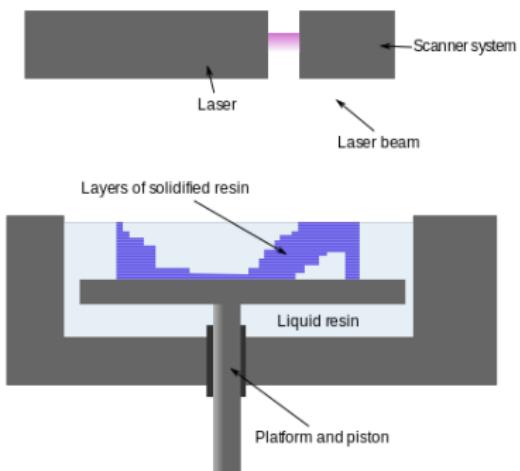
- extrude material through nozzle



Light Polymerised 3DP

8

- controlled light
- photopolymers

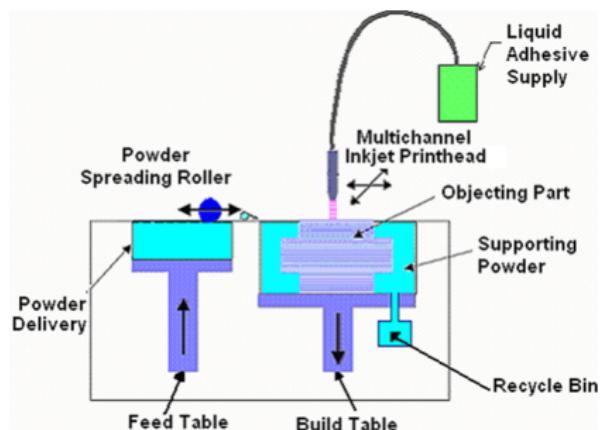


materialgeeza

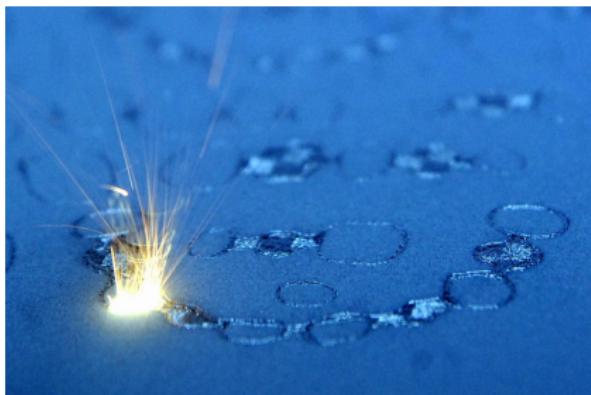


form1

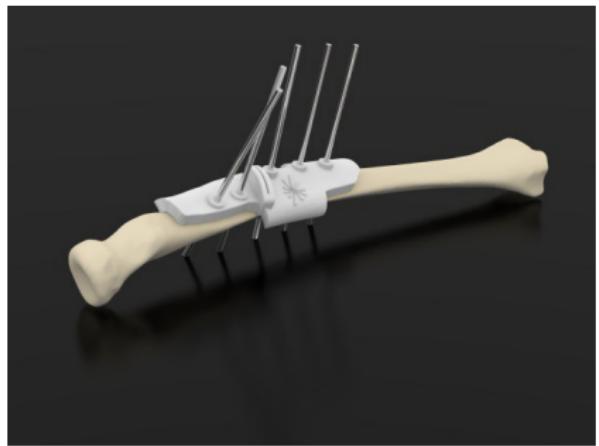
- spread fine powder layers
- selectively bind powder
- remaining powder serves as support



zhou + lu



eos



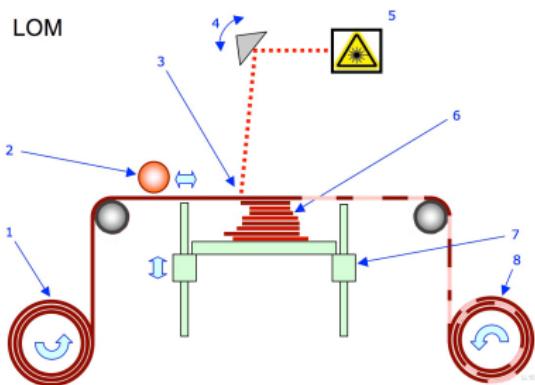
drill guide

by eos



morris swirler

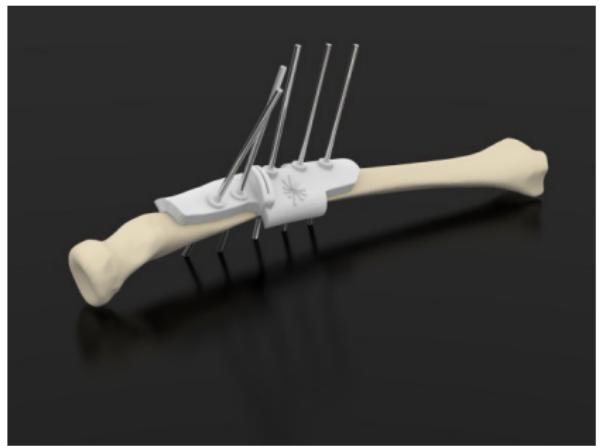
- automate lamination procedure
- can ink jet print on laminate



laurenvانlieshout



mcor



drill guide

by eos



morris swirler

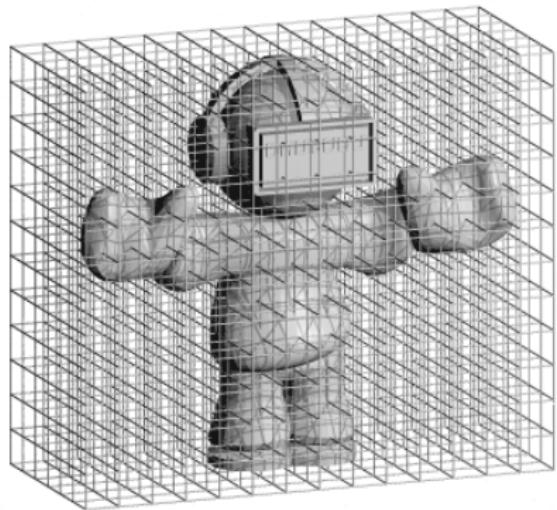
- zero gravity melting of wire with laser



by NASA Johnson Space Center

- one algorithm
- assume 3d printer
- could split into lego pieces

- overlay grid on solid
- represent grid cells called voxels

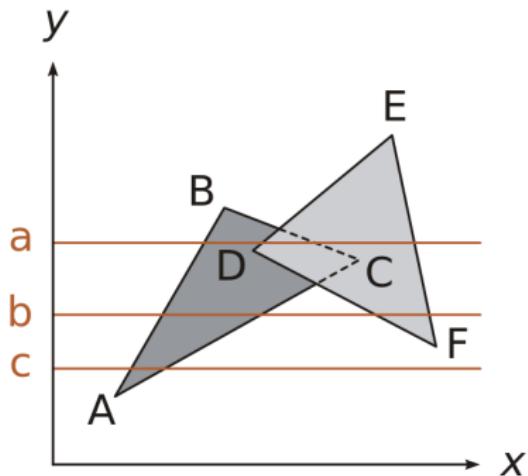
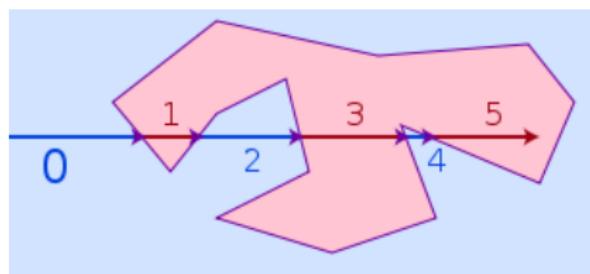


Arjan Westerdiep

Conversion from Surfaces to Voxels

16

- ray casting
- rasterization



pros

- one part
- regular and simple geometry

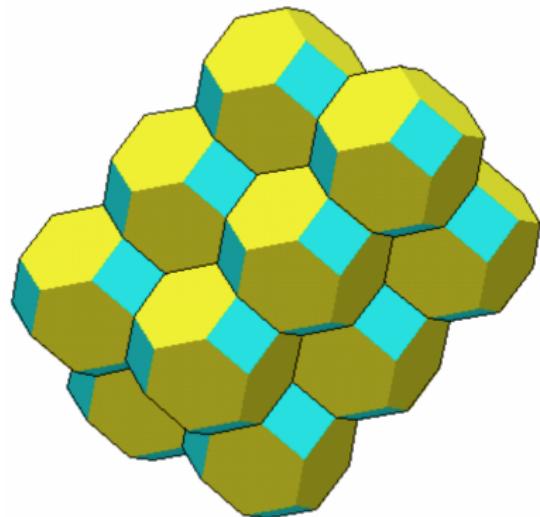
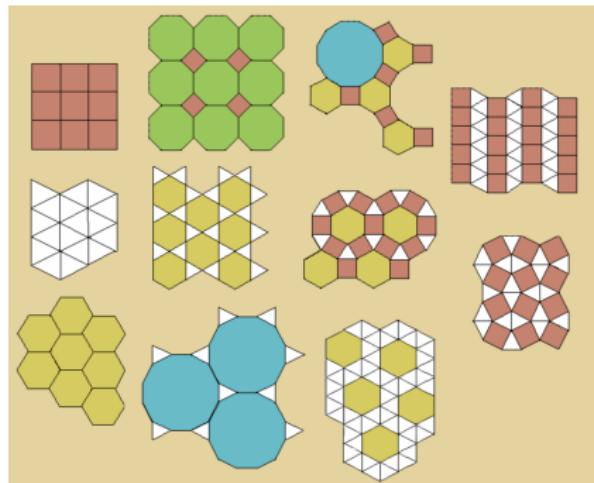
cons

- lots of parts to get good resolution
- not affine invariant

Voxelish Alternatives

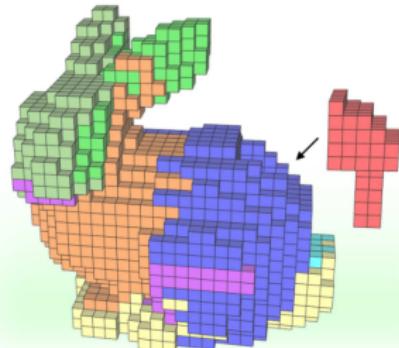
18

- octtree of power of 4 sized voxels
- tetrahedron
- other space tiling solids



in Tiling Space with Regular and Semi-regular Polyhedra

- interlocking voxel-based puzzle
- always interlocking puzzle
- only one assembly order



Recursive Interlocking Puzzles

Peng Song

Nanyang Technological University

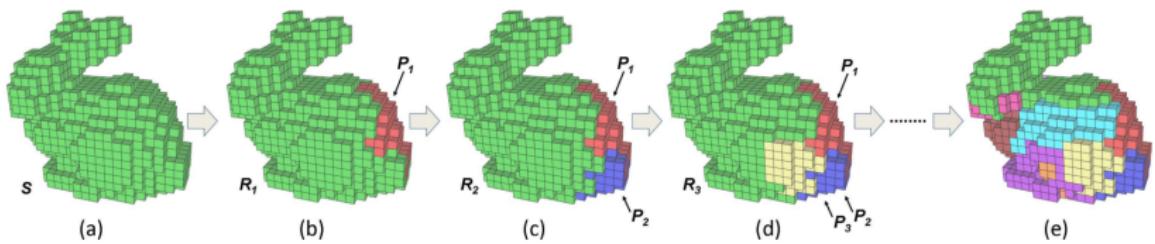
Chi-Wing Fu

Daniel Cohen-Or

Tel Aviv University

Recursive Interlocking Puzzles Steps

20



- break solids into parts using binary space partitioning (BSP)
- search for best decomposition using beam search

Chopper: Partitioning Models into 3D-Printable Parts

Linjie Luo^{1,2}

¹Princeton University

Ilya Baran³

²Disney Research

Szymon Rusinkiewicz¹

³Disney Research Zurich

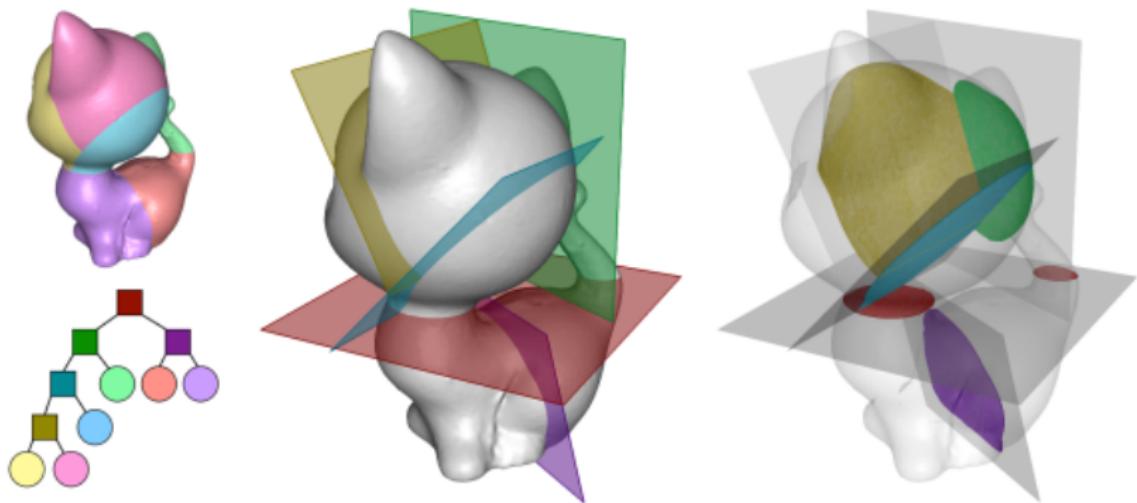
Wojciech Matusik⁴

⁴MIT CSAIL



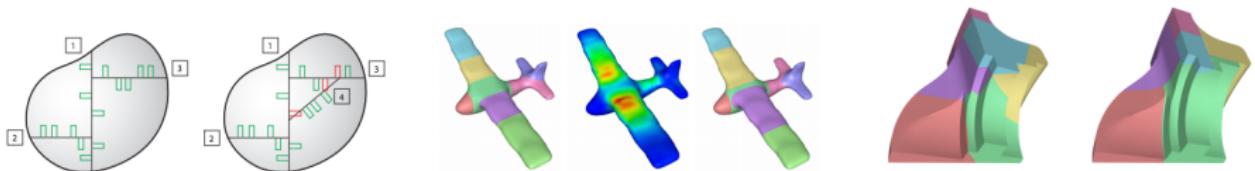
Chopper BSP

22



linear combination of

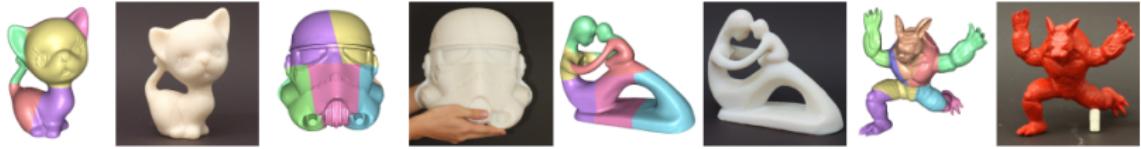
- number of parts
- connector feasibility
- structural soundness
- seam unobtrusiveness



- breadth first search of BSPs
- maintain certain number BSPs
- keep expanding best candidates

Chopper Results

25





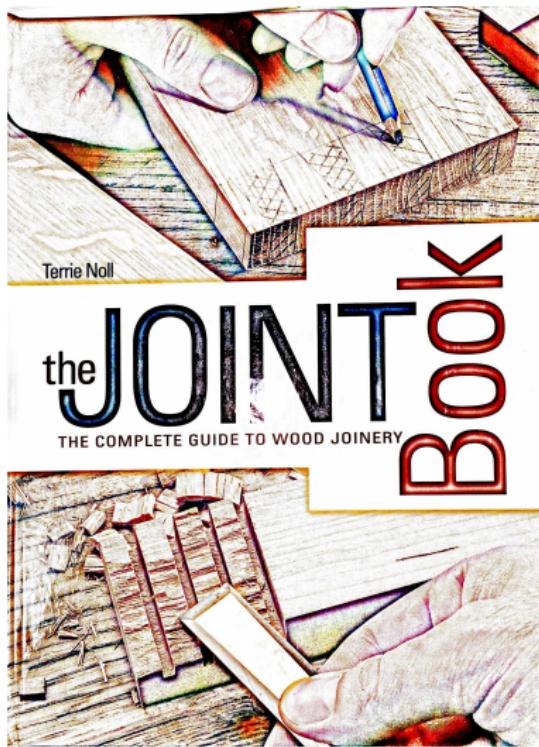
- simple connectors for simple parts
- seams for bending part

Shinobu Kobayahsi

- 1 D
- 2 D
- 2.5 D
- 3 axis
- 3 D

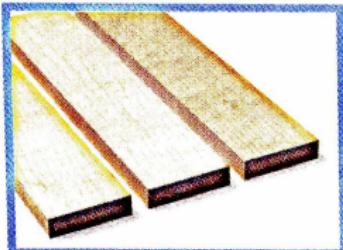
- unobtrusive / fidelity
- beautfy
- strength
- simplicity
- cost
- number of parts
- fool proof assembly
- reassembly
- reconfiguration
- hardware
- alignment

- introduction to 3D Joinery

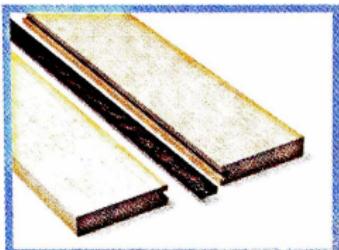


Edge and Scarf Joints

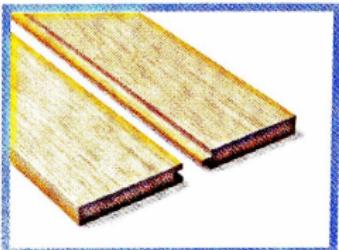
31



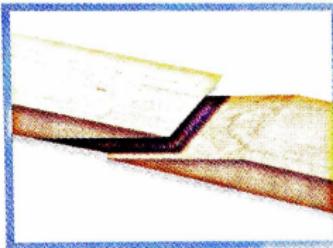
**Plain butt
glue joint**



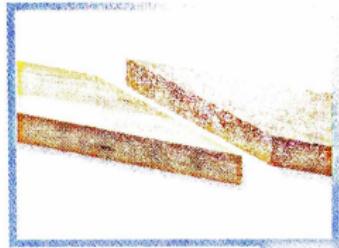
Splined joint



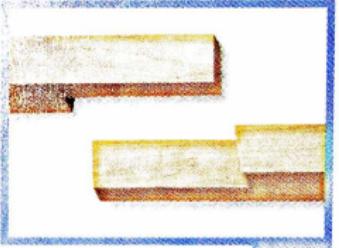
**Tongue and
groove**



**End-to-end
scarf**



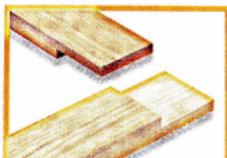
**Edge-to-edge
scarf**



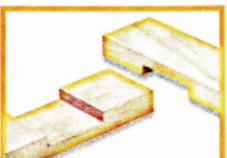
**Squint butted
scarf**

Lapped and Housed Joints

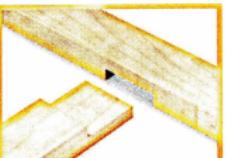
32



End lap



Center lap

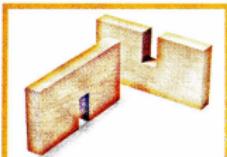


Angled T-lap

page
45

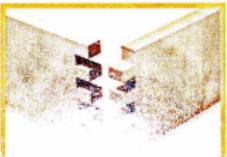
page
48

page
51



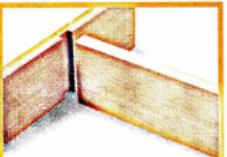
**Jigged edge
lap**

page
53



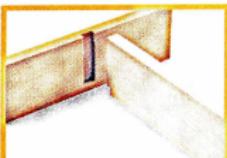
**Box joint
on the table saw**

page
55



**Full housing
by hand**

page
60



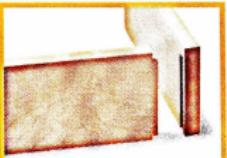
**Full housing on
the table saw**

page
62



**Routed housed
rabbet**

page
64

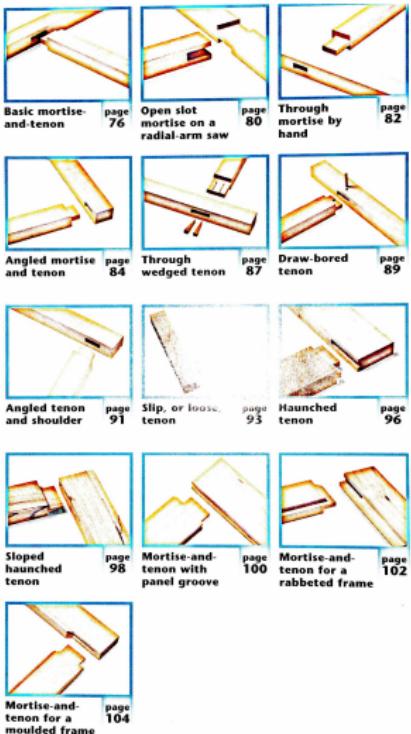


**Stop-routed
housed rabbet**

page
66

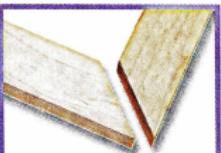
Mortise and Tenon Joints

33

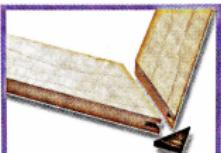


Miters and Bevels Joints

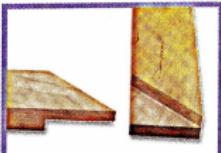
34



Frame miter
by hand

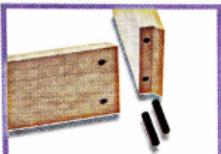


Feathered
miter on a
radial-arm saw

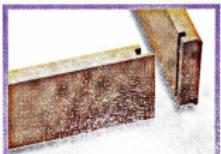


Lap miter

page
116

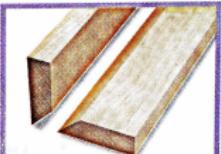


Housed rabbet
miter



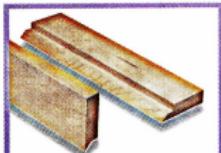
Locked miter

page
120



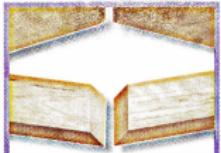
Waterfall joint

page
122



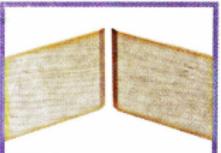
Rabbet miter

page
124



Compound
miter by
machine

page
126

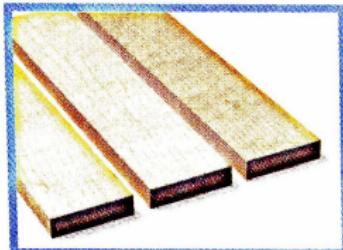


Compound
miter by hand

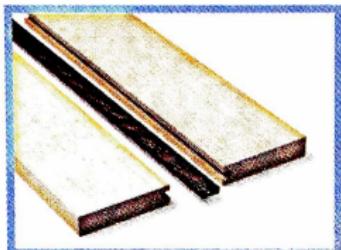
page
128

Dovetail Joints

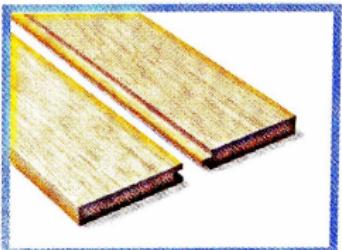
35



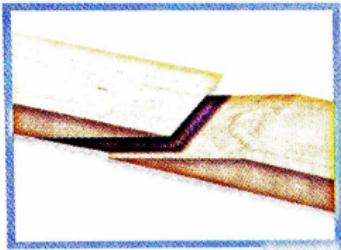
**Plain butt
glue joint**



Splined joint



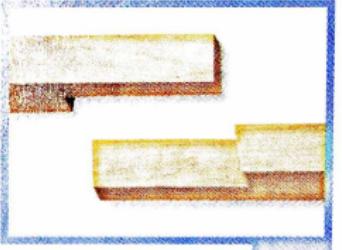
**Tongue and
groove**



**End-to-end
scarf**



**Edge-to-edge
scarf**



**Squint butted
scarf**

page
26

page
29

page
31

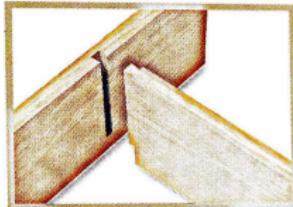
page
34

page
36

page
38

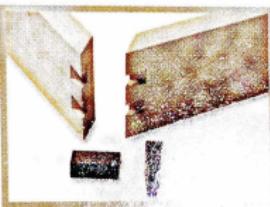
Dovetail and Key Joints

36



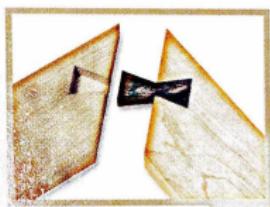
**Sliding
dovetail
drawer joint**

page
144



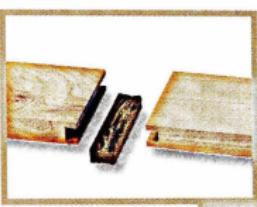
Dovetail keys

page
146



Butterfly keys

page
148



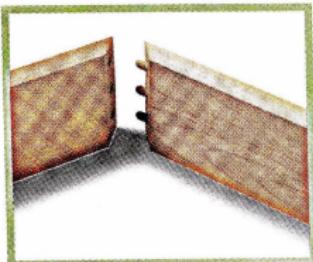
**Dovetail
splines**

page
150

The Joint Book

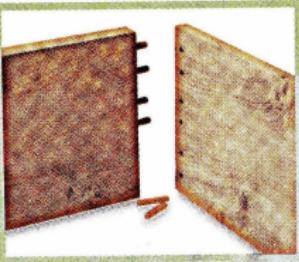
Dowel and Biscuit Joints

37



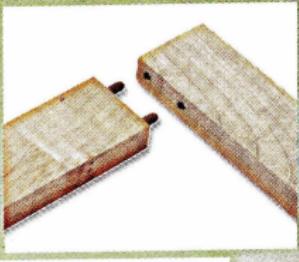
**Reinforced
width miter**

page
158



**Moulded-edge
carcass joint**

page
160



**Dowled
framing joint**

page
162



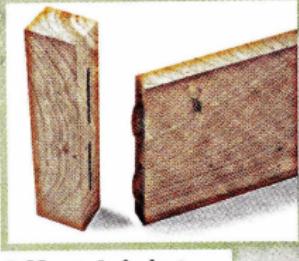
**Flush framing
joint**

page
166



**Biscuated T
orientation**

page
168



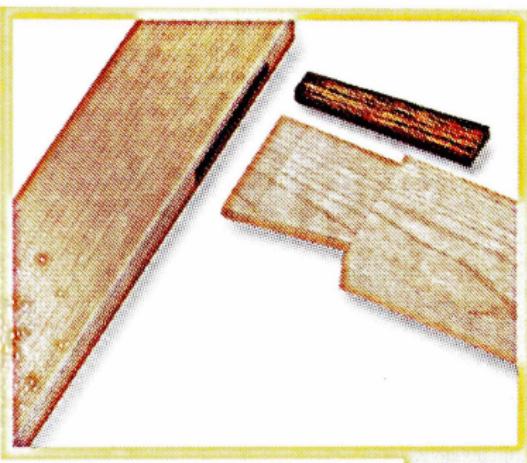
Offset L joint

page
170



Keyed tenon

page
178



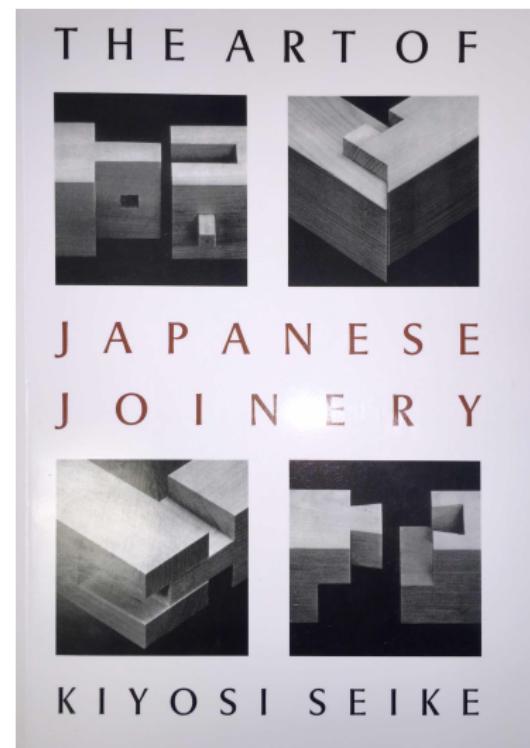
**Half-dovetail
tenon**

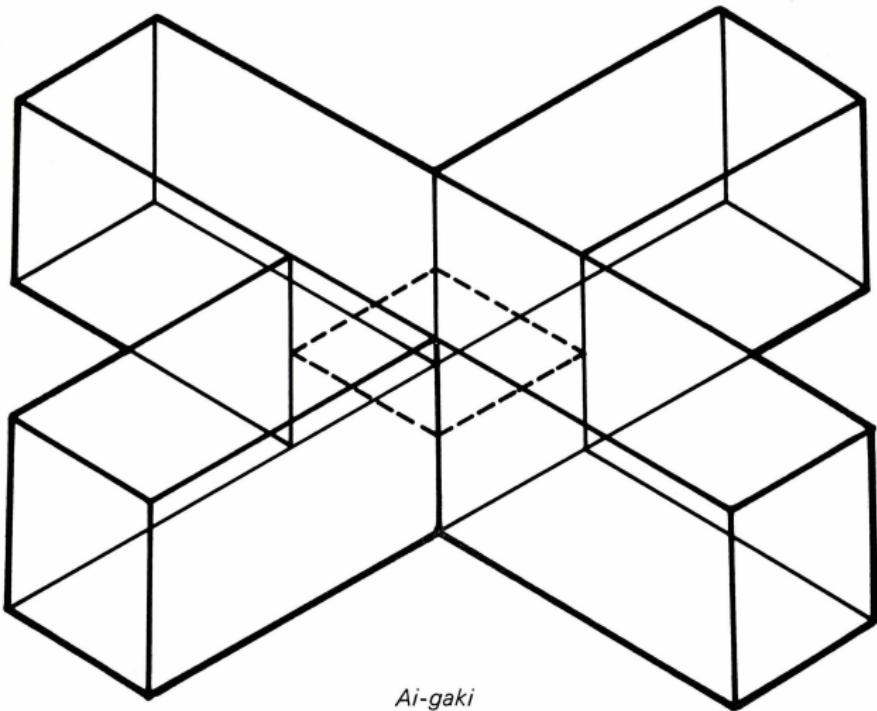
page
180

Log Cabin

40

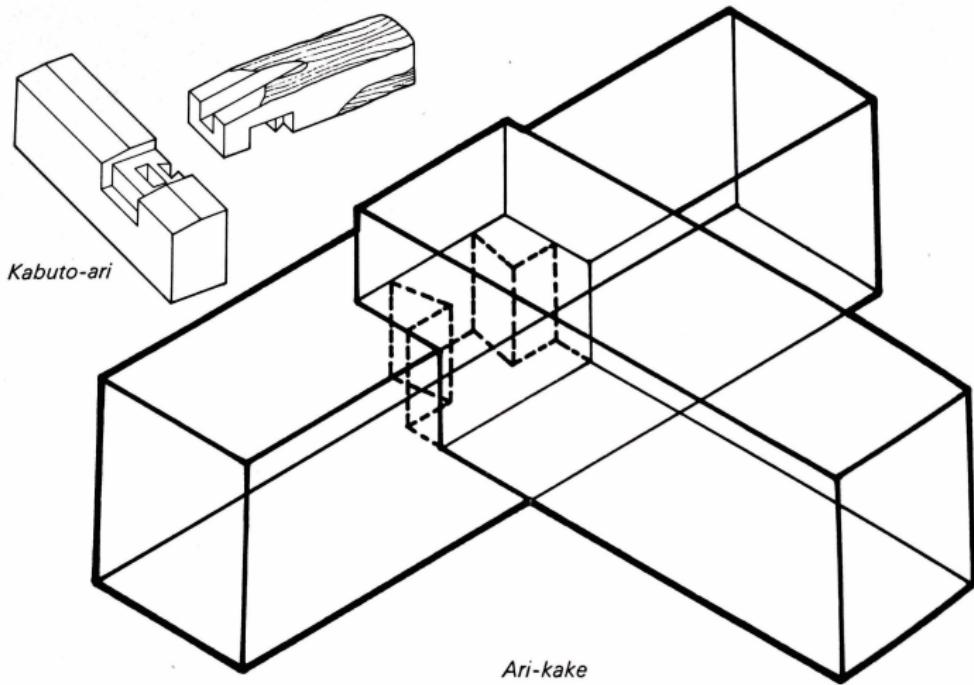


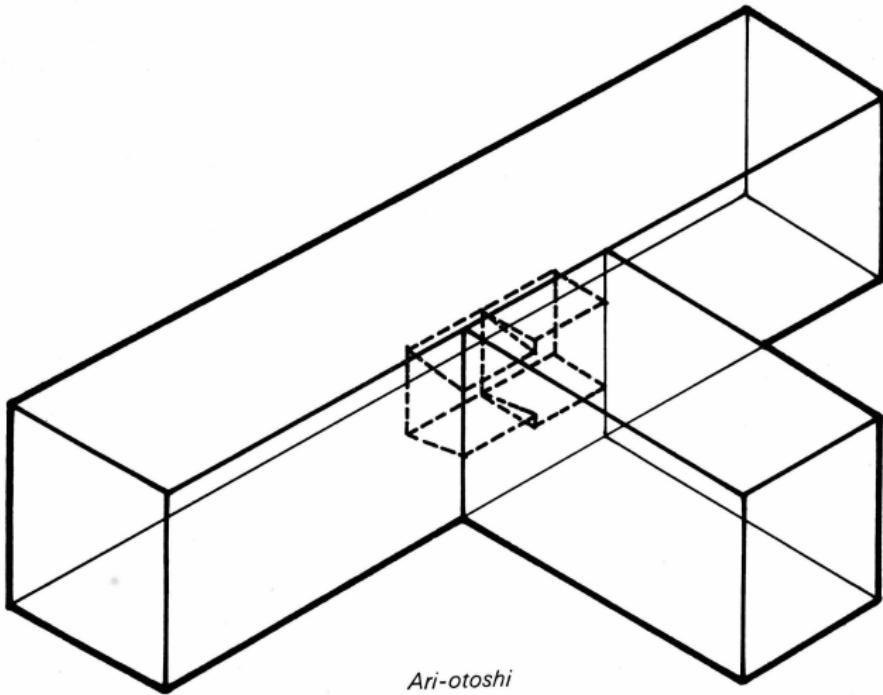




Ai-gaki

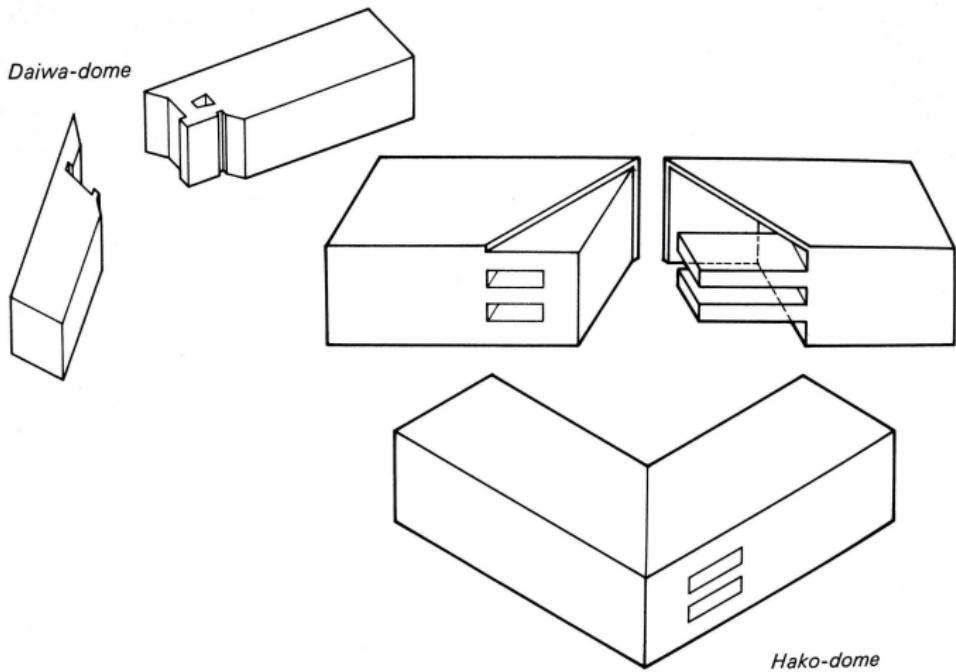
Japanese Joinery Book

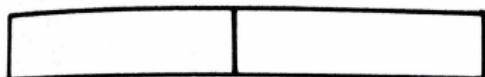




Ari-otoshi

Japanese Joinery Book

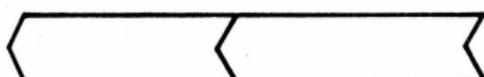




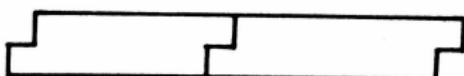
Straight Joint



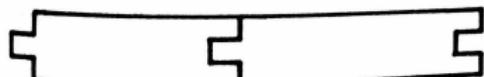
Scarf Joint



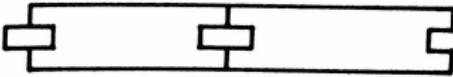
V-Groove or Bird's Mouth Joint



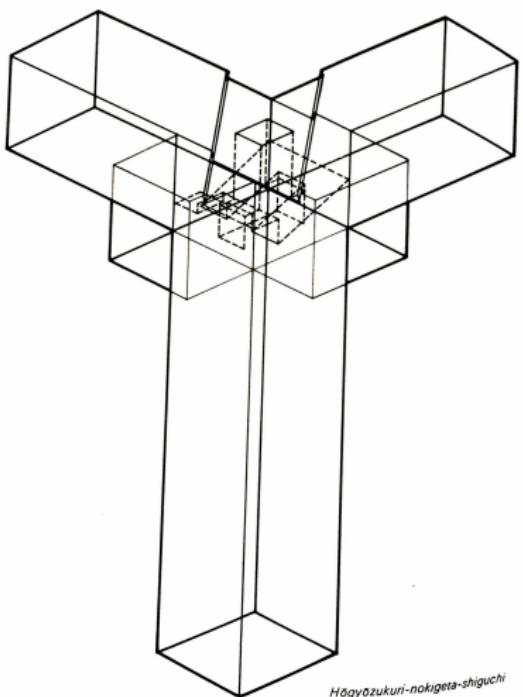
Shiplap Joint



Tongue and Groove Joint

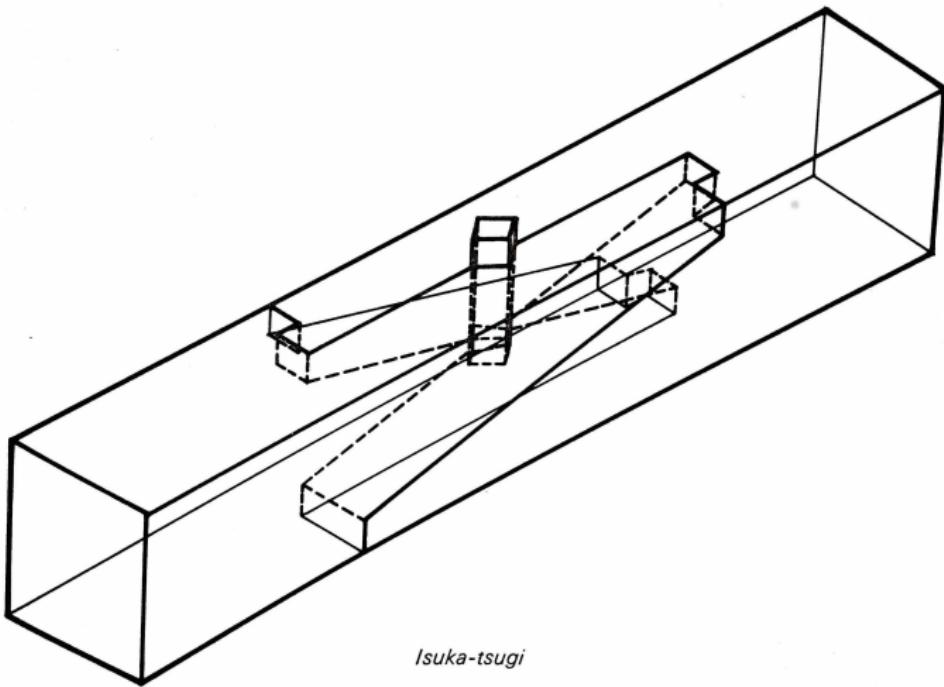


Splined Joint



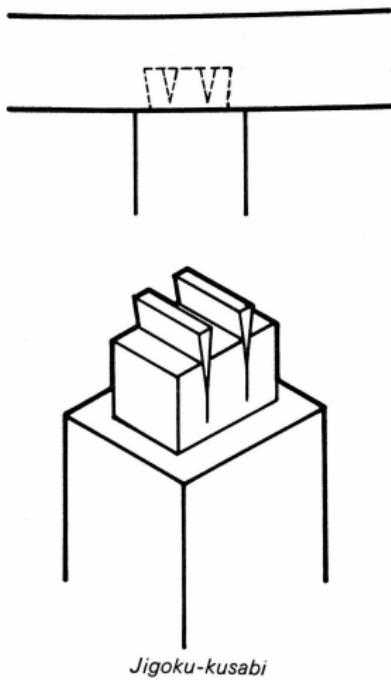
Hogyozukuri-nokigeta-shiguchi

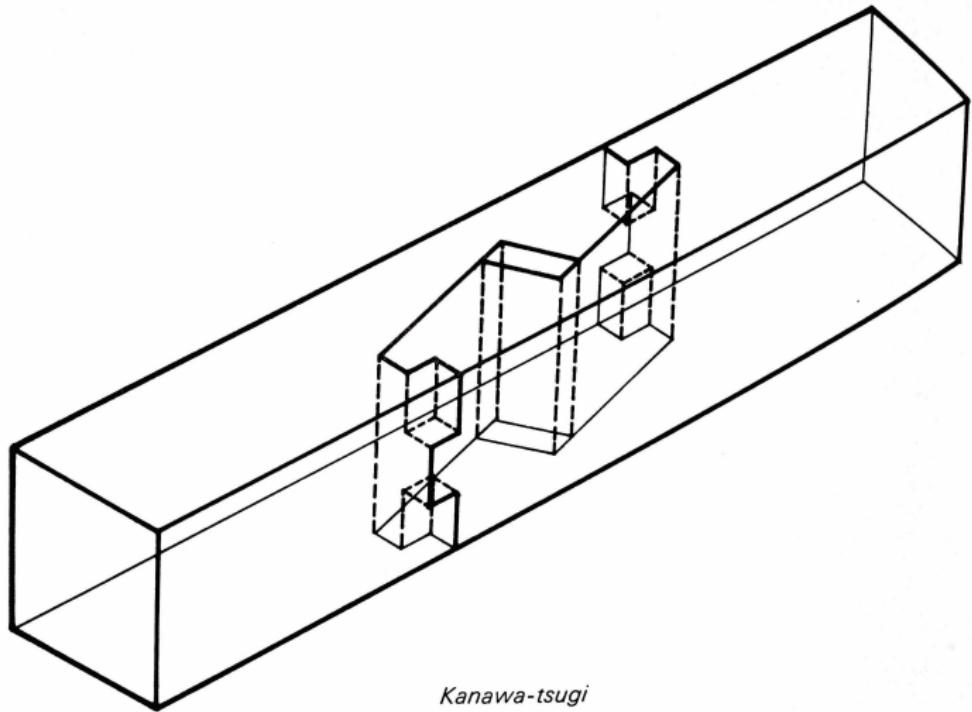
Japanese Joinery Book



Isuka-tsugi

Japanese Joinery Book

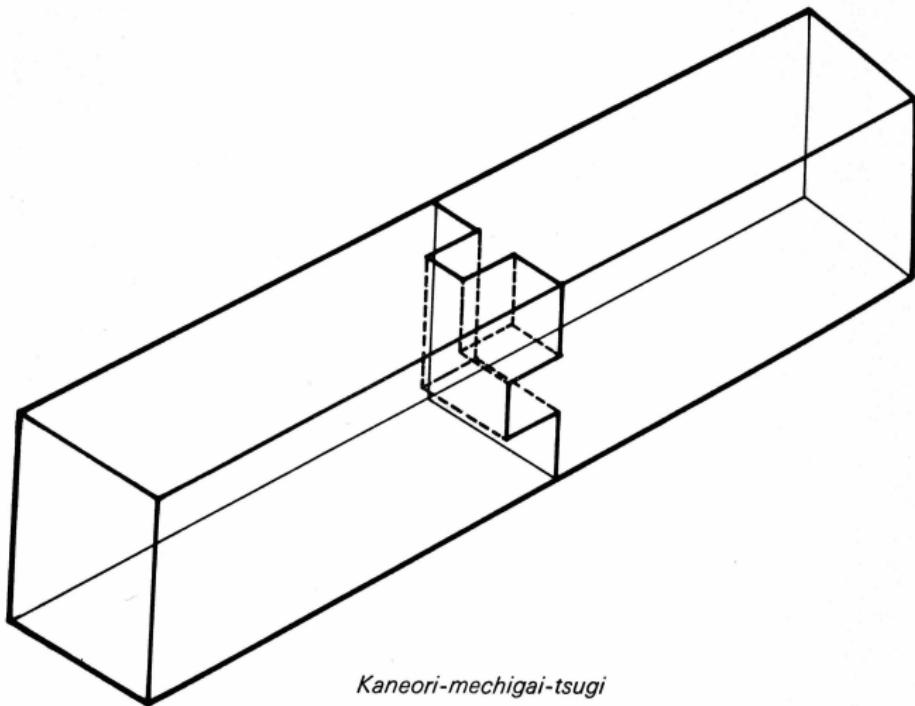




Kanawa-tsugi

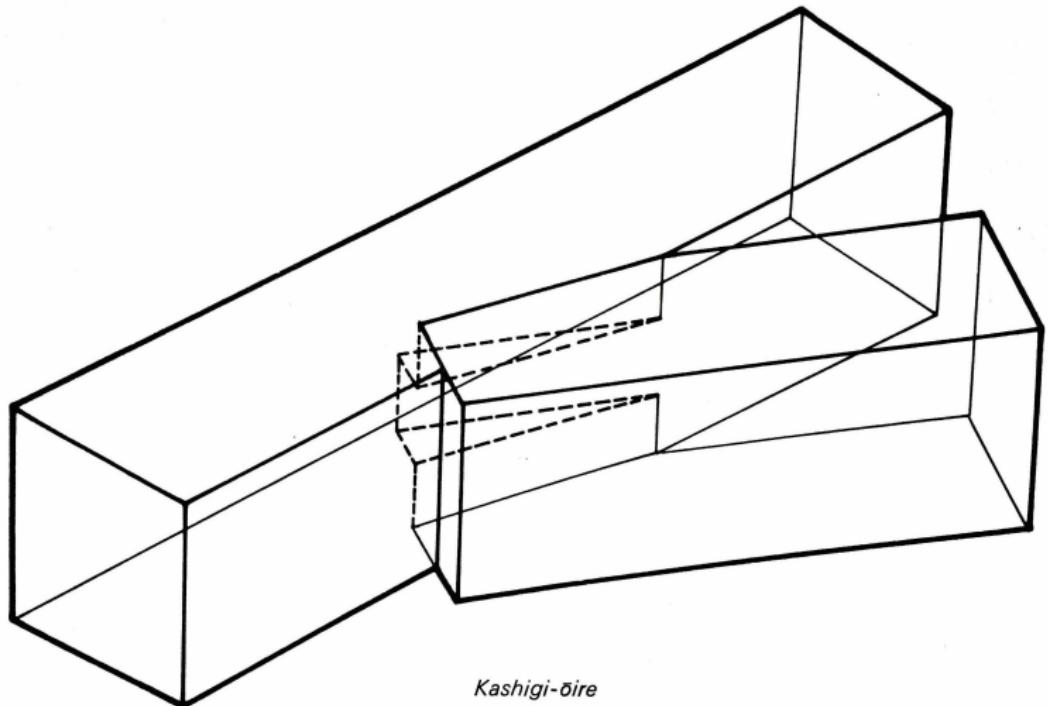
Japanese Joinery Book

© 2007, 2011.



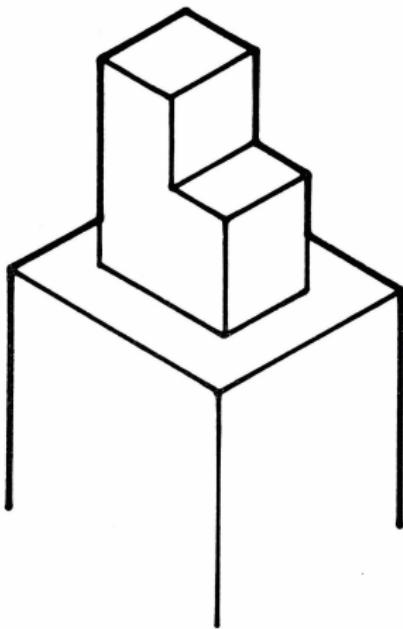
Kaneori-mechigai-tsugi

Japanese Joinery Book



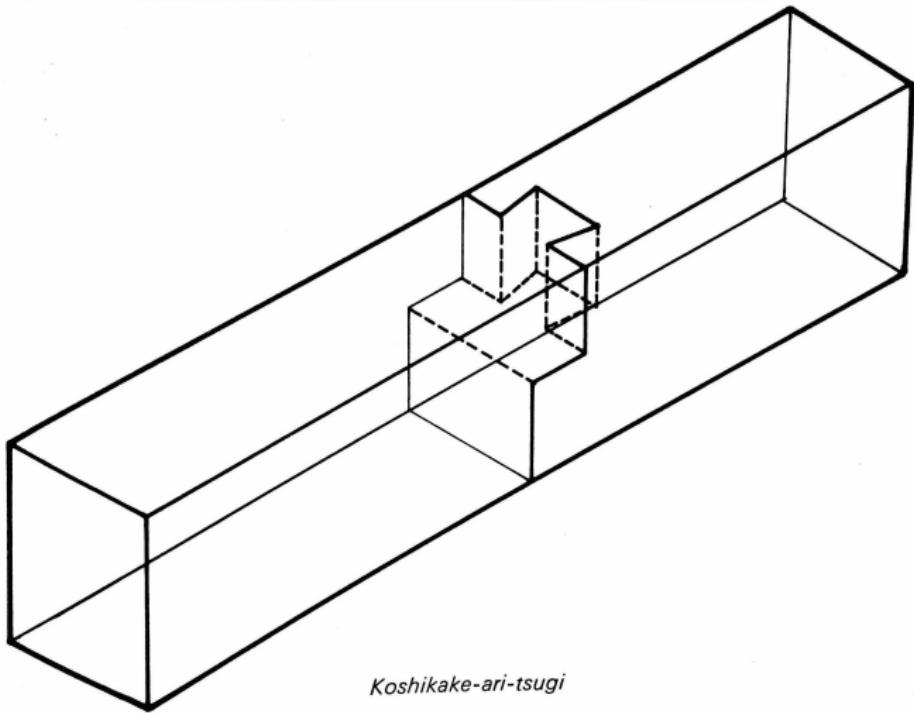
Kashigi-ōire

Japanese Joinery Book

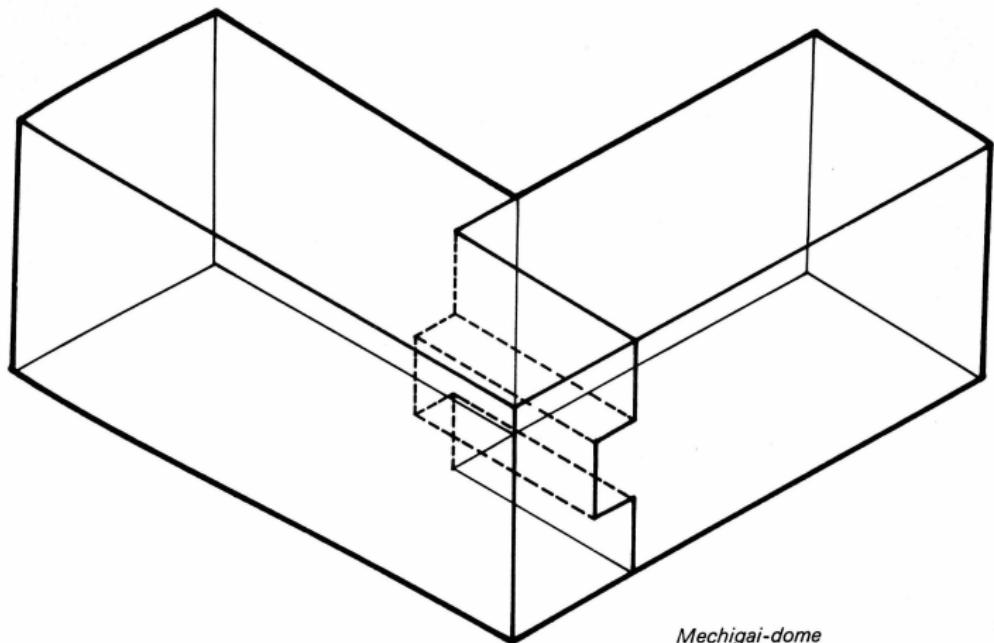


Kone-hozo Tenon

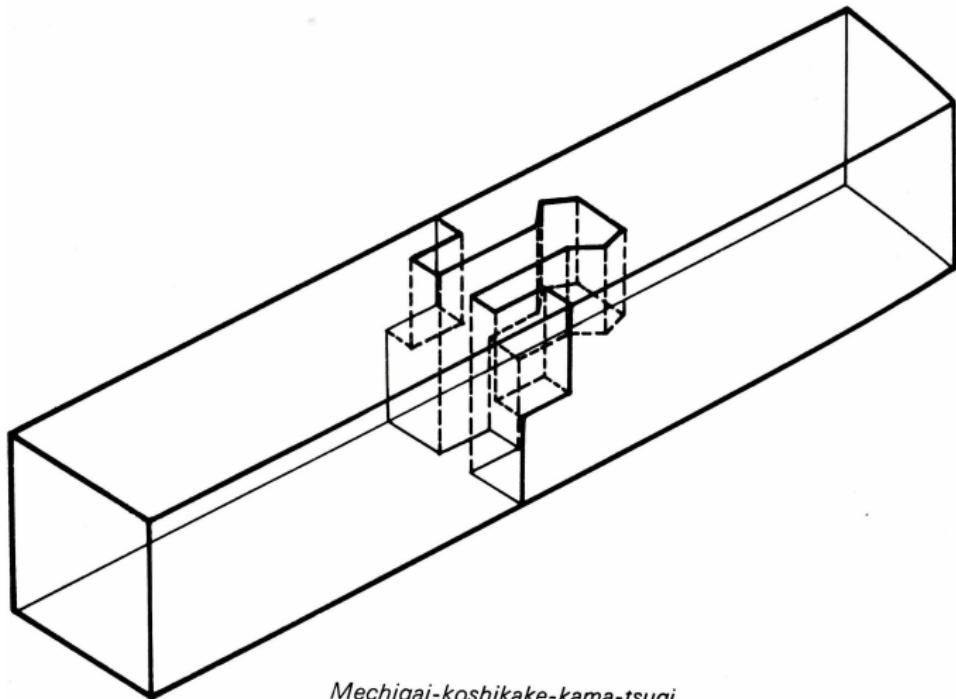
Japanese Joinery Book



Koshikake-ari-tsugi

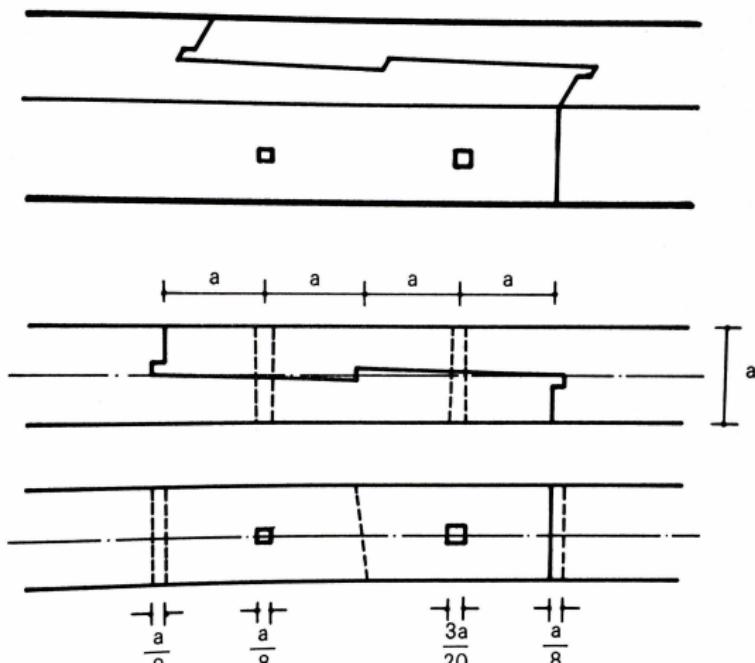


Mechigai-dome

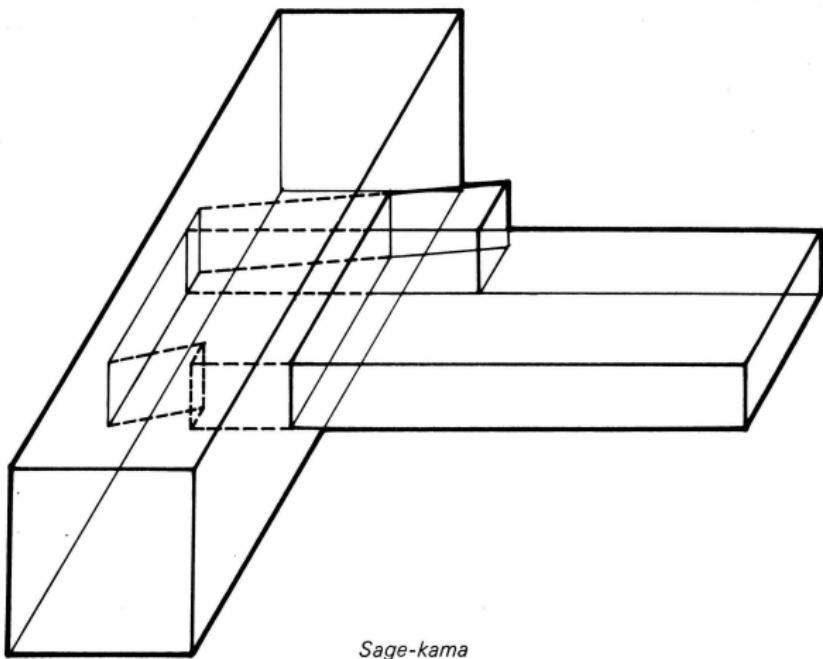


Mechigai-koshikake-kama-tsugi

Japanese Joinery Book

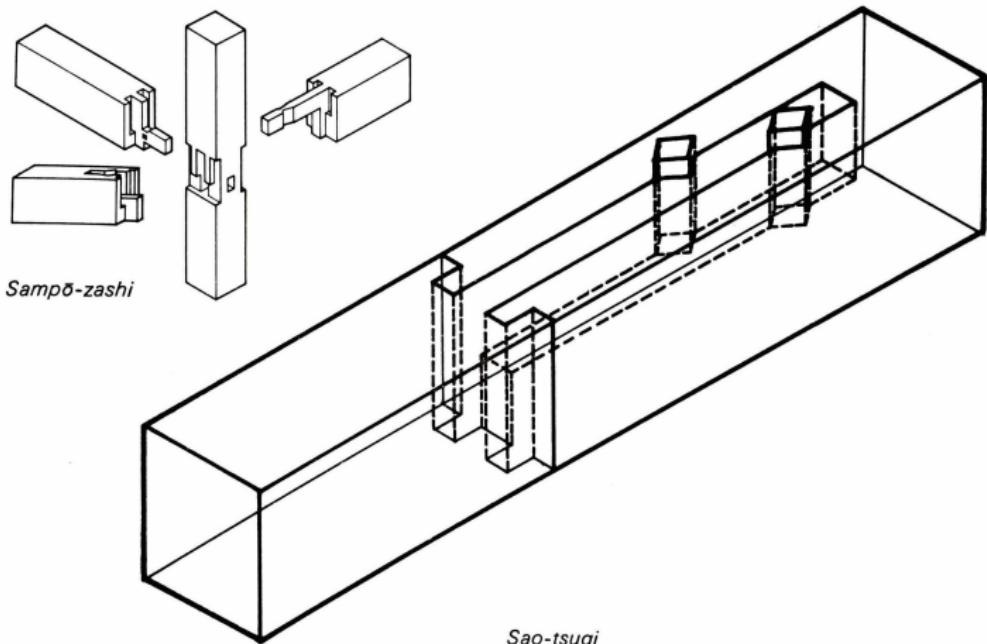


Okkake-daisen-tsugi

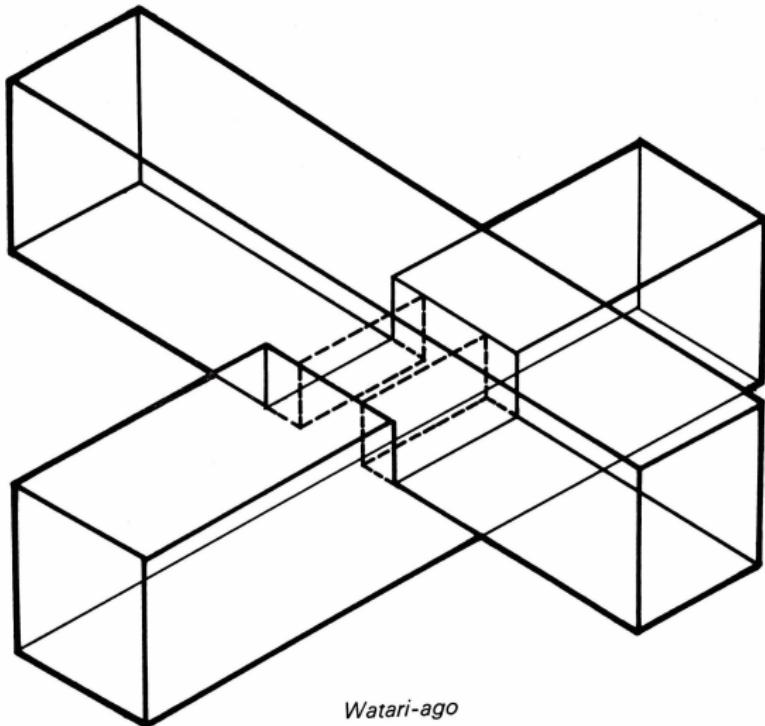


Sage-kama

Japanese Joinery Book



Japanese Joinery Book



Watari-ago

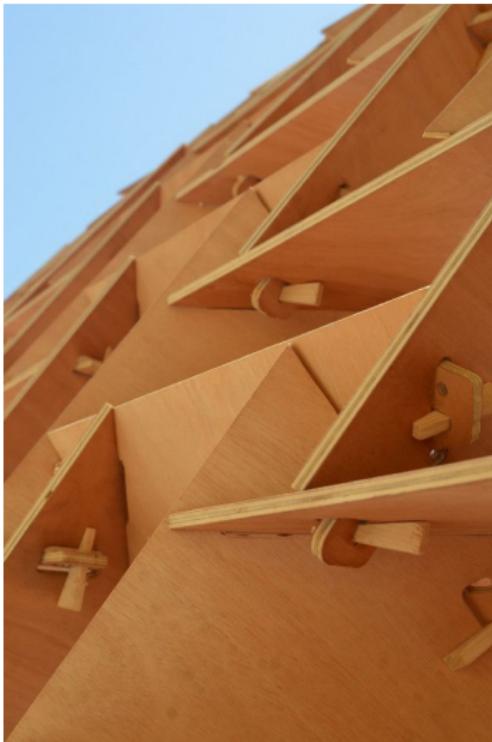
Japanese Joinery Book

Modern Kawai Tsugite

61

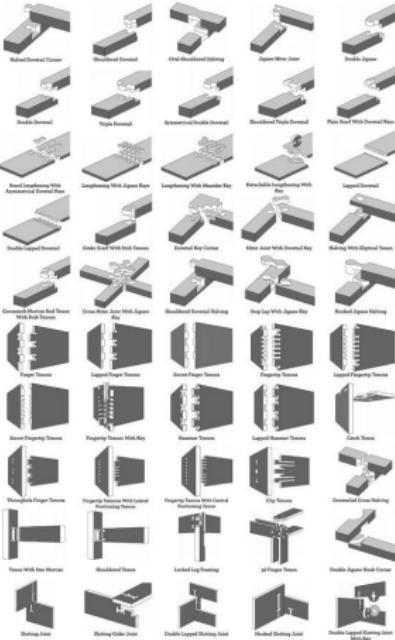


Shinobu Kobayahsi

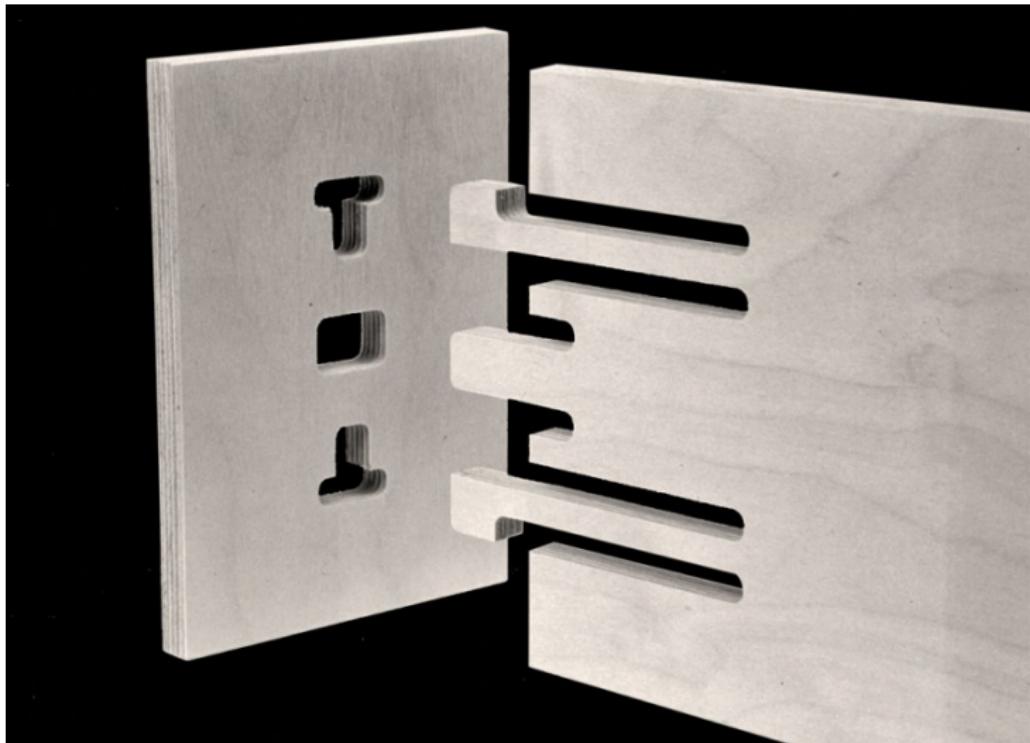


at Malta Design Week

50 DIGITAL JOINTS



Jochen Gros



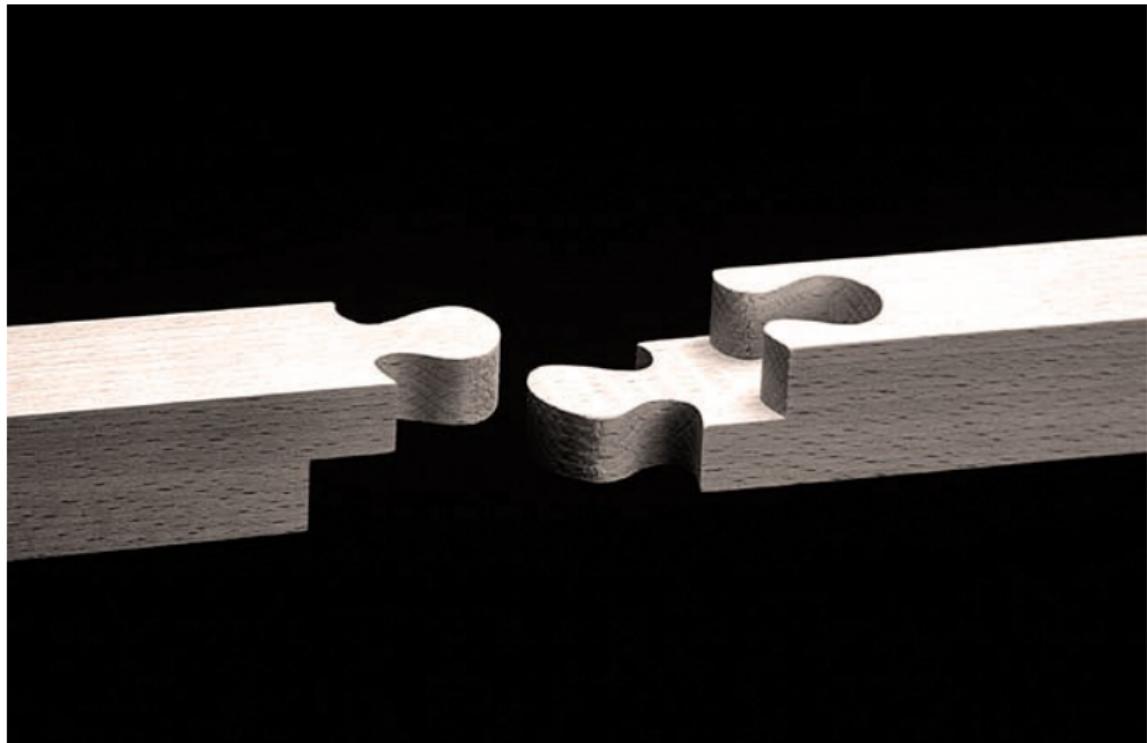
Jochen Gros



Jochen Gros

double jigsaw

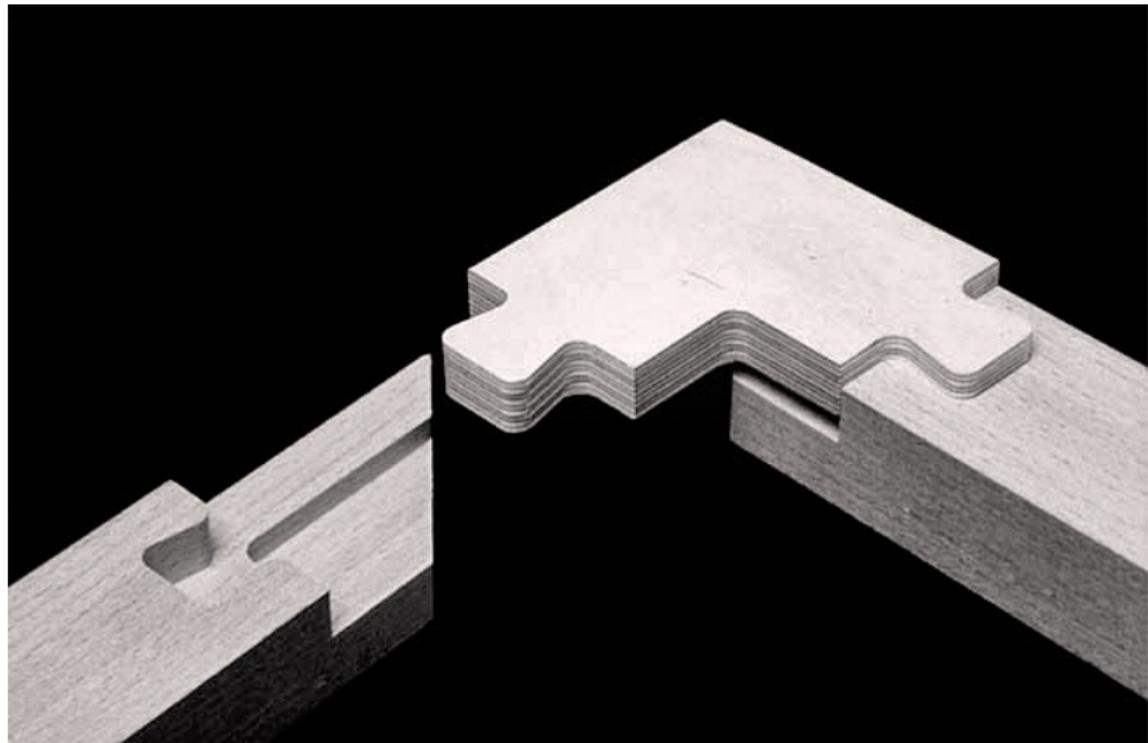
66



Jochen Gros

dovetail key corner

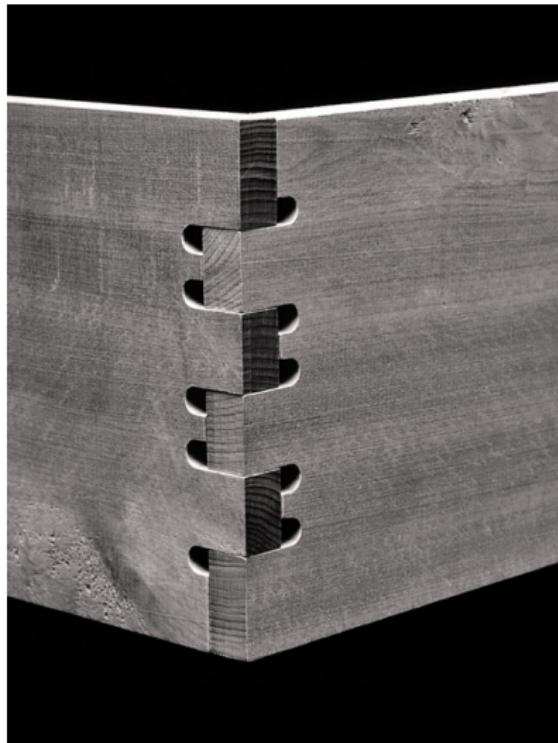
67



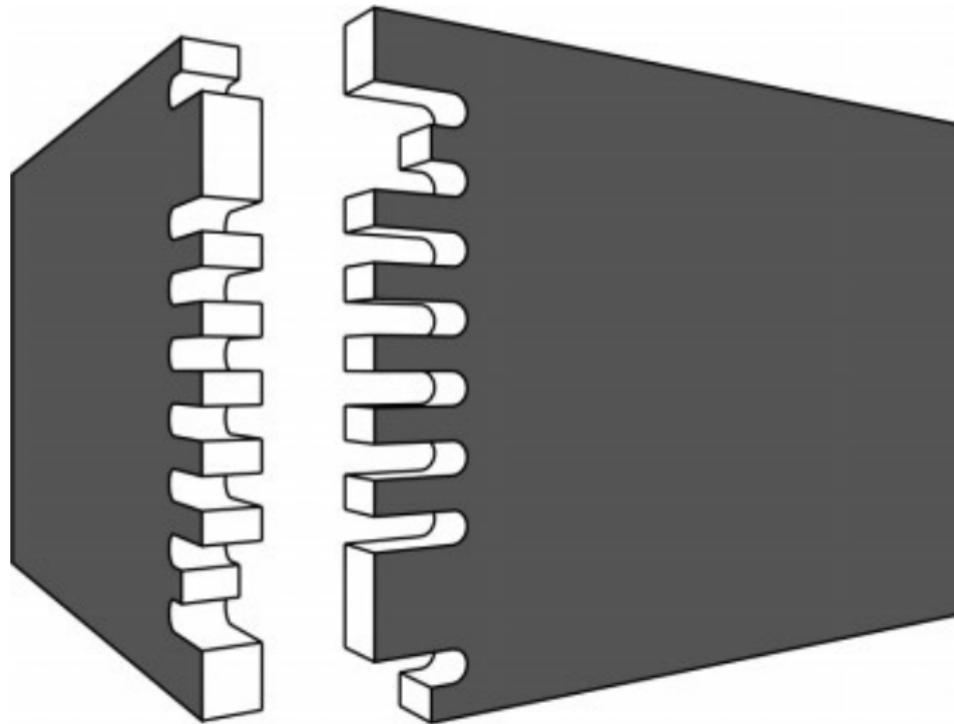
Jochen Gros

finger tenons

68

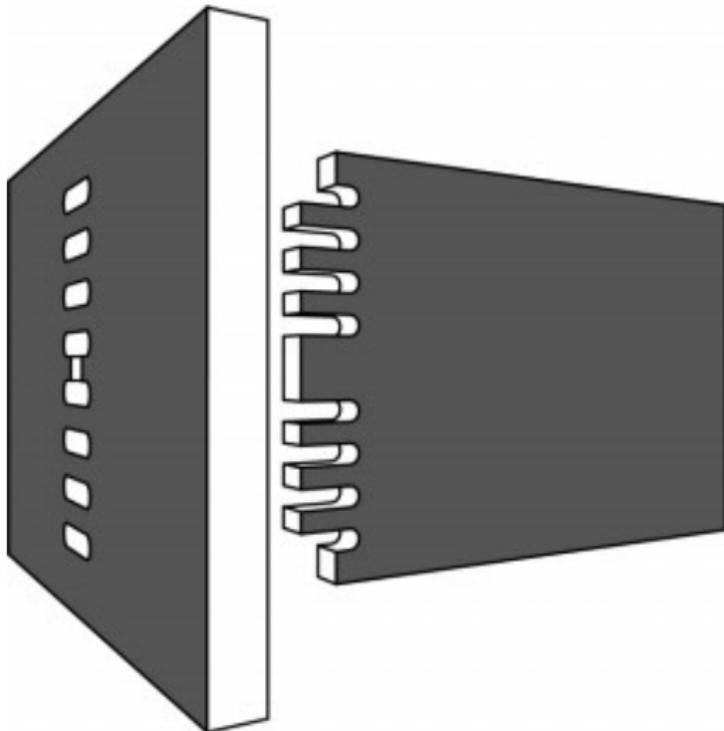


Jochen Gros



Jochen Gros

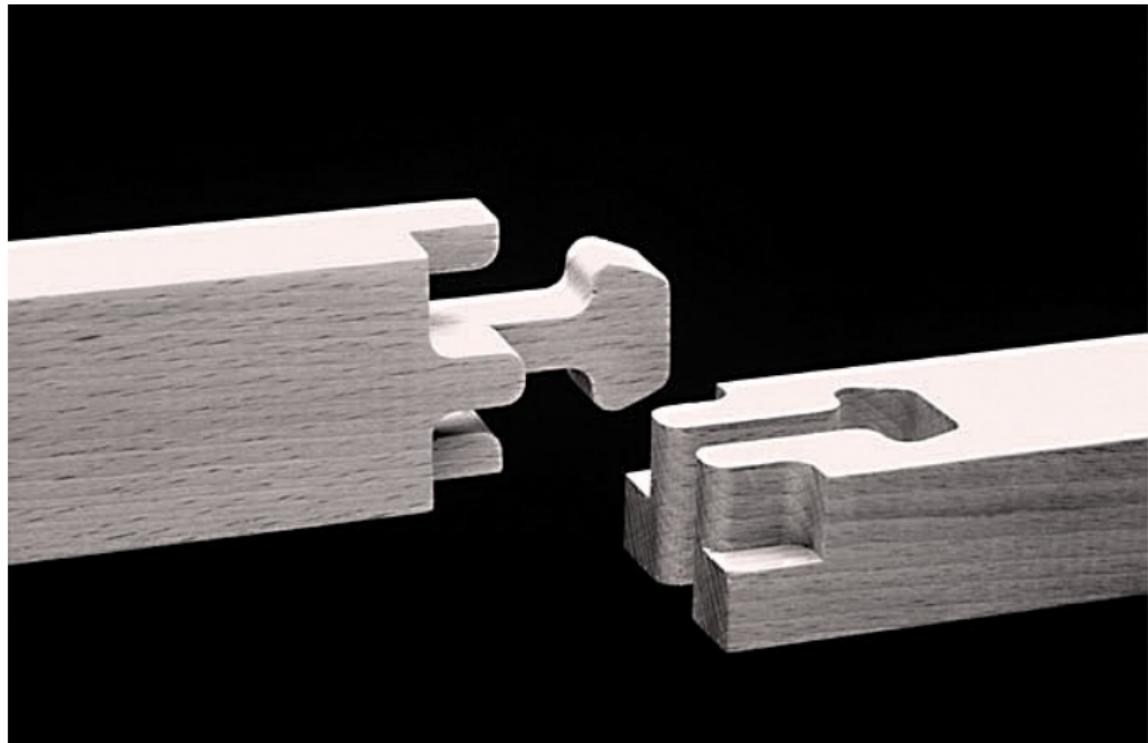
fingertip tenons with central positioning tenon 70



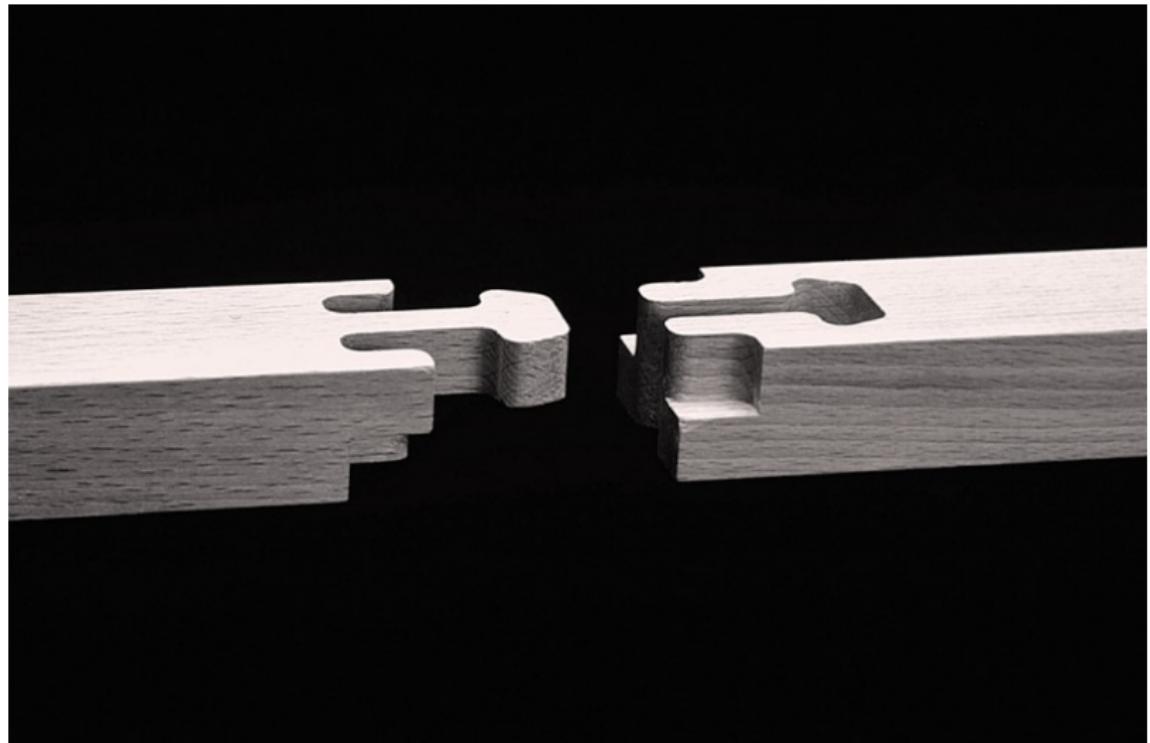
Jochen Gros

gooseneck-1

71



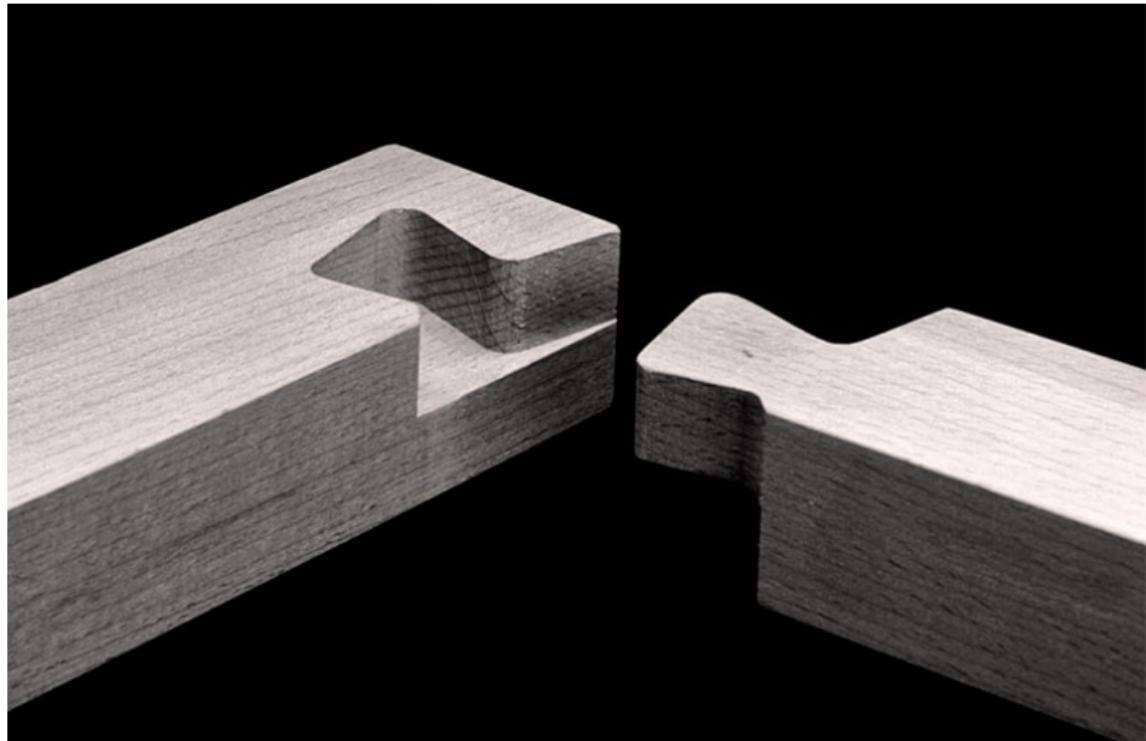
Jochen Gros



Jochen Gros

halved-dovetail-corner

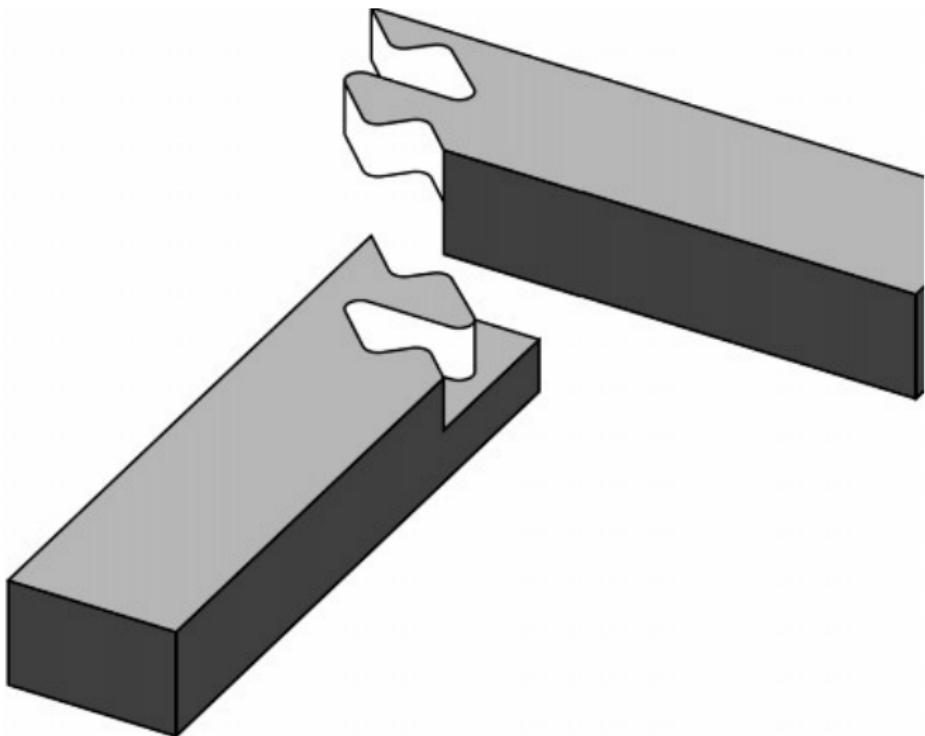
73



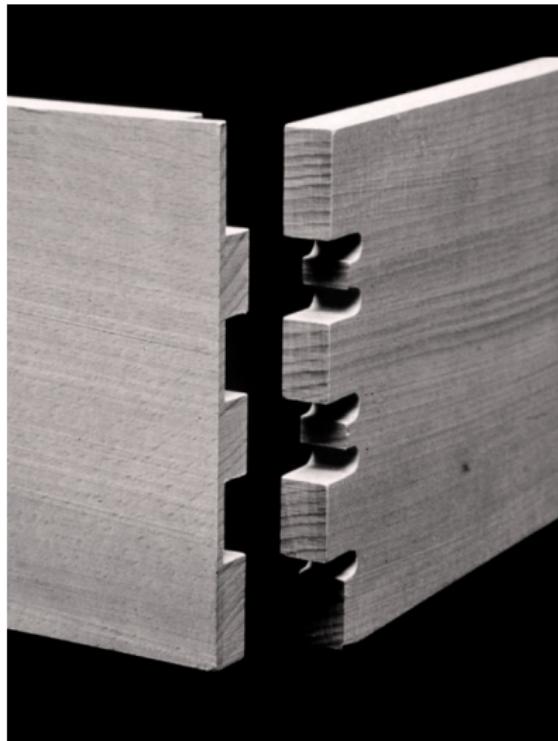
Jochen Gros

jigsaw mitre joint

74



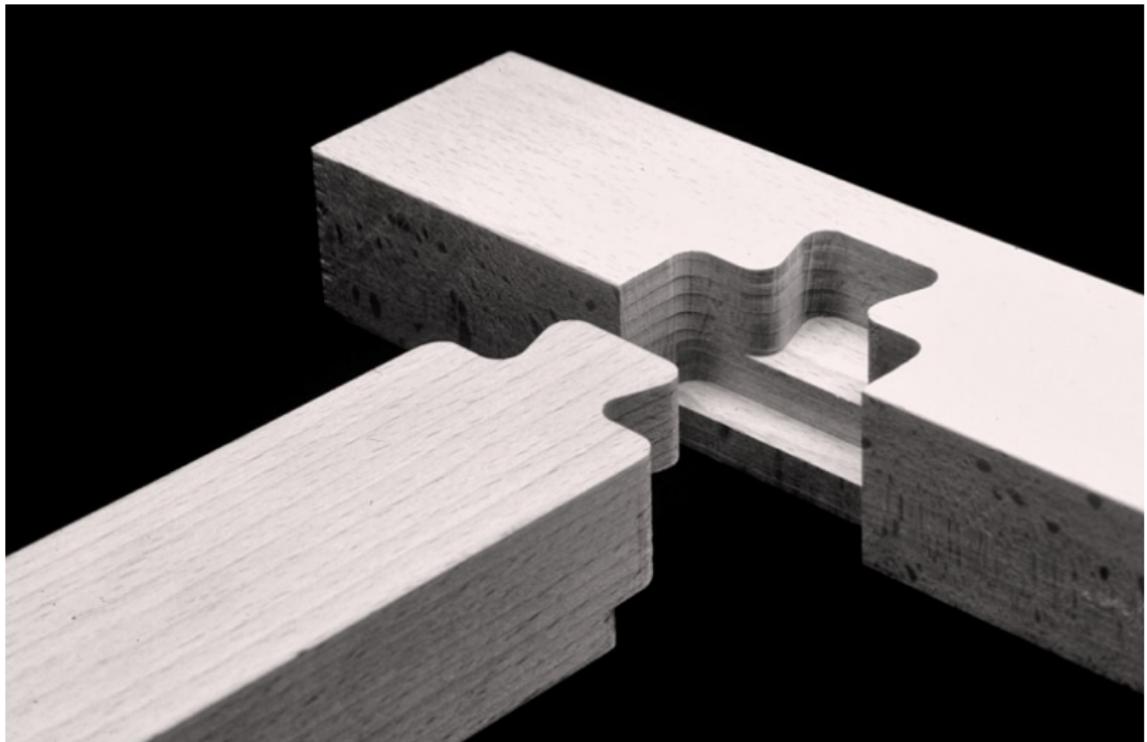
Jochen Gros



Jochen Gros

shouldered dovetail halving

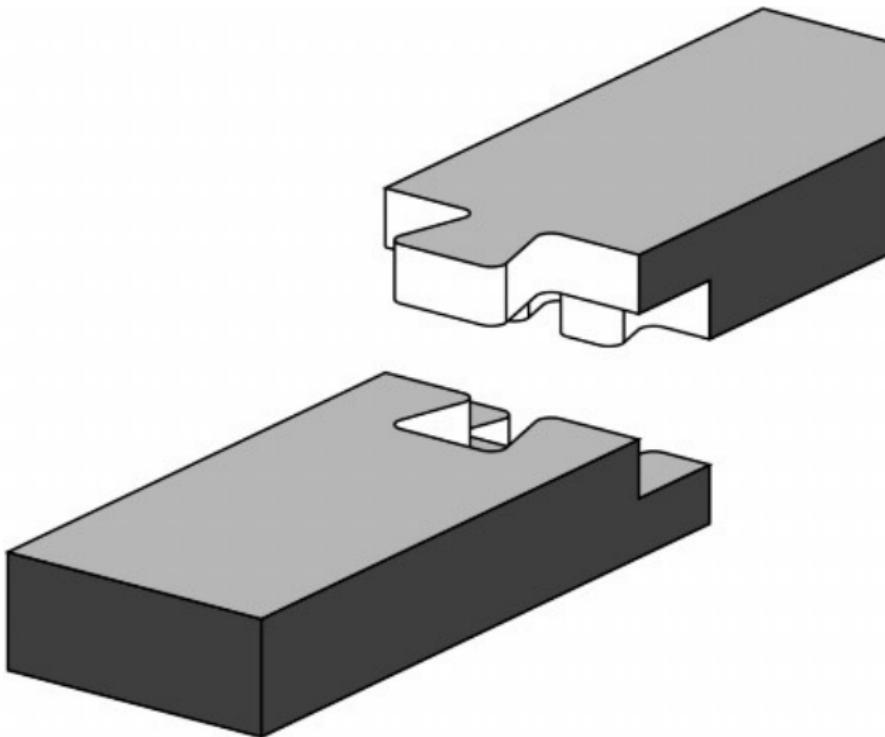
76



Jochen Gros

triple dovetail

77

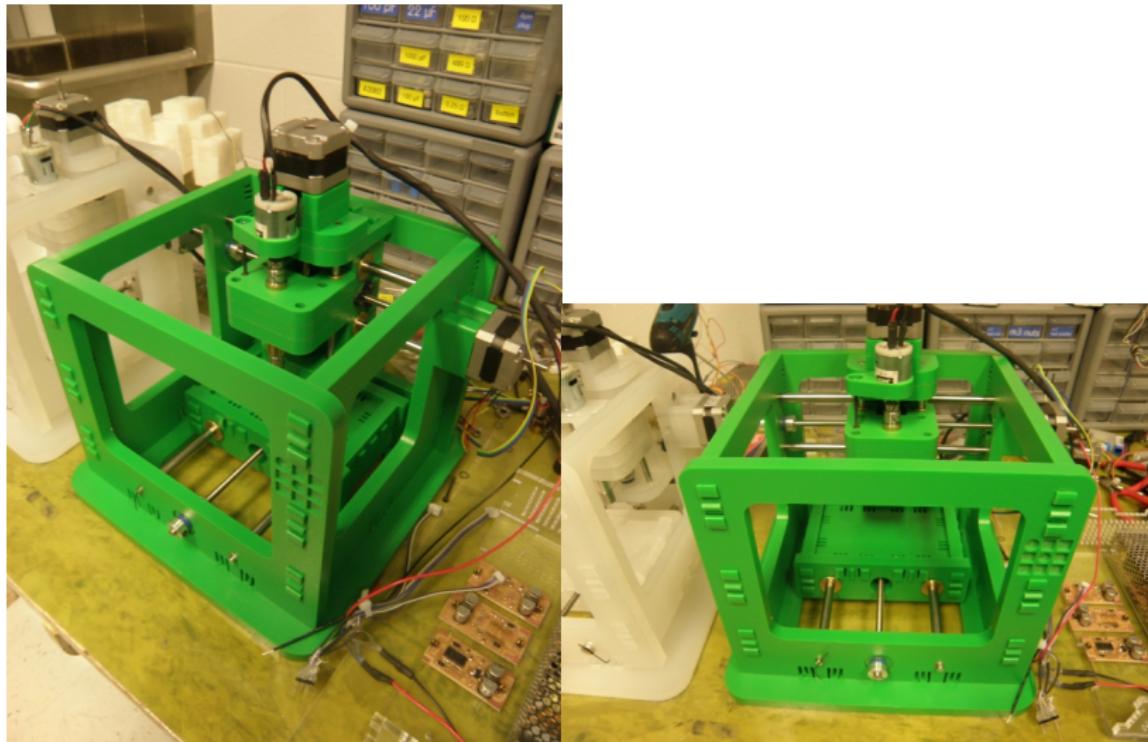


Jochen Gros

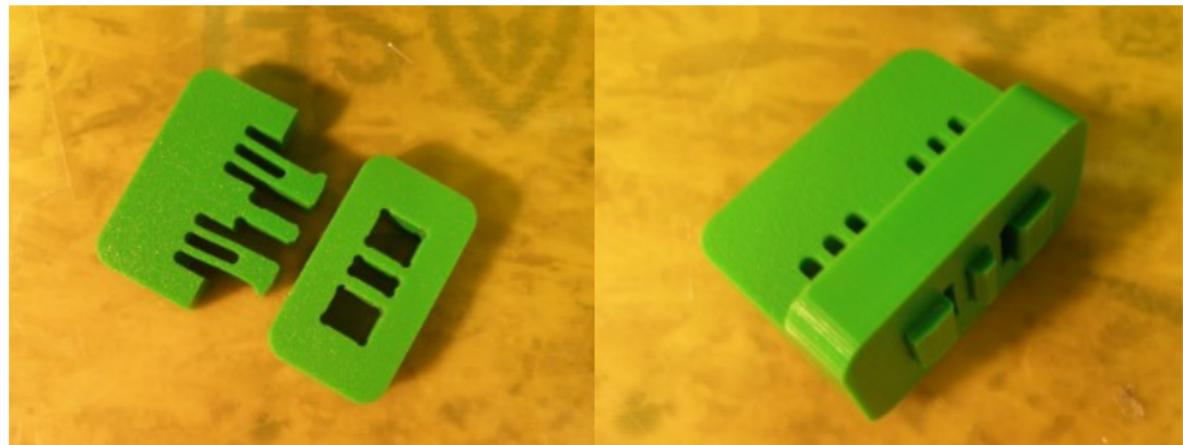


mtm snap based mill

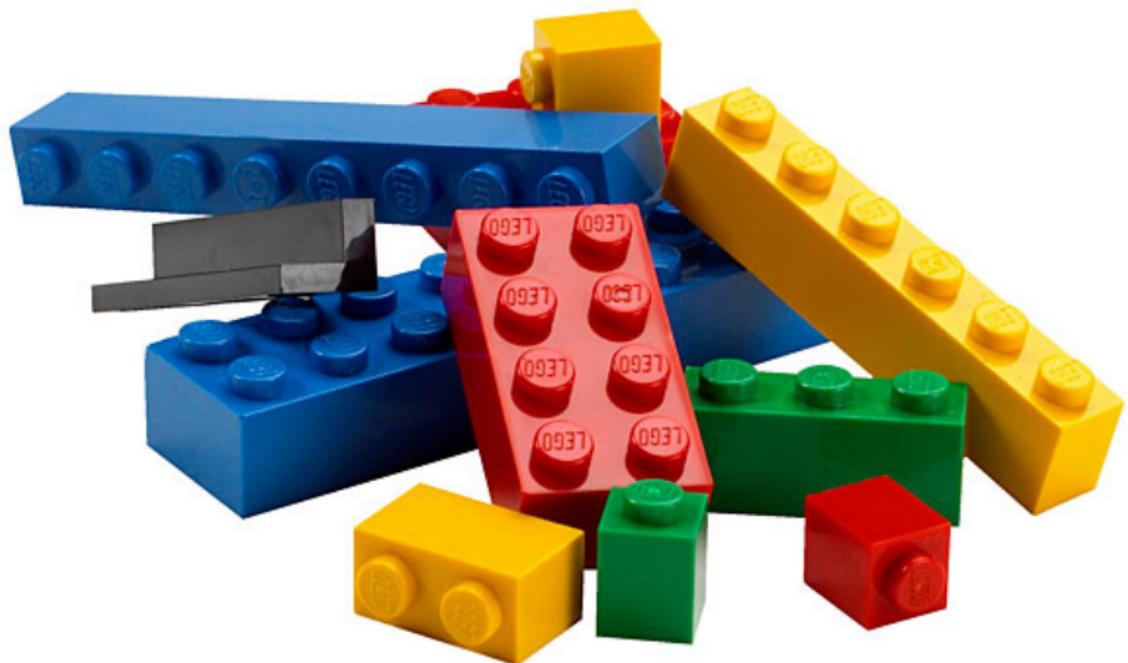
79



Jonathan Ward

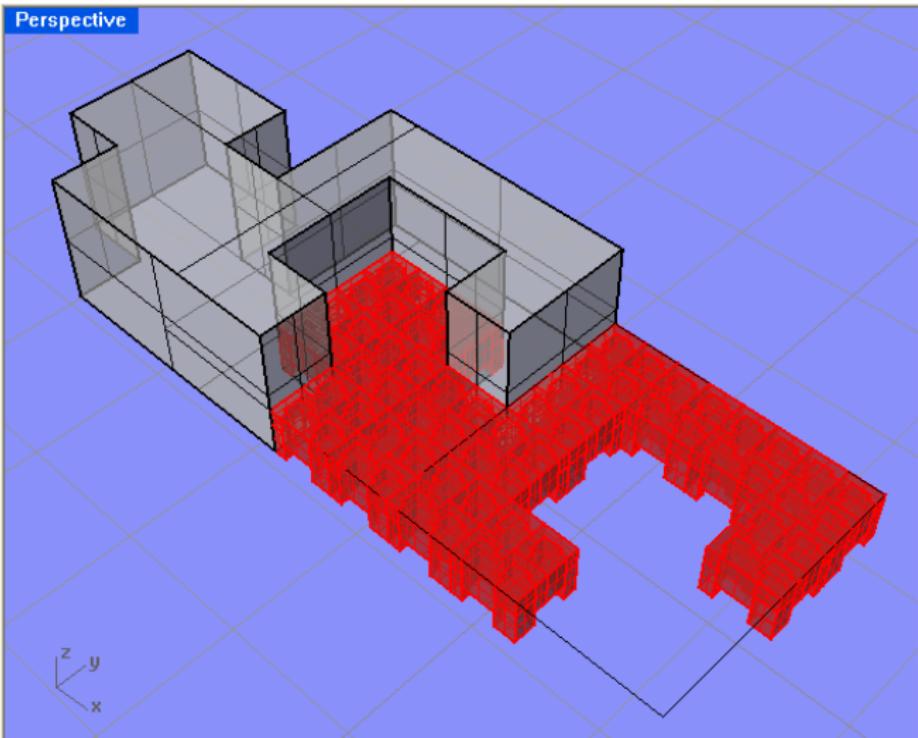


Jonathan Ward

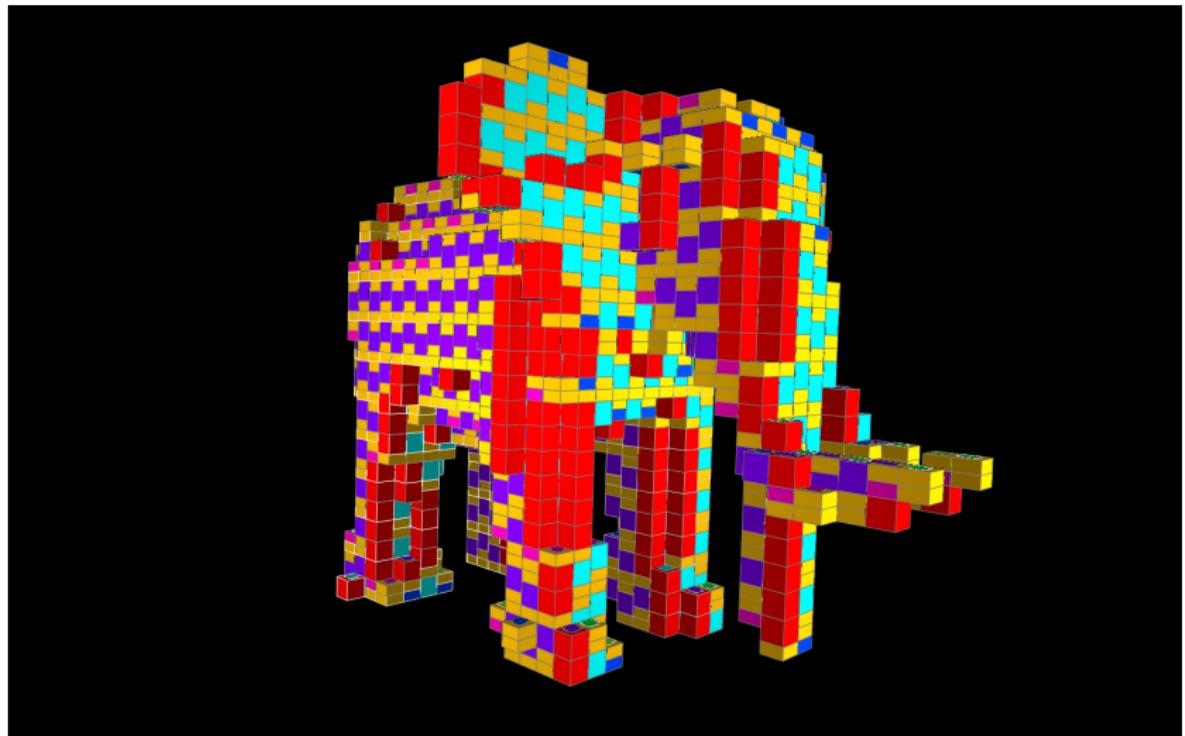


Better Lego

82



Jonathan Ward



Jonathan Ward

Universal Construction Kit

84



fffffat



by studio woolf

Modular Bench Joinery

86

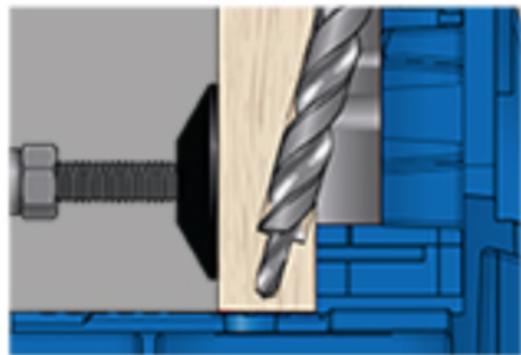


by spon0039

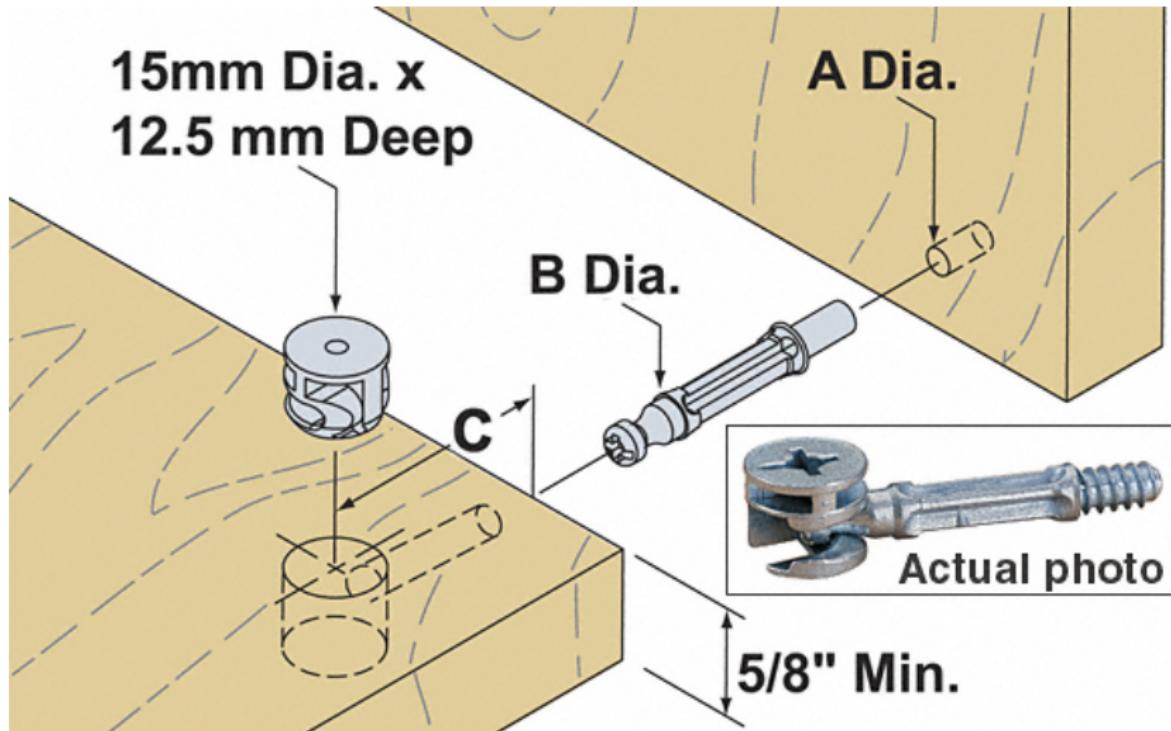


Keystones by Studio Minale-Maeda

- Incorporating alignment marks or something for the jig into a CNC routing process would be pretty great.
- So a novice just has to apply the jig, drill, screw.



KregTool



by Ikea

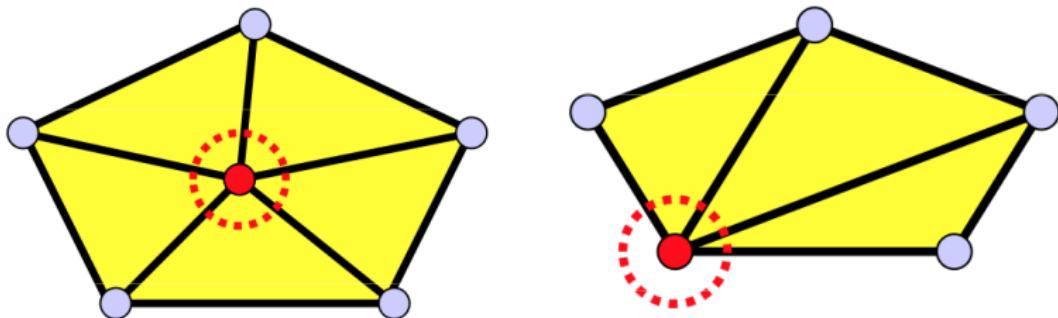
- connectors
- ties
- new legos
- reconfiguration
- all in one delivery
- fool proof assembly
- harvest more traditional methods

- millable
- printable

- big enough
- reachable

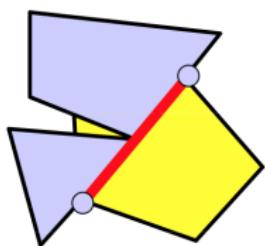
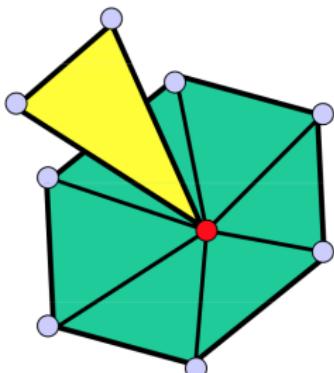
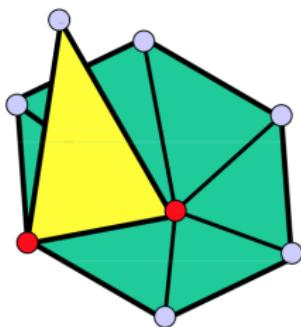
- closed, orientable and manifold mesh
- strong/thick enough
- supportable
- stands up

- closed if each edge is incident to exactly two faces



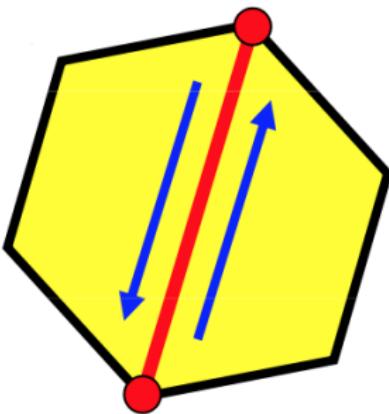
by Dr. Ching-Kuang Shene

- each edge is incident to one or two faces
- faces incident to a vertex form a closed or open fan



by Dr. Ching-Kuang Shene

- orientation is the cyclic order of incident vertices
- compatible if the two vertices of common edge are in opposite order



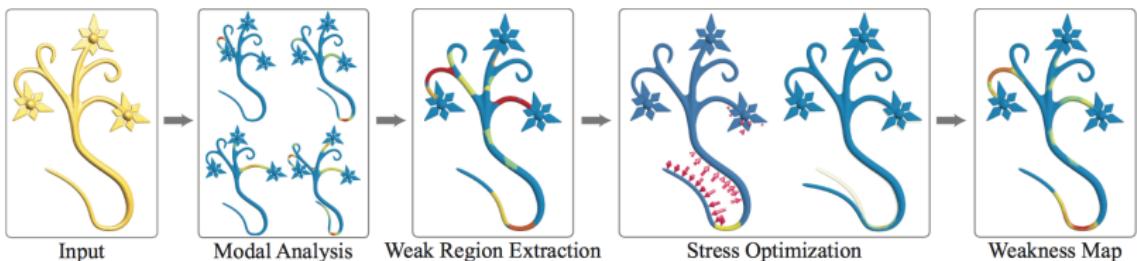
by Dr. Ching-Kuang Shene

- fill holes
- remove non-manifold problems

- perform structural analysis
- thicken according to weakness

Worst-case Structural Analysis

Qingnan Zhou,^{*} Julian Panetta,[†] and Denis Zorin[†]
New York University



Clever Support: Efficient Support Structure Generation for Digital Fabrication

J. Vanek¹ and J. A. G. Galicia¹ and B. Benes¹

¹Purdue University

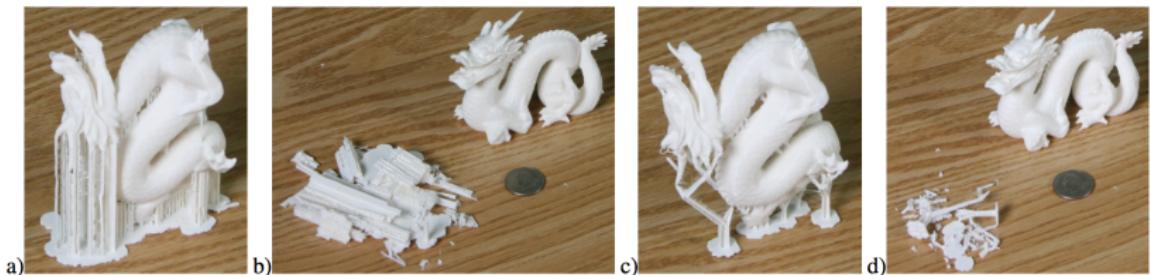


Figure 1: The support material generated by the built-in 3D printing software for MakerBot® Replicator™ 2 a) and the amount of support material b). Our solution c) reduces the amount of the support material d), leads to faster printing, and higher quality of the fabricated model.

Make It Stand: Balancing Shapes for 3D Fabrication

Romain Prévost¹

Emily Whiting¹

Sylvain Lefebvre²

Olga Sorkine-Hornung¹

¹ETH Zurich ²INRIA



(a)



(b)



(c)



(d)



- Mechanisms
- Review Reading 4

- *50 Digital Joints* by Jochen Gros
- *The Art of Japanese Joinery* by Kiyosi Seike
- *The Joint Book: The Complete Guide to Wood Joinery* by Terrie Noll
- *Mesh Basics* by Dr. Ching-Kuang Shene
<http://www.cs.mtu.edu/~shene/COURSES/cs3621/SLIDES/Mesh.pdf>
- *Chopper: Partitioning Models into 3D-Printable Parts* by Luo + Baran Rusinkiewicz + Matusik
- *Recursive Interlocking Puzzle Pieces* by Song + Fu + Cohen-Or
- *Worst-case Structural Analysis* by Zhou + Panetta + Zorin
- *Make It Stand* by Prevost + Whiting + Lefbvre + Sorkine-Hornung
- *Clever Support: Efficient Support Generation for Digital Fabrication* by Vanek + Galicia + Benes