

Encoding Building Products

Creating a design workflow for a modular infill system using
Discrete Building Information Modelling and Design Grammars

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P5

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Delegate of the Board of Examiners:
Dr. Ir. S. van der Spek

Background



Image 2

Image 3 (2022)

Mass-Customization in the house building industry allows **customization** while **lowering costs**, increase **quality** and **reduce building times**

(Larsen, 2019)

Mass-Customization in Architecture



BASIS		
Bouwkosten totaal	€ 0	
Tussenwoning	0x	€ 113.700
Hoekwoning	0x	€ 131.900
Hierin zijn opgenomen:		Prijspeil 1 juli 2022
1. Woonsmaak		
✓ Basis		€ 0
2. Woningtype		
✓ 2 lagen met kap		€ 117.900
3. Plattegrond		
✓ Breedte 4800 mm - Diepte 8680 mm		€ -4.200
4. Woningopties		
5. Energieconcept		
✓ BENG, incl lucht / water WP		in basisprijs
6. Offerte	Image 3	

parametric adjustments

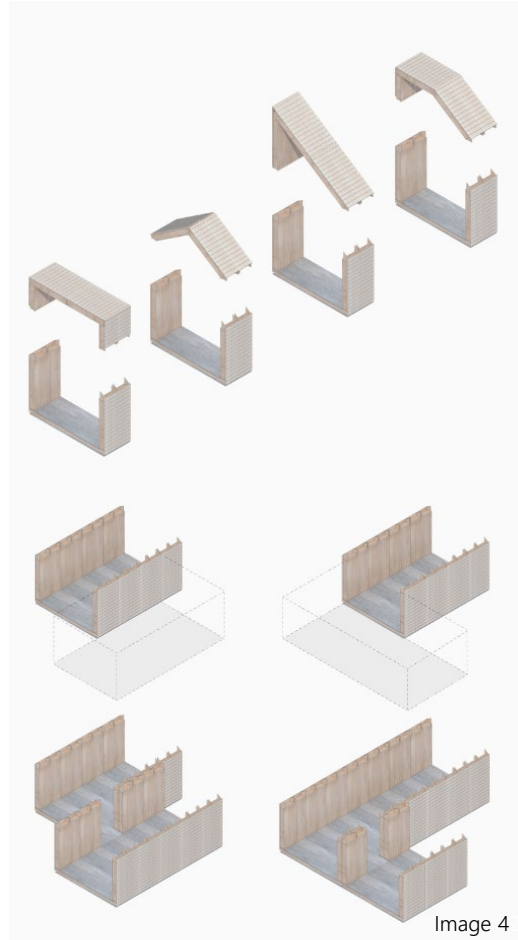


Image 4

In-house system architecture



CORNER M

w318 l318 h2400

A basic corner post for 2.4m high walls.



CORNER S

w318 l318 h2100

A short corner post for 2.1m high walls.



CORNER XL

w318 l318 h3000

A basic corner post for 3.0m high walls.



WALL G1

w318 l600 h3071

A gable end wall block that works with a 42 degree pitched roof.



WALL G2

w318 l600 h3611

A gable end wall block that works with a 42 degree pitched roof.



WALL G3

w318 l600 h4152

A gable end wall block that works with a 42 degree pitched roof.



WALL G4

w318 l600 h4692

A gable end wall block that works with a 42 degree pitched roof.



WALL M

w318 l600 h2400

A basic wall block, creating a 2.4m high space.

Image 5

open-source system architecture

Problem Statement

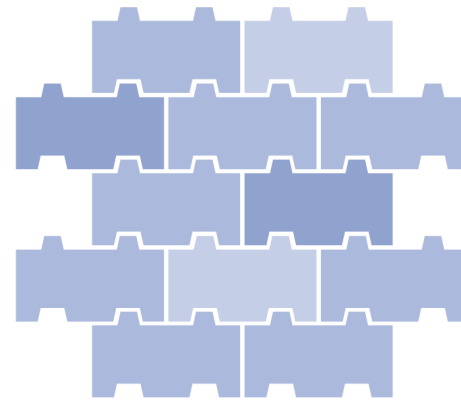
System Name	Parametric In-House System	Discrete In-House System	Open Source System
BIM-Compatibillity	✗	✗	✓
Modification Degree	low	medium	high
Mass-Production	high	medium	low
usabillity for end-user	high	medium	low

The open source system allows **high participation**, but is **difficult to operate** and is **expensive** through missing link to mass production

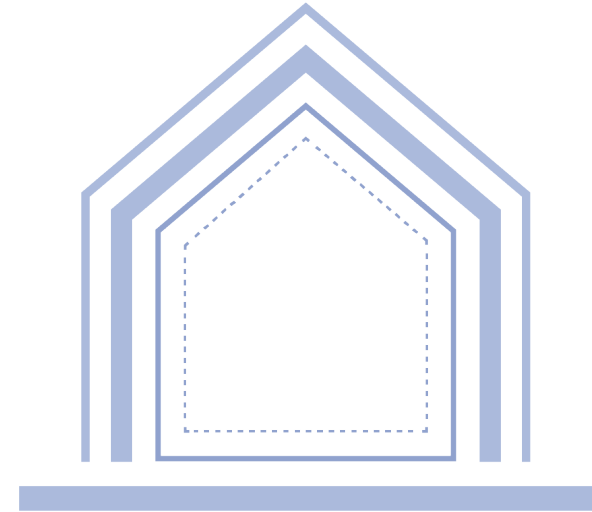
Background Research



building information modelling



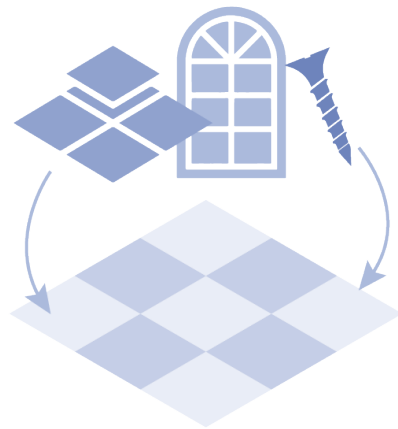
discrete architecture



open building

Research Question

- How to create a **computational design tool** that encodes **building products** into a **participatory** and **discrete** architectural workflow?



intergrate multiple components
in grid-based system



participation potential of
stakeholders

Research Objectives



workflow to develop discrete
building modules



interactive tool to create
individualized designs

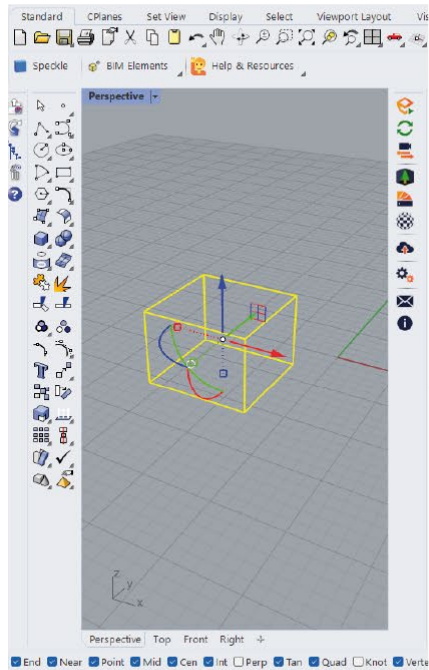


application of workflow
with infill system

Literature Review



Participation Methods

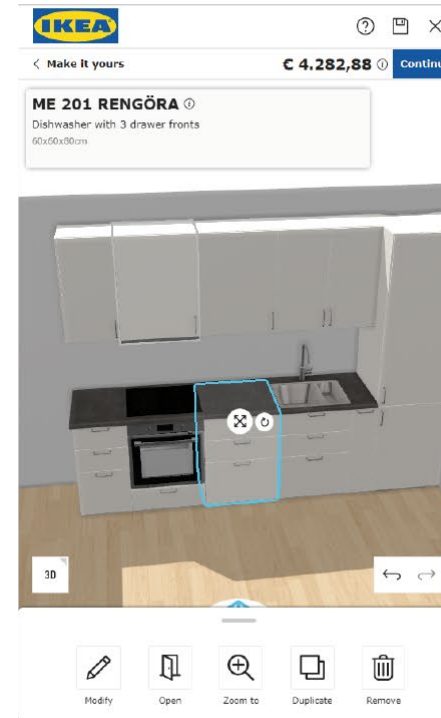


Implicit Modeling

Image 6

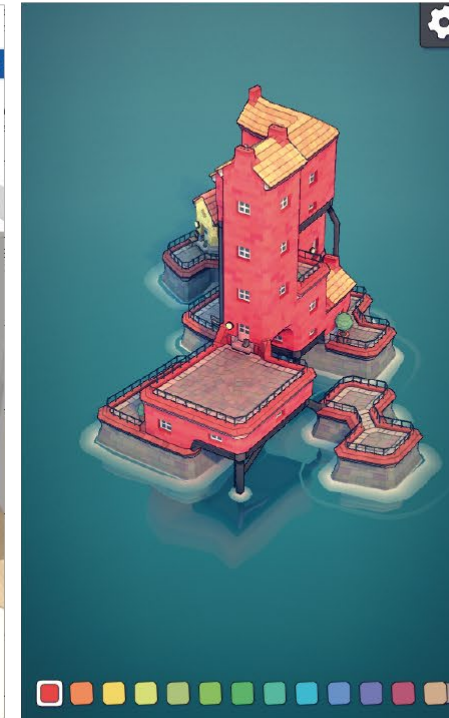


Parametric Configuration



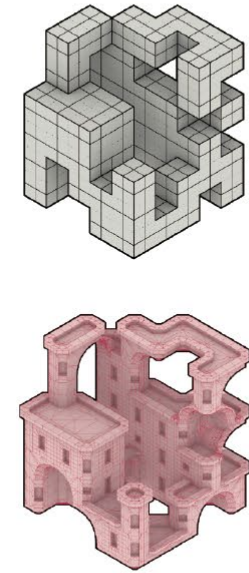
Part Configuration

Image 7



Procedural Generation

Image 8



Assisted Sculpting

Image 9

Rating of Participation Methods

Case Study	Implicit Modeling	Parametric Configurator	Part Configurator	Procedural Generation	Assisted Sculpting
application example	Rhino AutoCAD Sketchup	IKEA Kitchen Planner	IKEA Kitchen Planner	Townscaper Chasioti (2020)	Savov (2020) Park (2022)
experts influence on design	✓ high	≈ medium	✗ low	≈ medium	≈ medium
users influence on desing	✓ high	✗ low	✓ high	≈ medium	✓ high
difficulty of use	✗ very high	✓ low	≈ medium	✓ low	≈ medium
feedback to design decisions	✗ no	✓ yes	✓ yes	✓ yes	✓ yes
	6	7	7	8	8

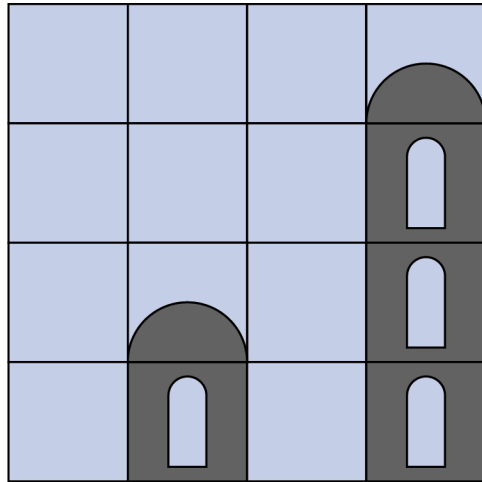
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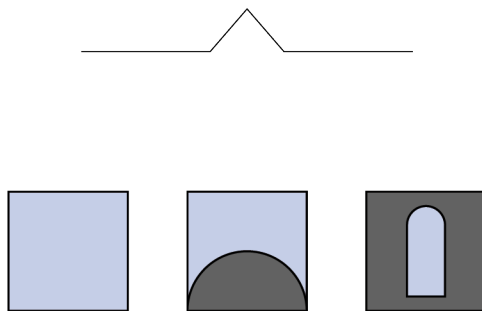
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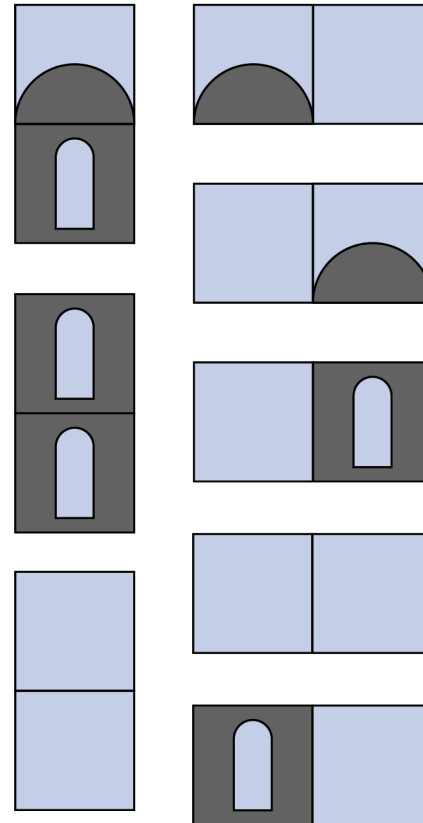
Wave Function Collapse Algorithm



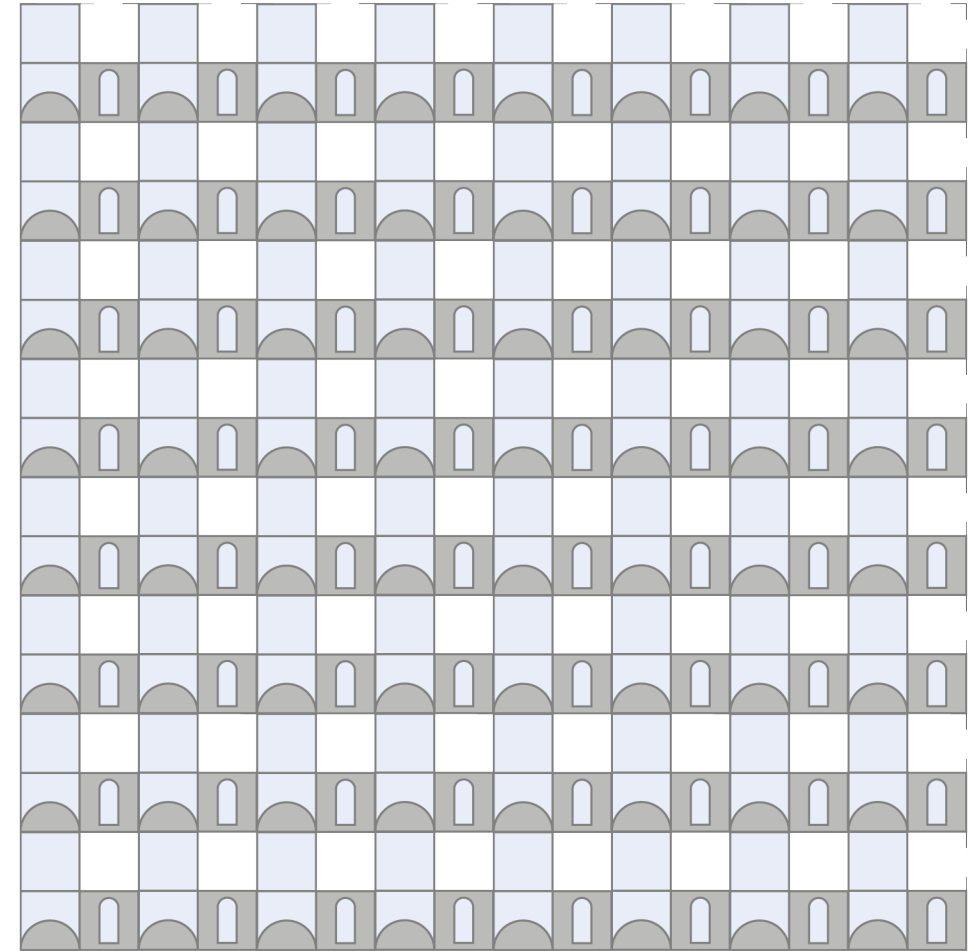
basic image



3 unique tiles

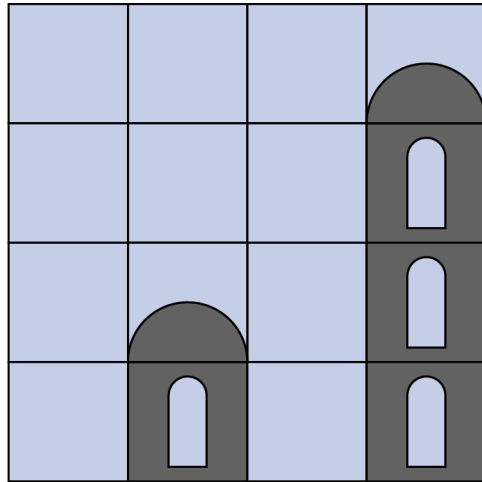


8 combinations

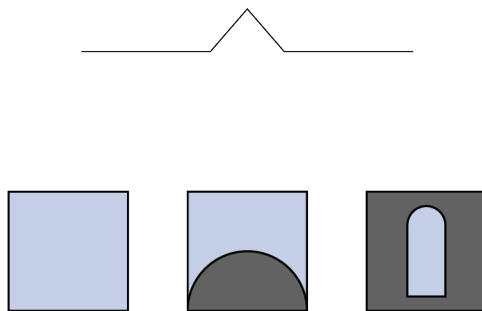


application on 8*8 matrix

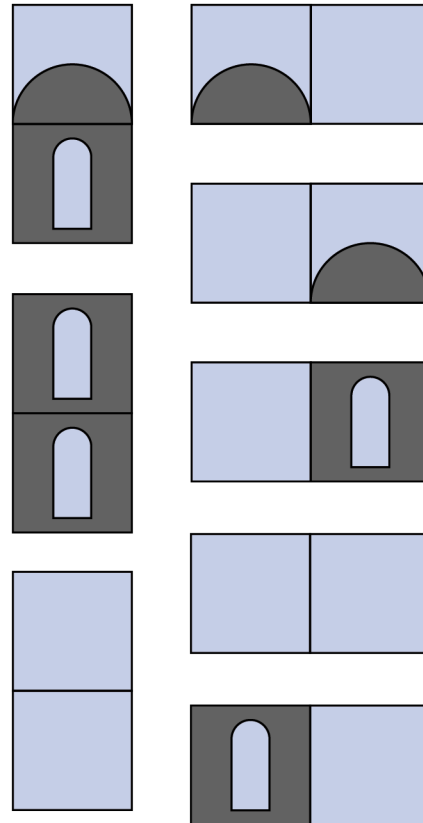
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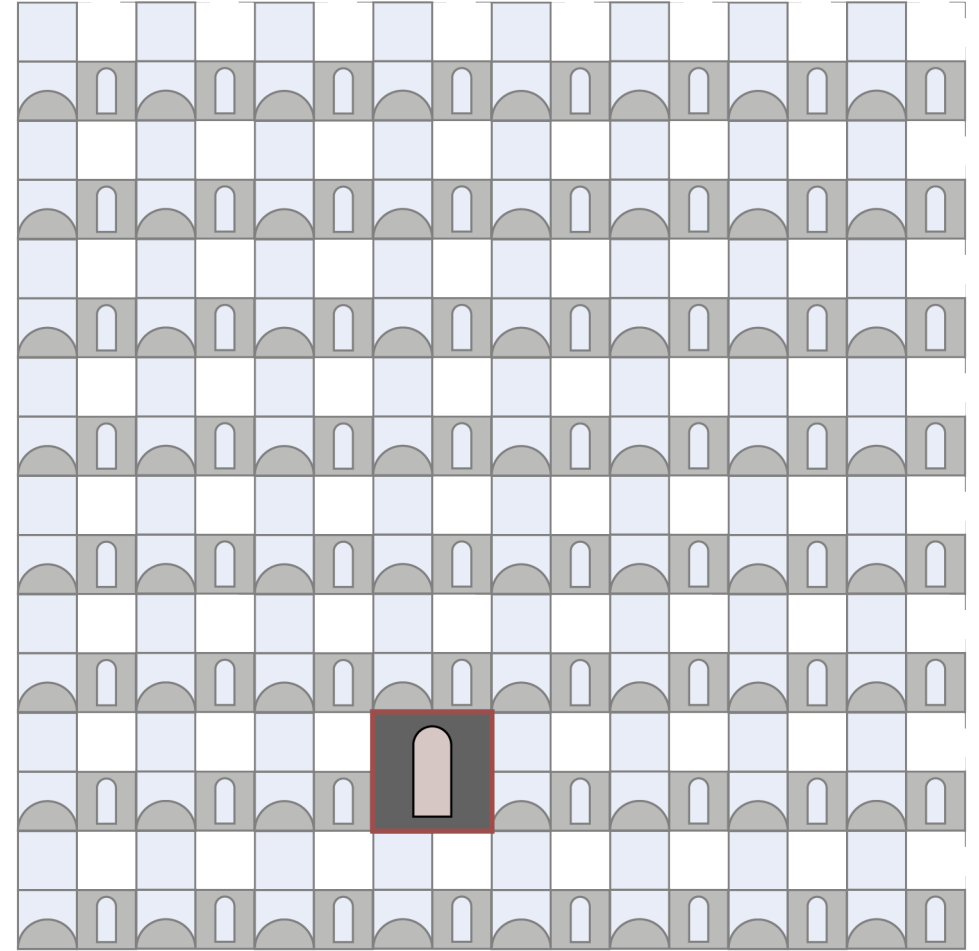
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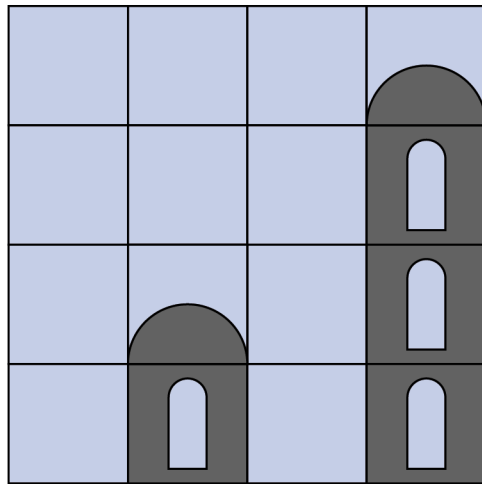


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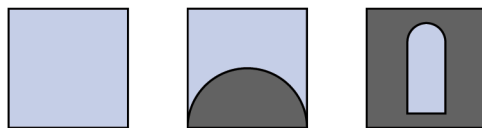


application on 8*8 matrix

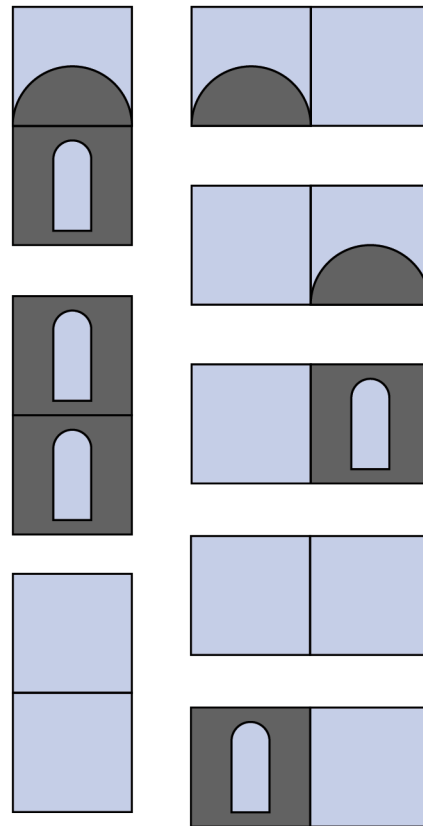
Wave Function Collapse Algorithm



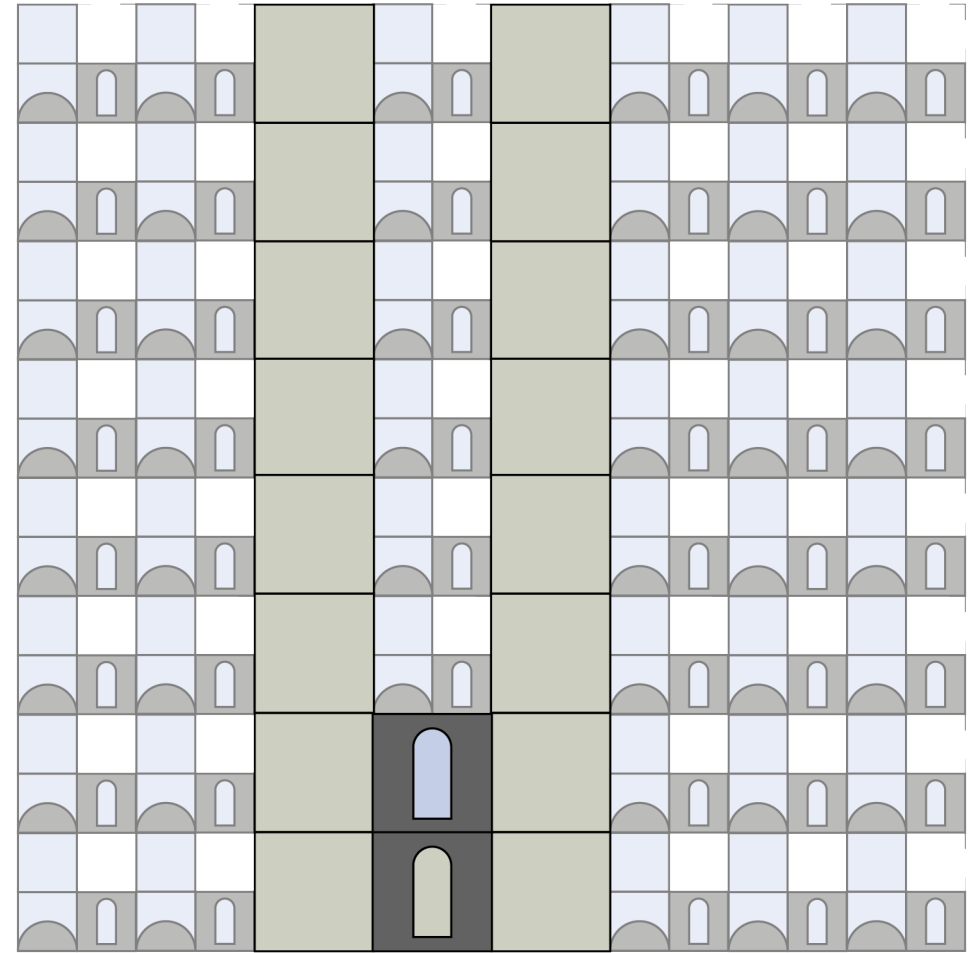
basic image



3 unique tiles

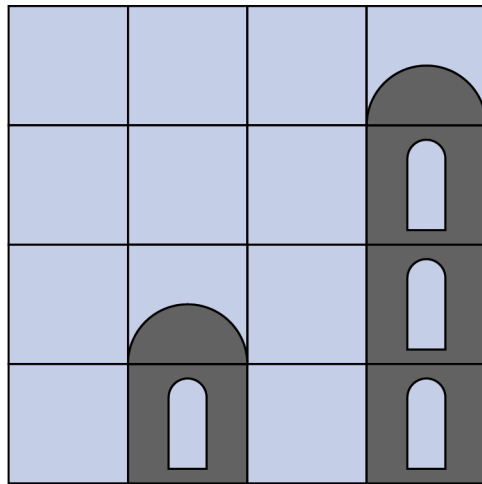


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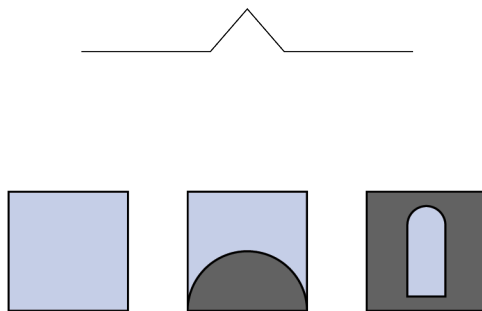


application on 8*8 matrix

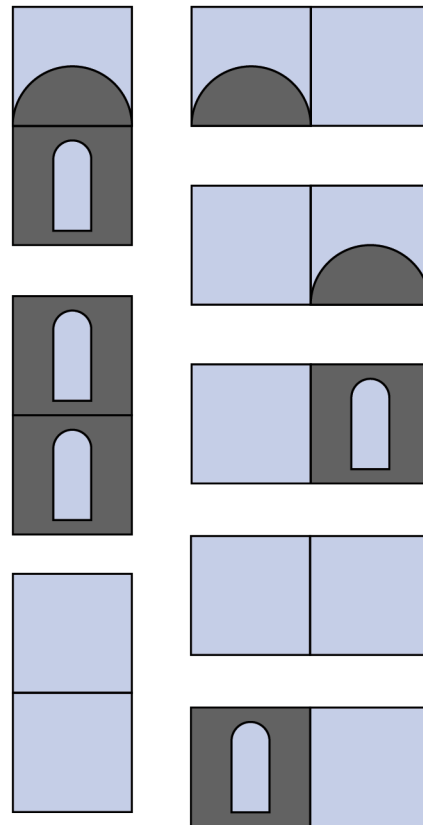
Wave Function Collapse Algorithm



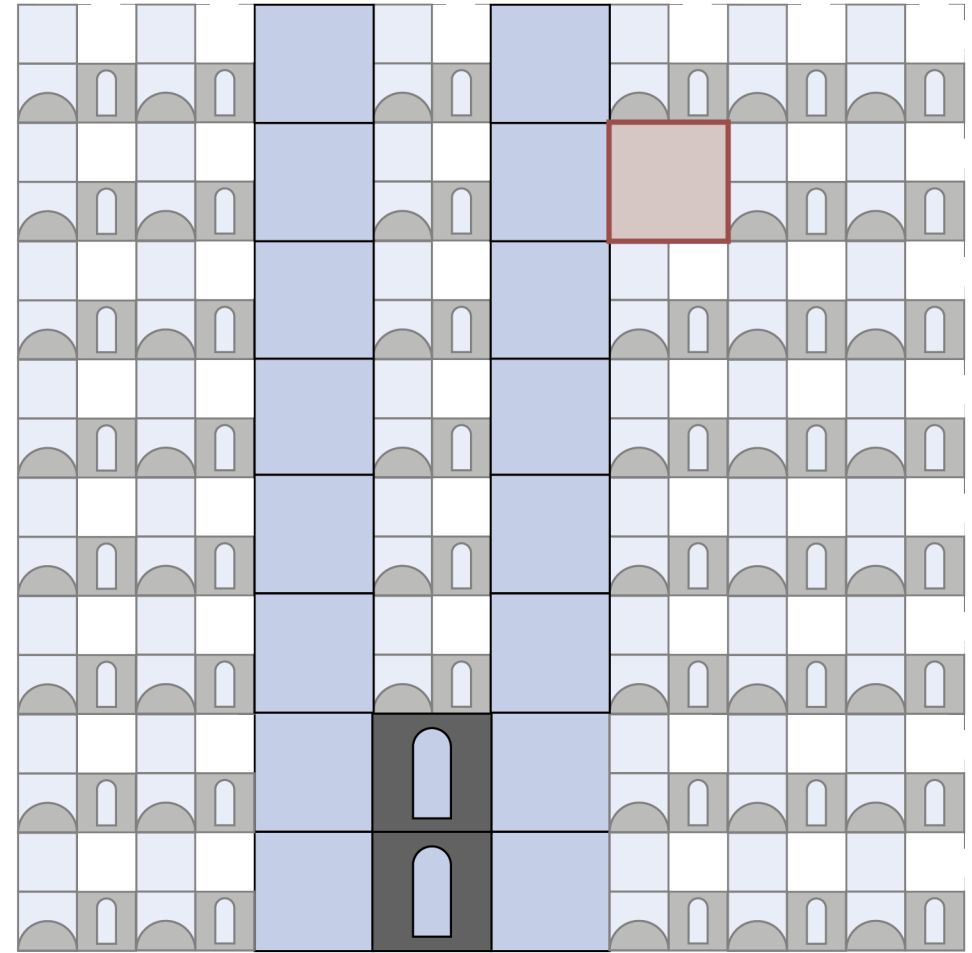
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3 unique tiles

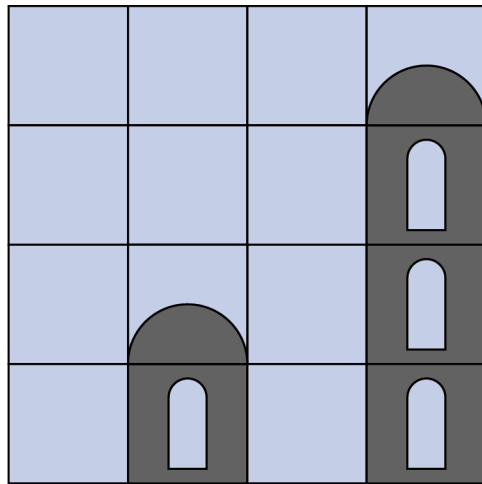


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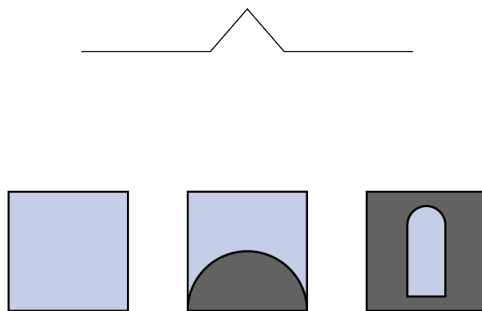


application on 8*8 matrix

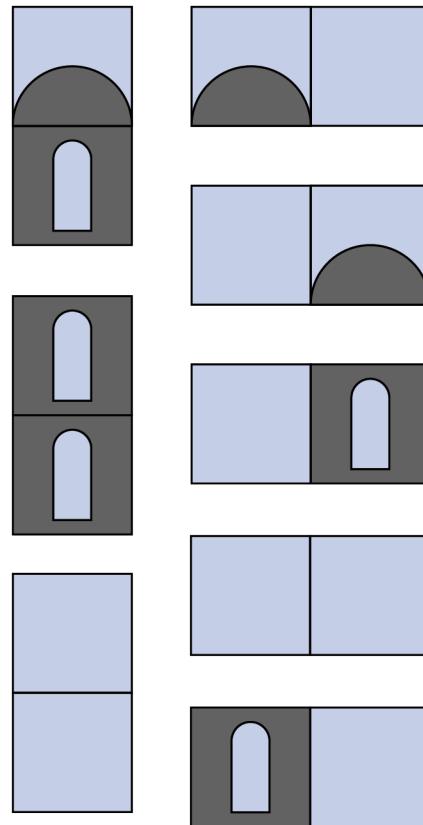
Wave Function Collapse Algorithm



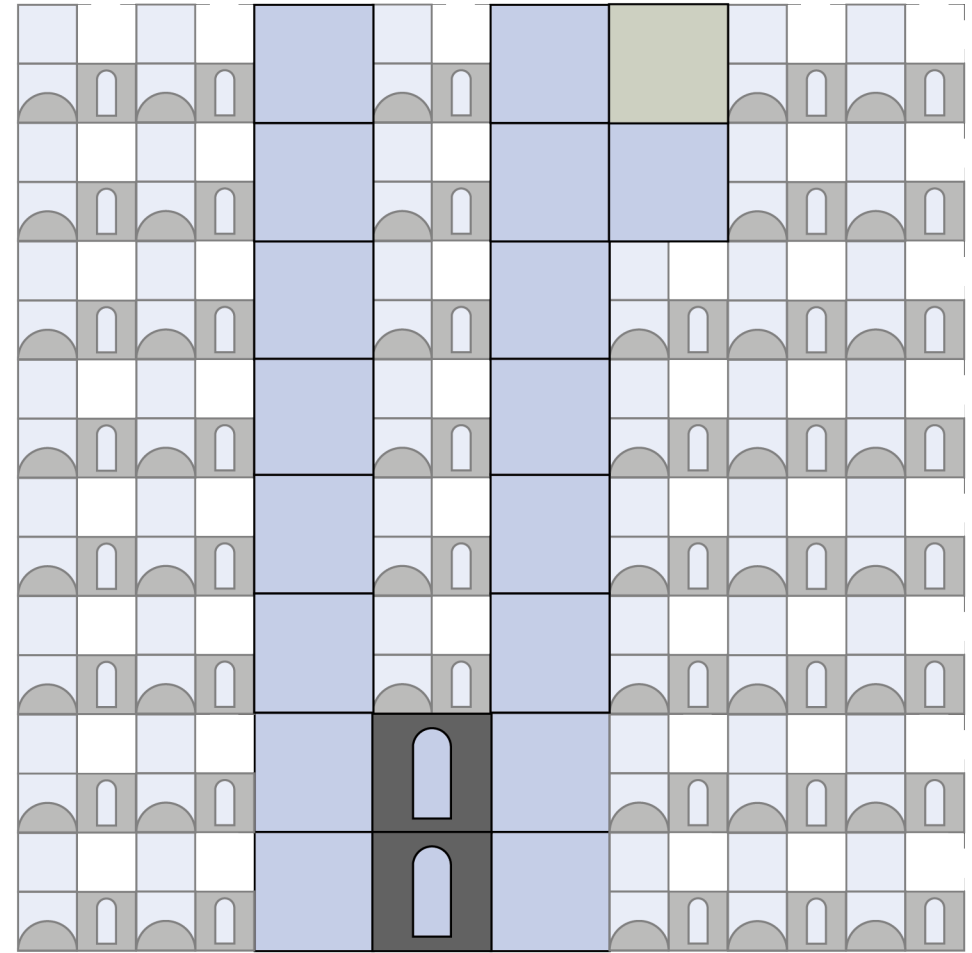
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3 unique tiles

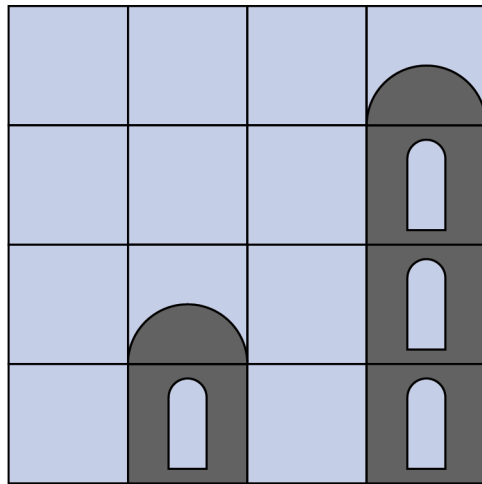


8 combinations

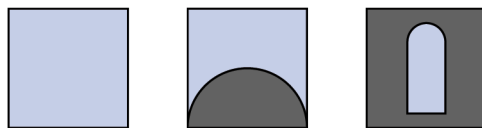


application on 8*8 matrix

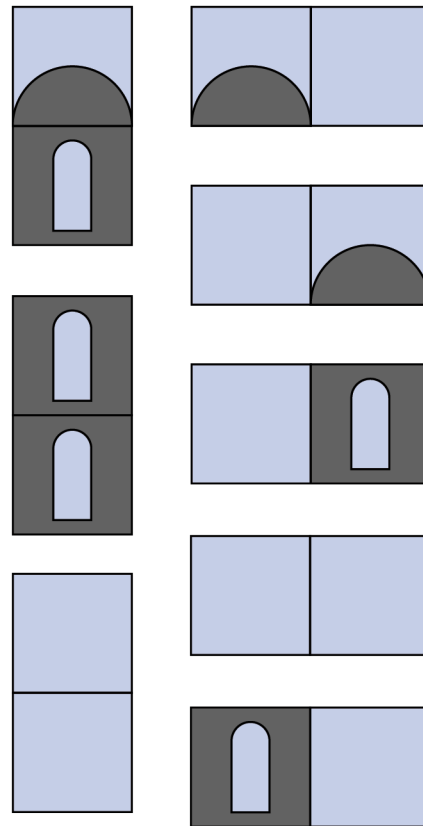
Wave Function Collapse Algorithm



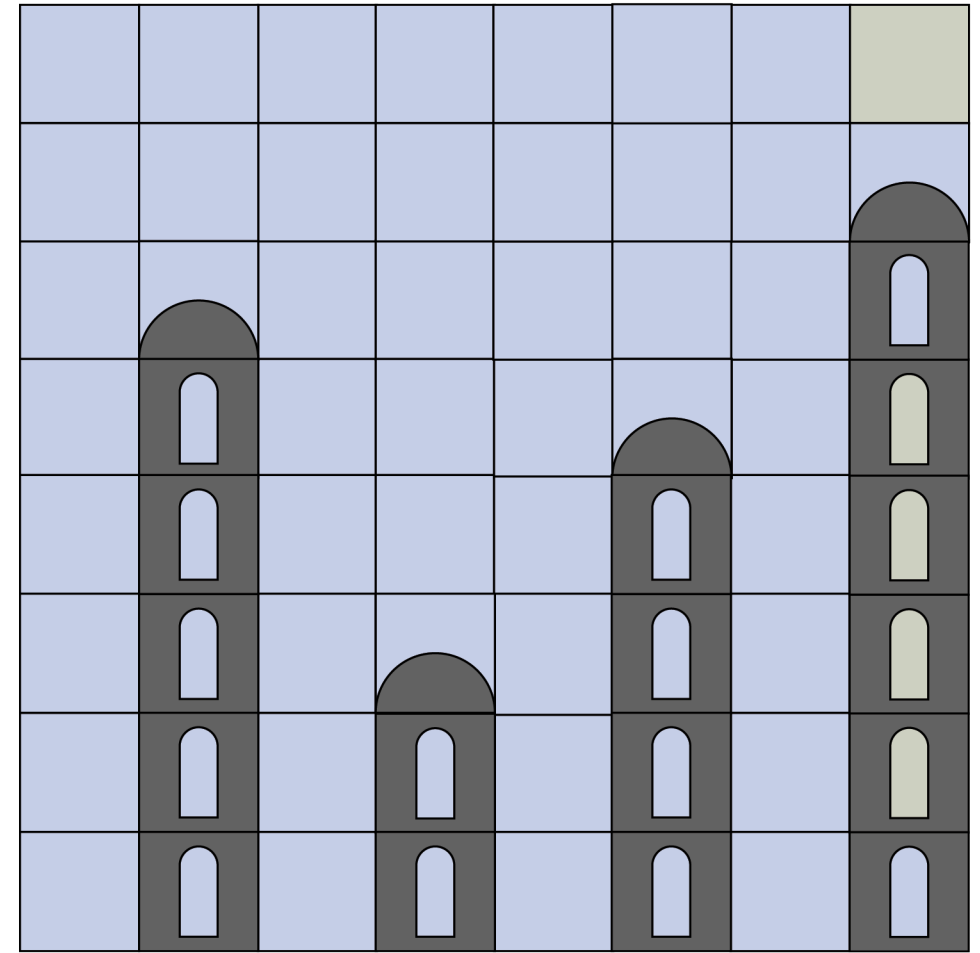
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3 unique tiles

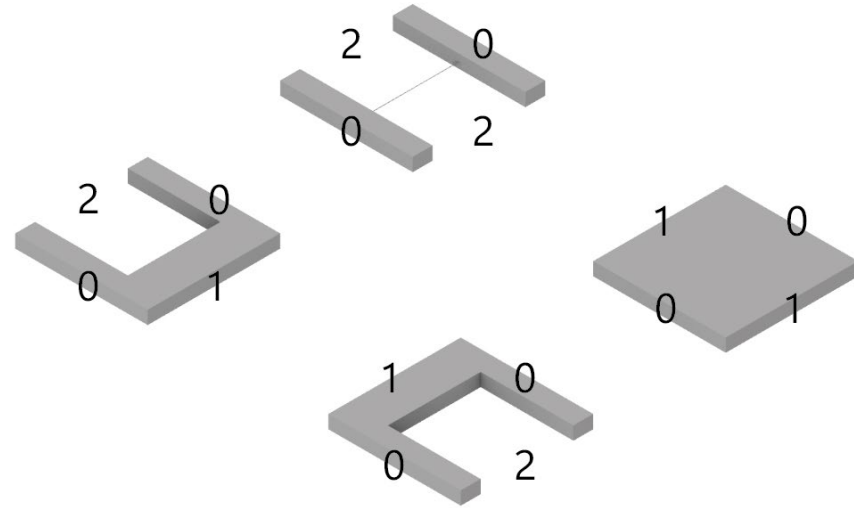


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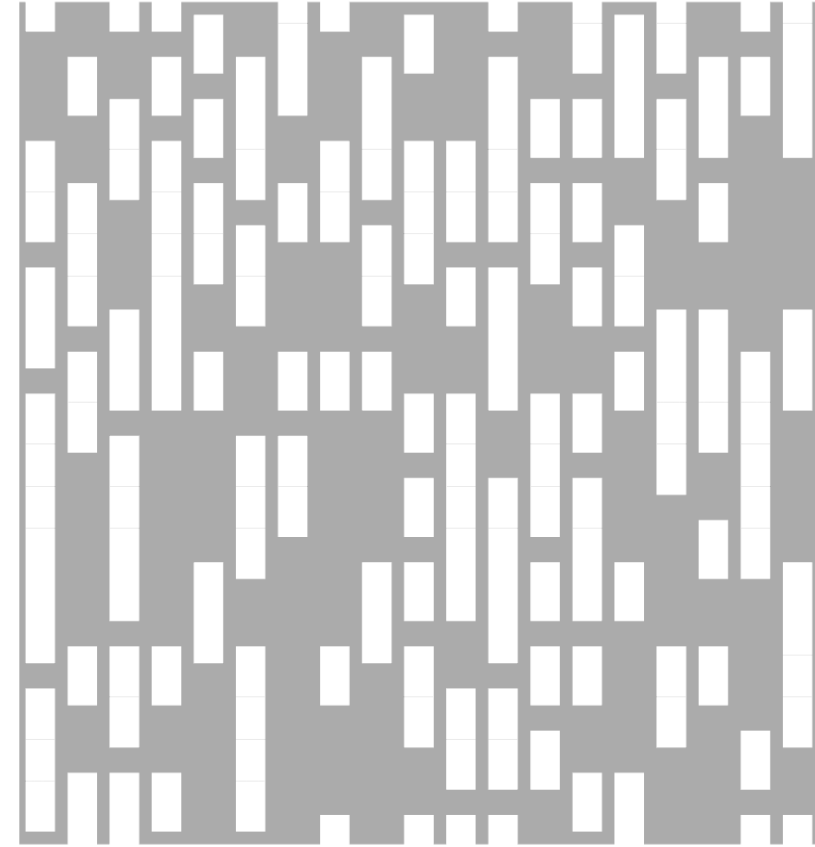


application on 8*8 matrix

Applying the WFC: 2D Tiles

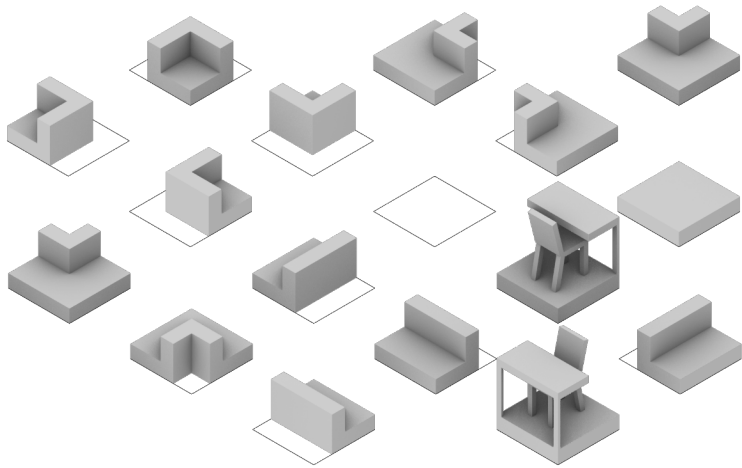


Input Tiles

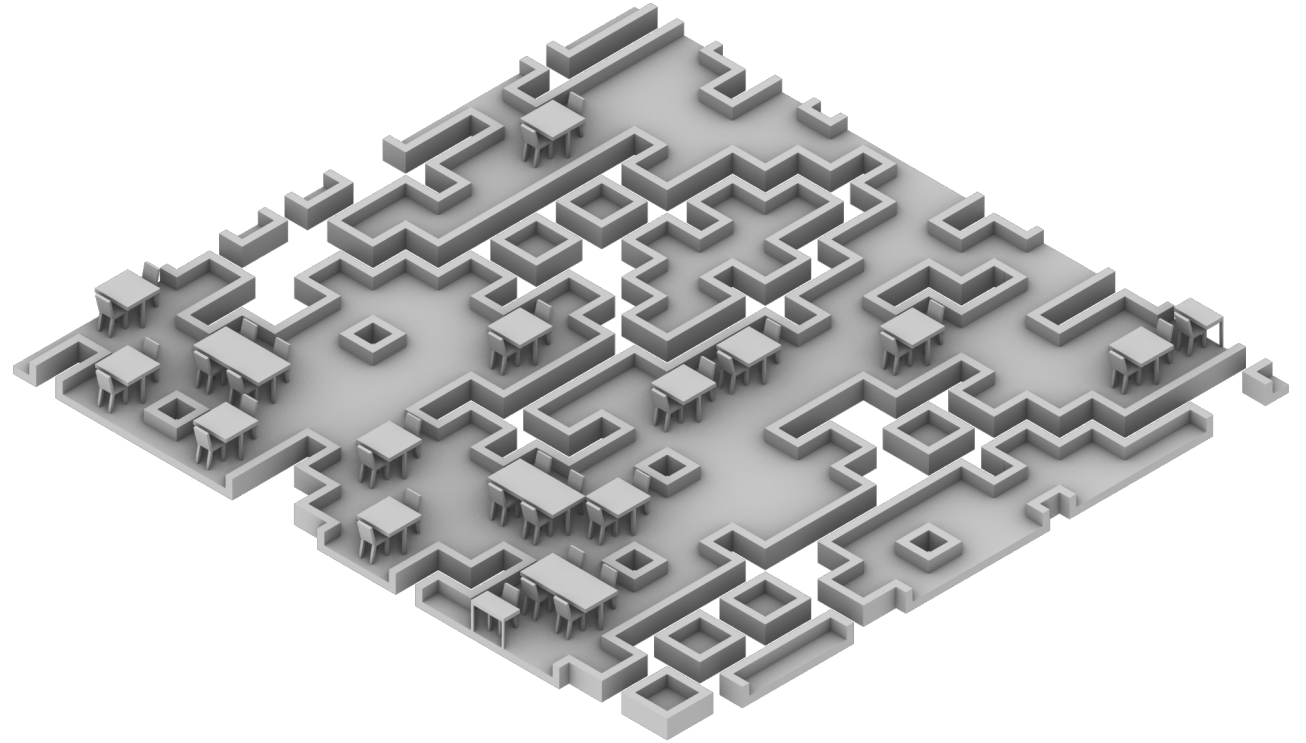


Output 20x20

Applying the WFC: 3D Tiles



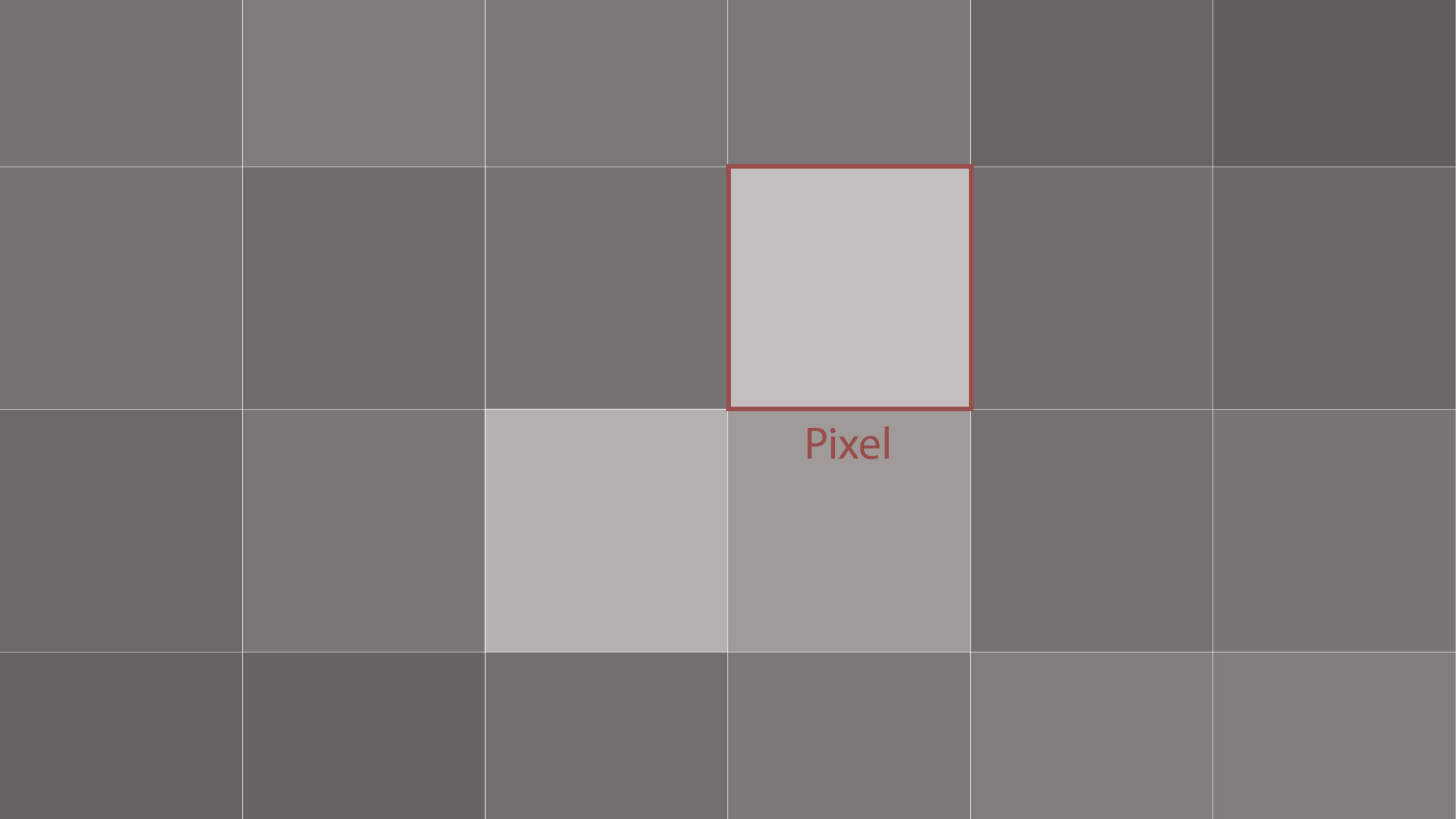
Input Tiles



Output 20x20

Boolean Marching Cubes





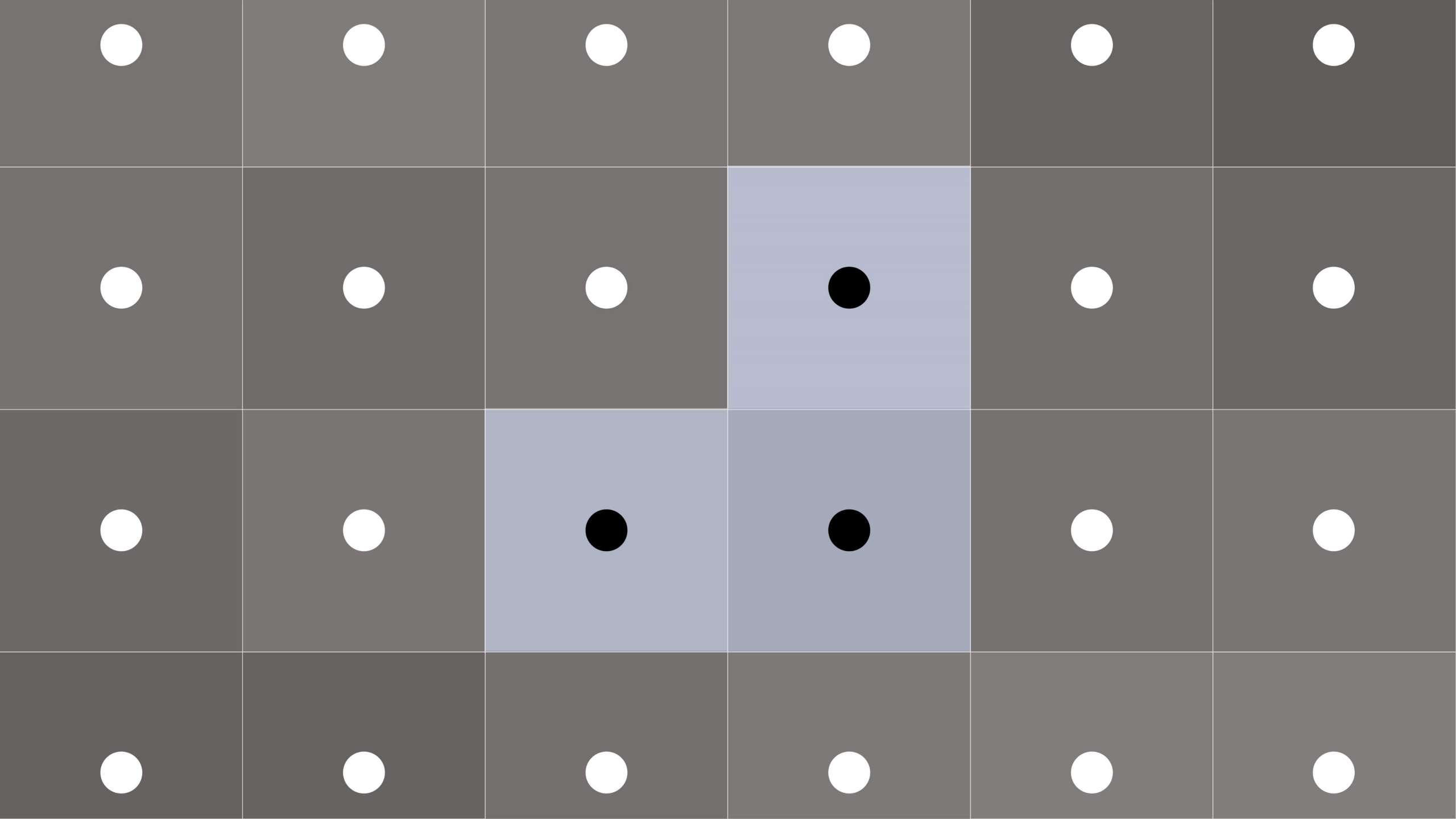
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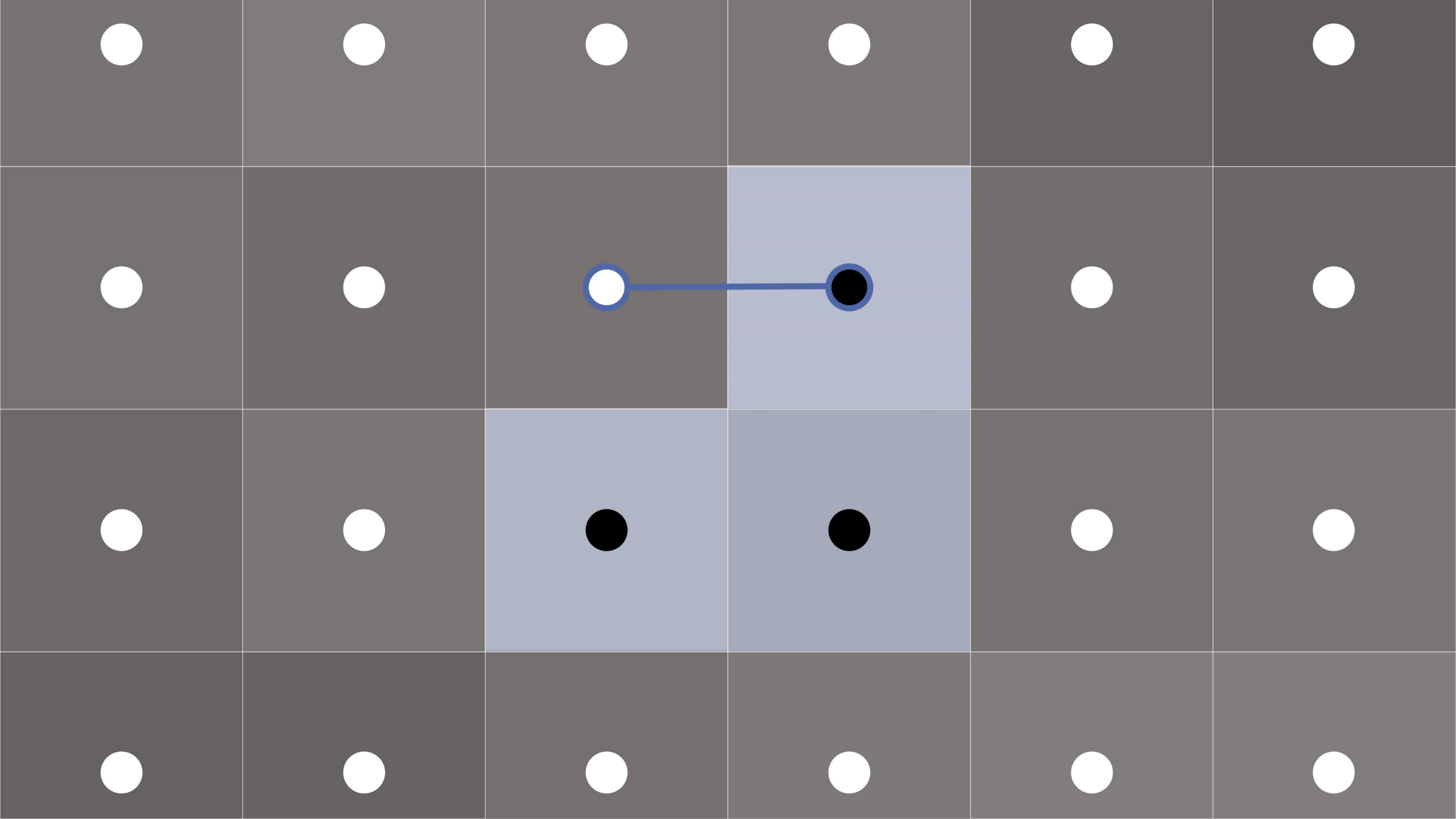
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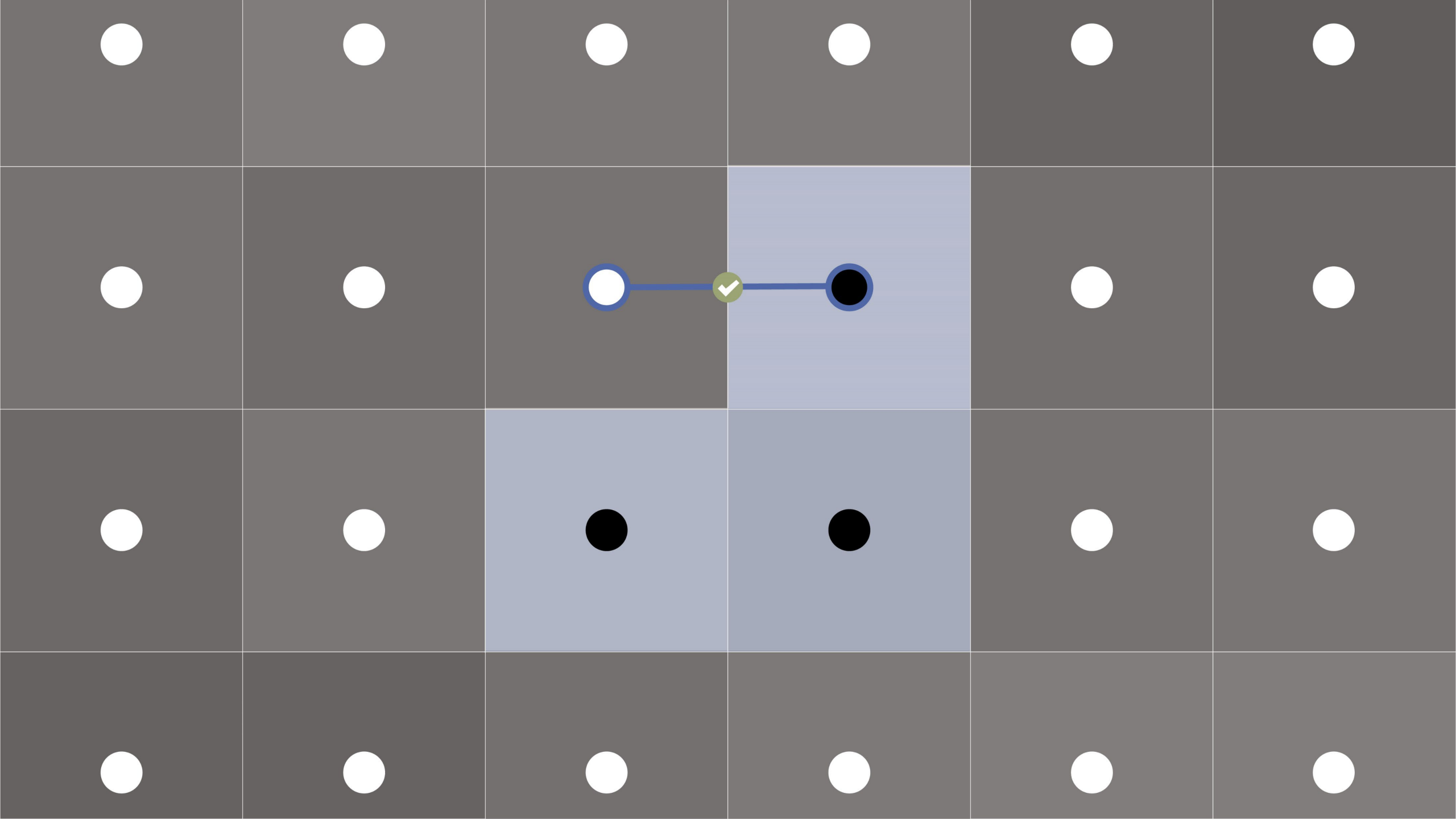
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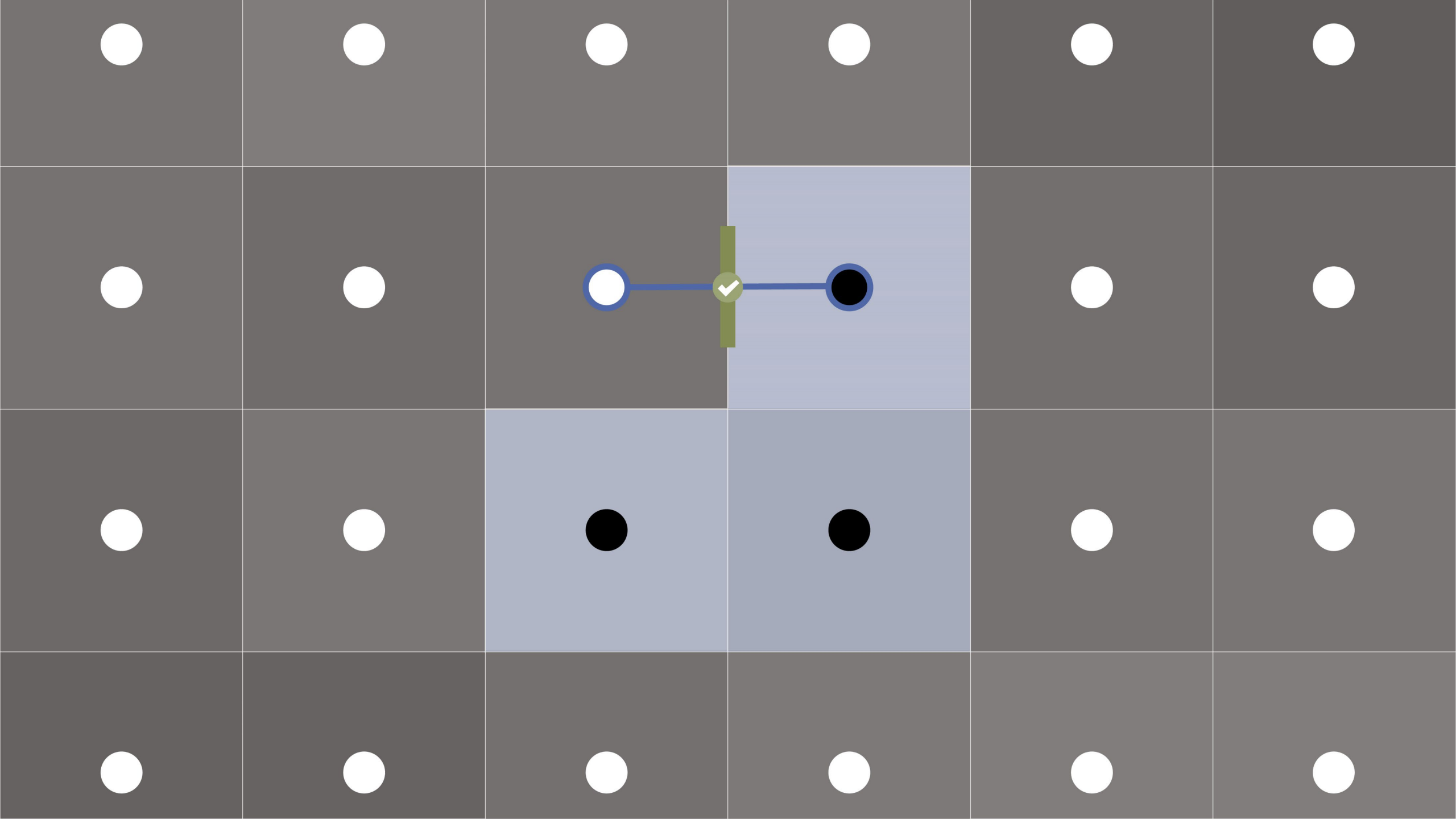
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#736F6E	#666261	#7B7776	#C4C0BF	#736F6E	#6B6766
#7B7776	#817D7C	#B5B1B0	#9F9B99	#7B7776	#7B7776
#666261	#666261	#7B7776	#7D7978	#817D7C	#817D7C

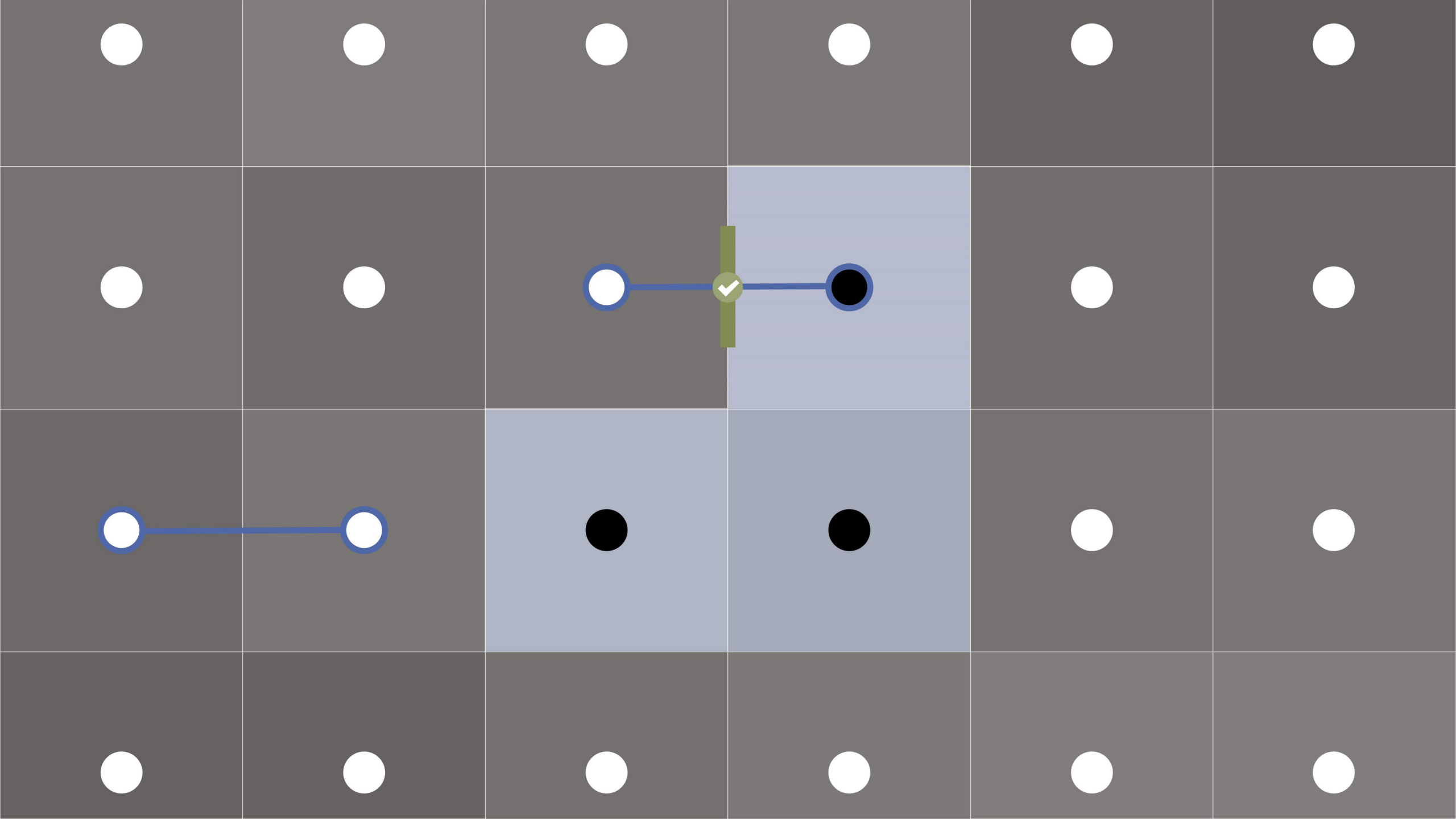
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#736F6E	#666261	#7B7776	#C4C0BF	#736F6E	#6B6766
#7B7776	#817D7C	#B5B1B0	#9F9B99	#7B7776	#7B7776
#666261	#666261	#7B7776	#7D7978	#817D7C	#817D7C

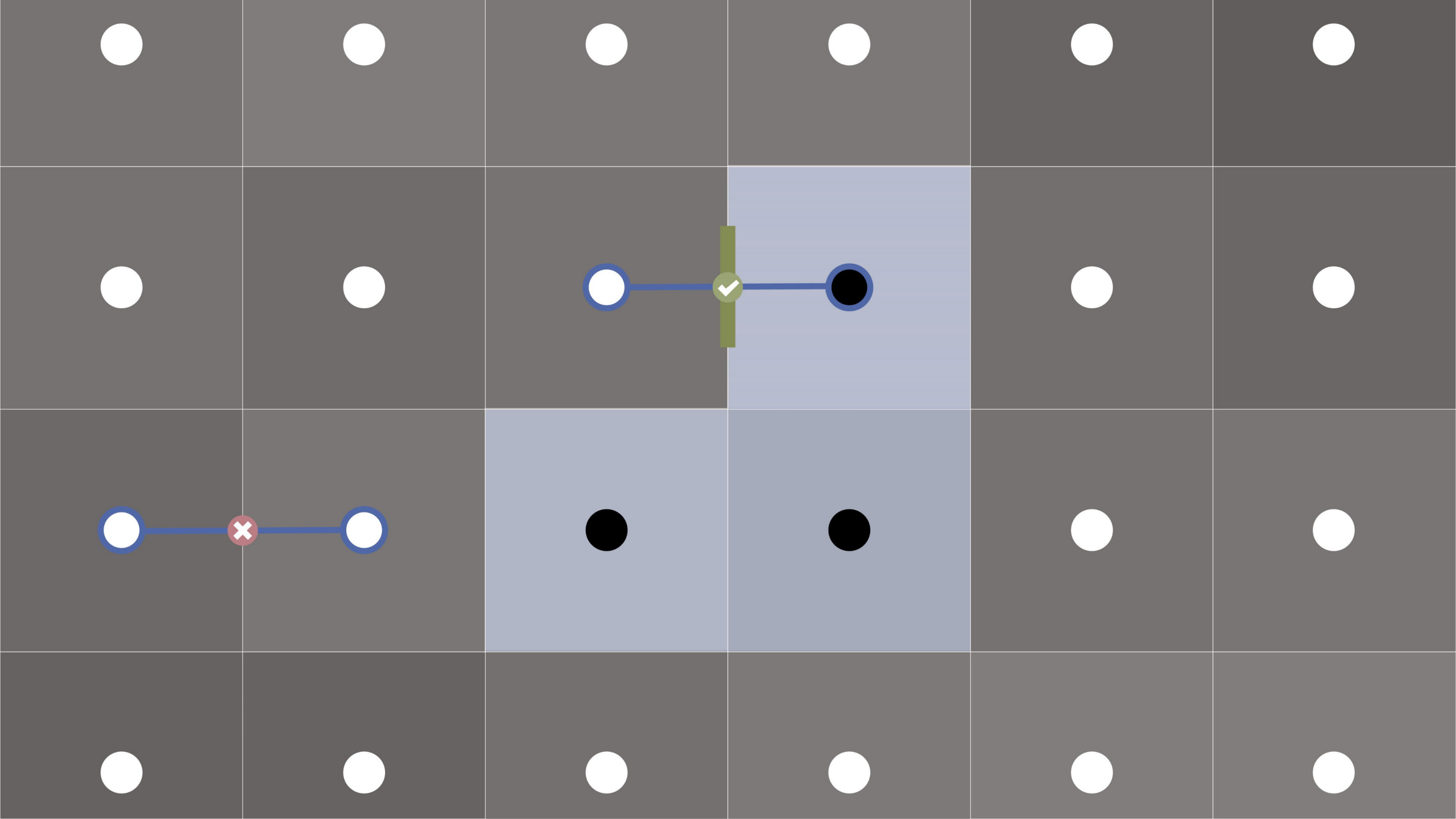


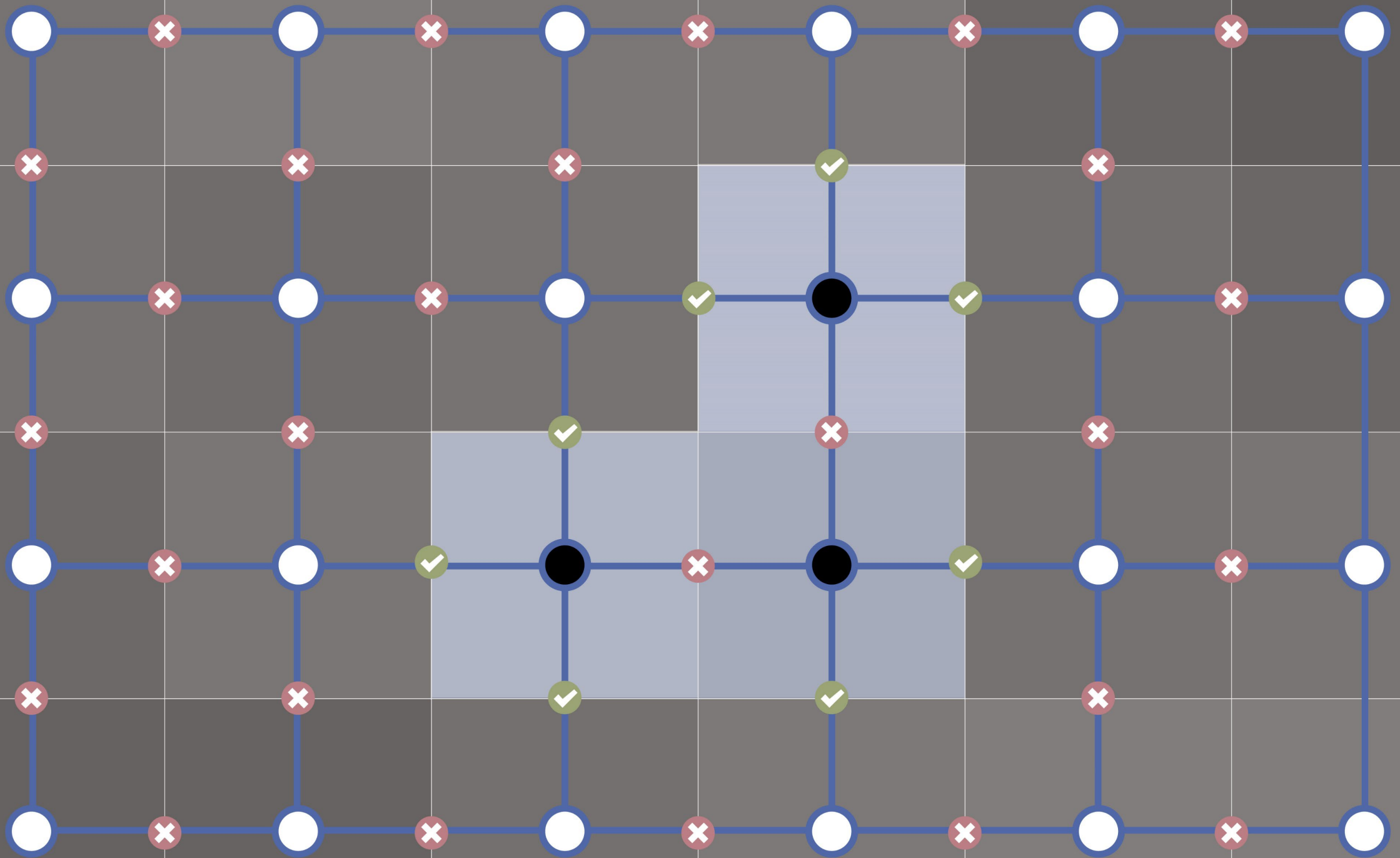


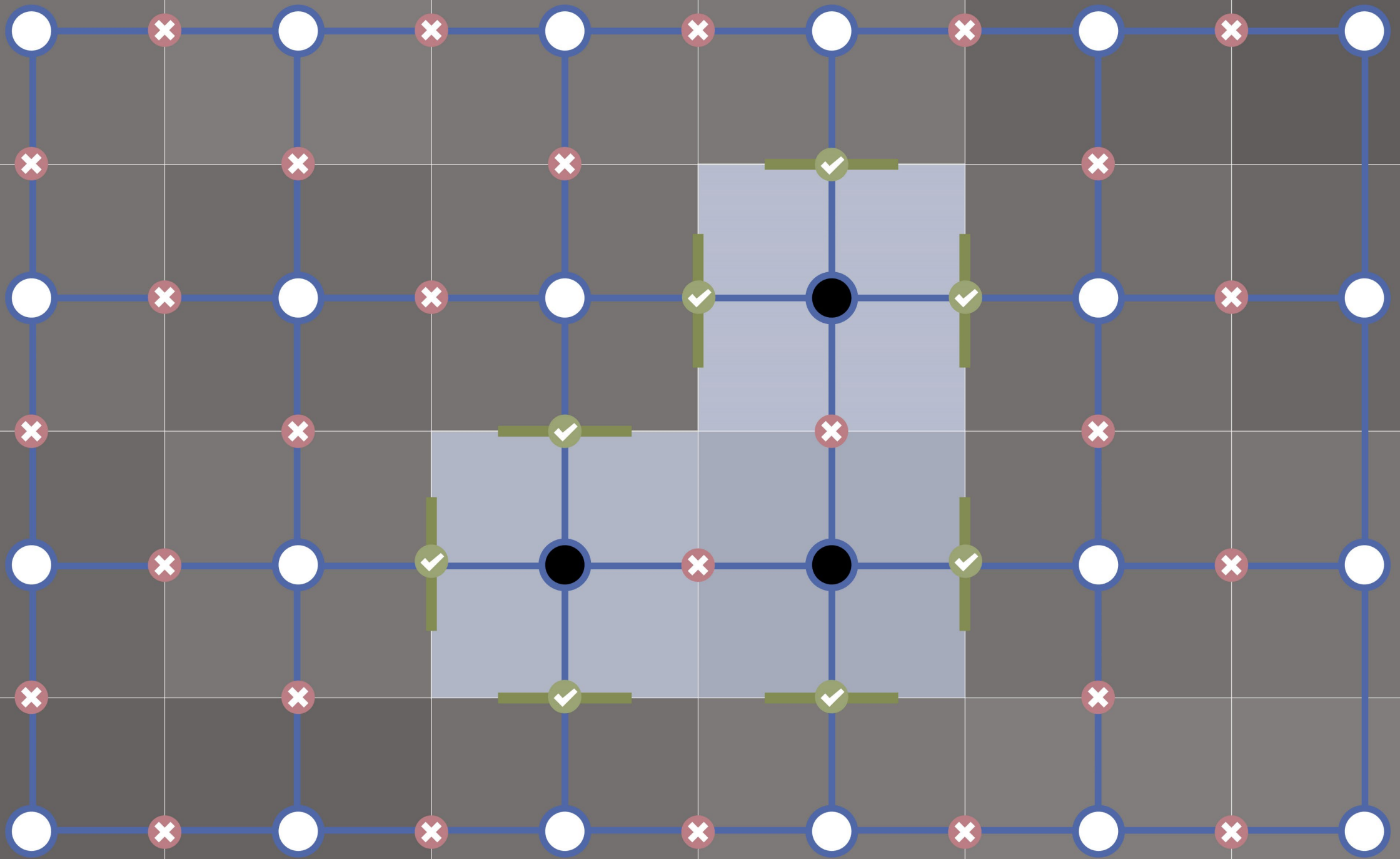


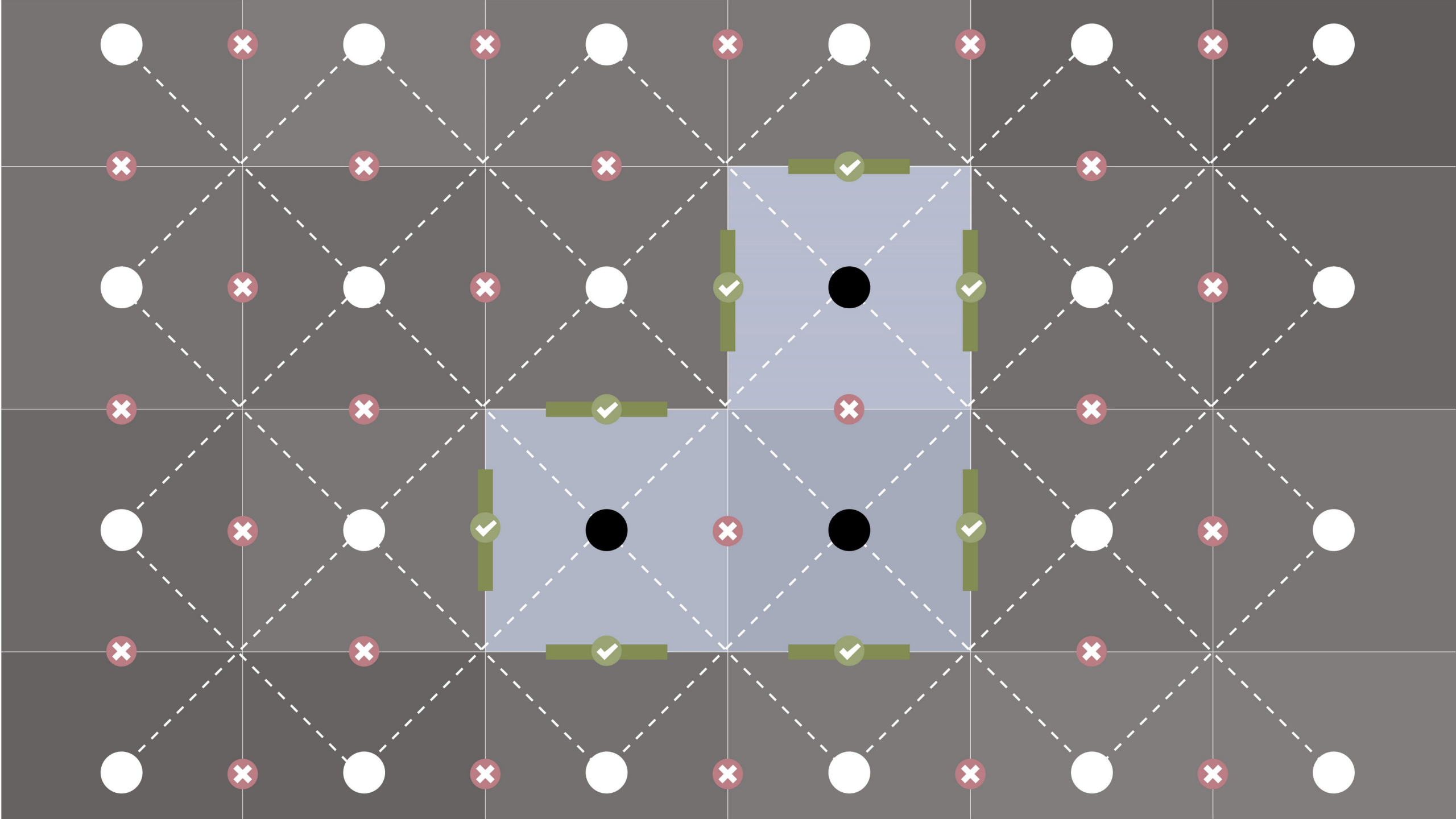


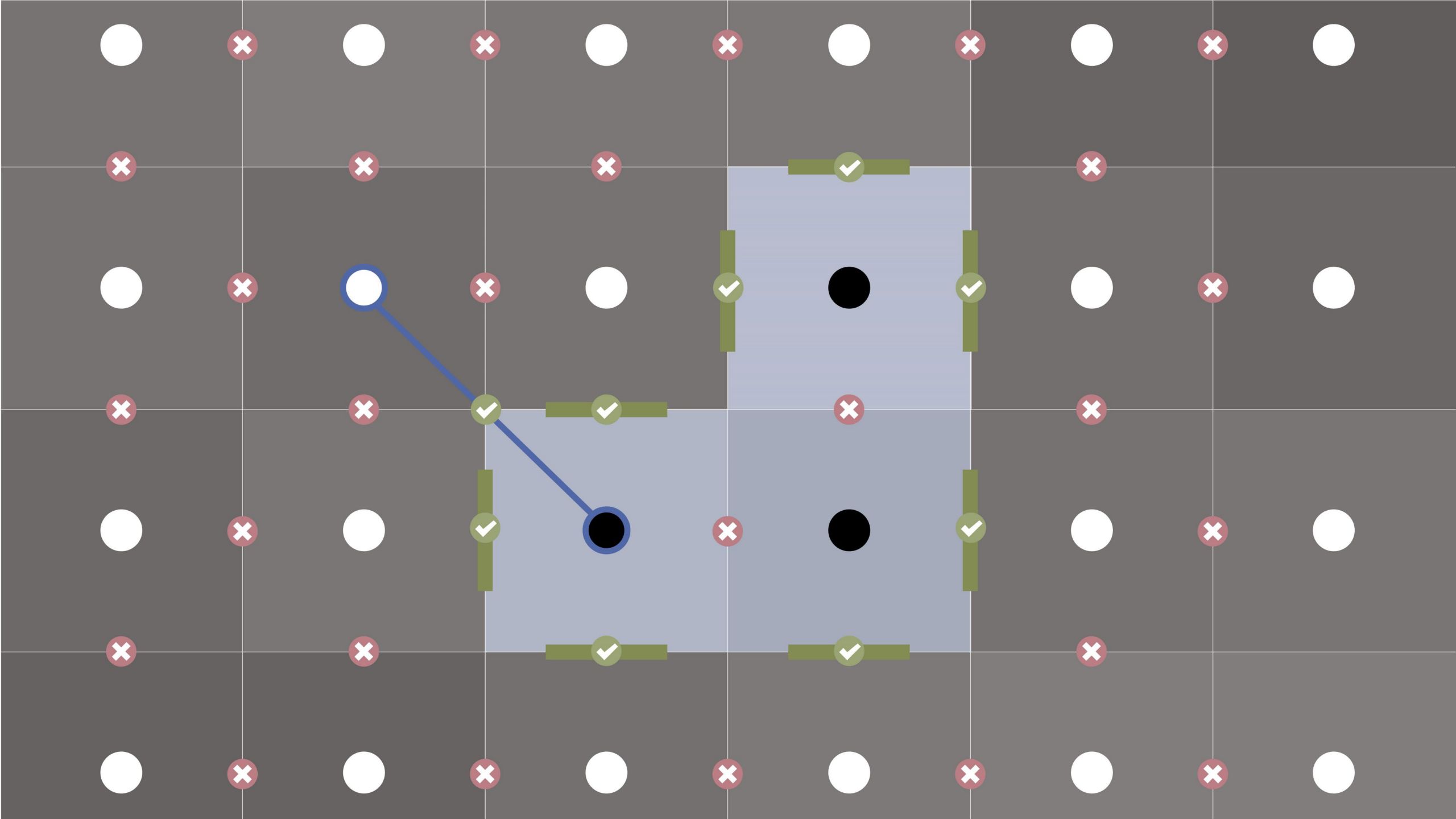


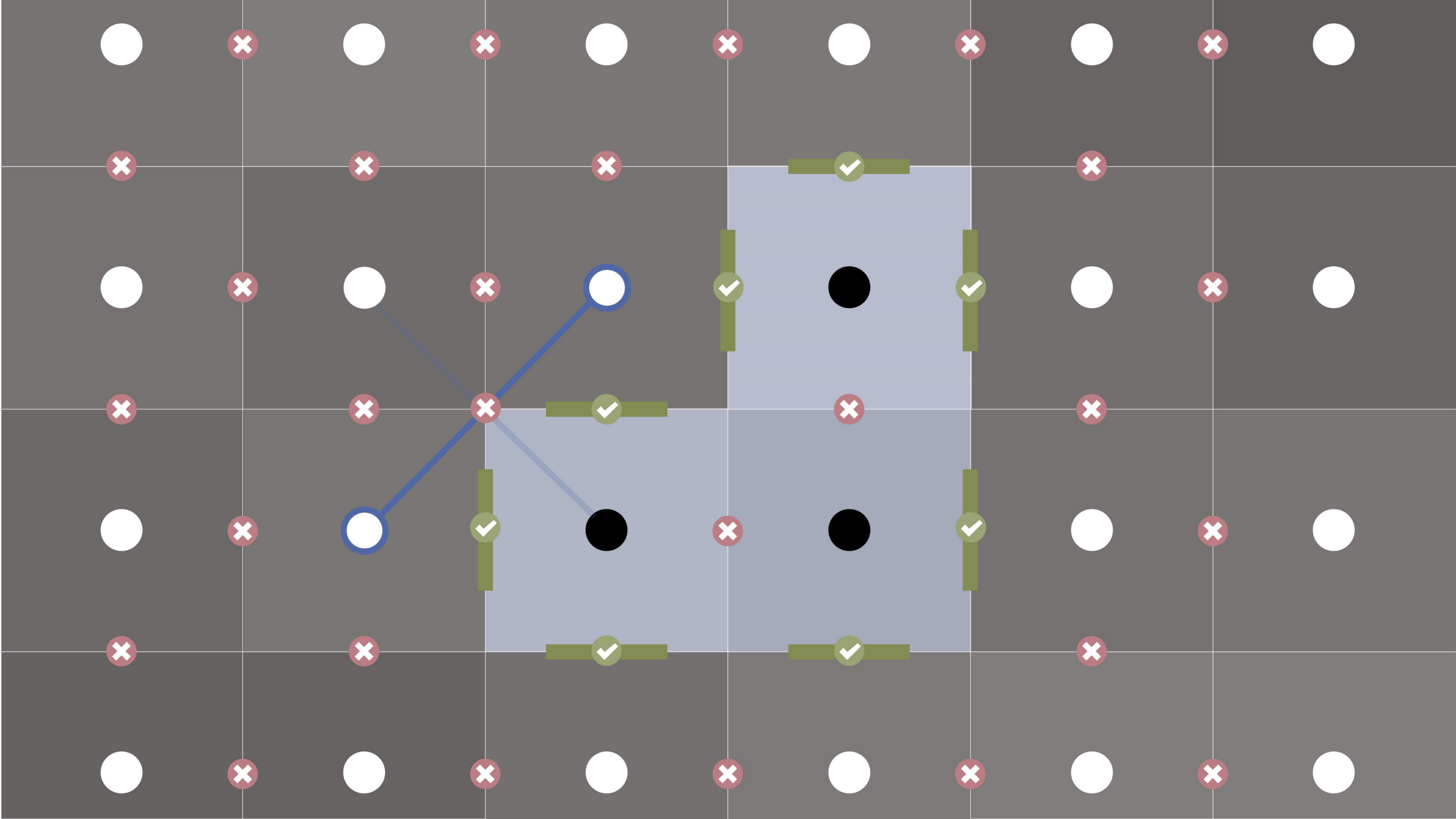


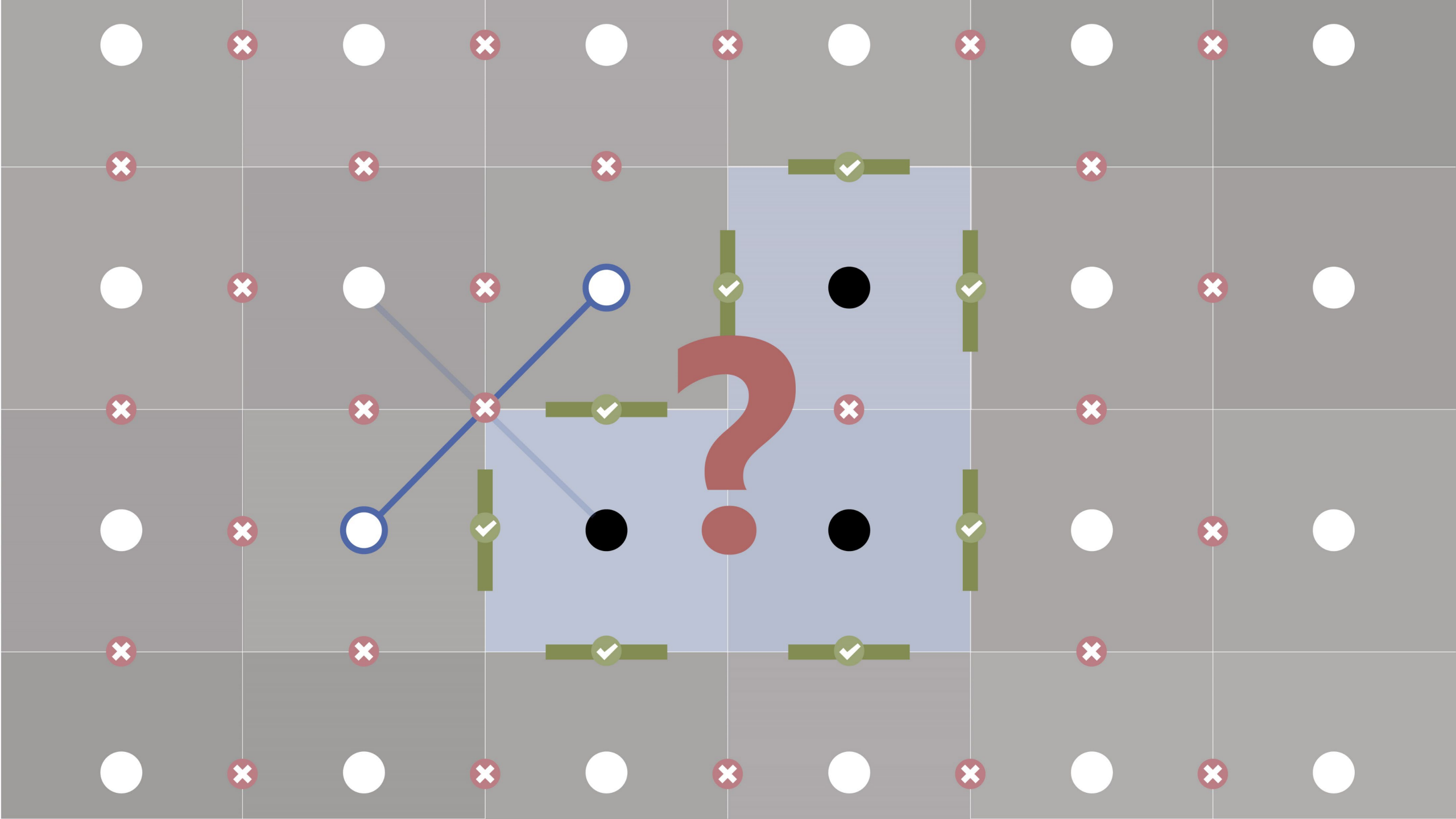


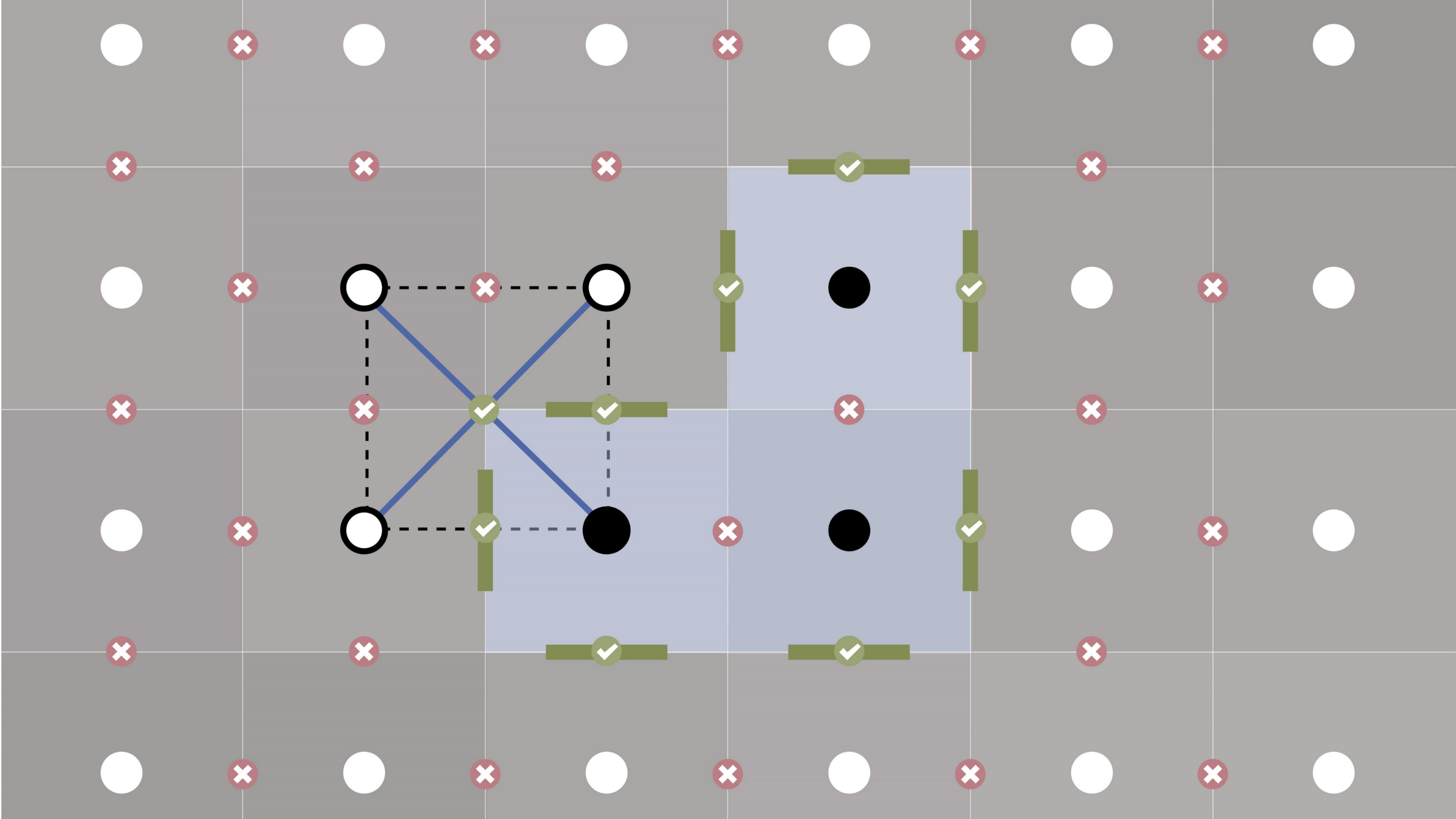


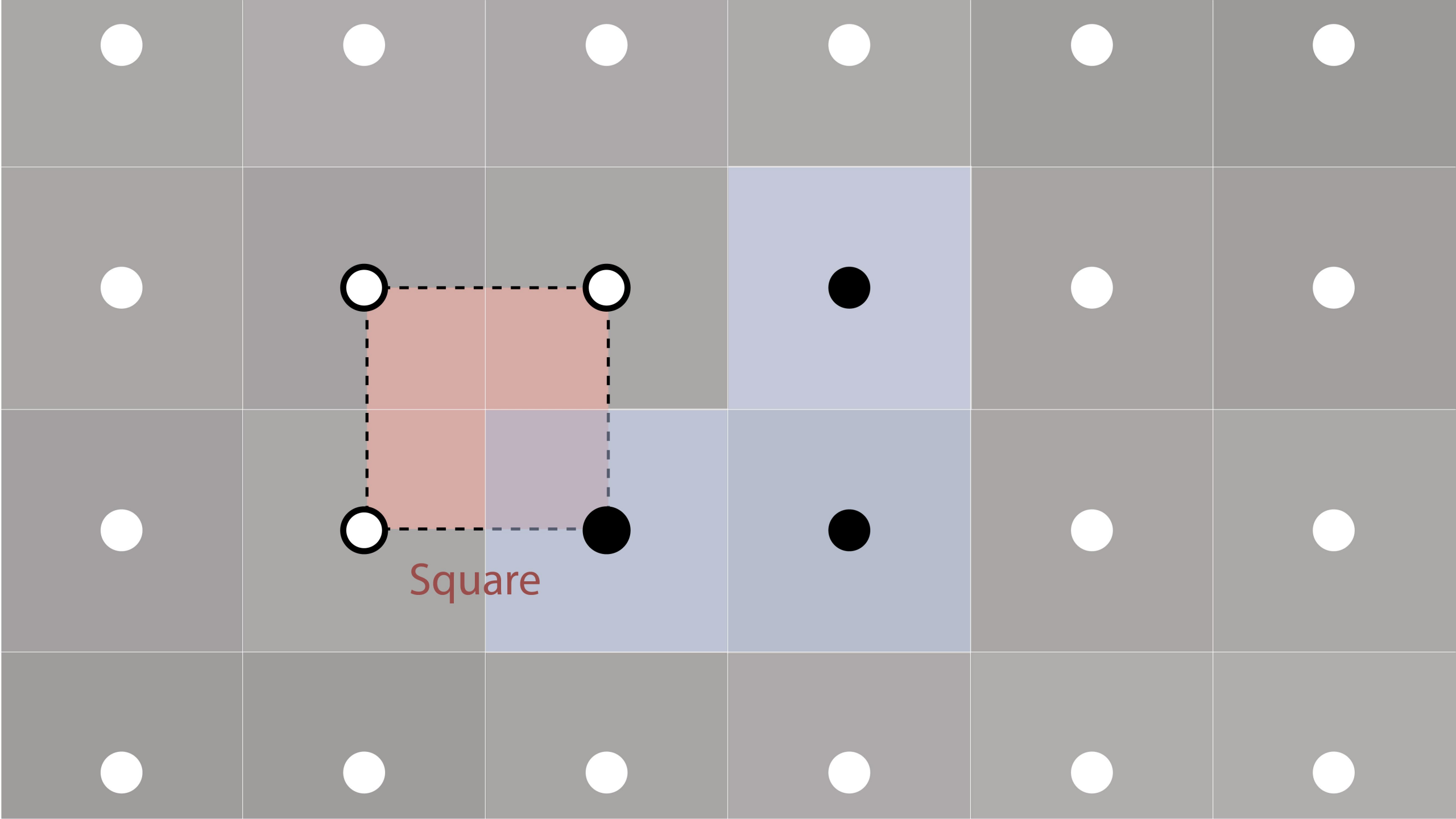


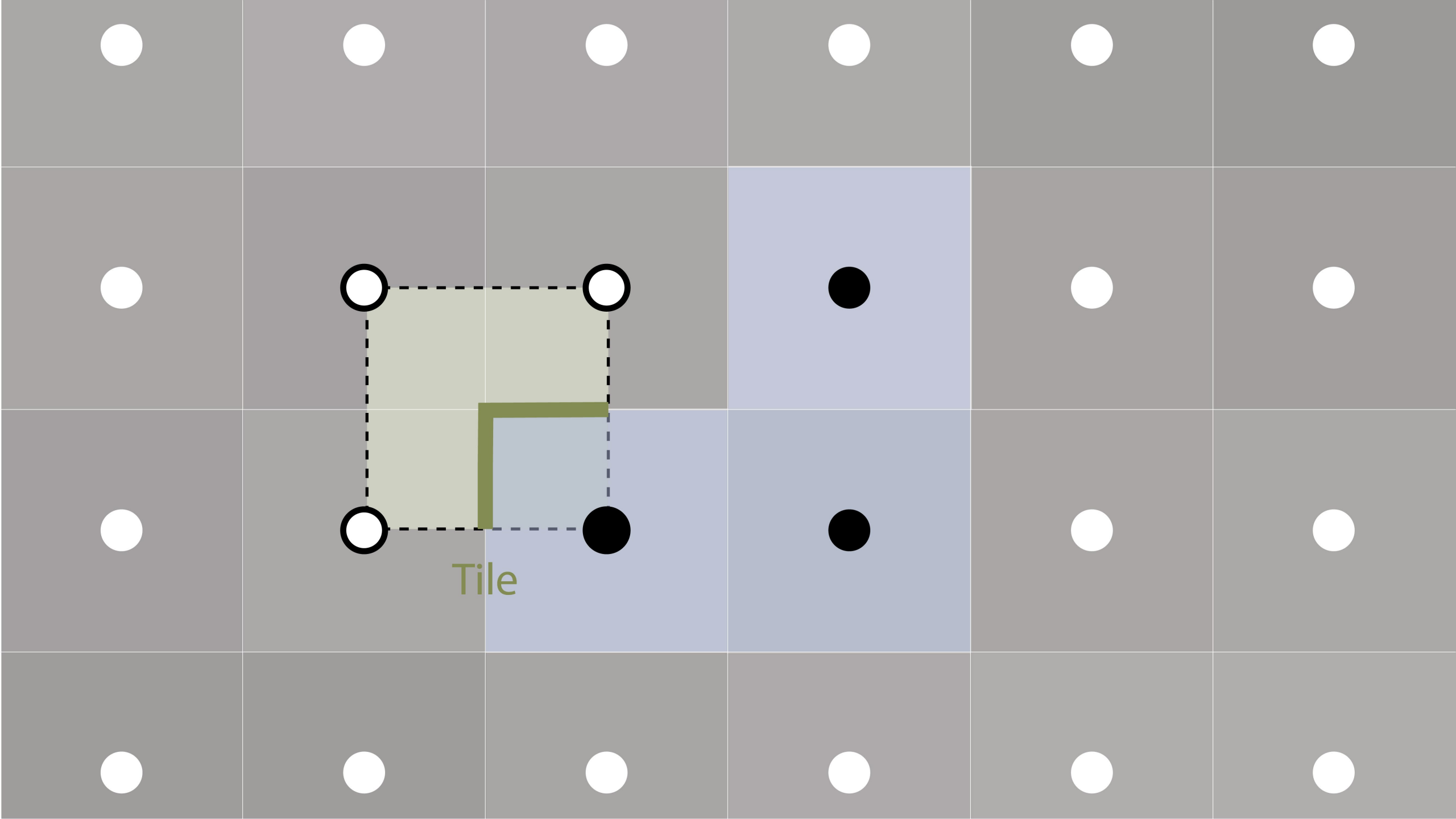




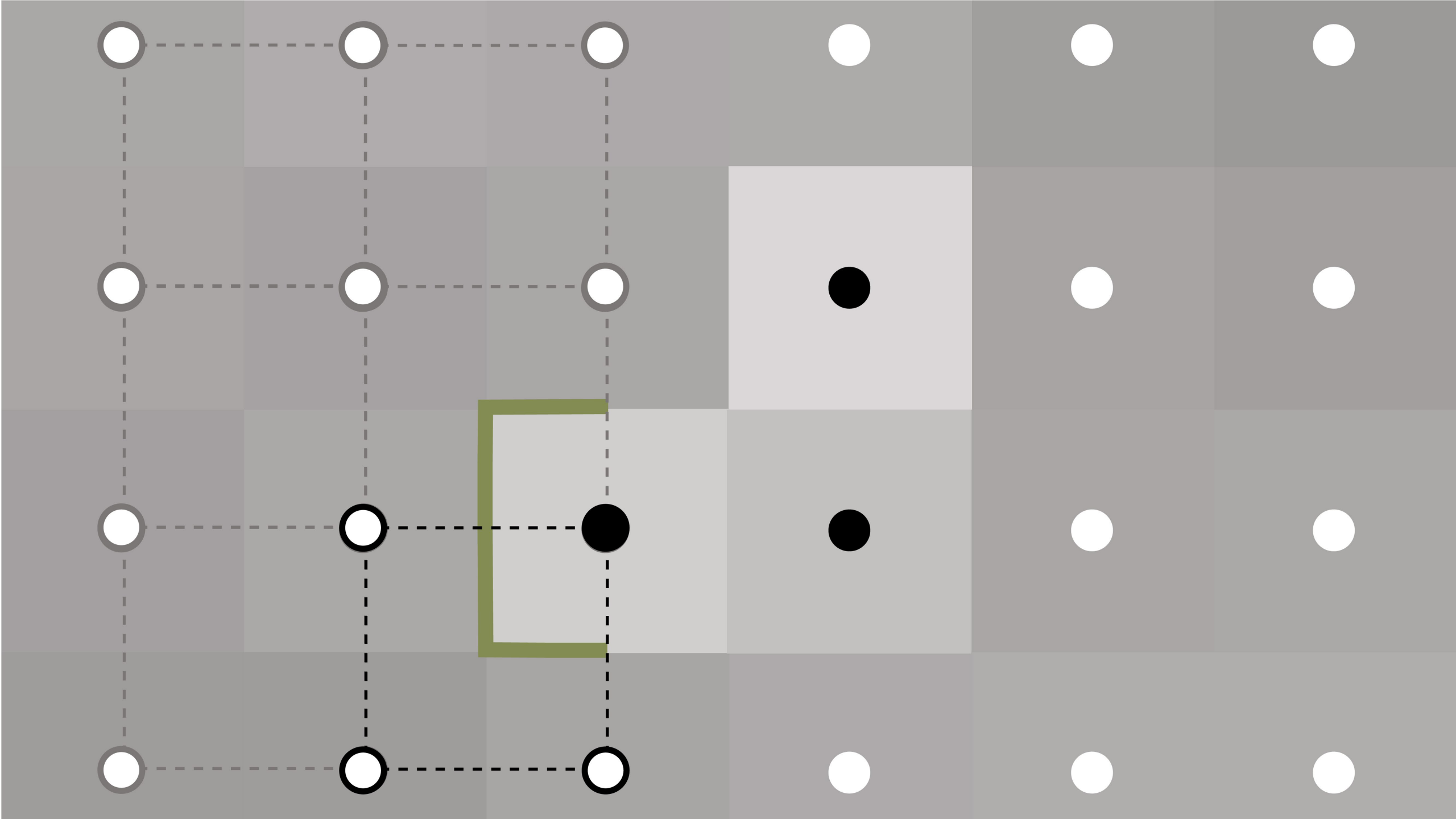


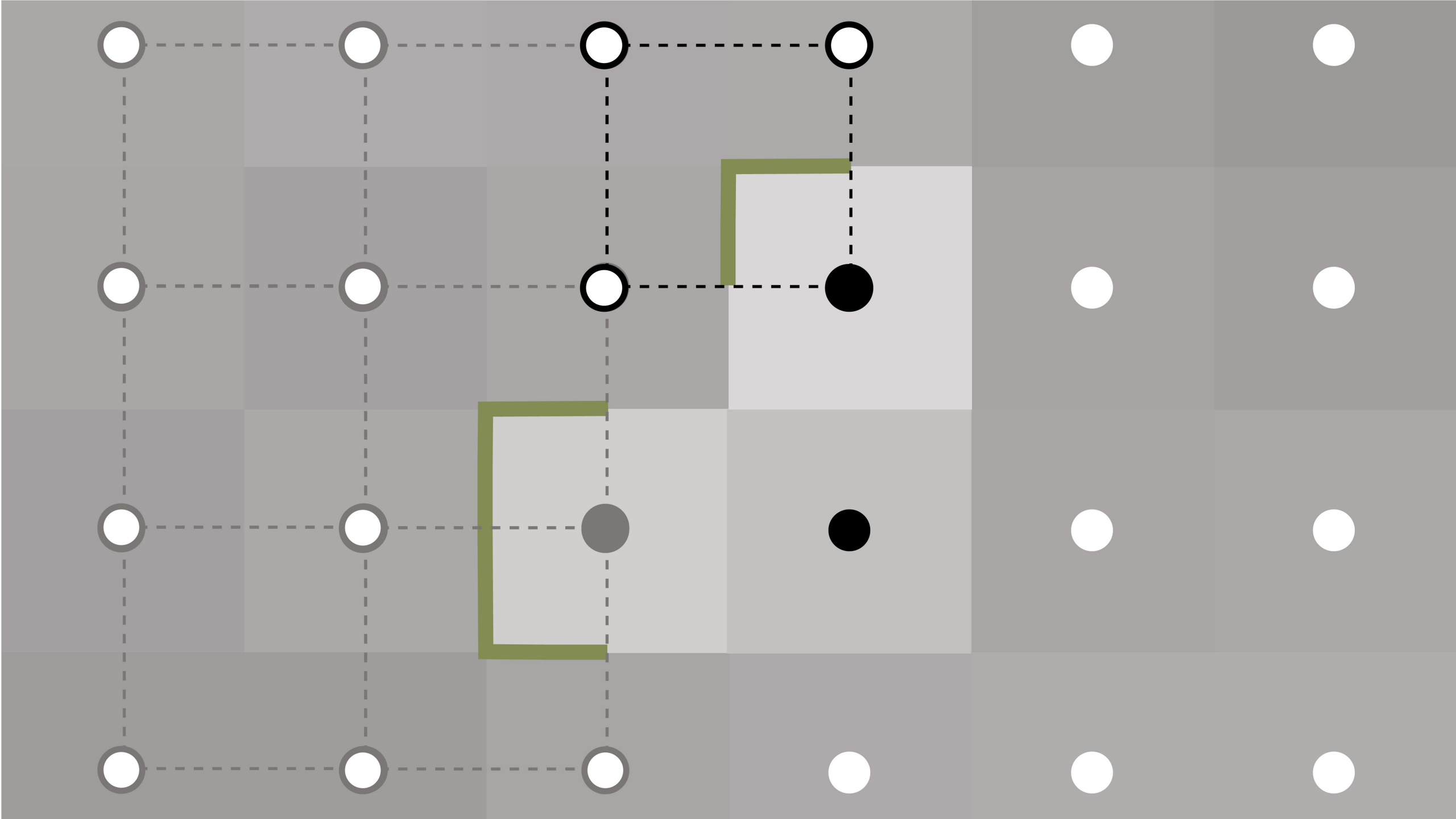


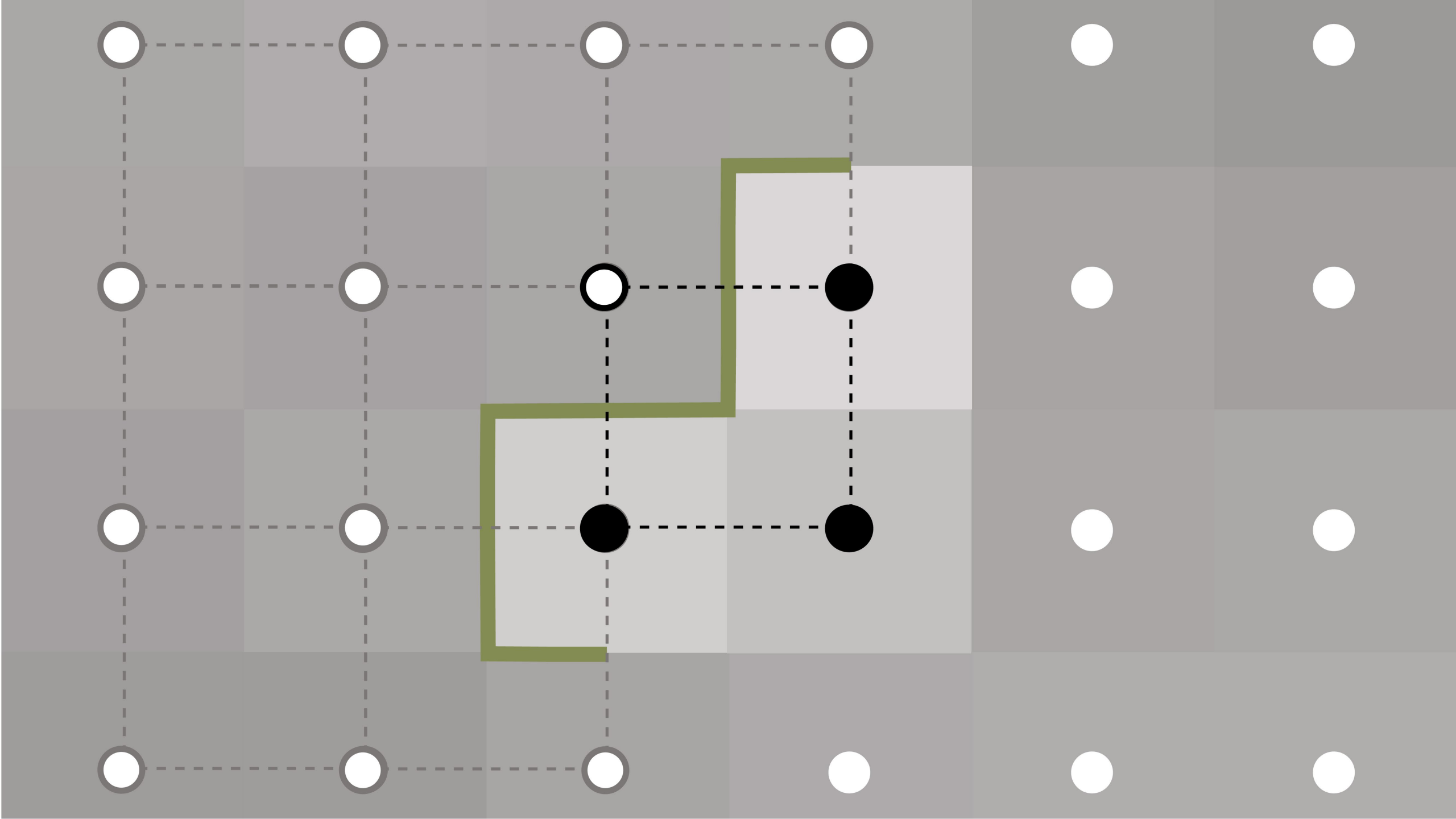


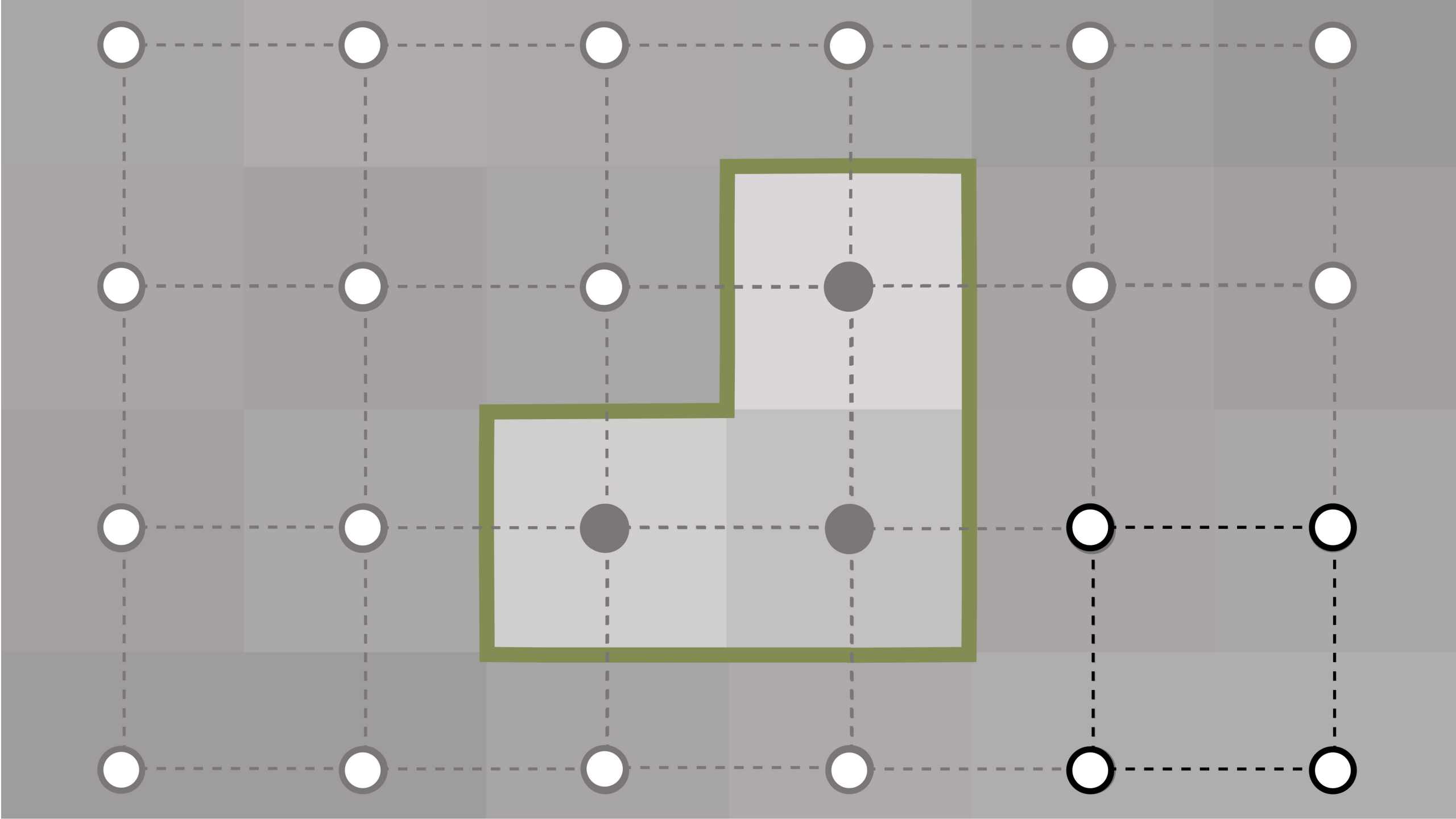


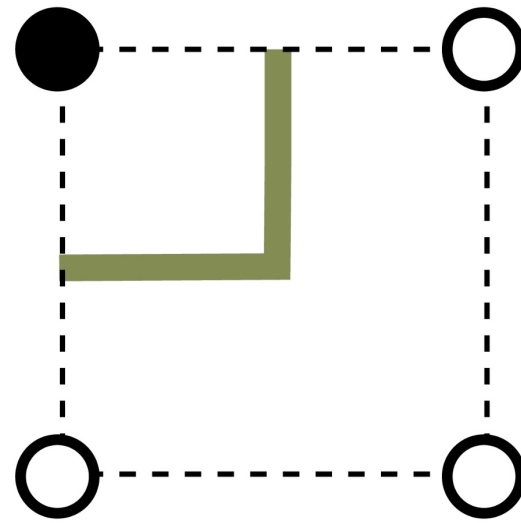
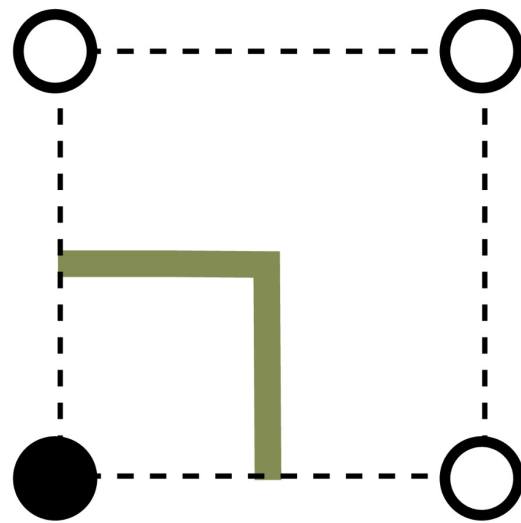
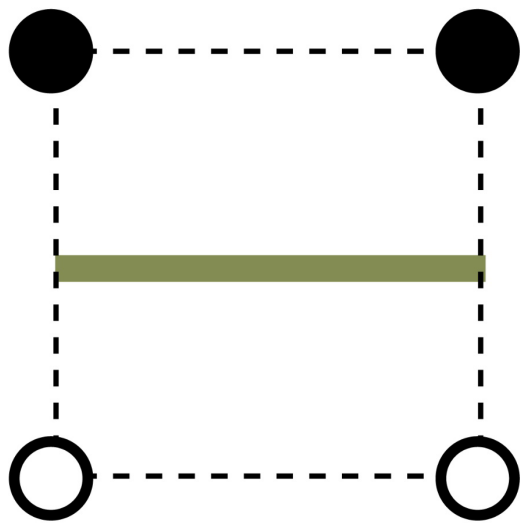
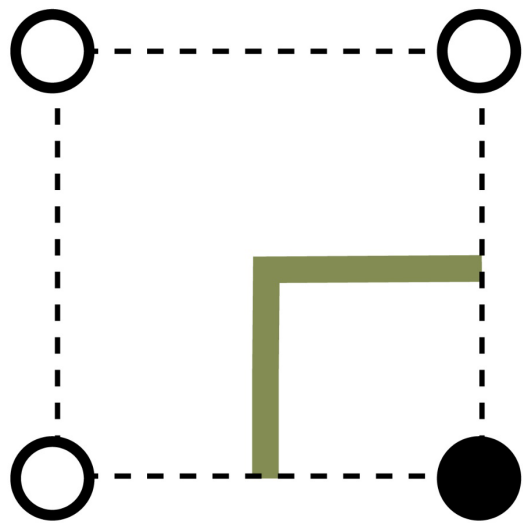
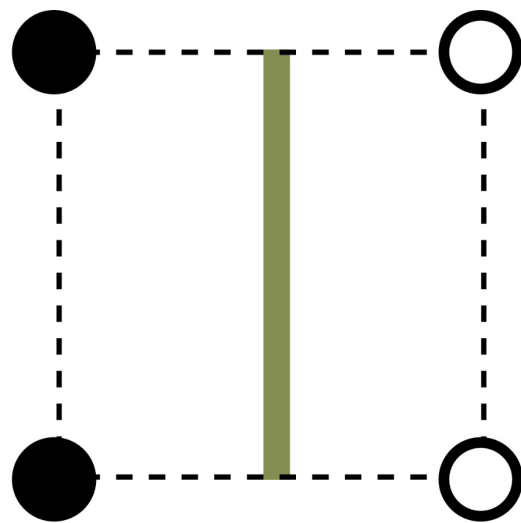
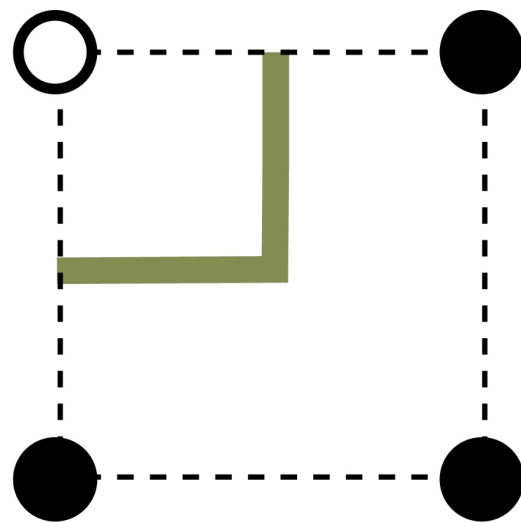
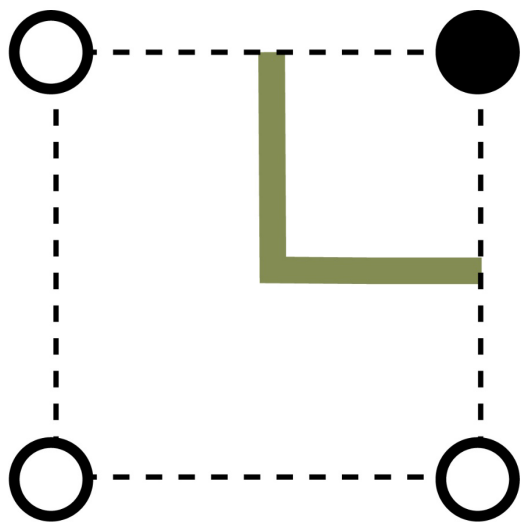
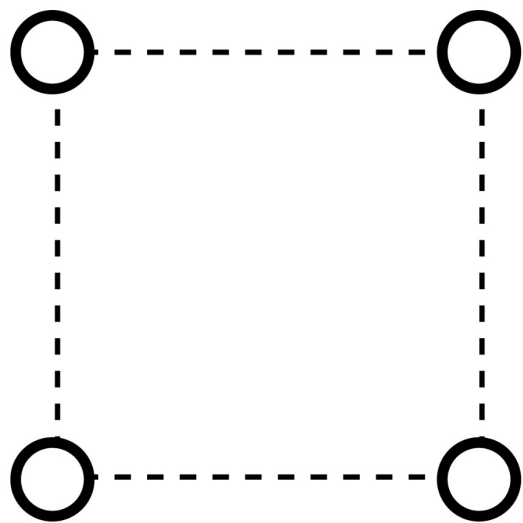
Tile

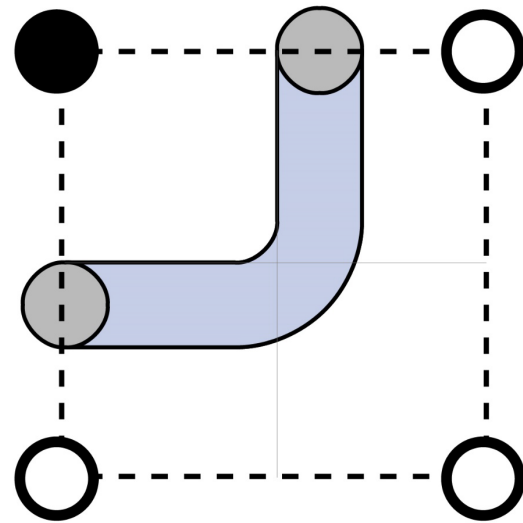
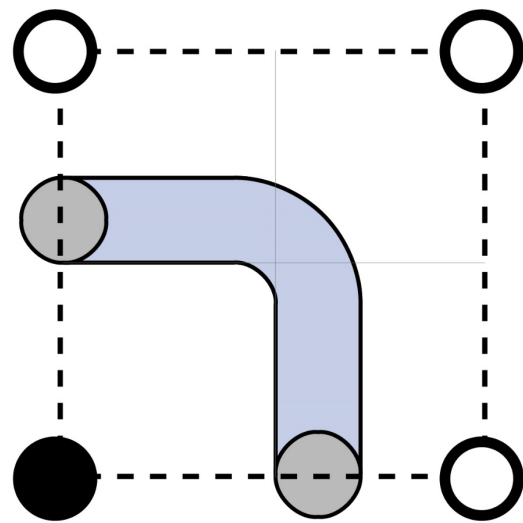
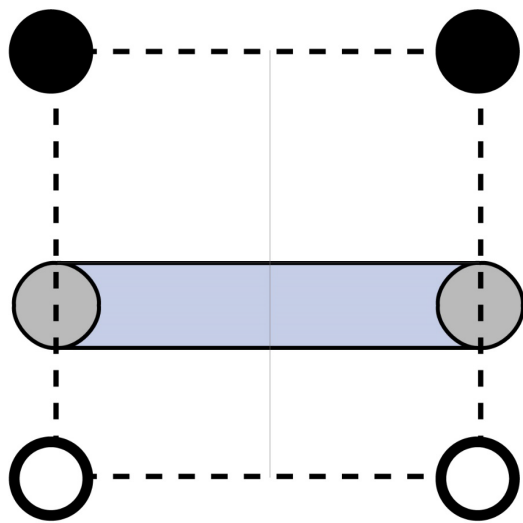
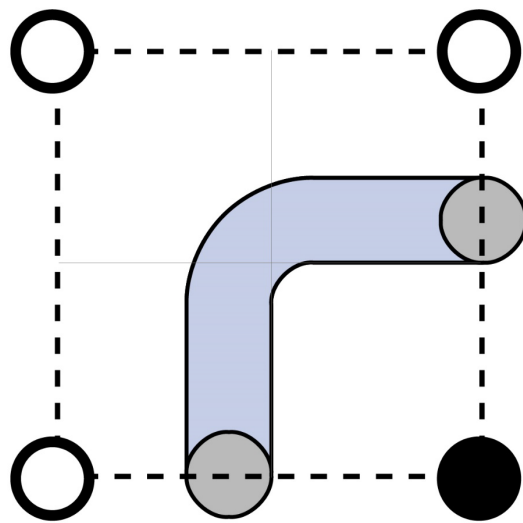
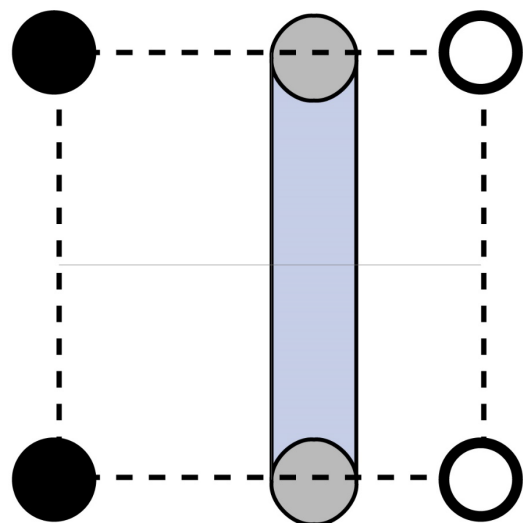
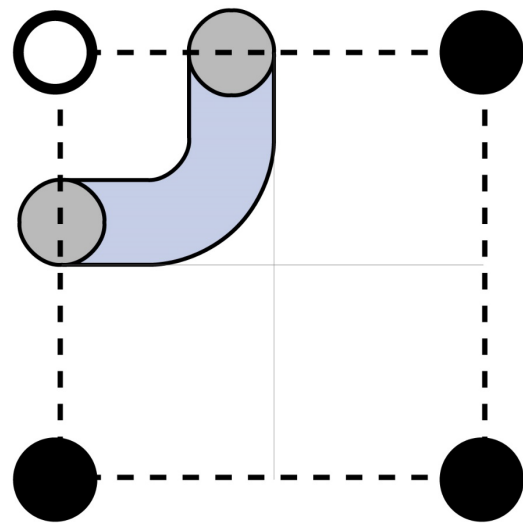
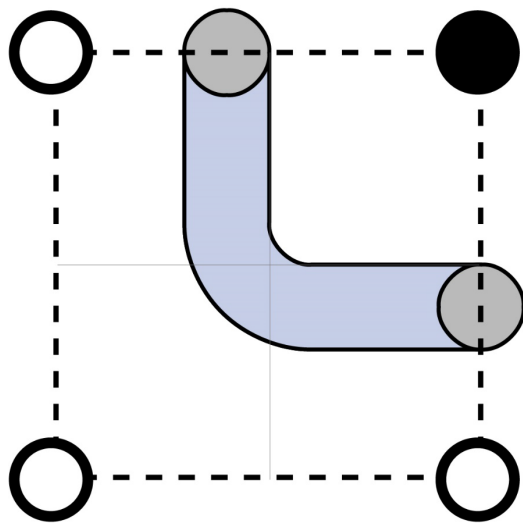
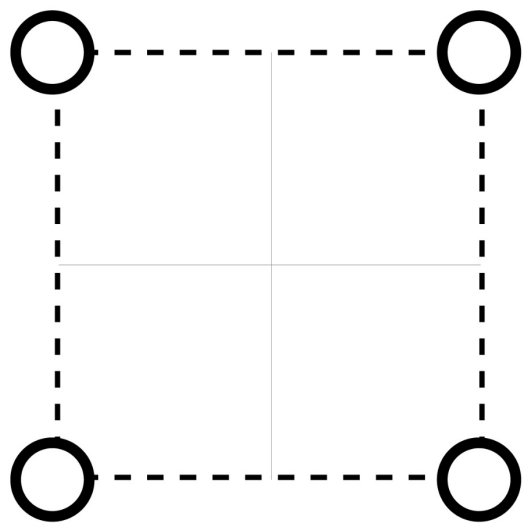


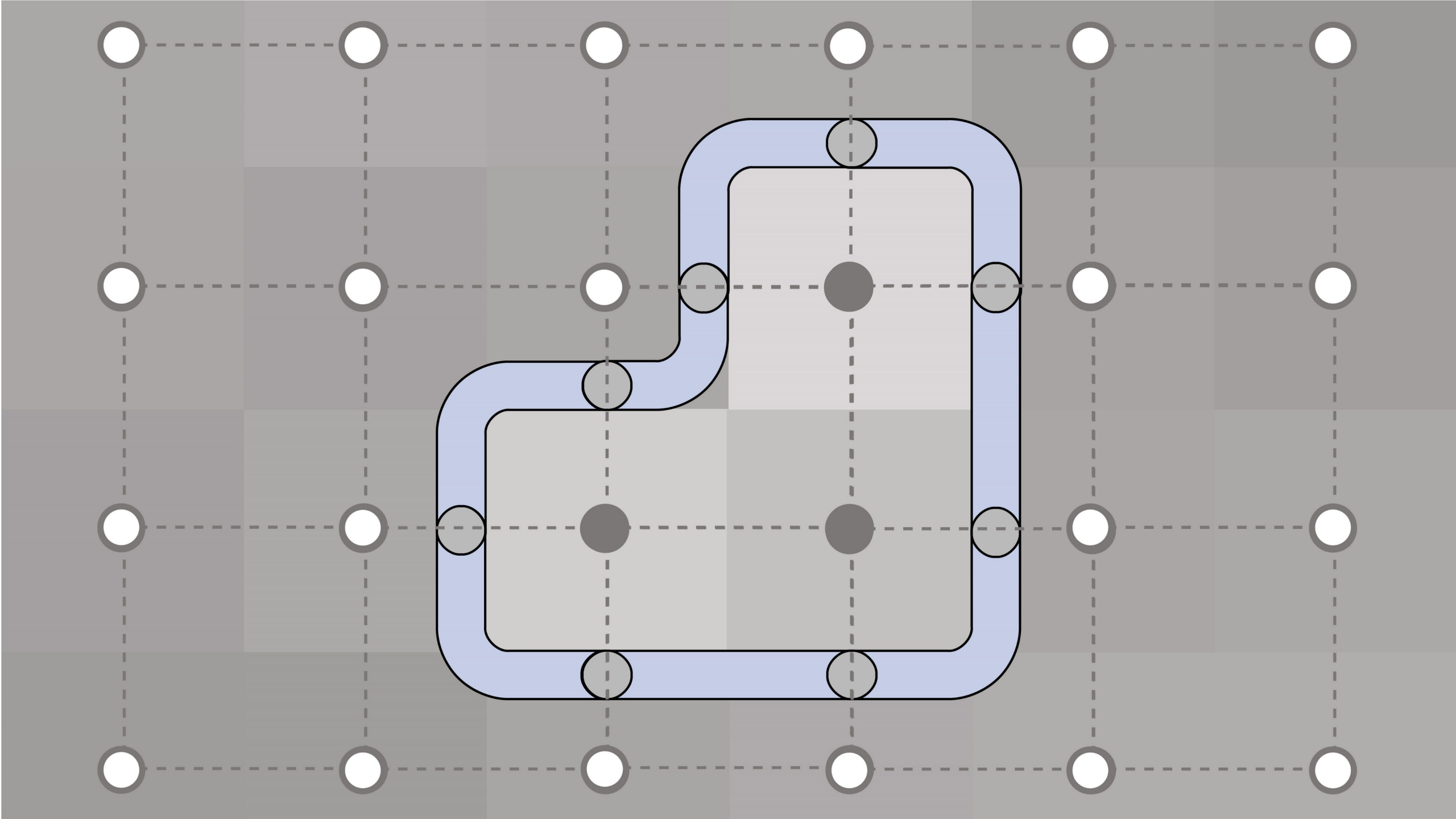


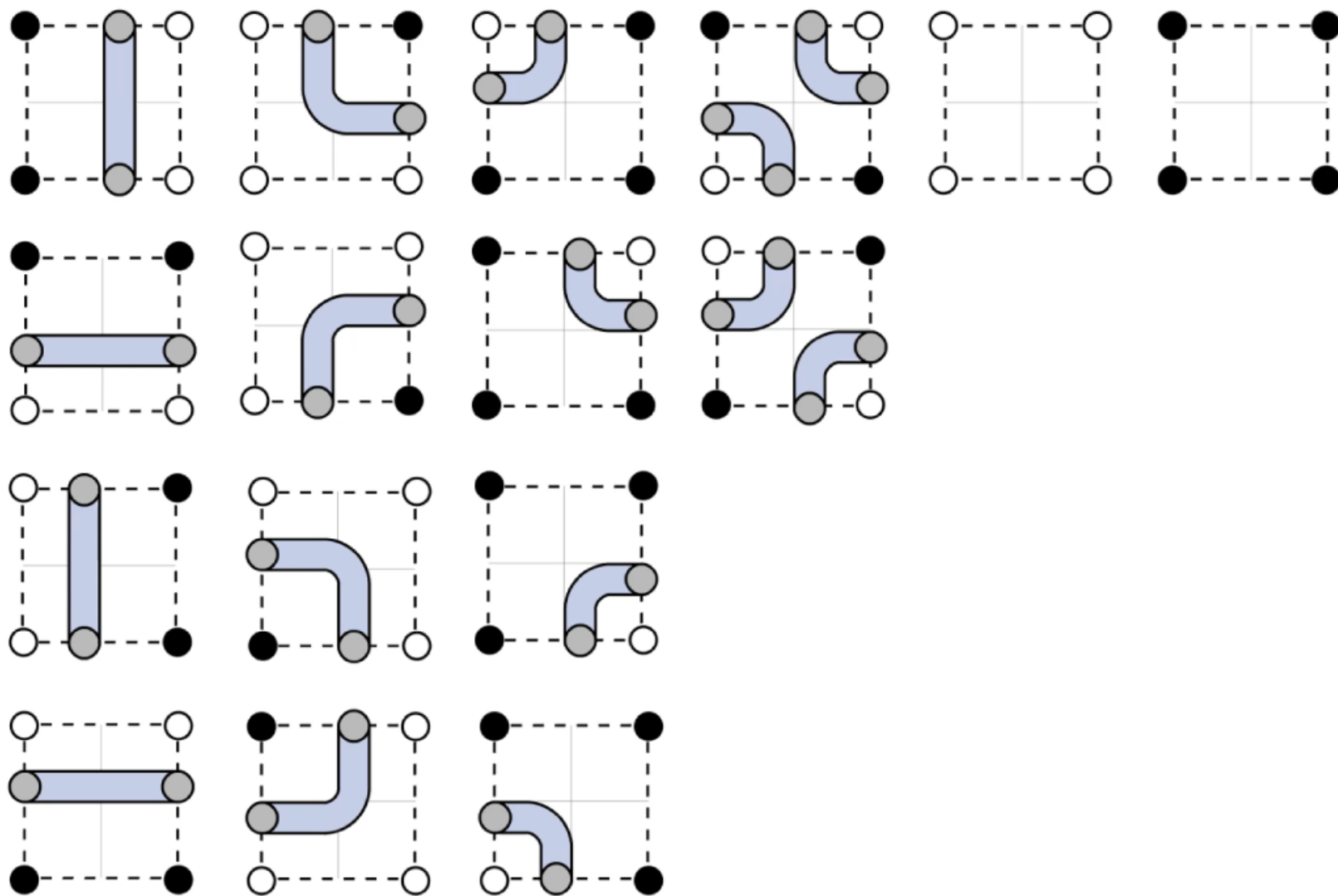


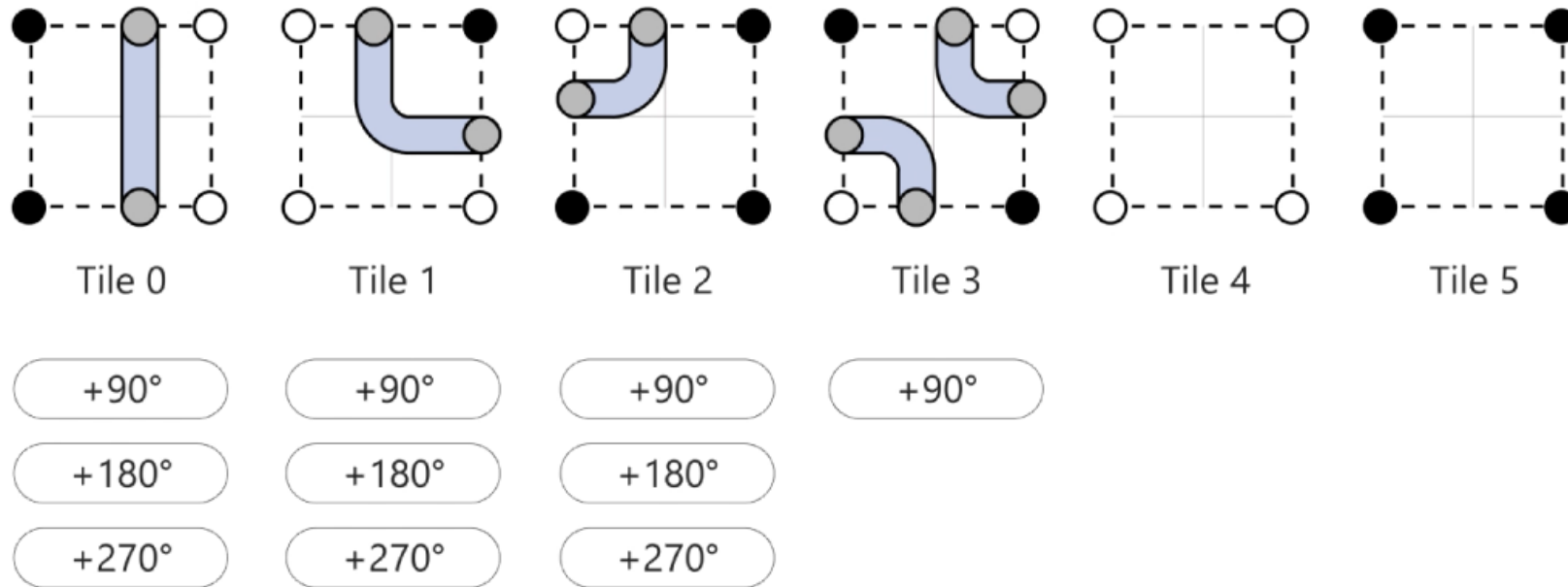


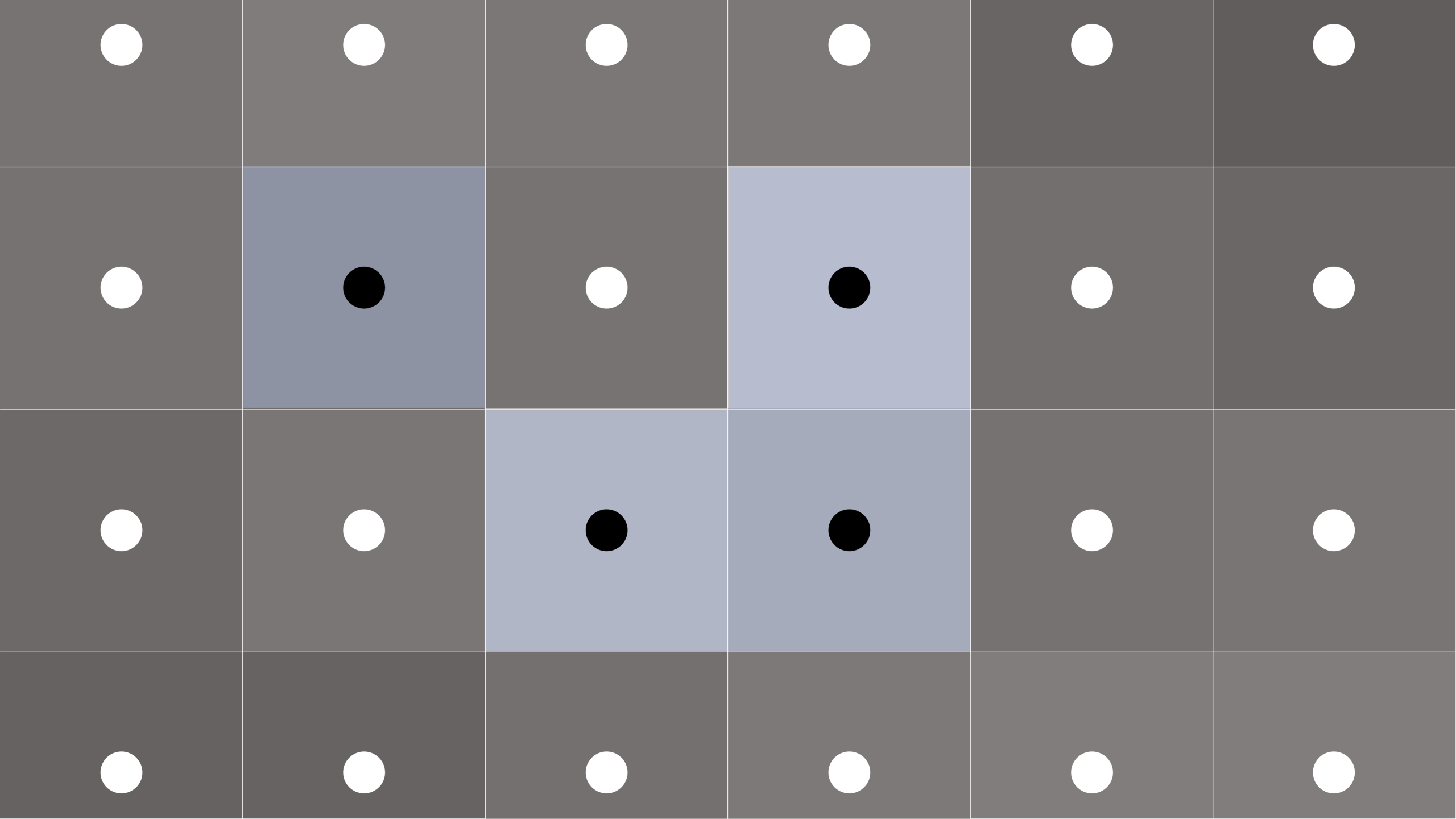


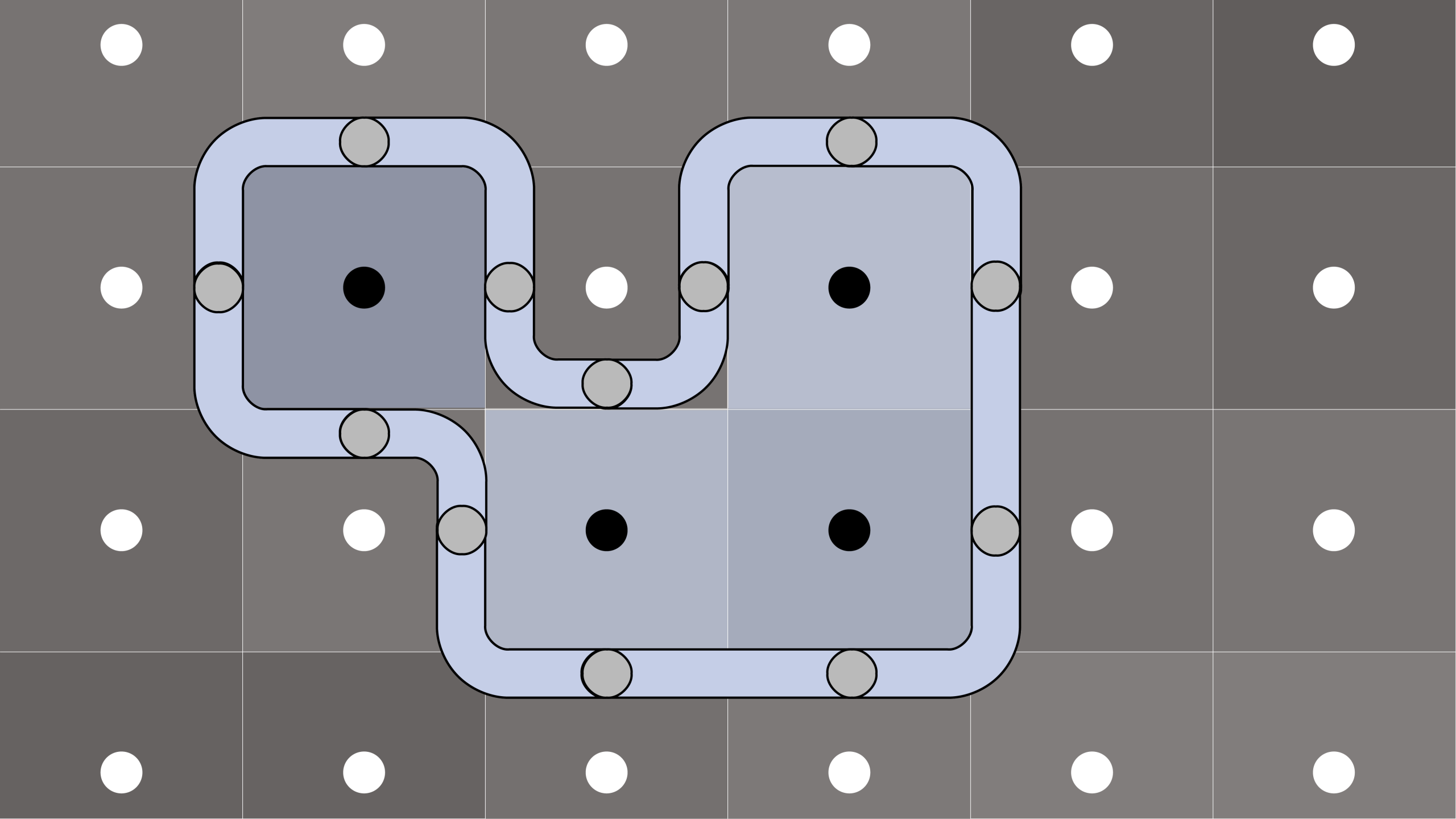


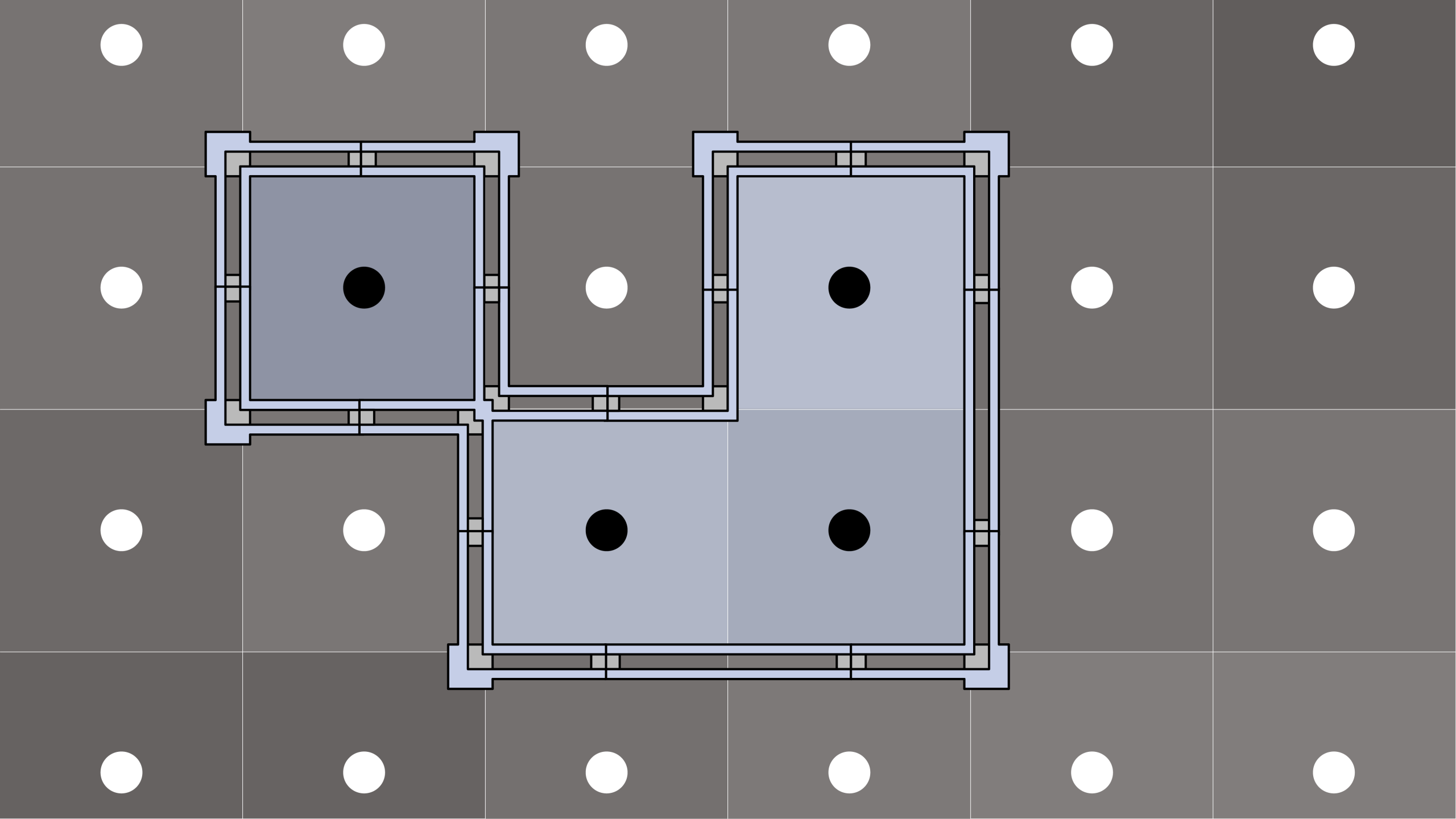




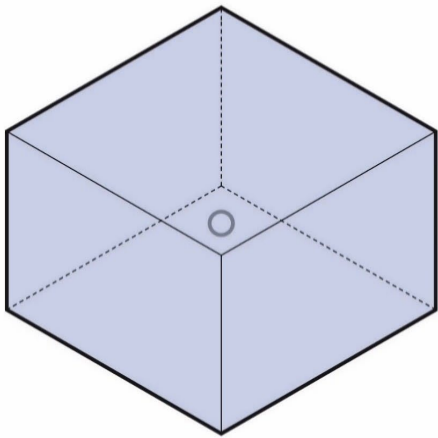




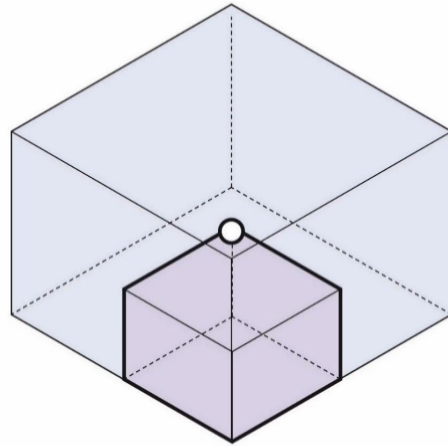




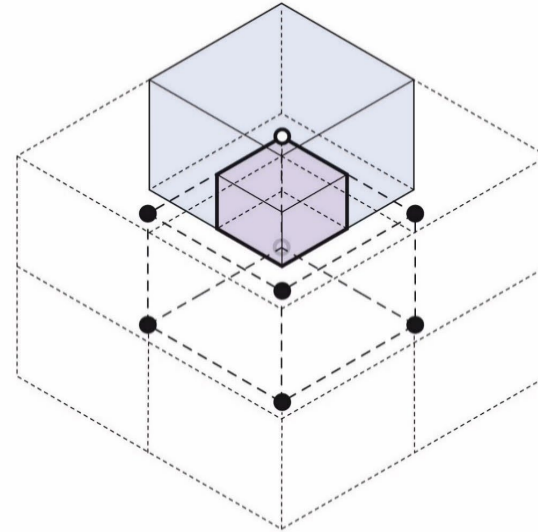
Third Dimension



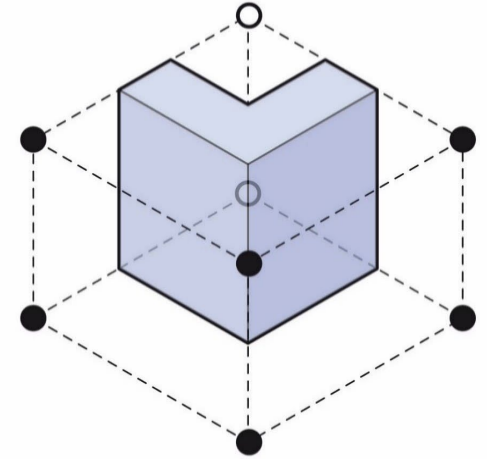
Voxel



Sub-Voxel

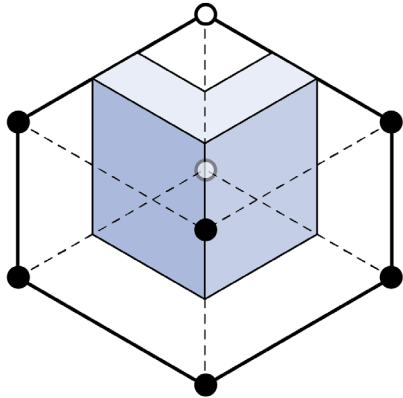
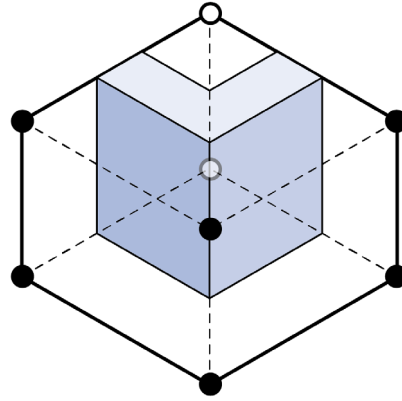


Cube

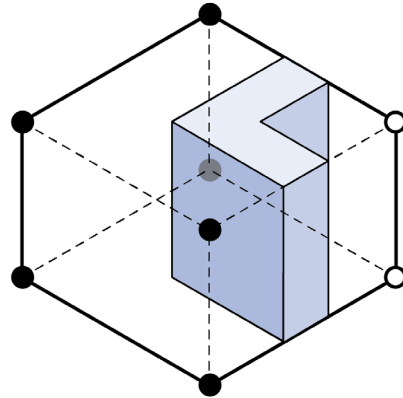


Computational Tile

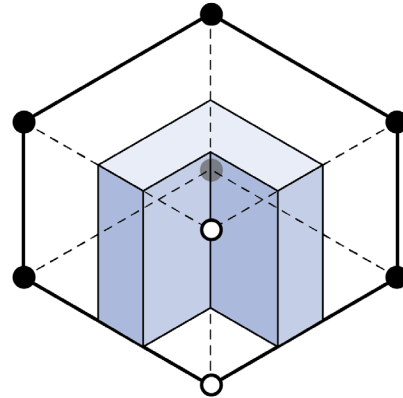
Reducing the Cubes



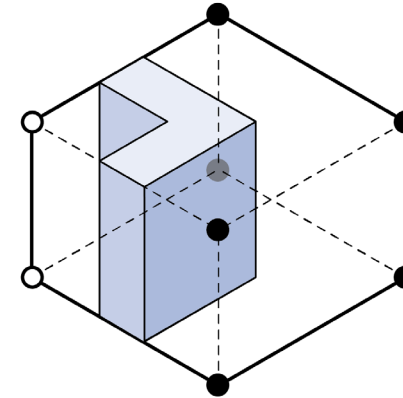
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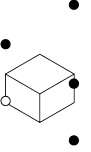
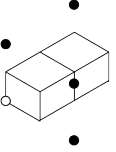
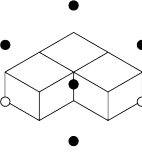
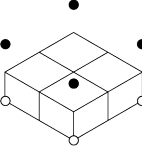
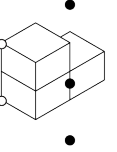
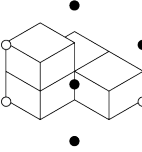
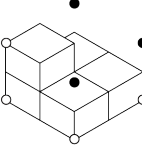
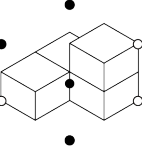
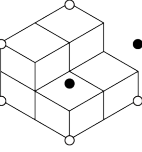
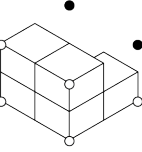
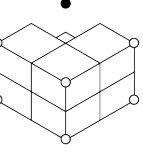
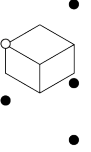
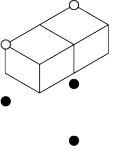
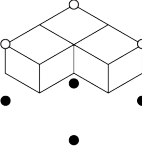
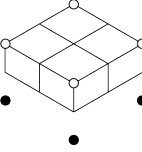
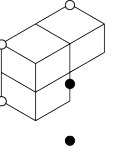
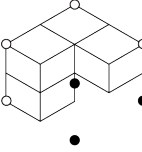
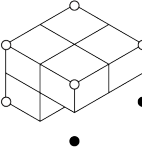
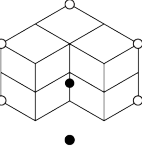
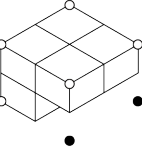
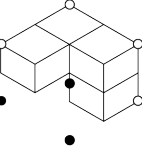
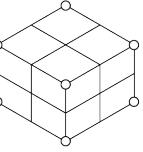
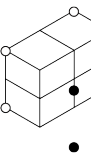
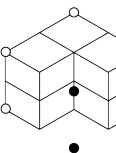
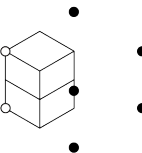
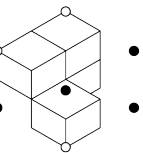


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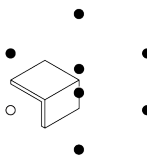
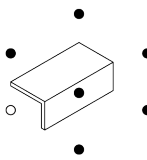
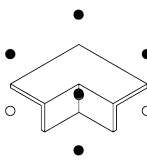
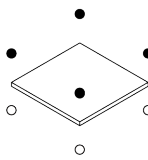
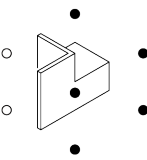
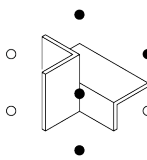
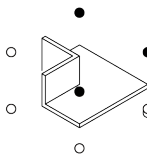
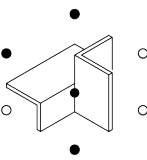
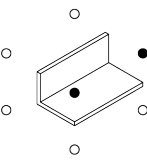
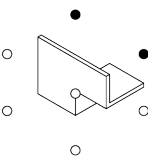
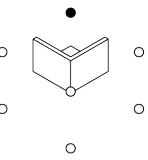
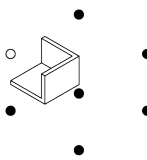
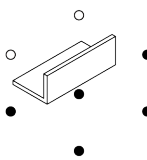
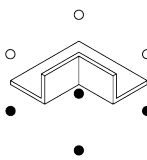
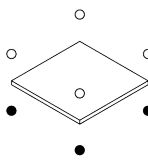
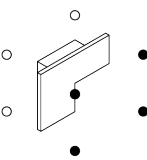
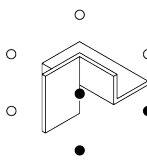
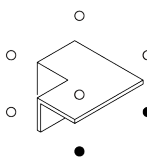
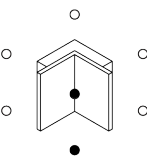
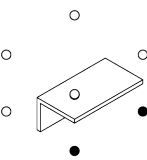
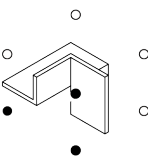
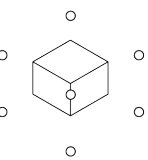
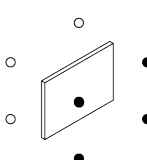
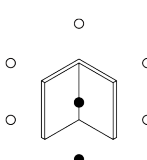
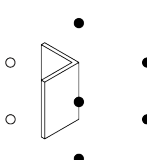
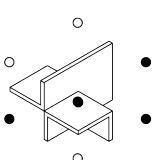


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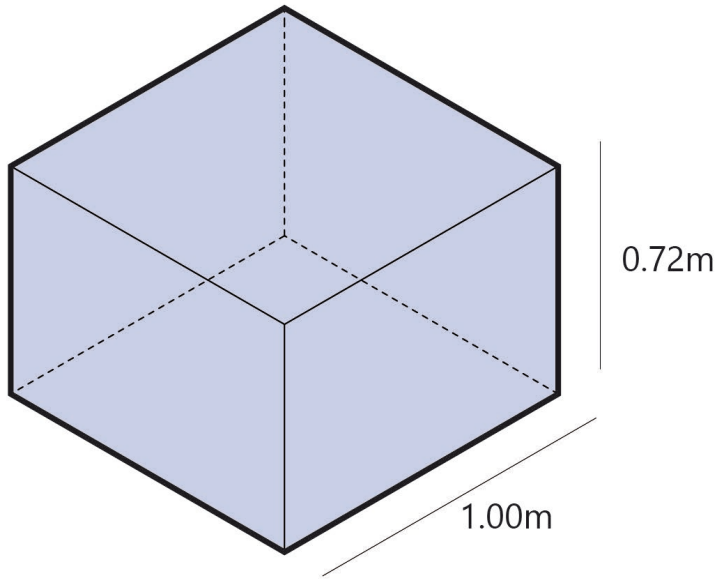
26 Unique Cubes

Roof Cubes											
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Floor Cubes											
	00000010	00000011	00000111	00001111	00100011	00100111	00101111	01100111	00111111	01000111	11101111
Wall Cubes											
	00110011	01110111	00100010								
											Special Cube
											
											10010011

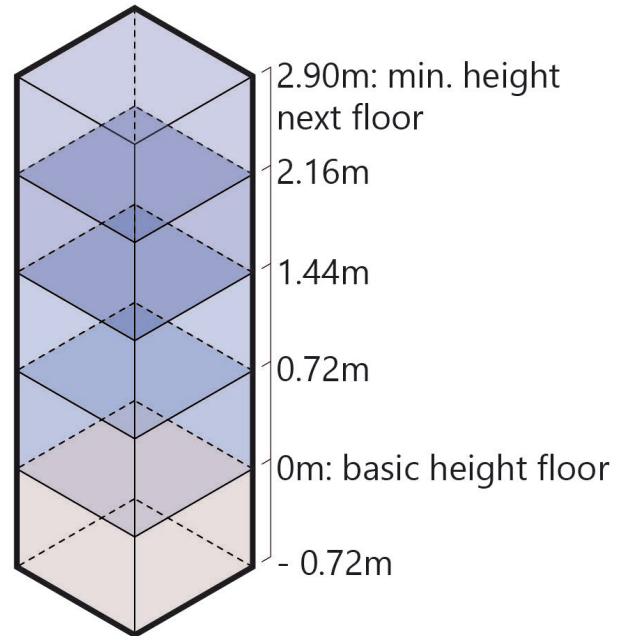
26 Unique Tiles

Roof Tiles											
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Floor Tiles											
	00000010	00000011	00000111	00001111	00100011	00100111	00101111	01100111	00111111	01000111	11101111
Wall Tiles											
	00110011	01110111	00100010								
Special Tile											
											10010011

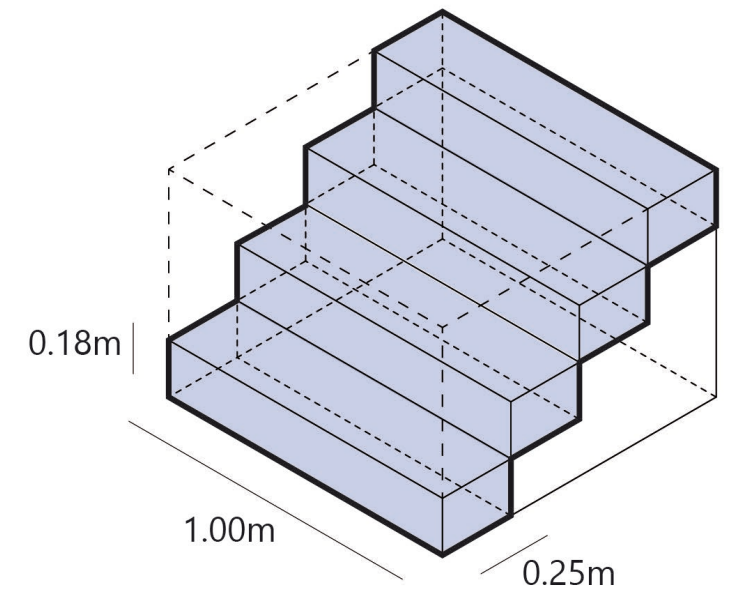
Dimensioning



Basis Voxel

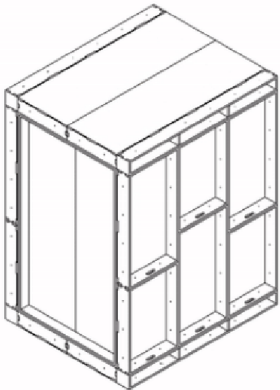
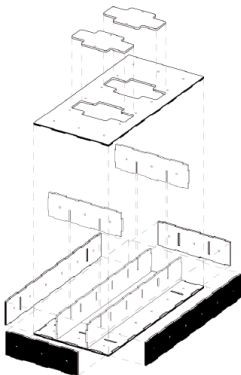
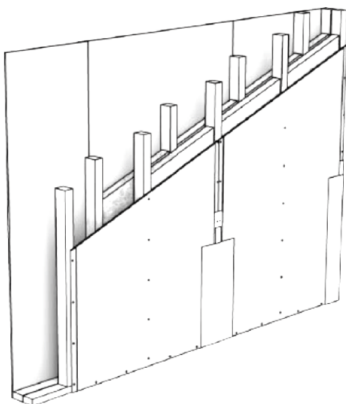


Voxel / Floor Relation



Voxel / Stair Relation

Developing an Infill System

System Name	Studio Bark UBuild	AUAR Home Office (ALIS Building Blocks)	Knauf W12 (wooden stud wall)
Visualization			
Prefabrication	✔ prefabricated frames	✔ complete prefabricated elements	✘ no prefabarication
Connection Type	In Element: Screws Element/ Element: Bolts and Nuts	In Element: Screws Element/ Element: Bolts and Nuts	Wood Screws
Materiality	18 mm plywood frame + cover	plywood frame, reinforcement + cover	sqared timber profiles (ca. 60x60) + gypsum cardboad cover
Discrete Elements	✔	✔	✘

Basic Module

Universal Screw Countersunk Head, 5x70

PartID: 1

Squared Timber Spruce 50x100

PartID: 4

OSB Board 15 mm, 720X1000

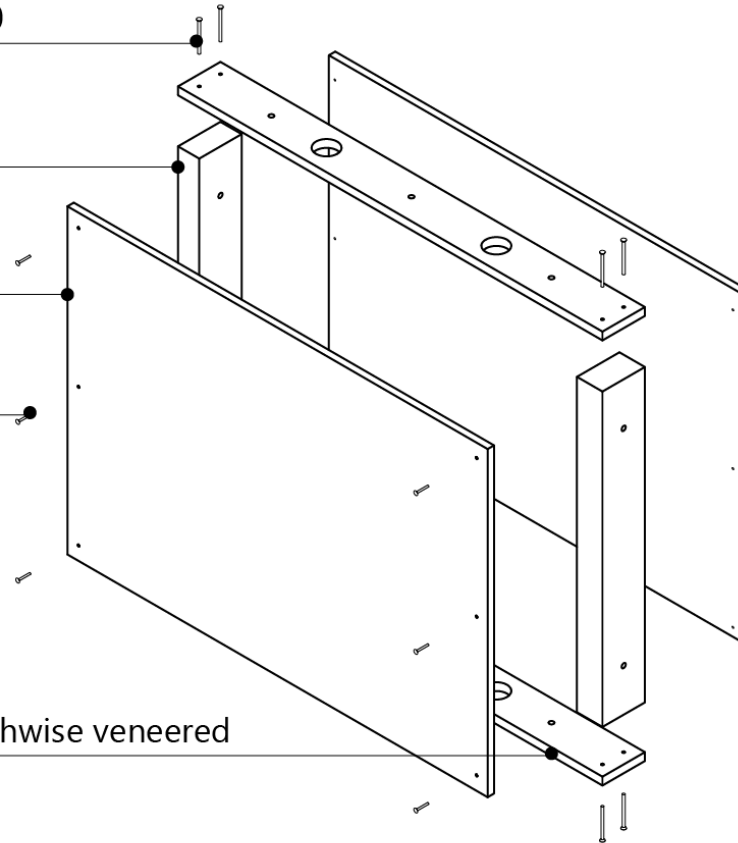
PartID: 3

Hexagon Nut M8 galvanized

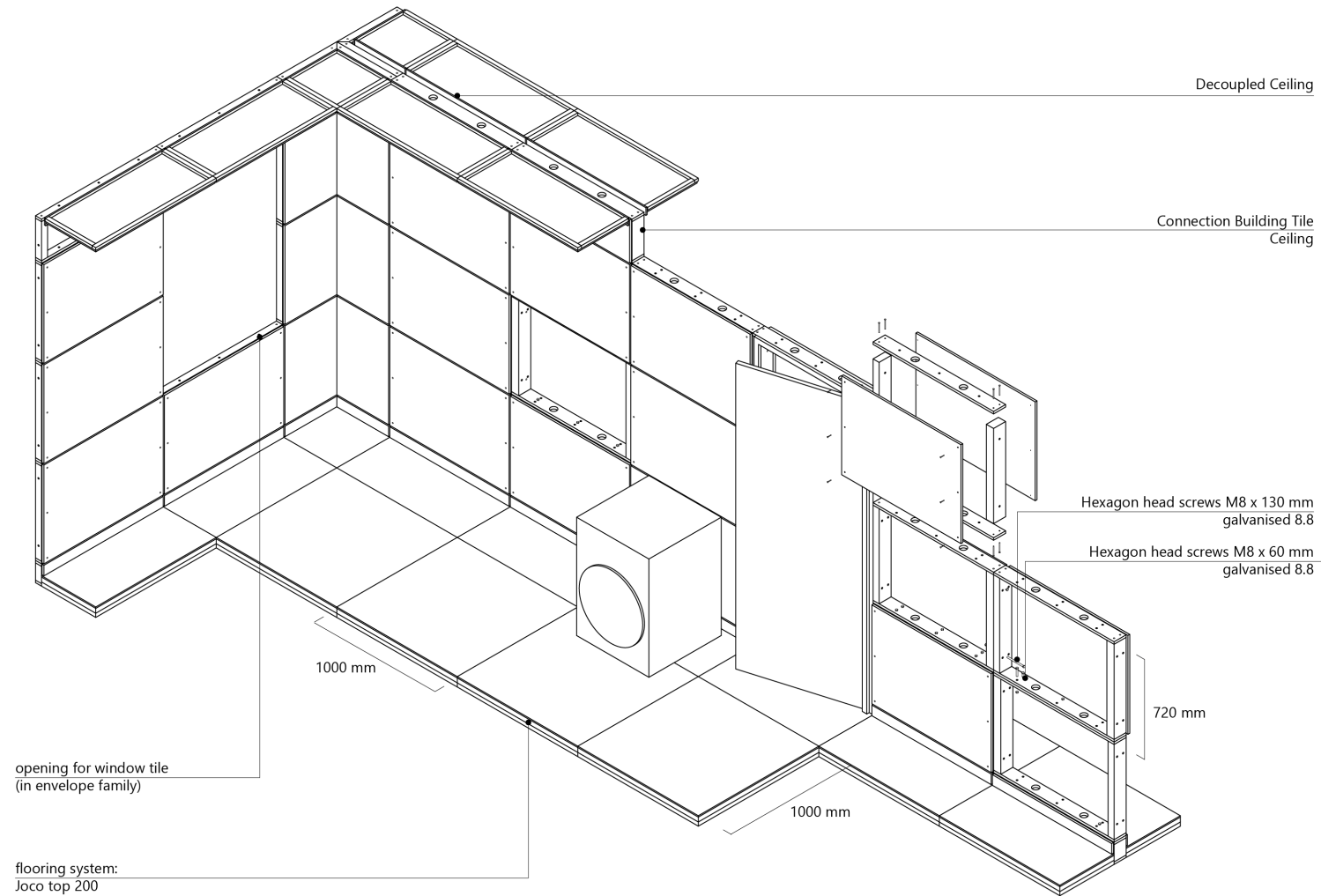
PartID: 2

Plywood 18mm, Poplar, IF20, B/BB, lengthwise veneered

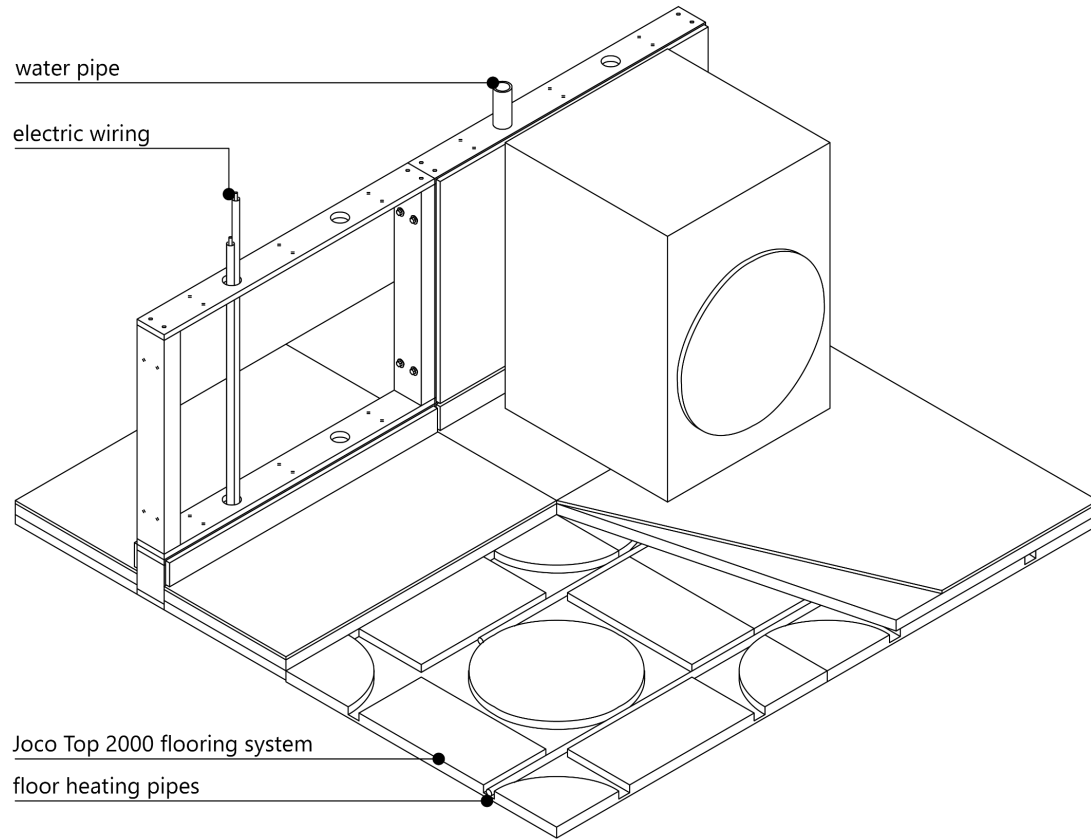
PartID: 5



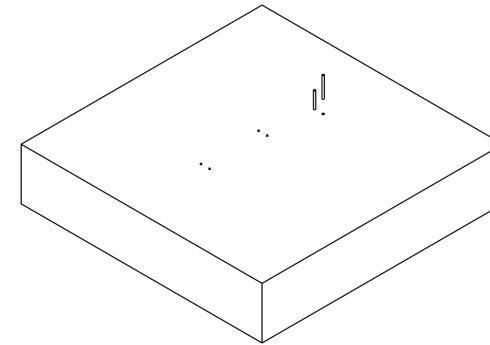
Application in Context



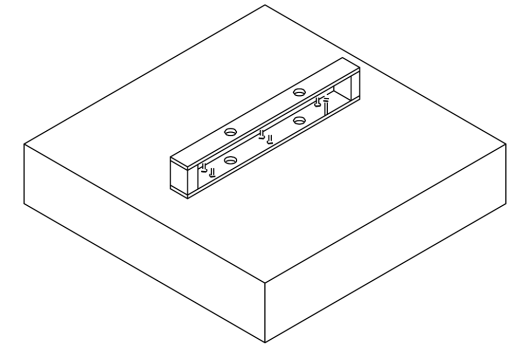
Detailing the System



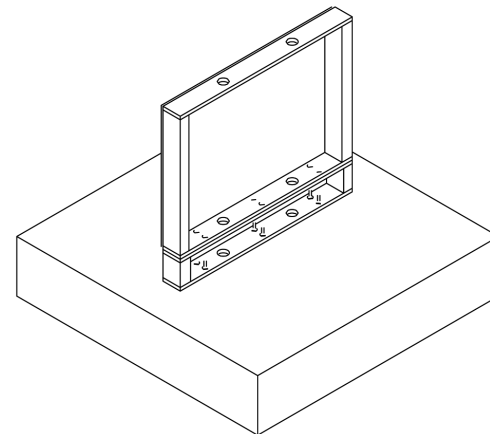
Service Integration



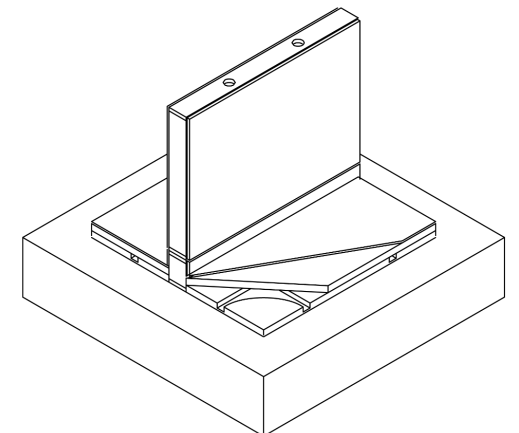
1 install rods on concrete plate



2 mount wall connector



3 install wall structure



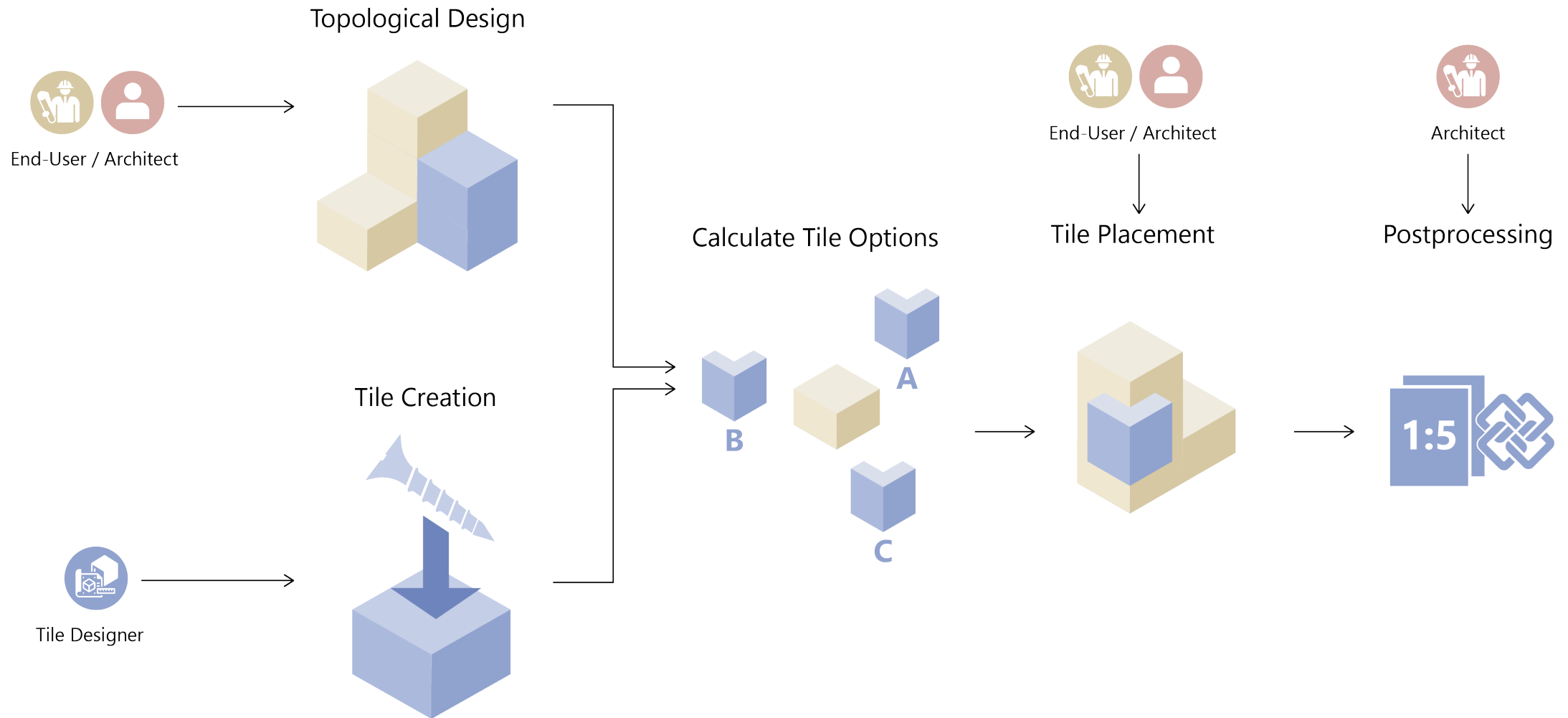
4 install floor + cladding

Assembly

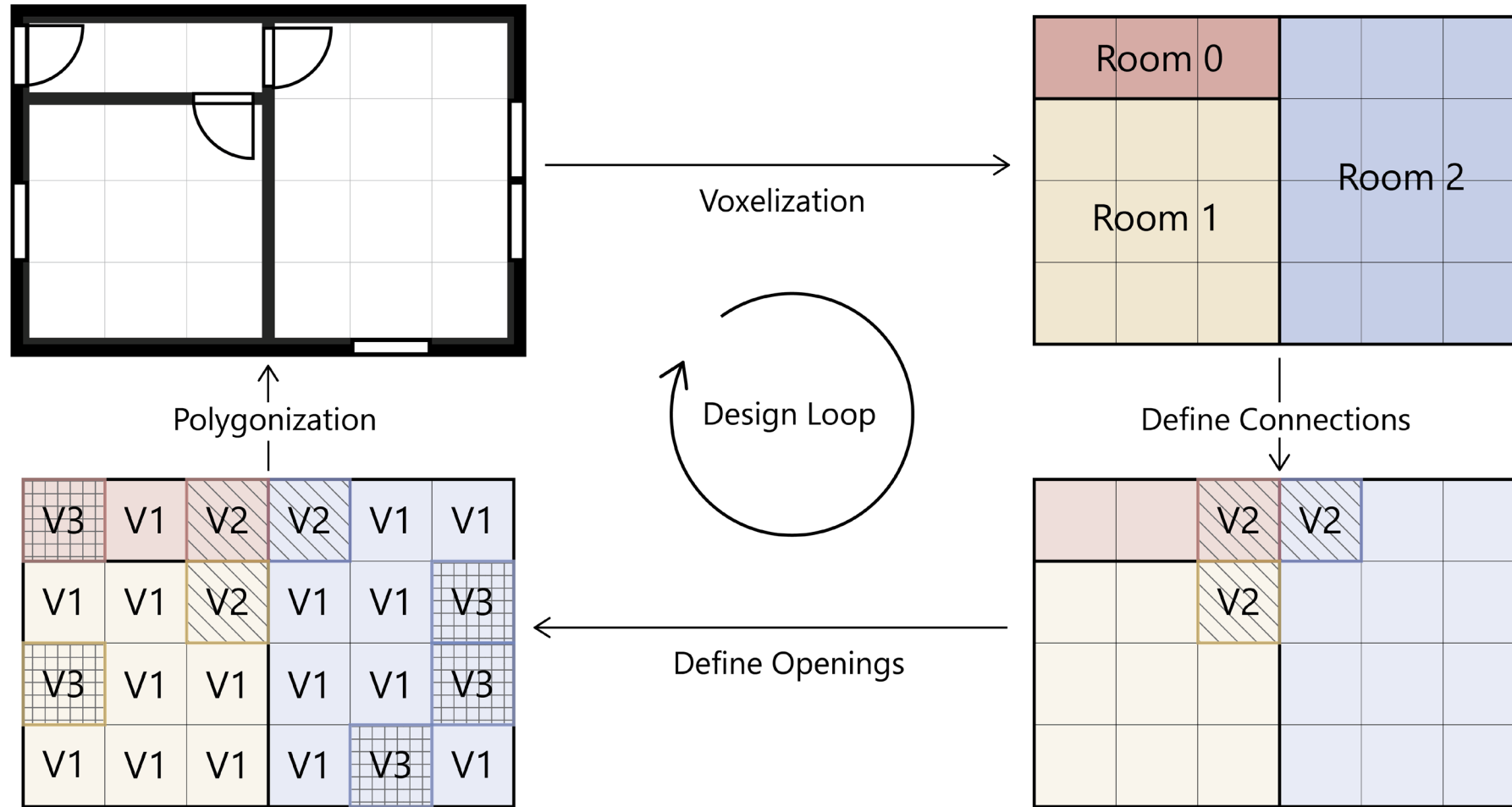
Design Tool



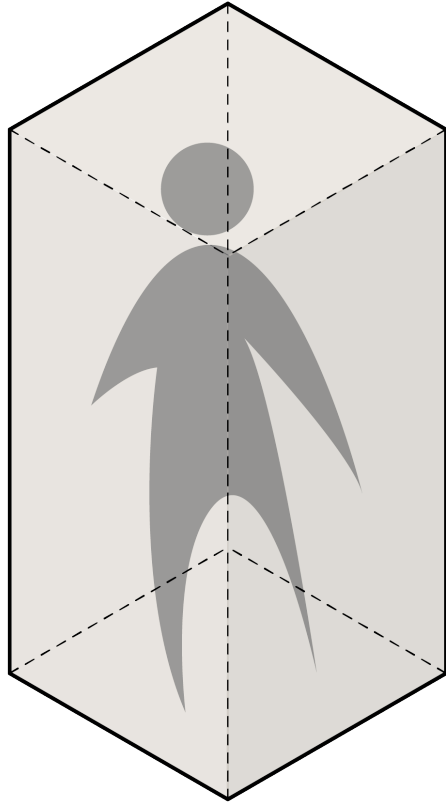
Design Tool Workflow



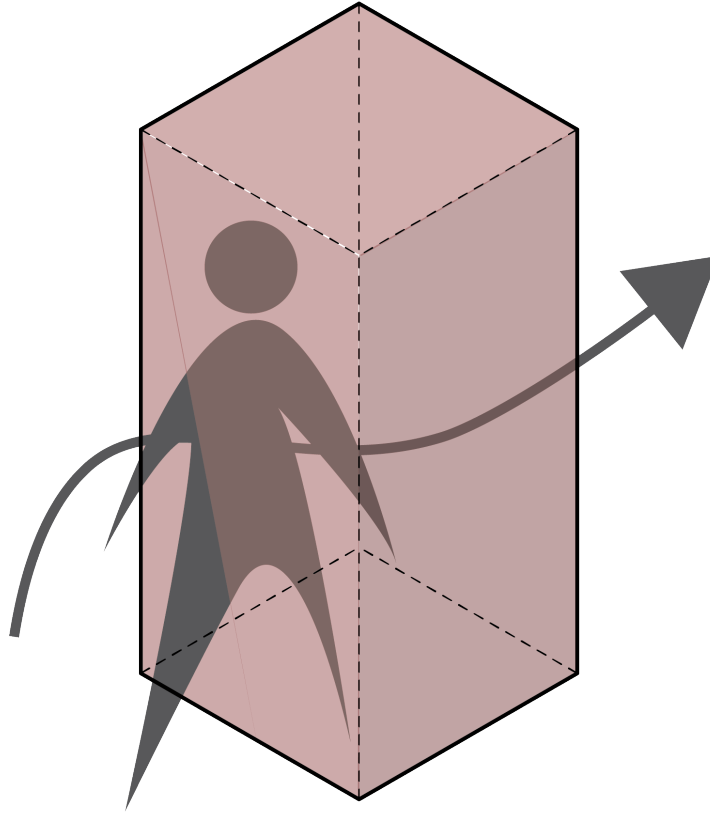
Topological Design



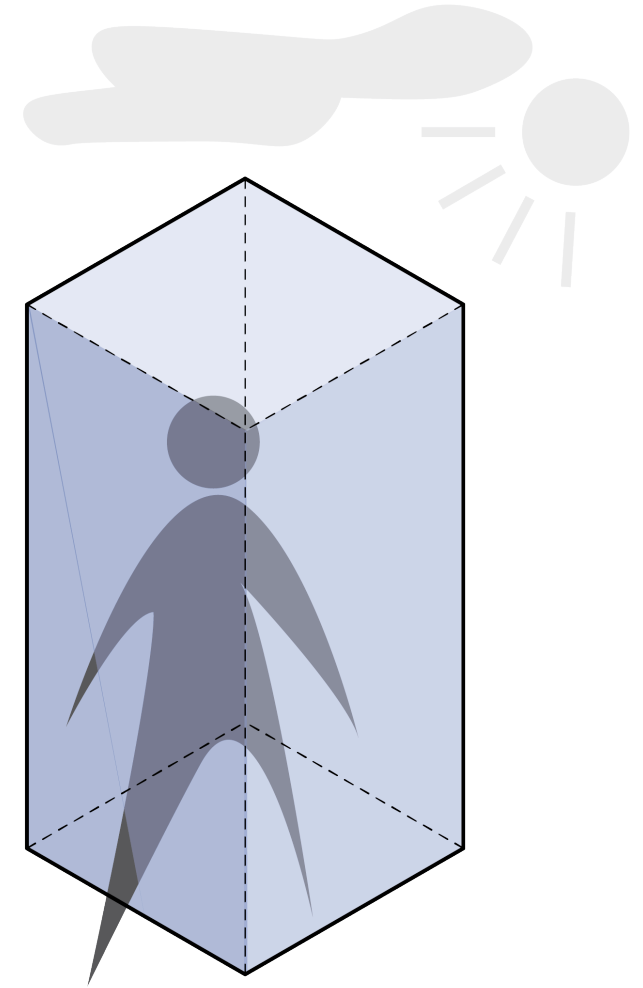
Voxels



Space Voxel

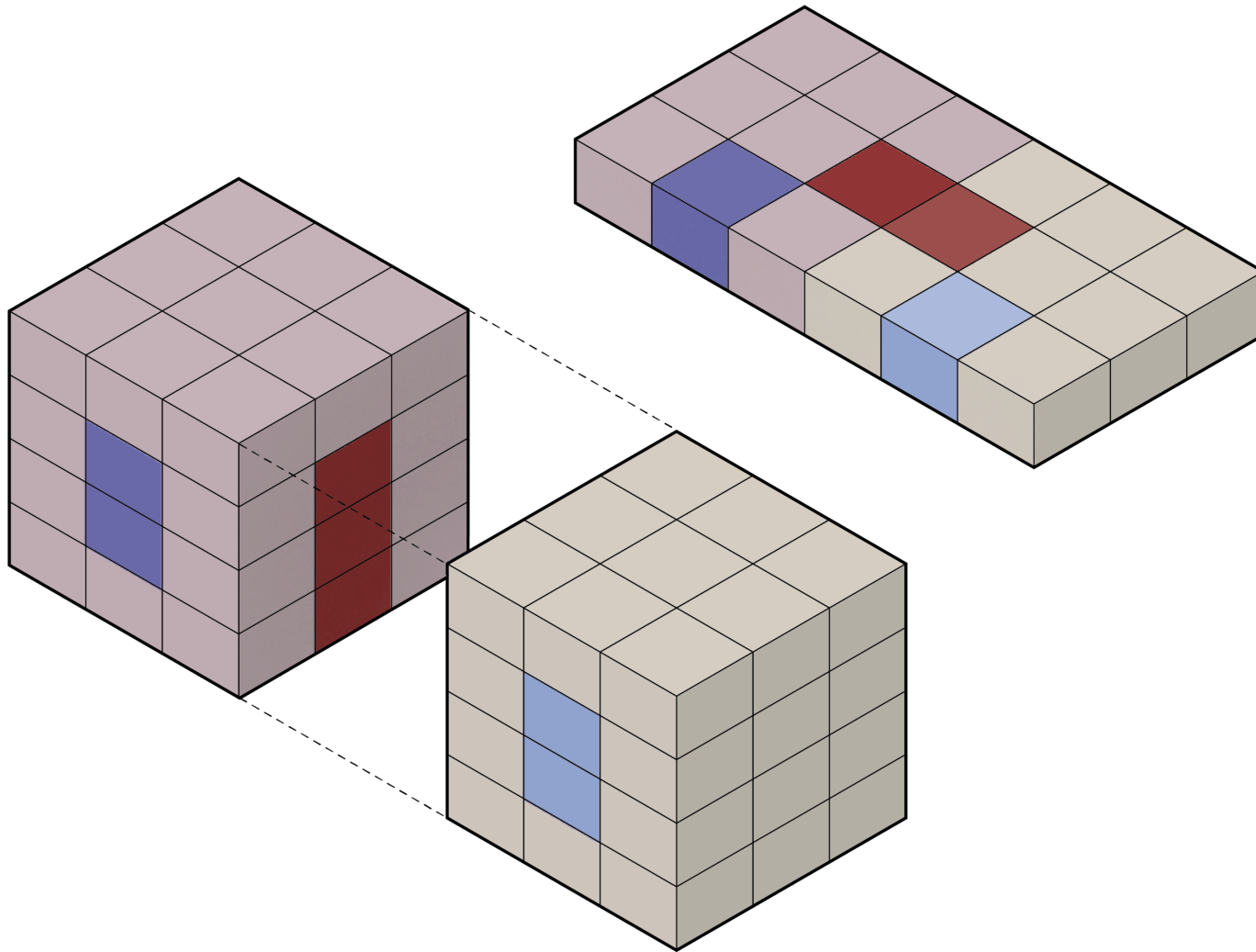


Connection Voxel

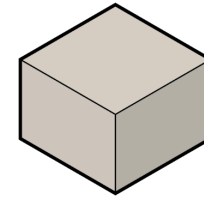


Opening Voxel

Topological Design

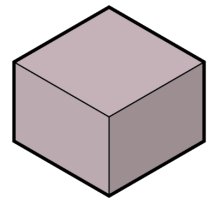


Voxels Room 0

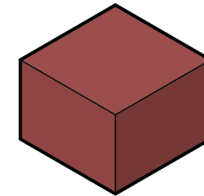


00_1_Room0_Space

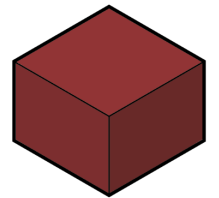
Voxels Room 1



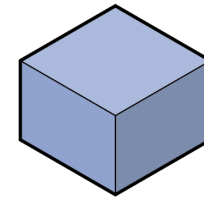
01_1_Room1_Space



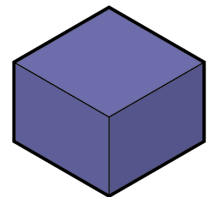
00_2_Room0_Connection



01_2_Room1_Connection

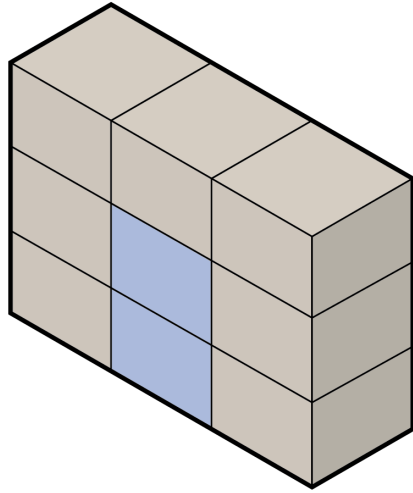


00_3_Room0_Opening

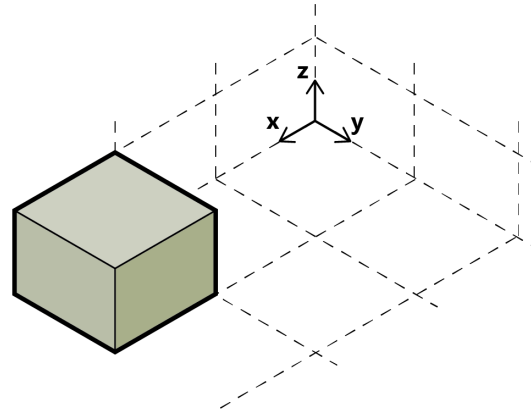


01_3_Room1_Opening

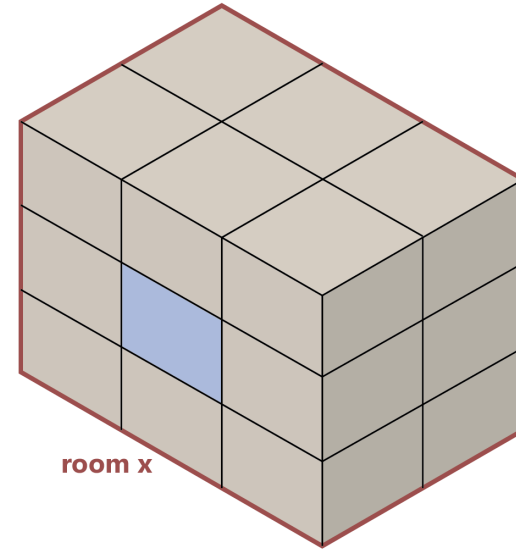
Design Rules



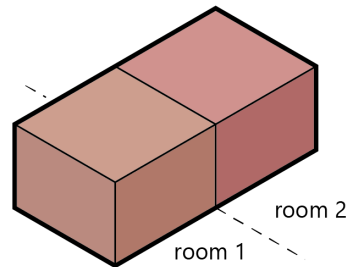
openings and connections need to be surrounded by space tiles, except to the floor



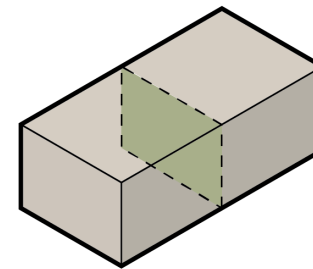
voxels can only be placed in the predefined grid



in one room, only voxels related to that room can be placed

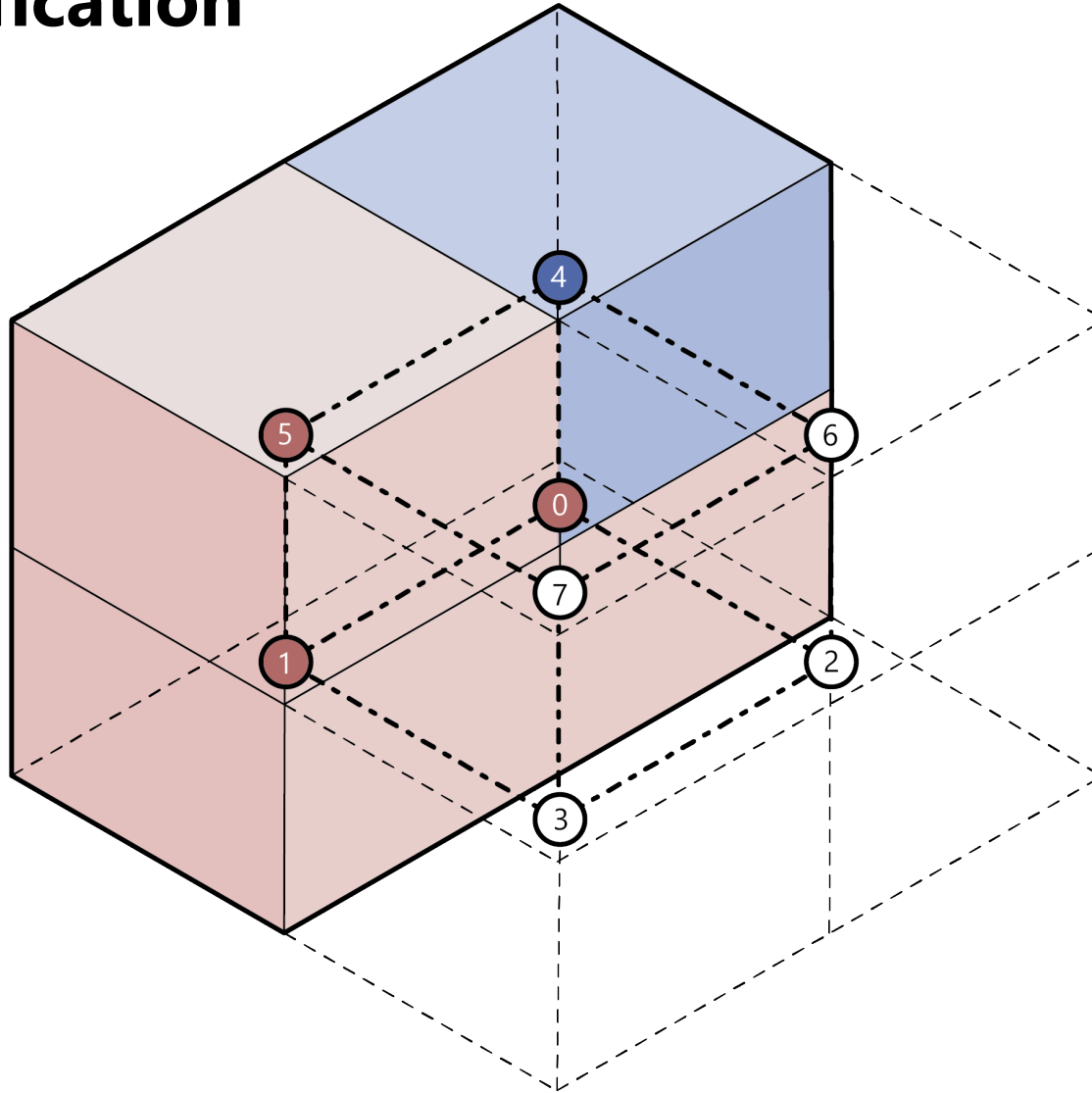


connection voxels need to be placed to adjacent connection voxels of another room



voxels need to connect at least with one face to another voxel

Codification



Vertex Codification

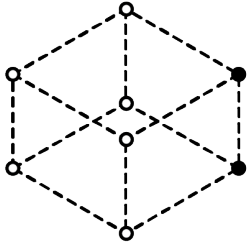
- 0 021
- 1 021
- 2 000
- 3 000
- 4 023
- 5 021
- 6 000
- 7 000

Combined Codification

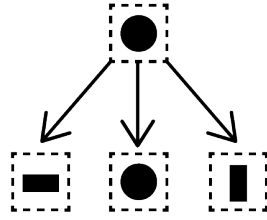
021021000000023021000000

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

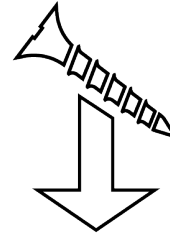
2 Tile Database



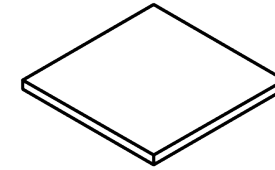
Unique Cubes



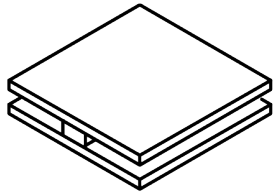
Families



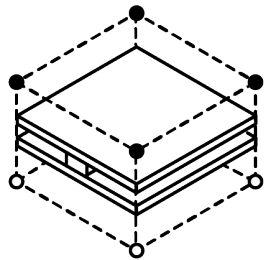
Building Products



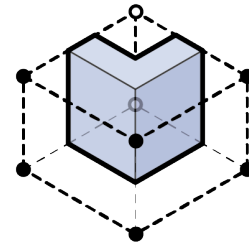
Parts



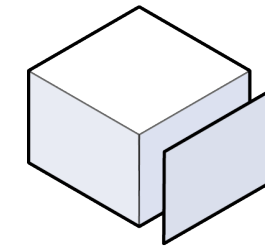
Components



Building Tiles

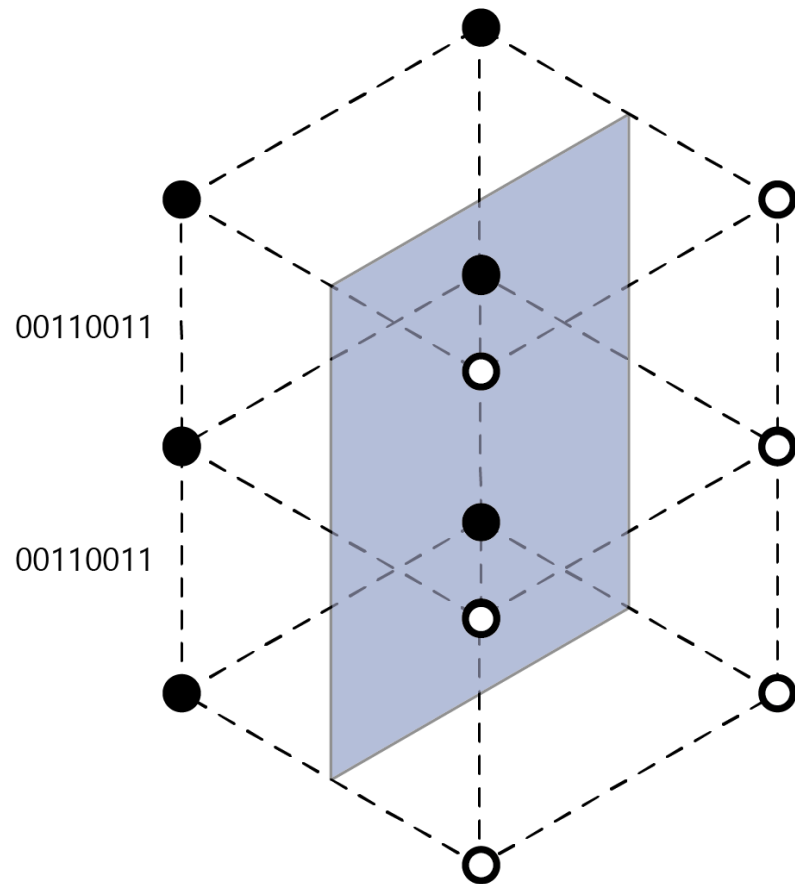
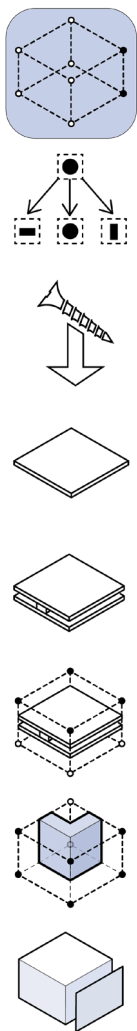


Computational Tiles



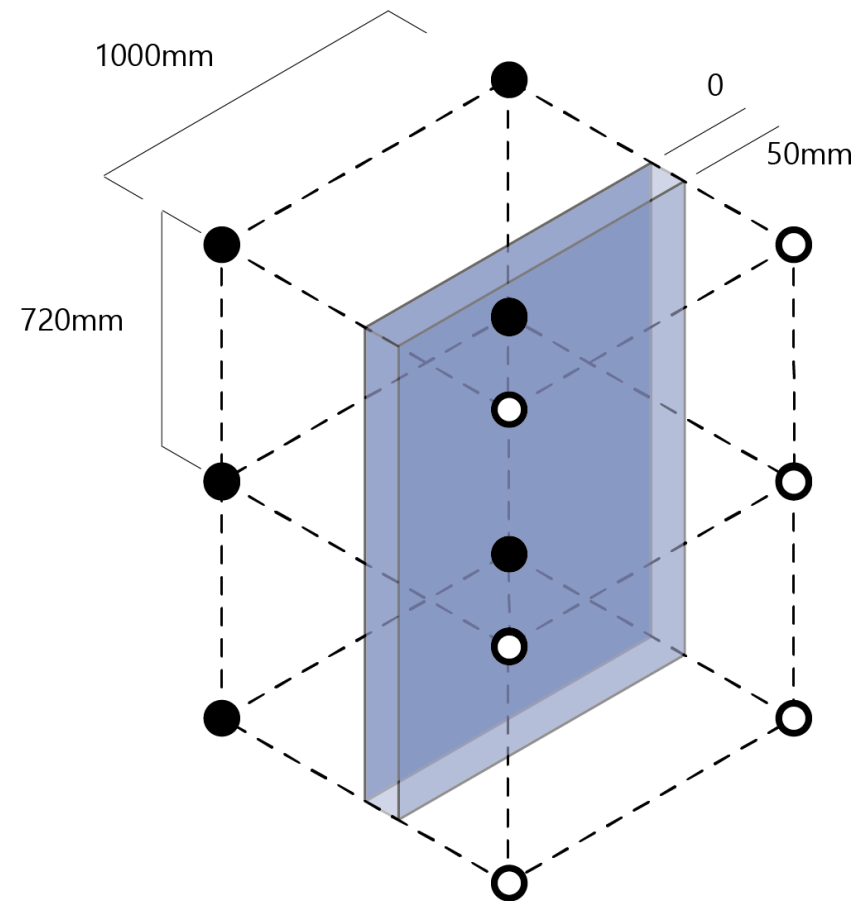
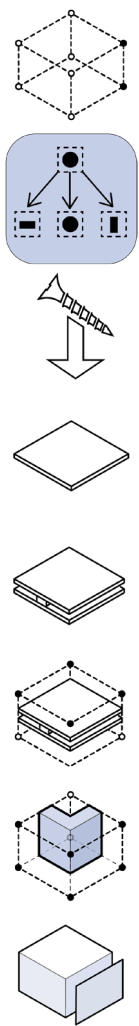
Faces

Create Unique Cubes



Unique Cubes
Unique_Cube_ID
Basic (y/n)
Identifier Rotation 0°
Identifier Rotation 90°
Identifier Rotation 180°
Identifier Rotation 270°
Identifier Rotation 0° + Mirror
Identifier Rotation 90° + Mirror
Identifier Rotation 180° + Mirror
Identifier Rotation 270° + Mirror

Create Tile Families



Tile Family
Family_ID
Description
Interior / Exterior (I /E)
Voxel Size X, Y
Voxel Size z

Import Building Products

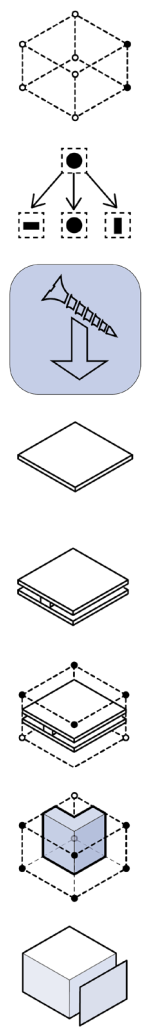


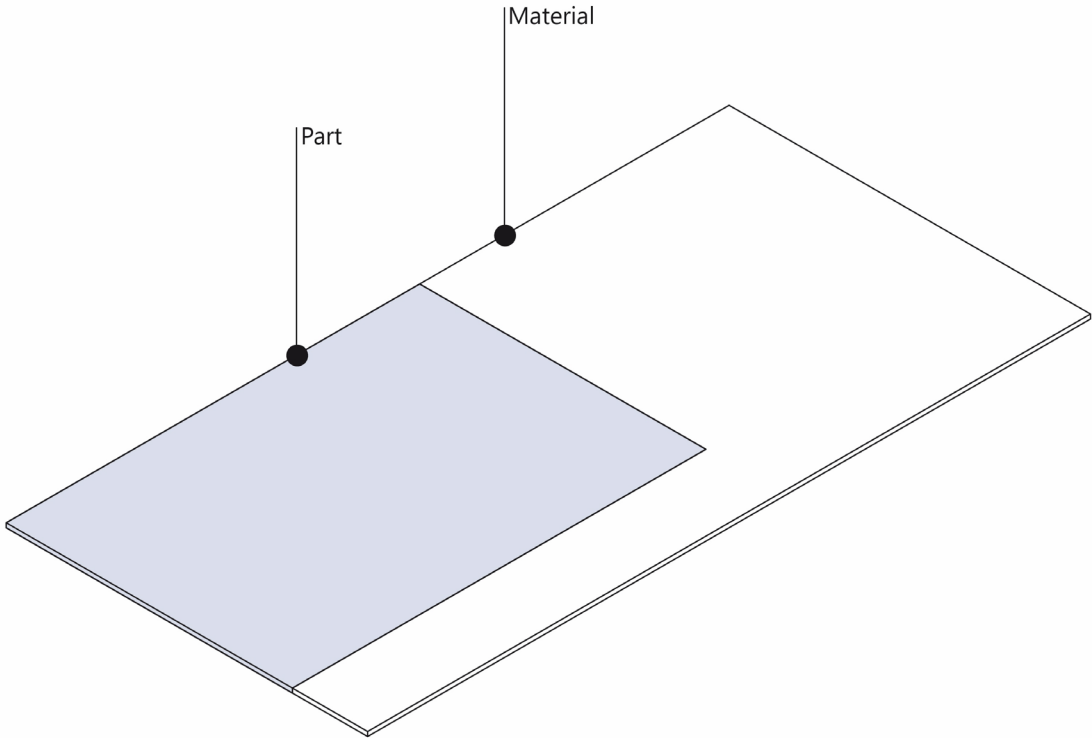
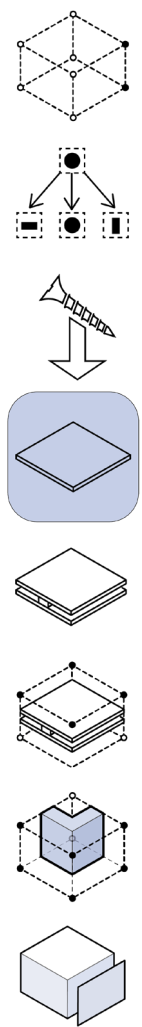
Image 10



Image 11

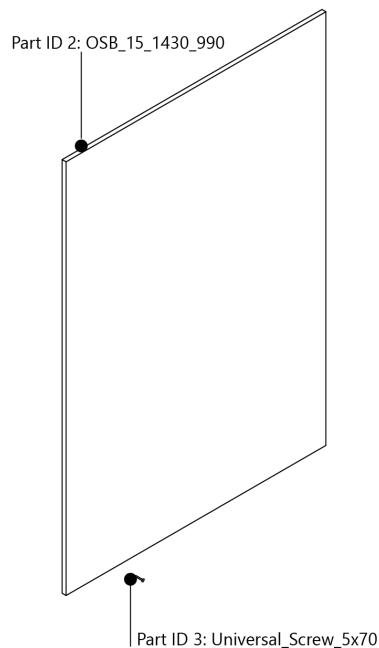
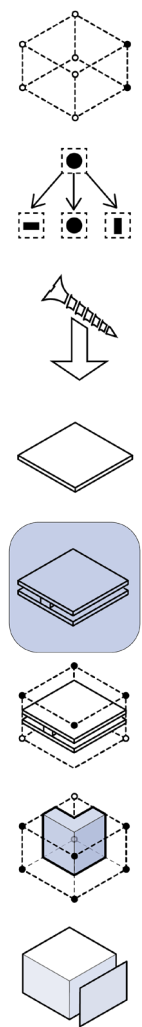
Building Products
BuildingProduct_ID
Description
Dimension X (mm)
Dimension Y (mm)
Dimension Z (mm)
Weight (kg)
EAN Code
Price EAN (€)
Quantity / Package
Norms Applied
Link Supplier (url)
Building Product Geometry (path)

Create Parts

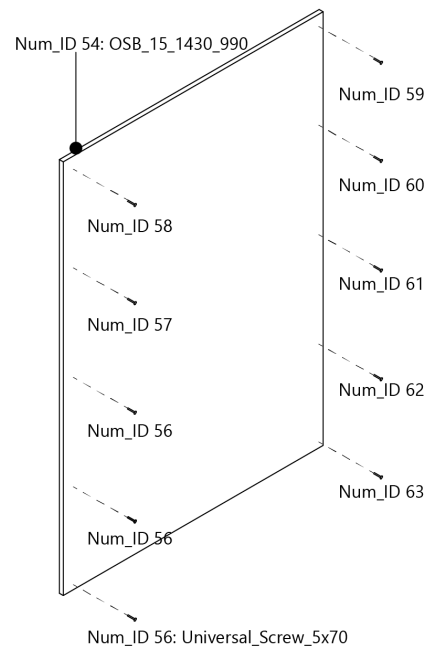


Parts
Part_ID
Description
BuildingProduct_ID
Building Product Description
Part == Building Product? (y/n)
Dimension X (mm)
Dimension Y (mm)
Dimension Z (mm)
Additional Finishing
Parts / Building Product
Additional Finishing
Part Geometry (path)

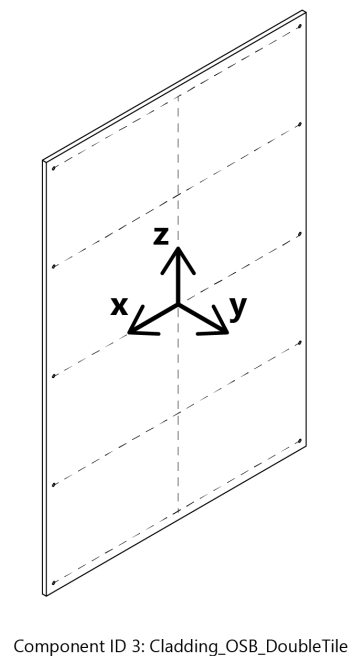
Create Components



2 Parts



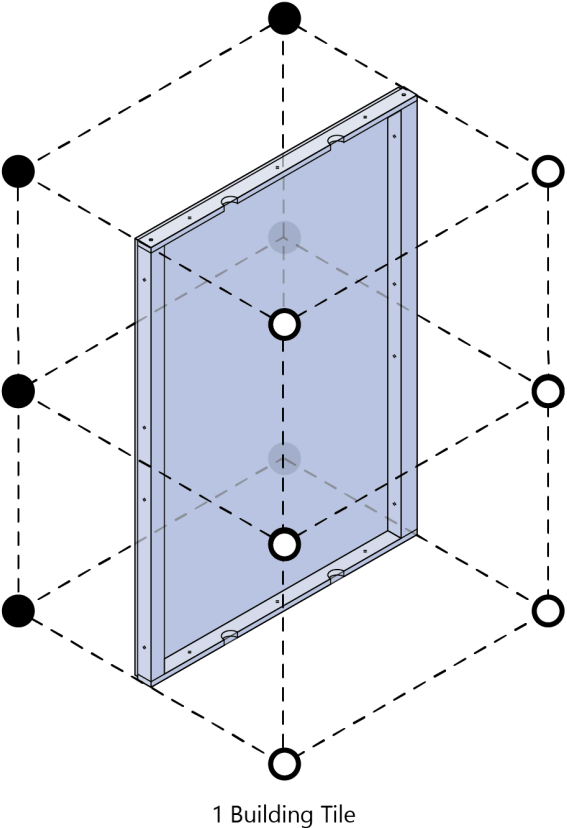
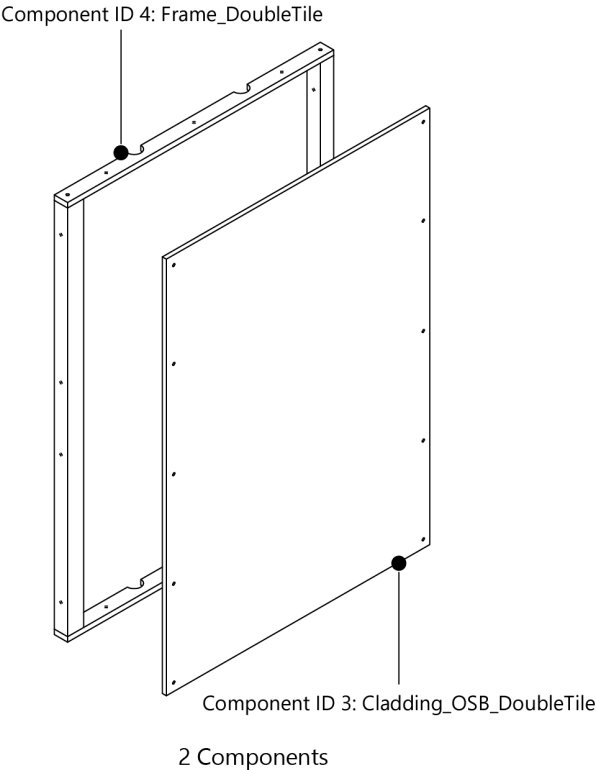
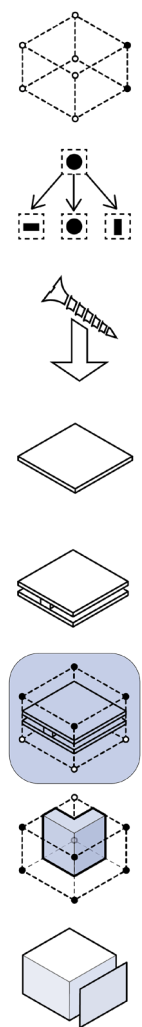
11 Part Instances



1 Component

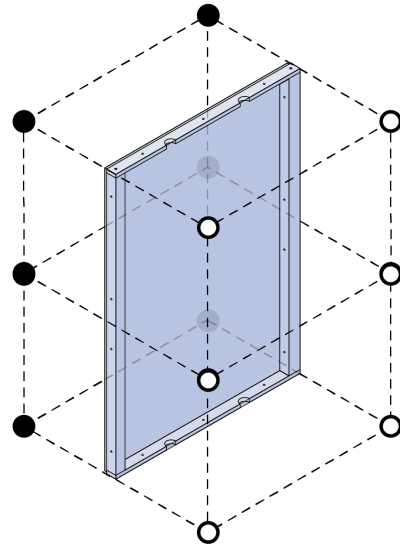
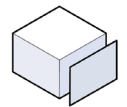
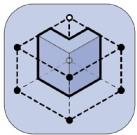
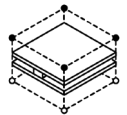
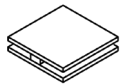
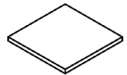
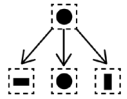
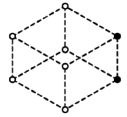
Components
Num_ID
Component_ID
Description
Part_ID
Part Description
Part Rotation
Part Position X (mm)
Part Position Y (mm)
Part Position Z (mm)
Component Geometry (path)

Create Building Tiles

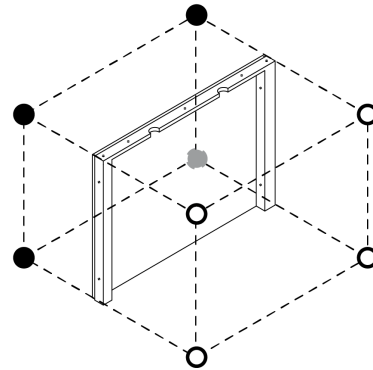


Building Tiles
Num_ID
BuildingTile_ID
Family_ID
Description
Component_ID
Component Description
Component Rotation
Component Position X (mm)
Component Position Y (mm)
Component Position Z (mm)
BuildingTile Geometry (path)

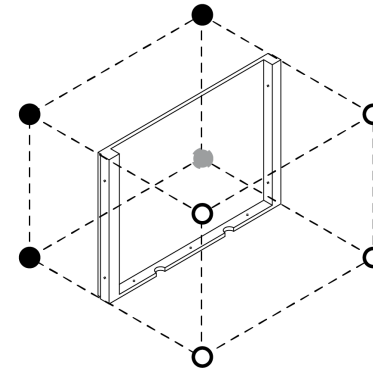
Create Computational Tiles



BuildingTile_ID 2



Computational Tile ID: 23



Computational Tile ID: 24

Computational Tiles

Ctile_ID

BuildingTile_ID

Unique Cube

Type (E/I; B/A)

Ctile == Building Tile (y/n)

Face0

Face1

Face2

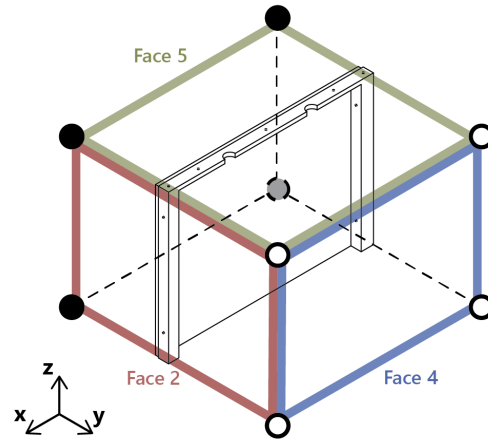
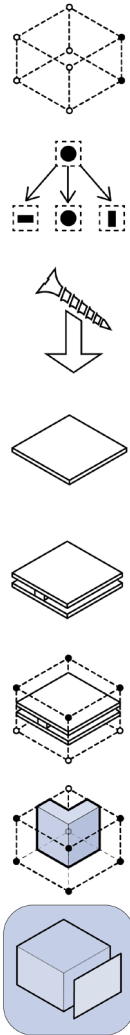
Face3

Face4

Face5

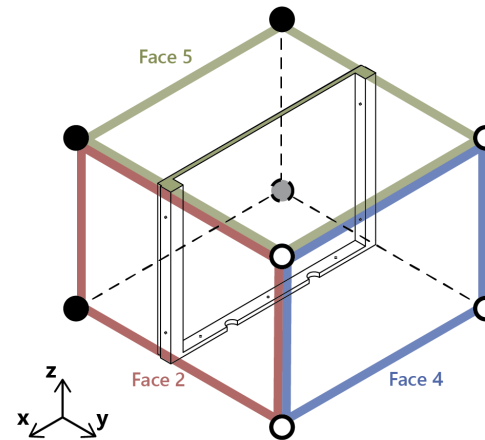
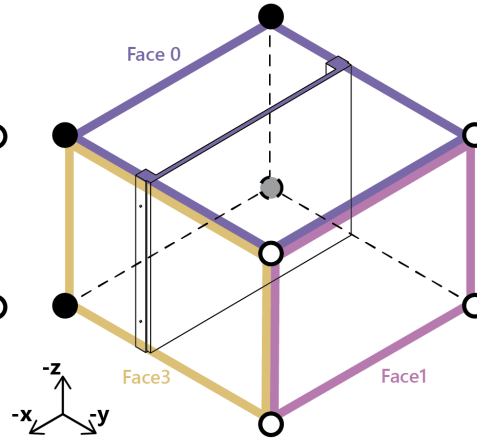
Ctile Geometry (path)

Create Faces



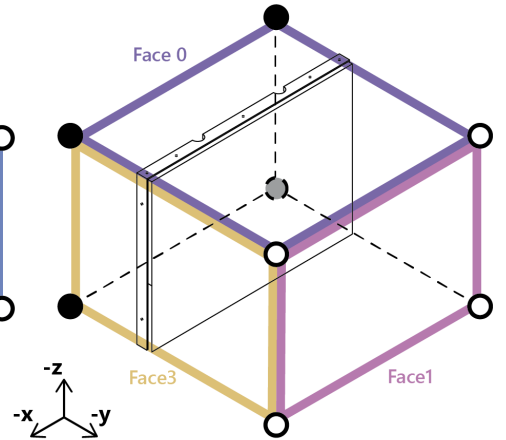
Computational Tile 23

Face 0 : Connection INT (Tile 24)
 Face 1 : empty
 Face 2 : Connection EXT (2 Screws)
 Face 3 : Connection EXT (2 Screws)
 Face 4 : empty
 Face 5 : Connection EXT (3 Screws)

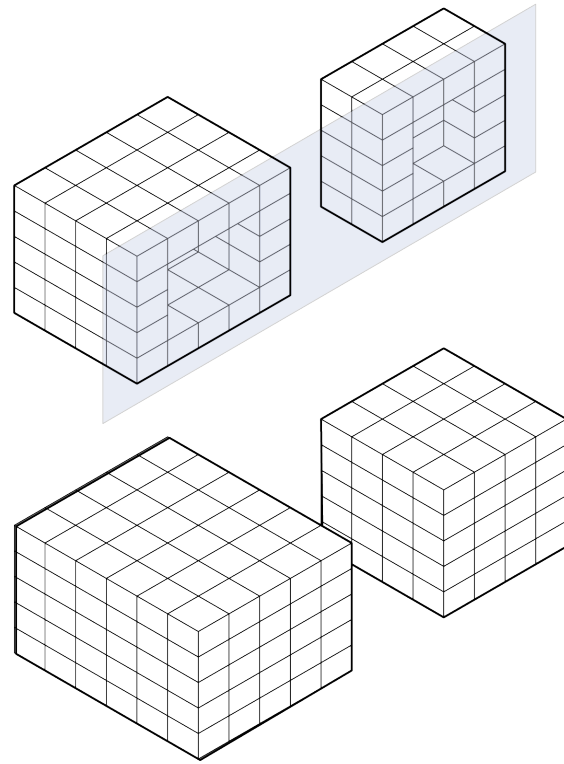


Computational Tile 24

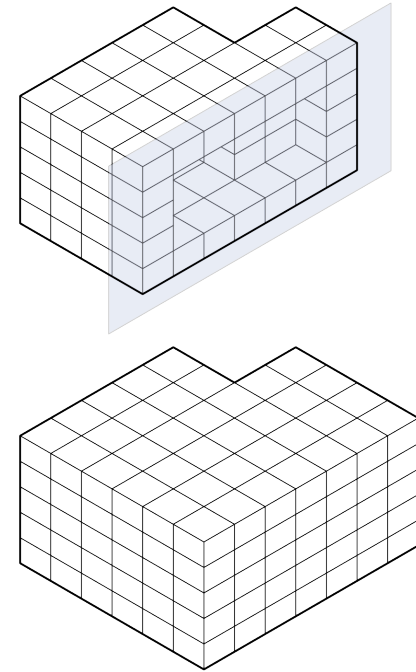
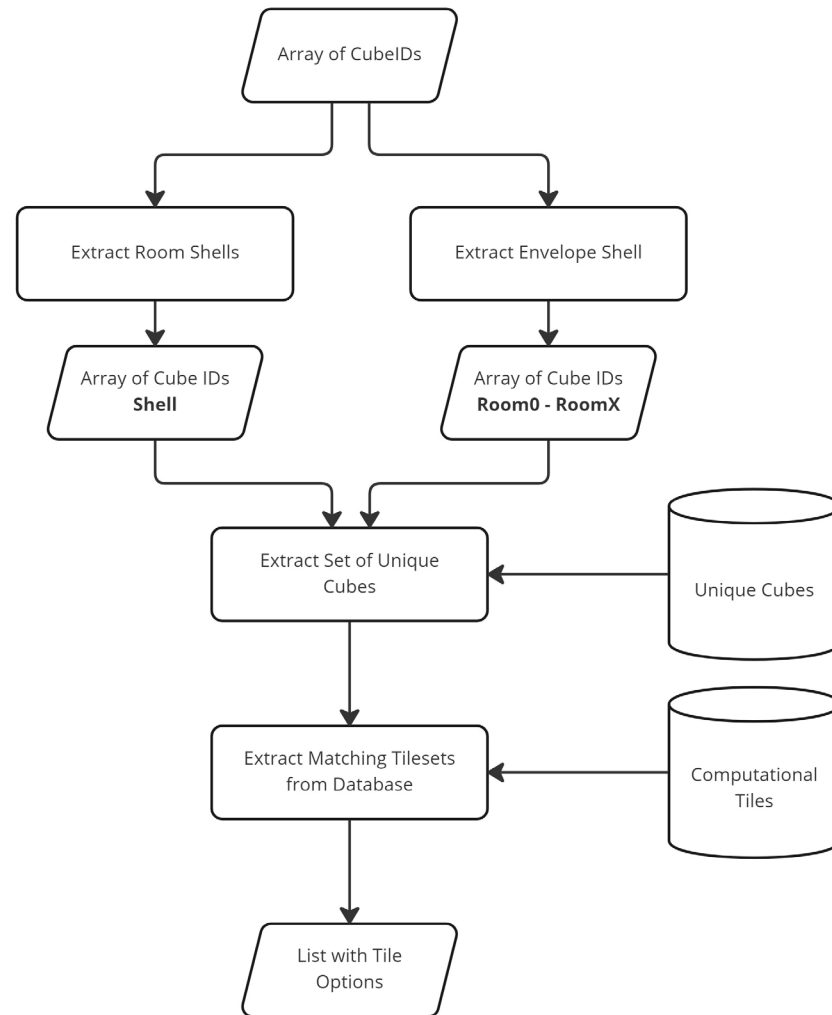
Face 0 : Connection EXT (3 Screws)
 Face 1 : empty
 Face 2 : Connection EXT (2 Screws)
 Face 3 : Connection EXT (2 Screws)
 Face 4 : empty
 Face 5 : Connection INT (Tile 23)



Calculate Tile Options

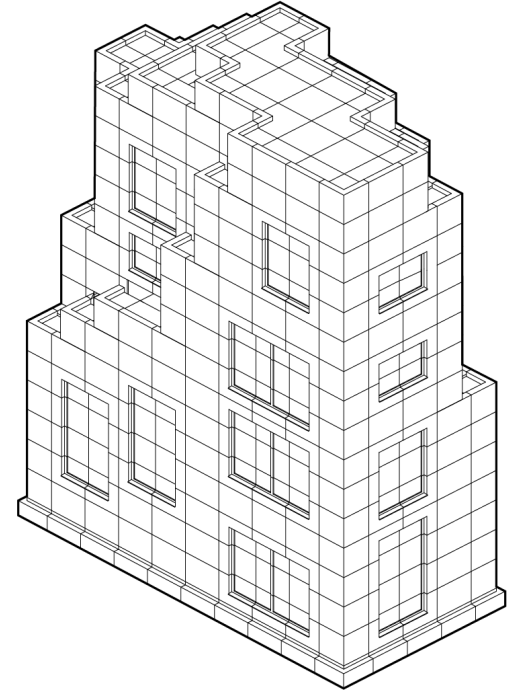
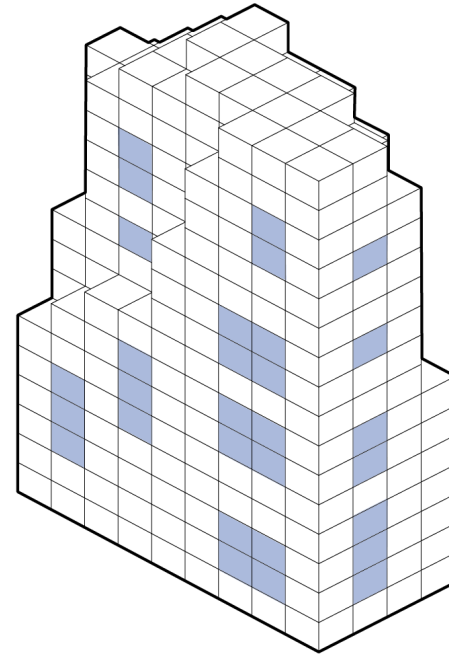
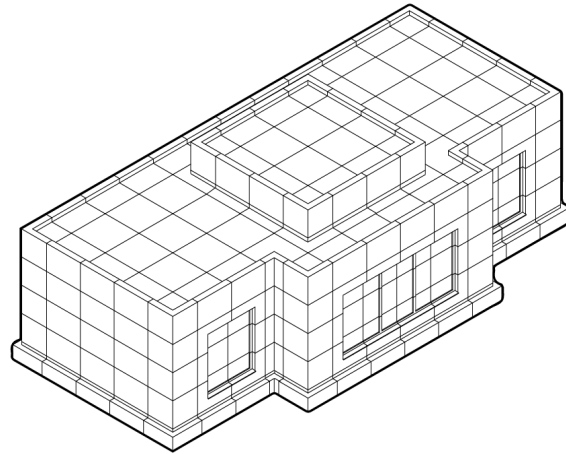
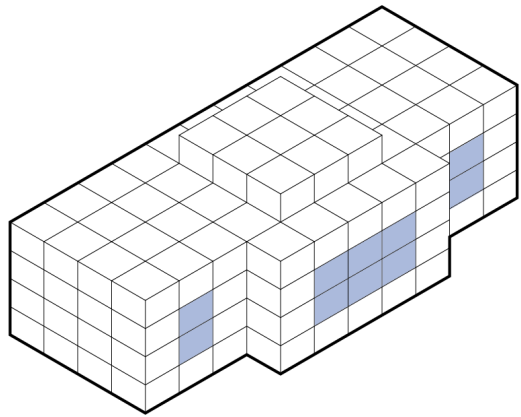


Array Room 1, 2

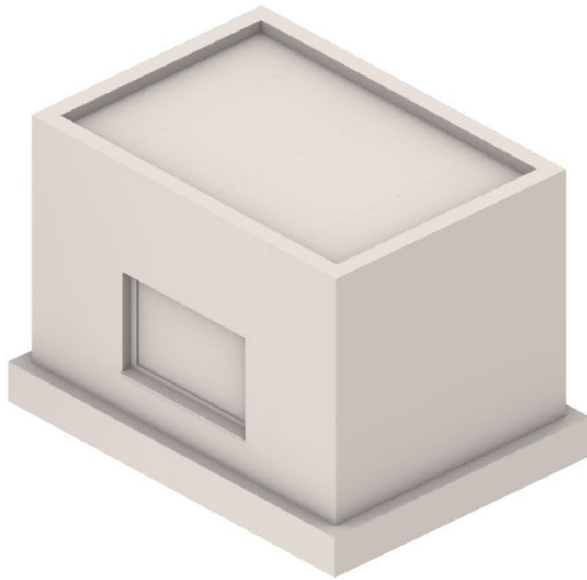


Array Envelope

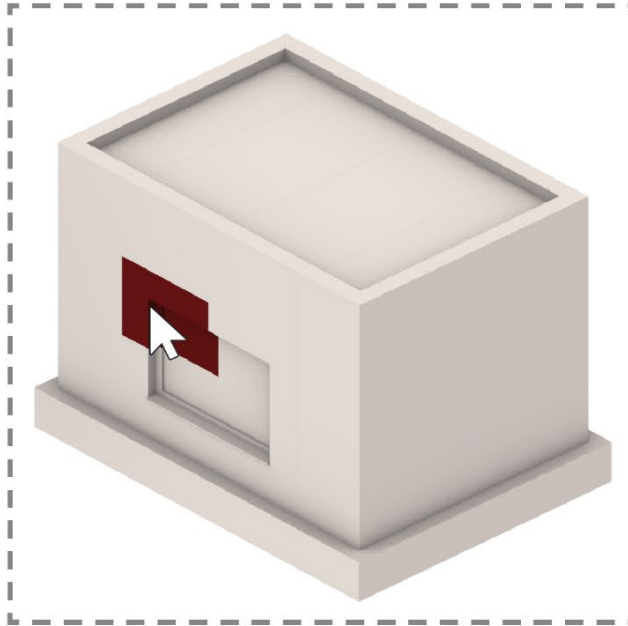
Initialization



Tile Placement



1 Placing first valid option

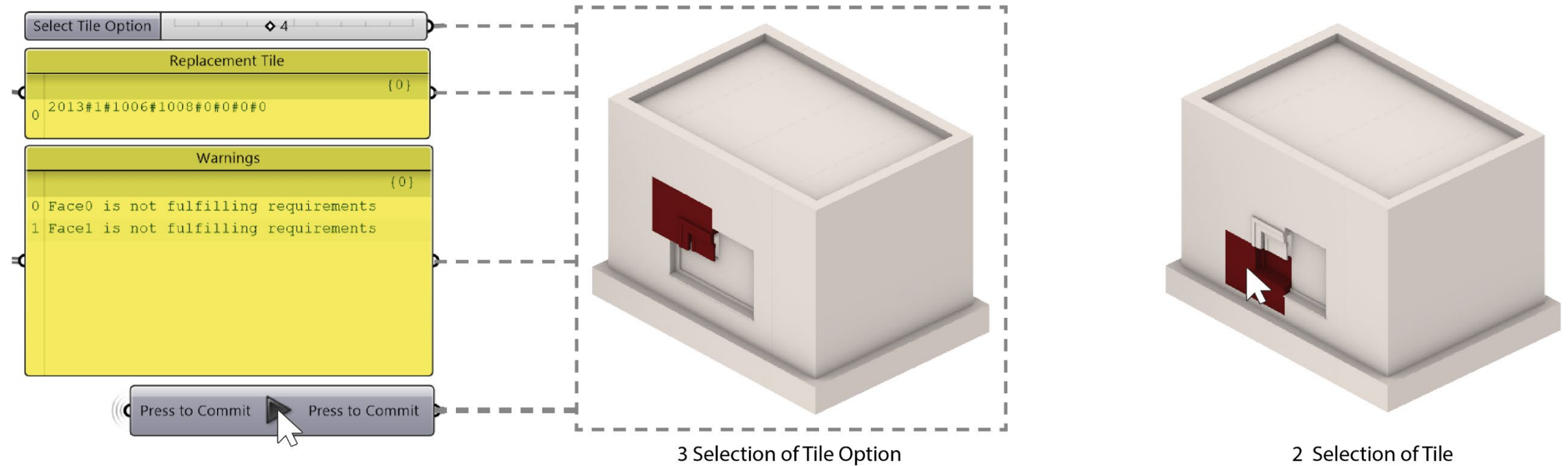


2 Selection of Tile

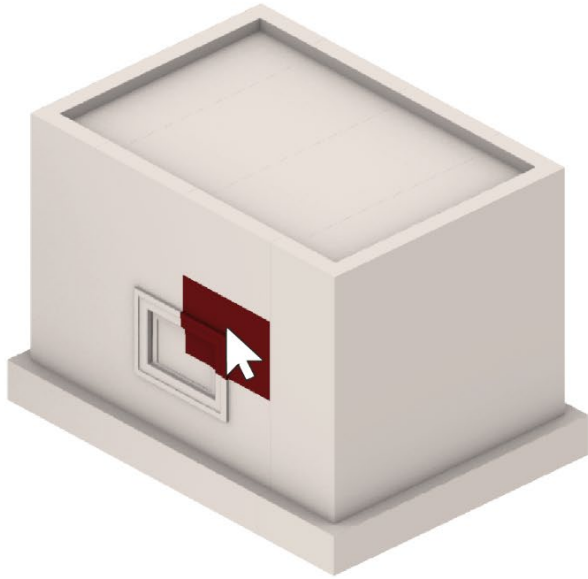
Tile Selected	
{0;0;0;0}	
0	2004#1#1002#1003#0#0#0#0

Tile Options for this Cube	
{0;0;0;0;0}	
0	2004#1#1002#1003#0#0#0#0
1	2005#1#1002#1003#0#0#0#0
2	2006#1#1002#1003#0#0#0#0
3	2013#1#1006#1008#0#0#0#1006
4	2017#1#1010#0#0#0#0#0

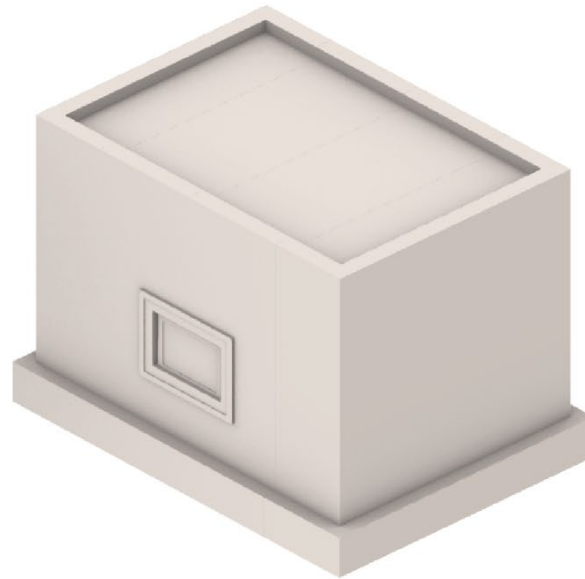
Tile Placement



Tile Placement

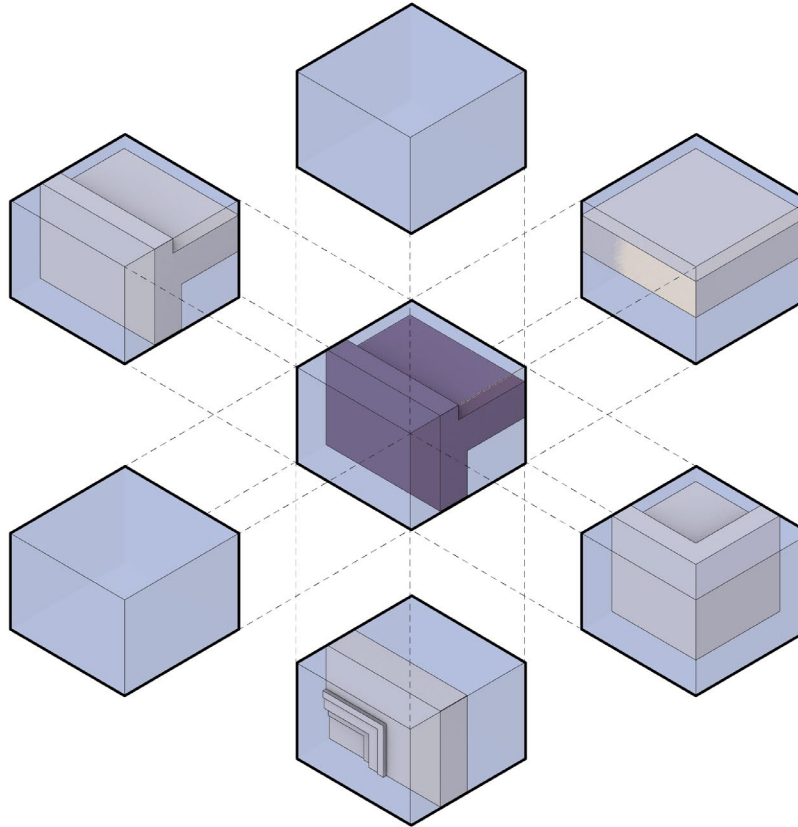
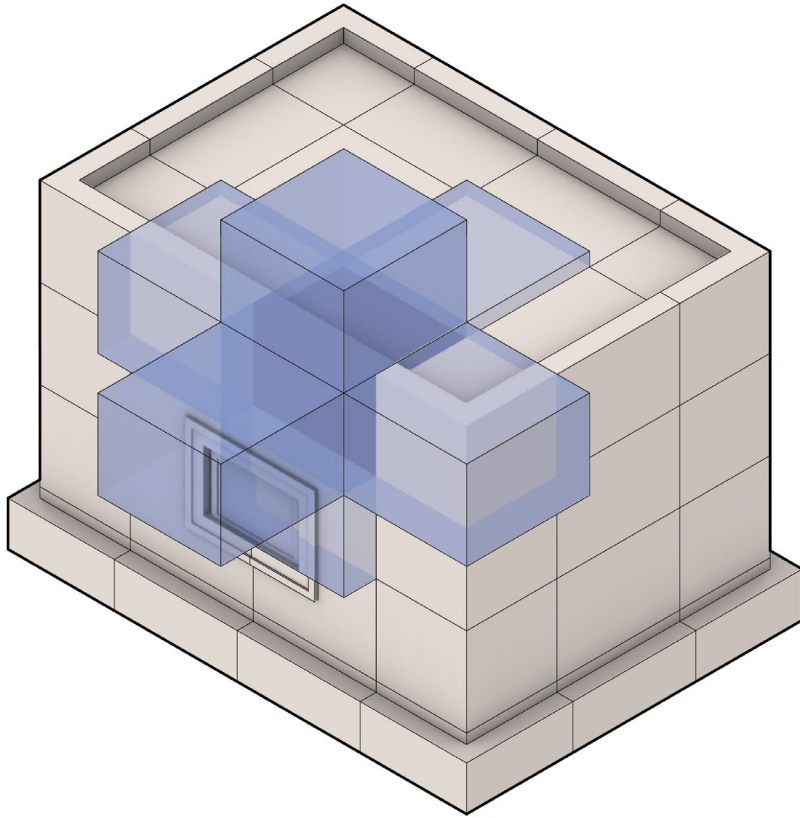


2 Selection of Tile

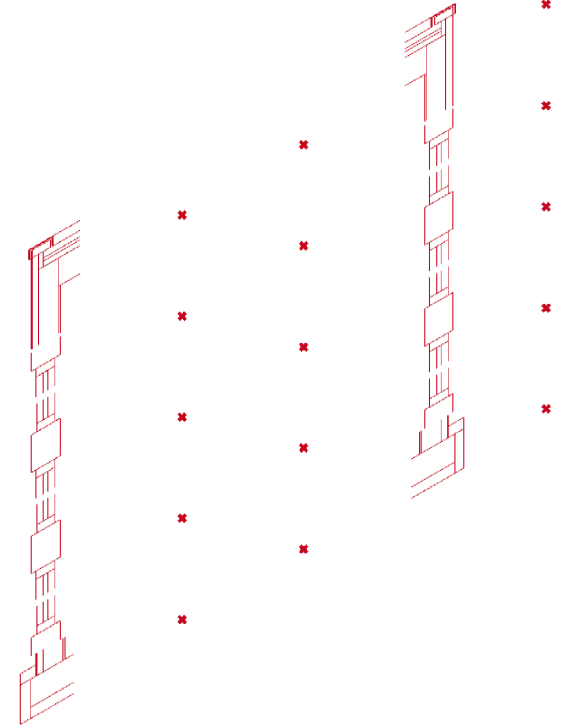
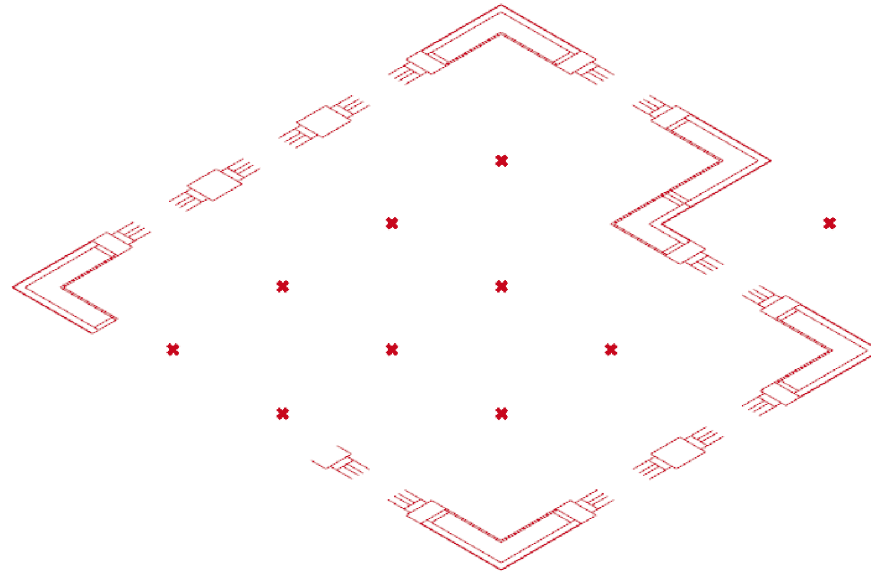
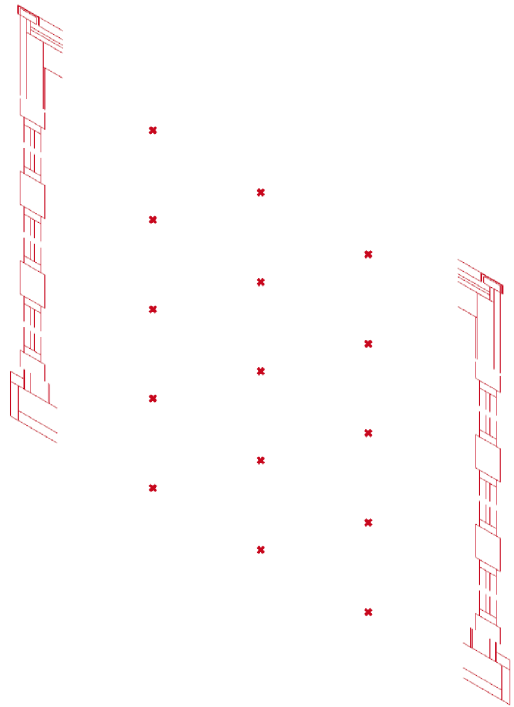


4 End - Final Commit

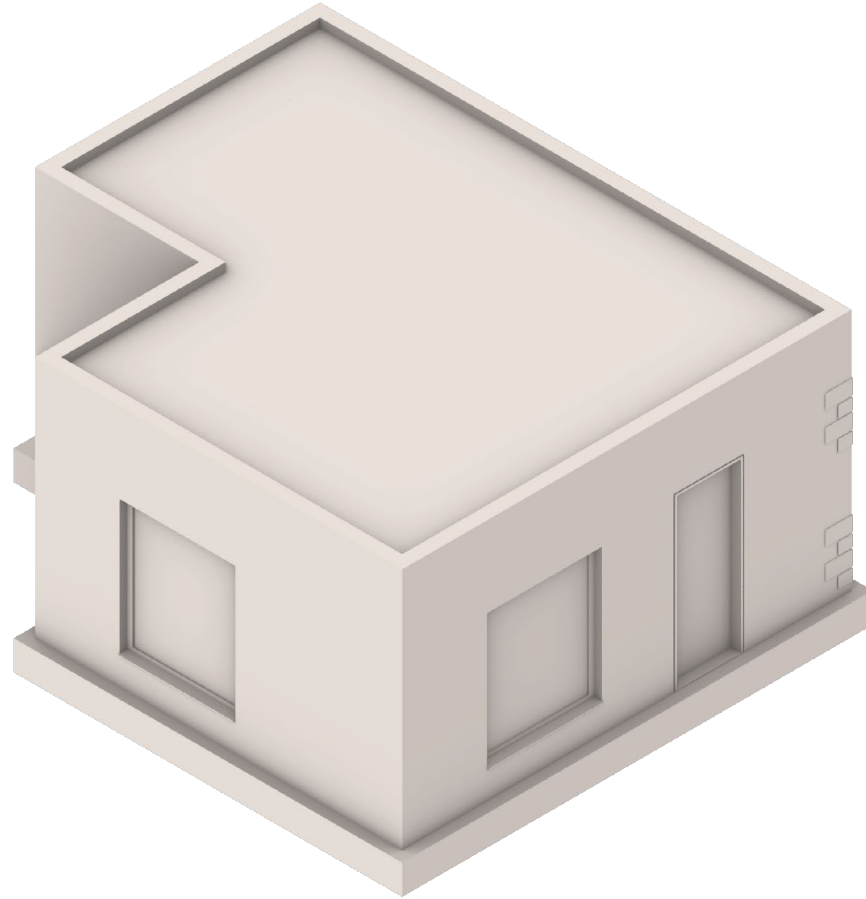
Tile Selection



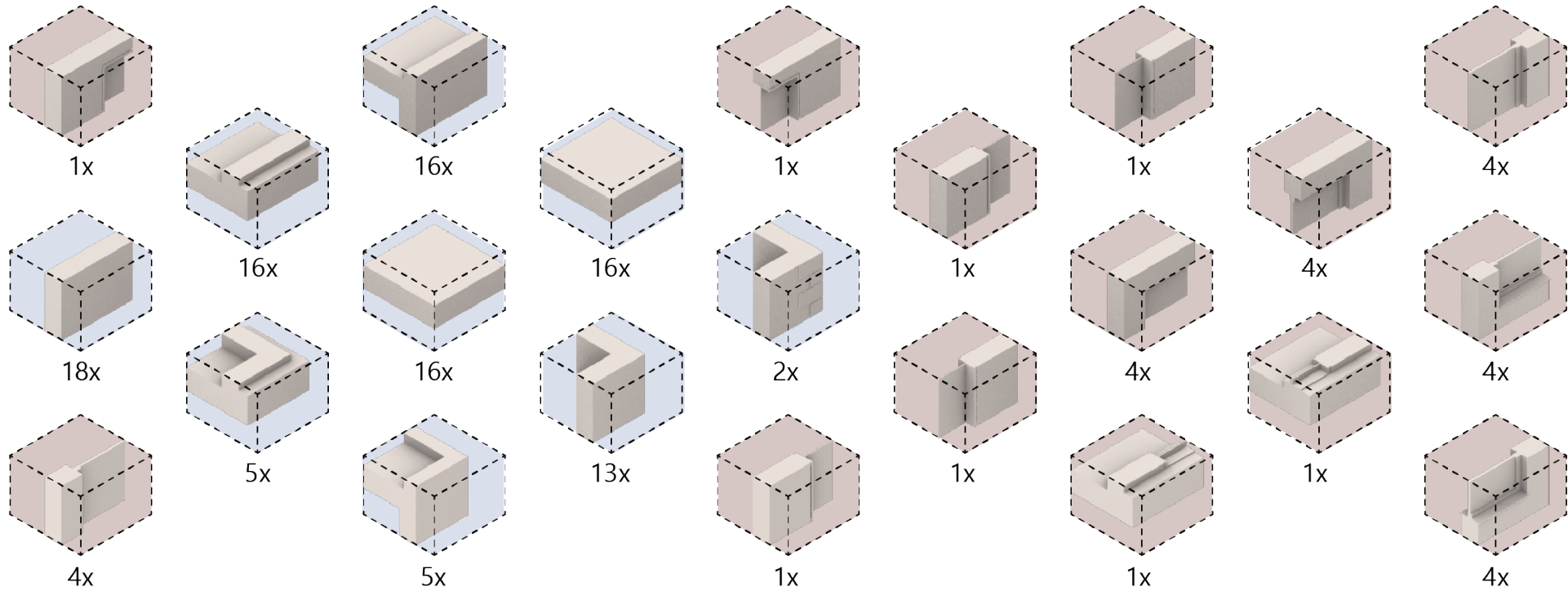
Postprocessing: Details



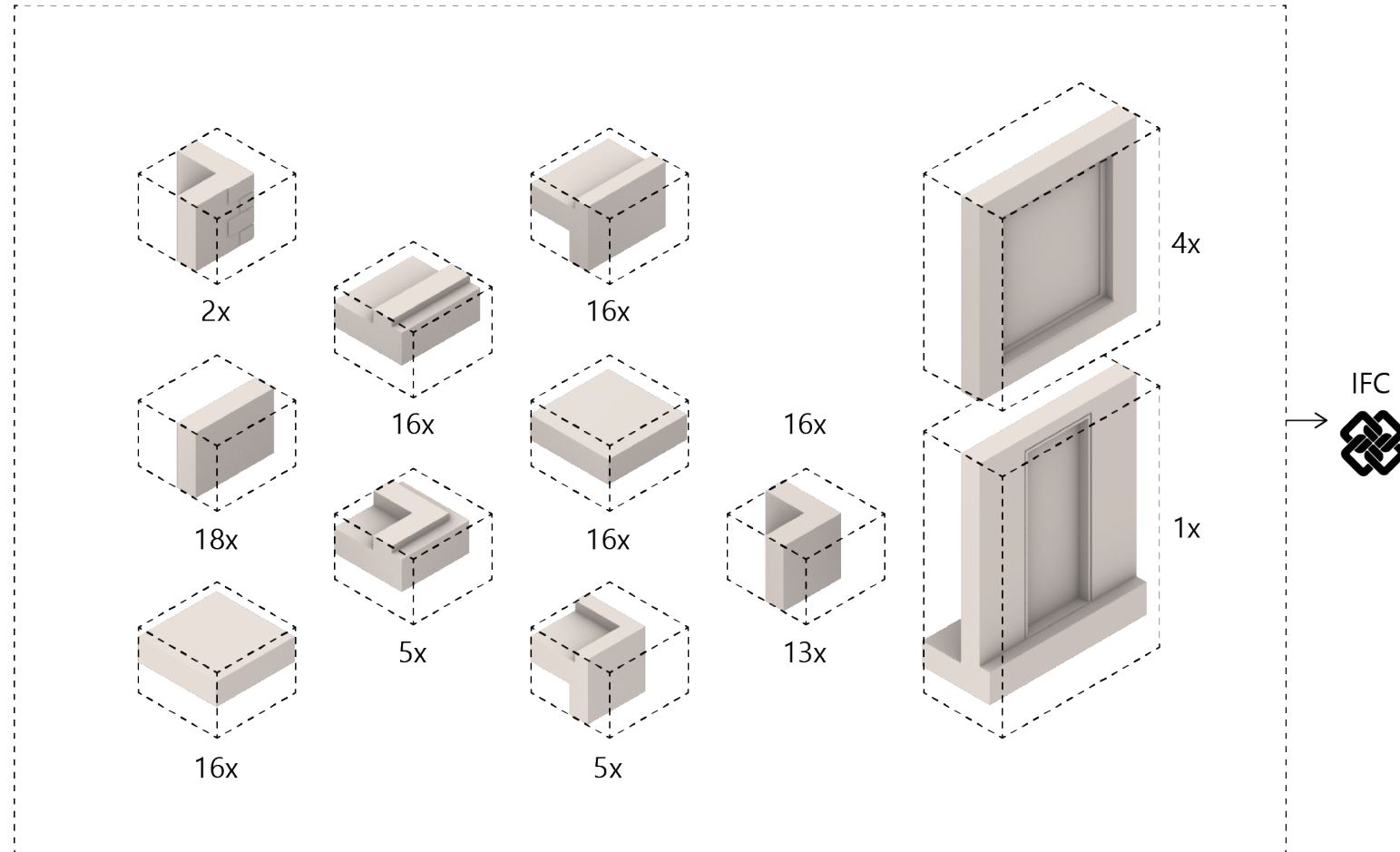
Postprocessing: Export



Postprocessing: Export



Postprocessing: Export



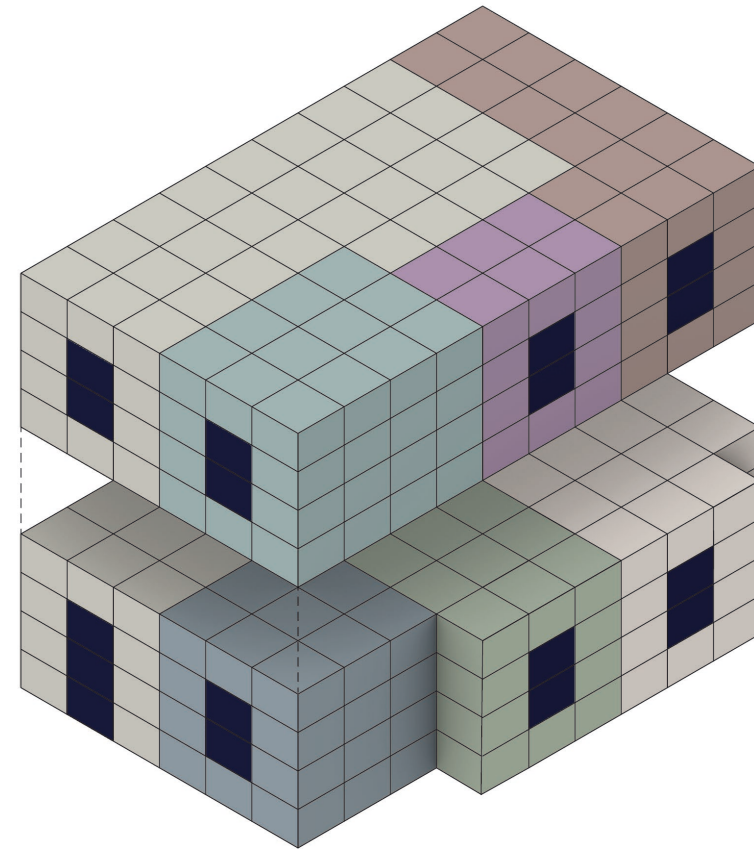
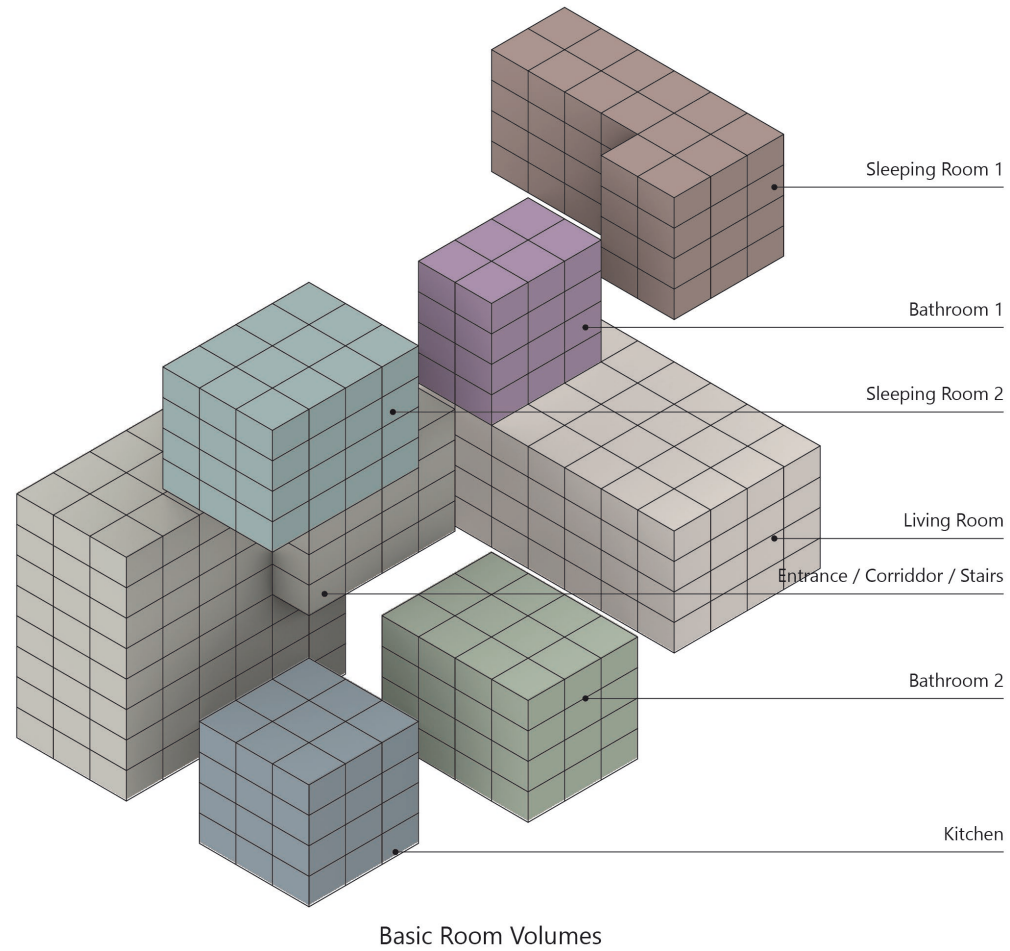
Toy Problem



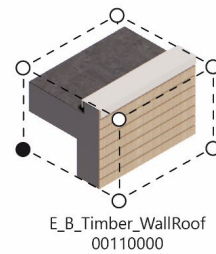
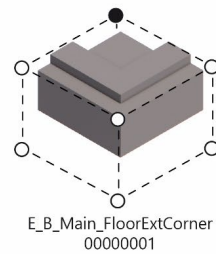
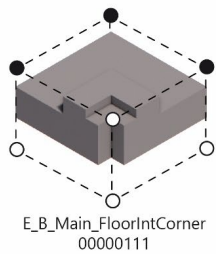
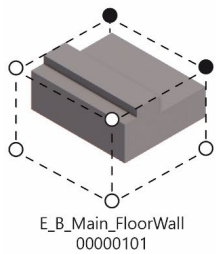
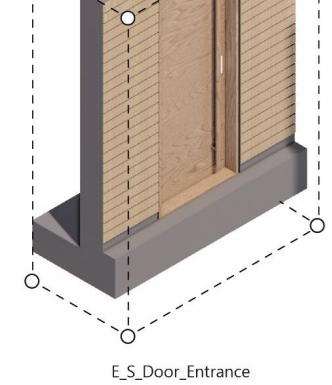
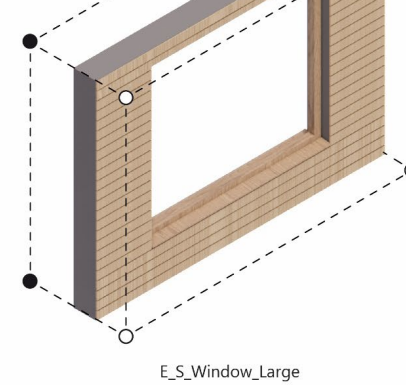
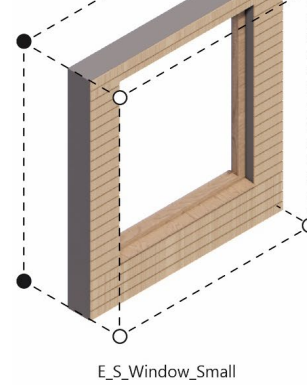
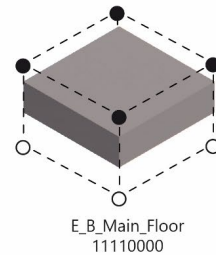
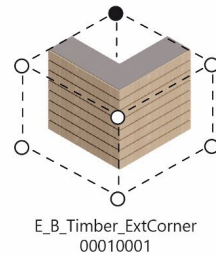
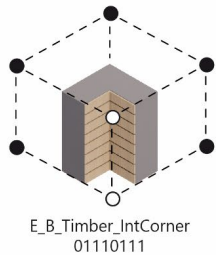
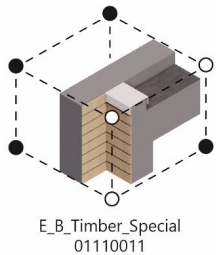
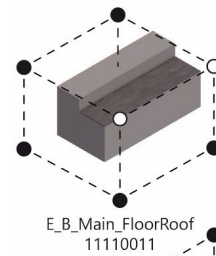
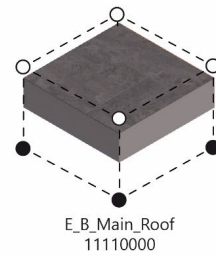
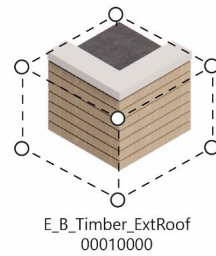
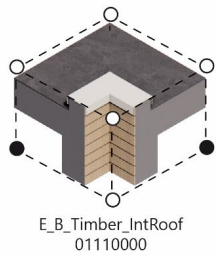
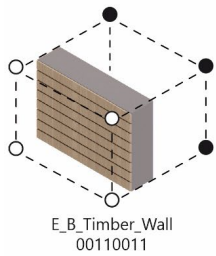
Context



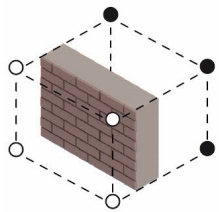
Topological Design



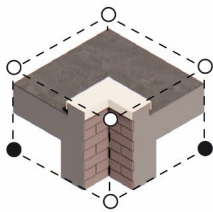
Envelope Tileset



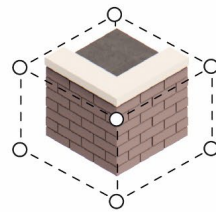
Envelope Tileset



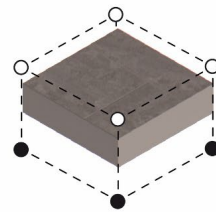
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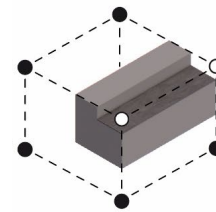
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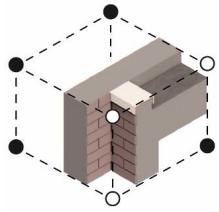
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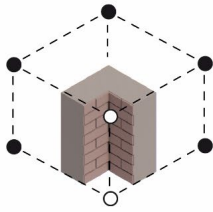
E_B_Main_Roof
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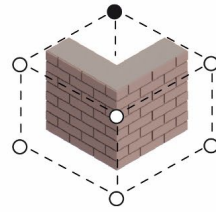
E_B_Main_FloorRoof
11110011



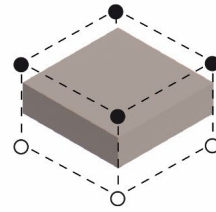
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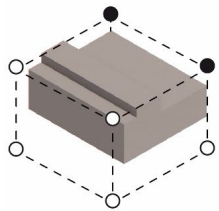
E_B_Brick_IntCorner
01110111



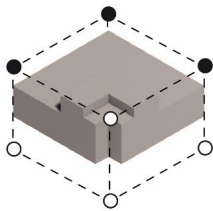
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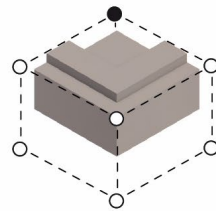
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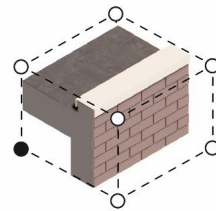
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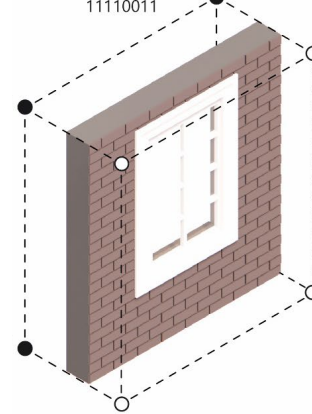
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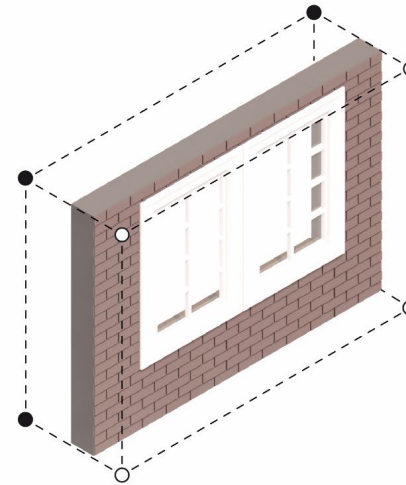
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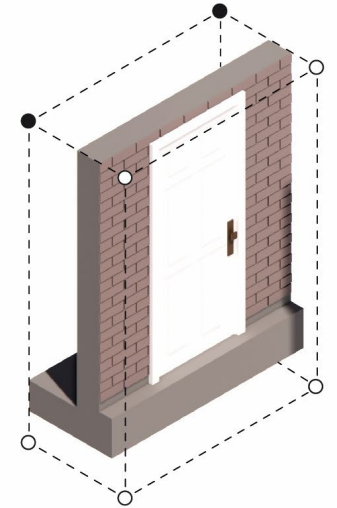
E_B_Brick_WallRoof
00110000



E_S_Window_Small

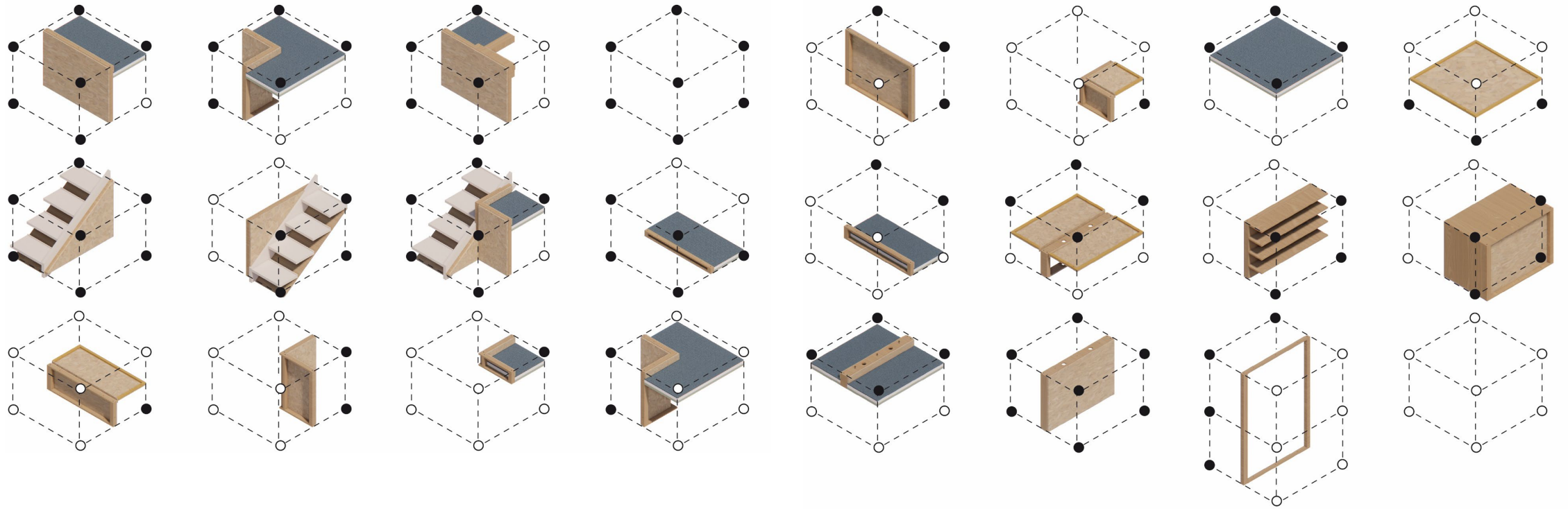


E_S_Window_Large

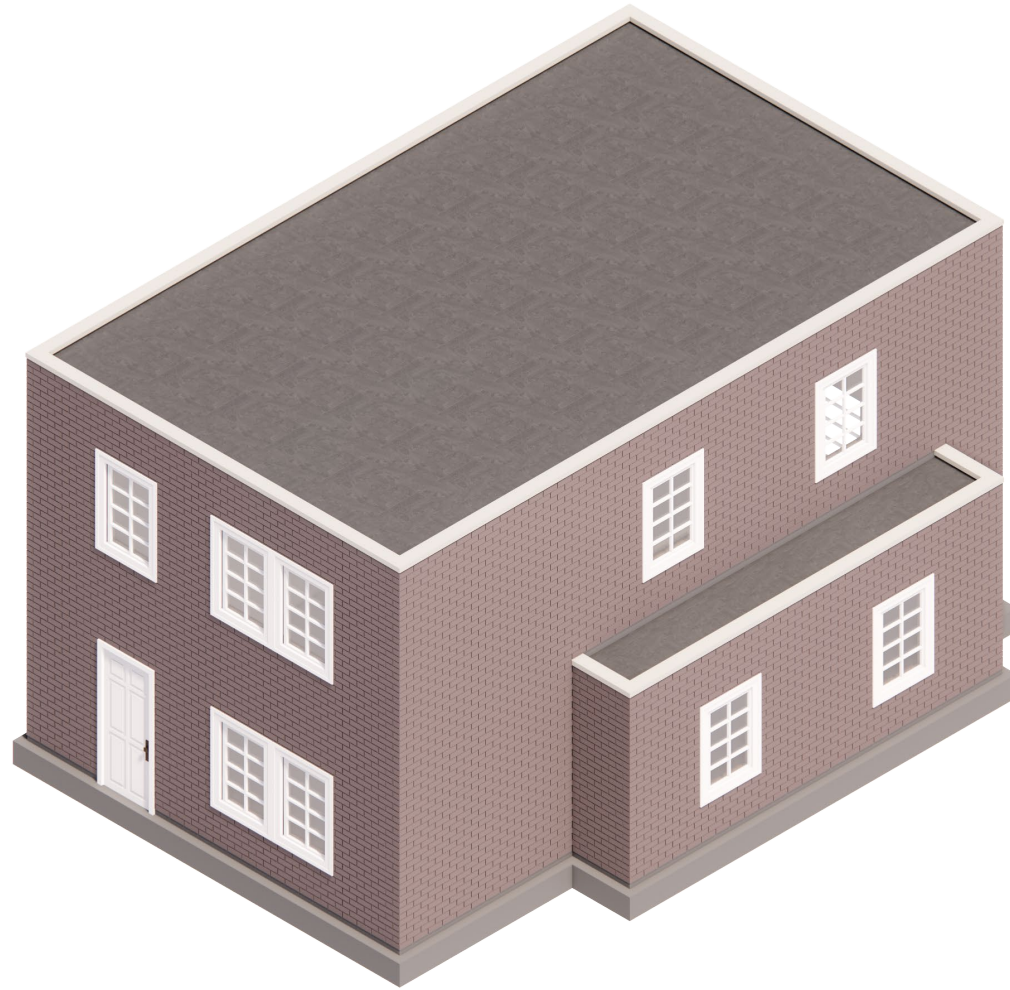


E_S_Door_Entrance

Interior Tileset



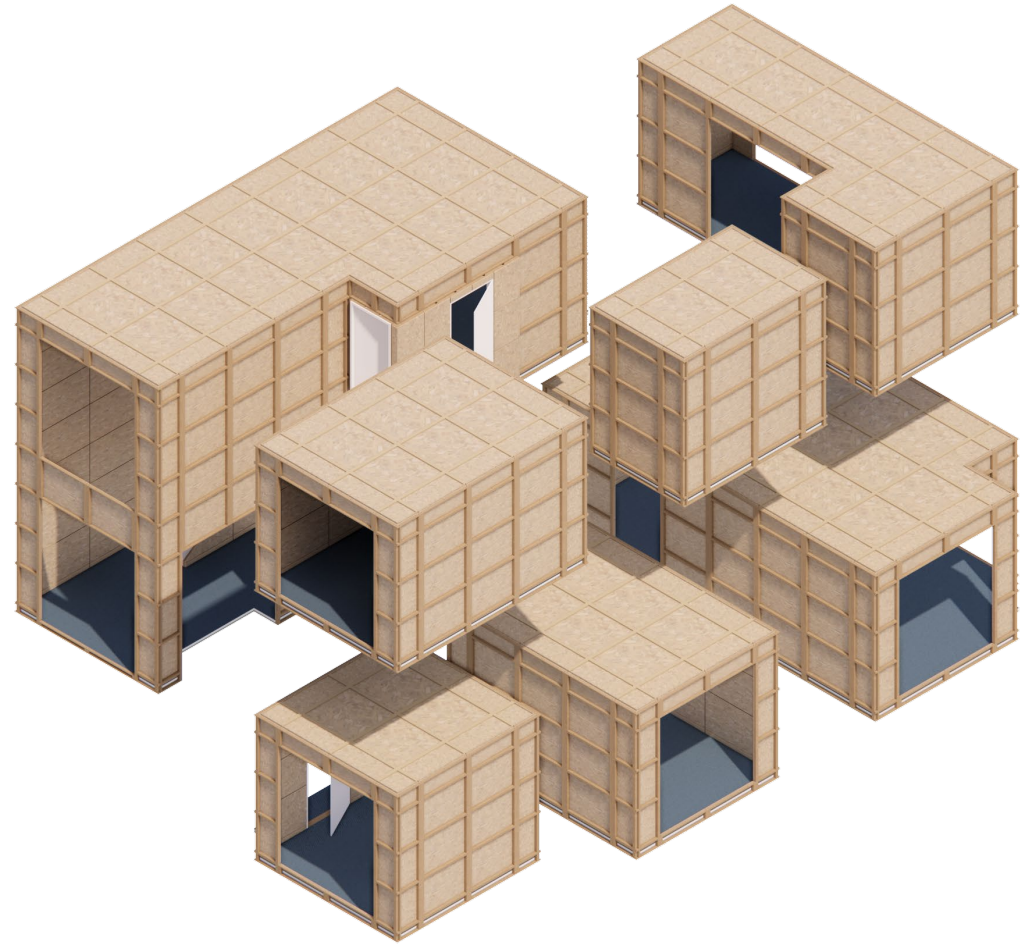
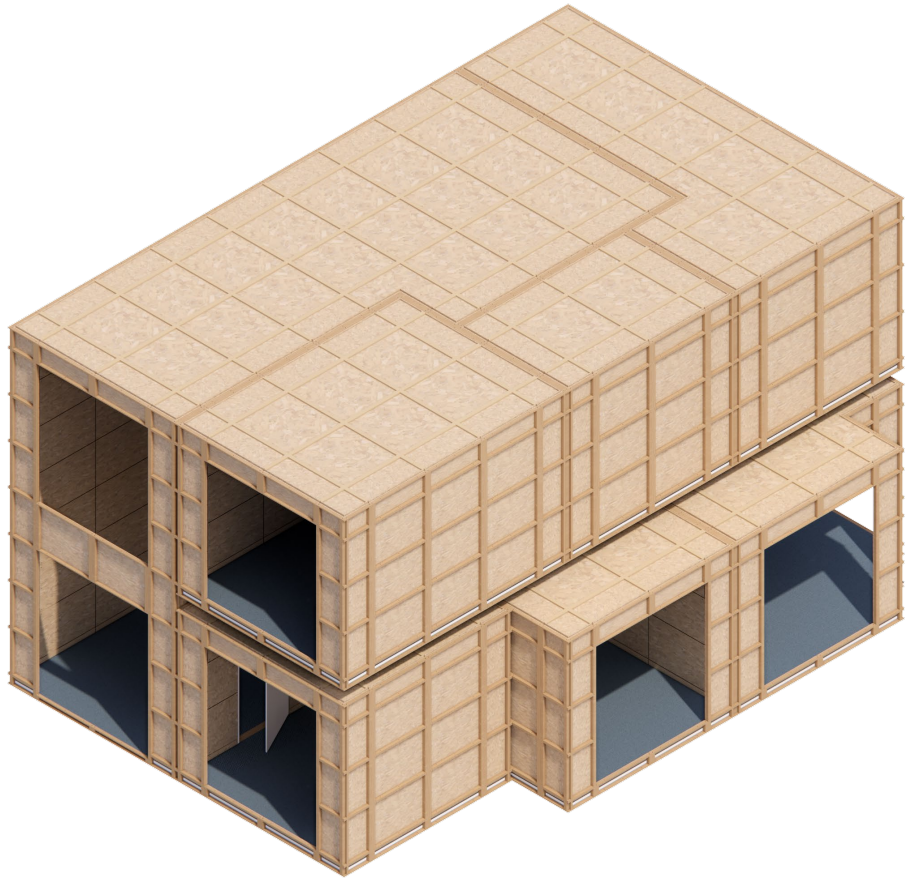
Tile Placement - Envelope



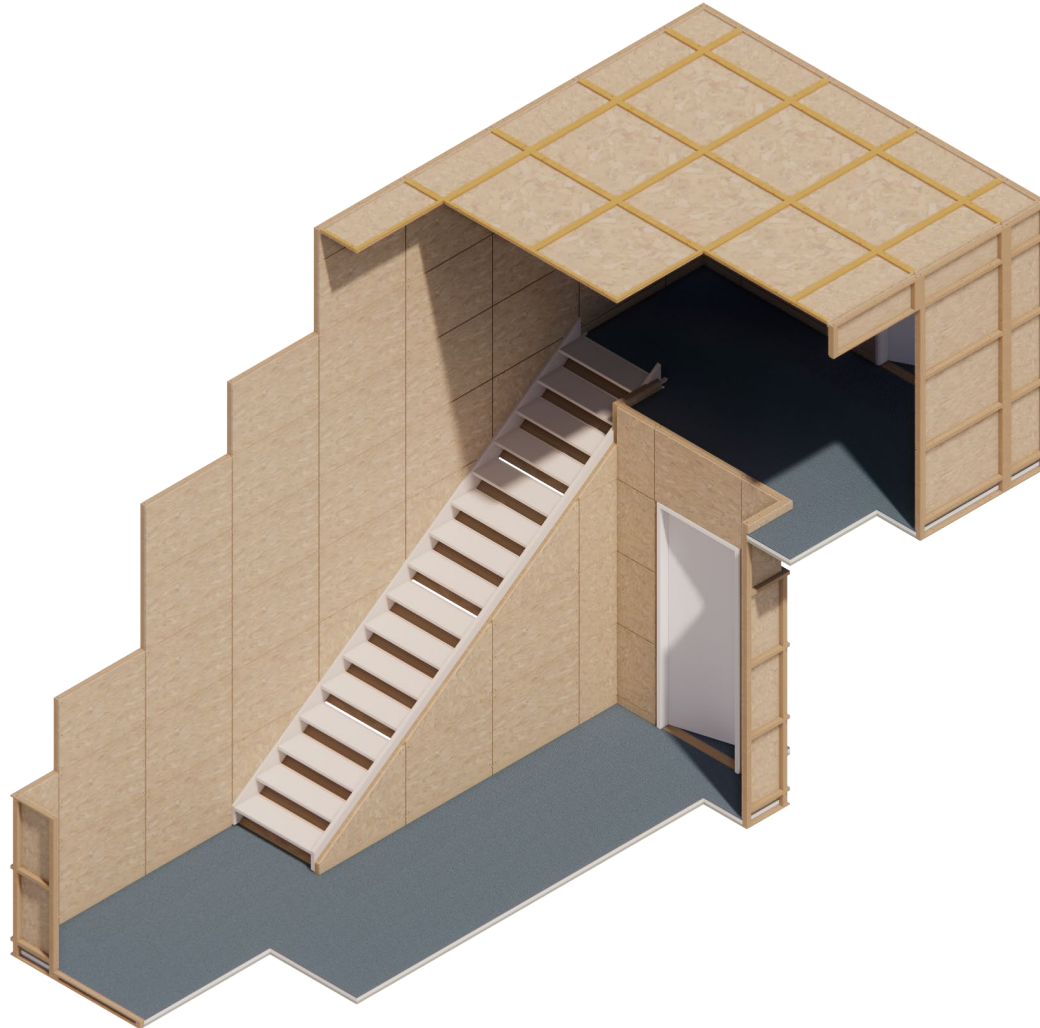
Tile Placement - Envelope



Tile Placement - Interior



Tile Placement – Stair Integration

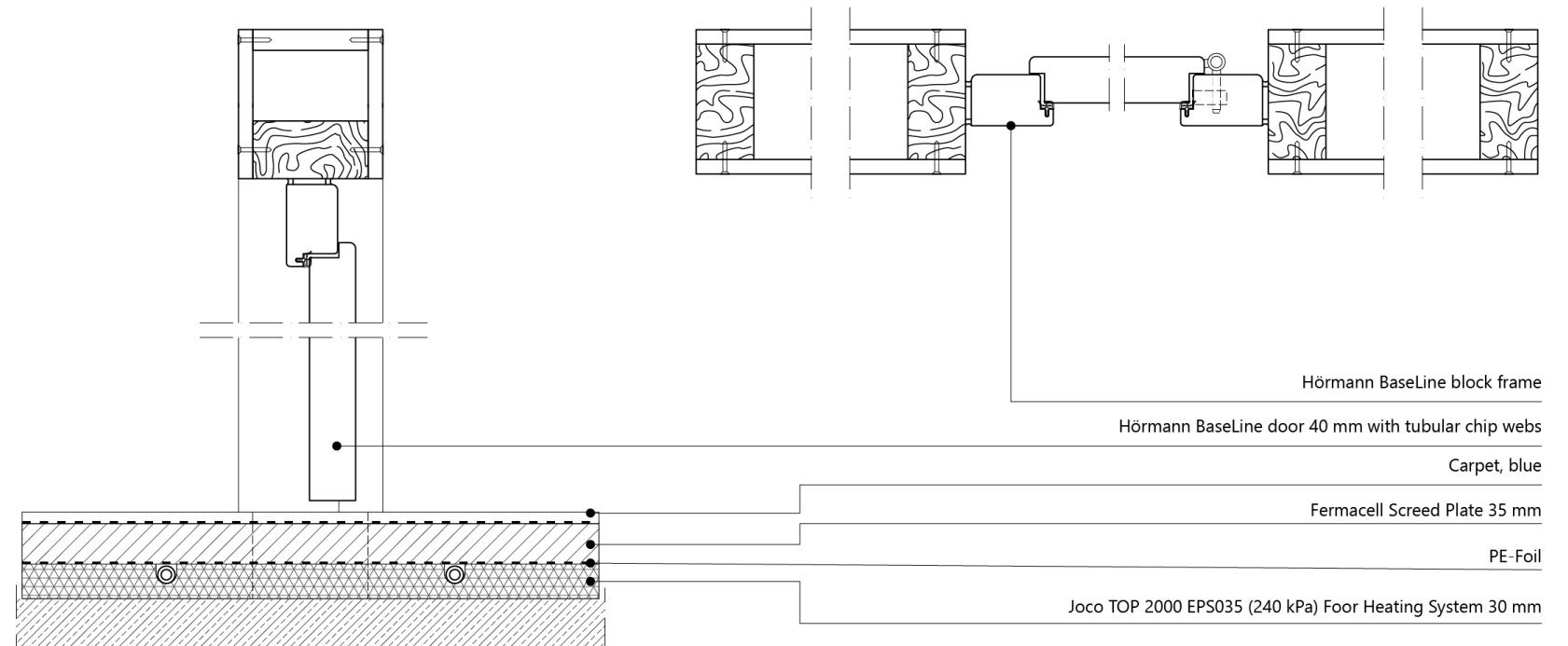


Evaluation



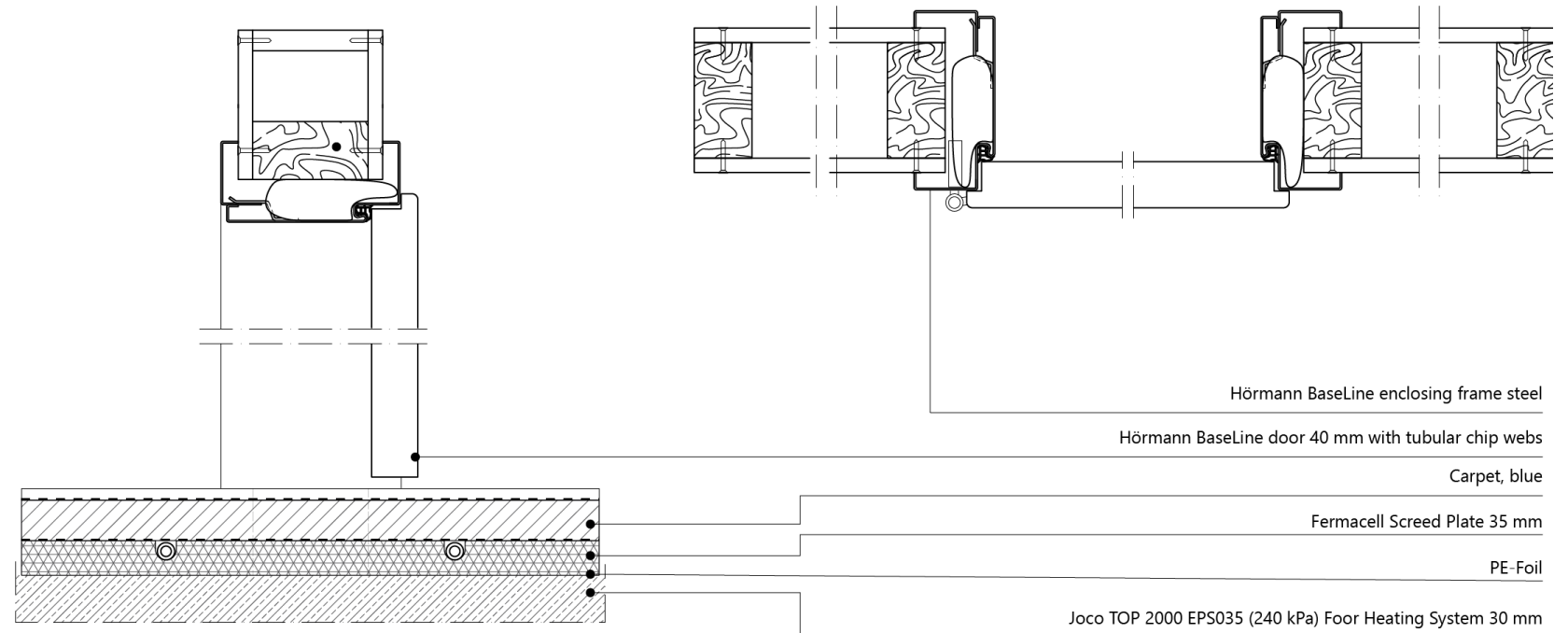
Implement Building Products

Block Frame



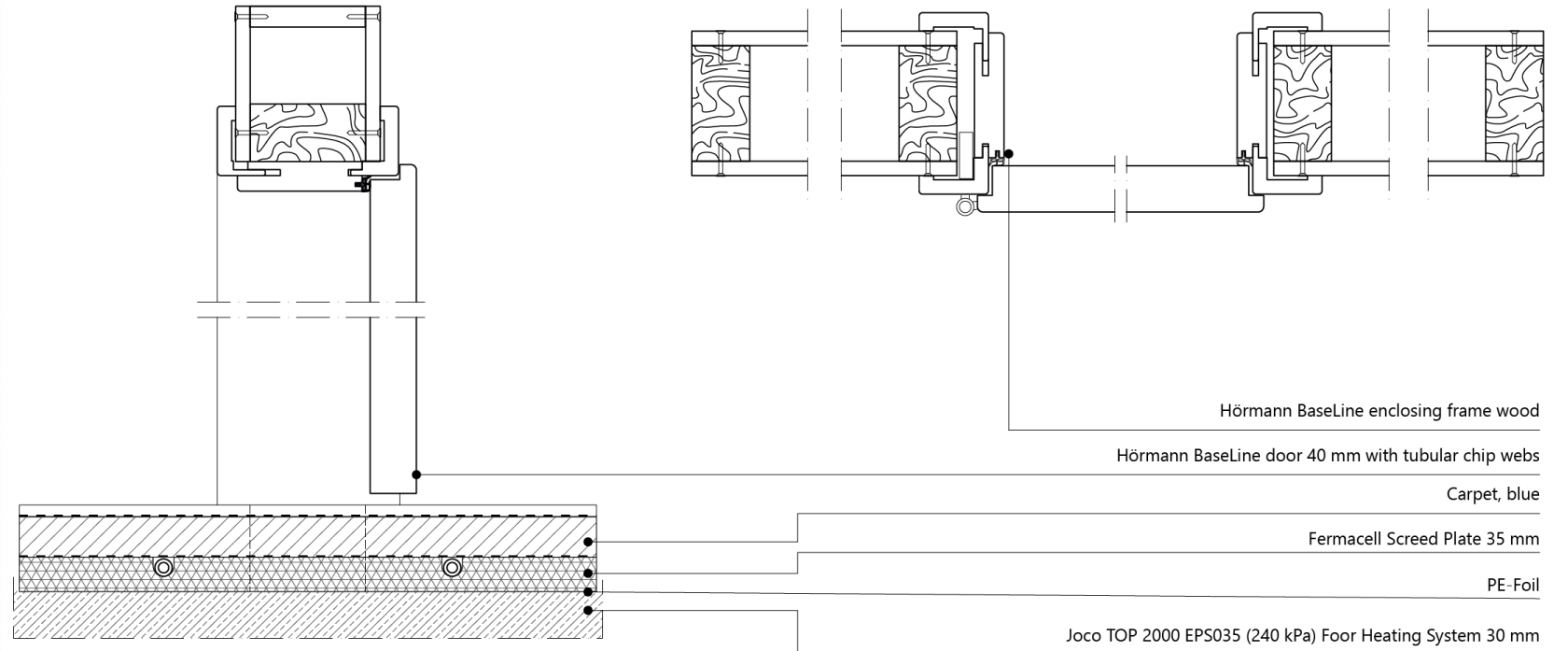
Implement Building Products

Enclosing Frame Steel

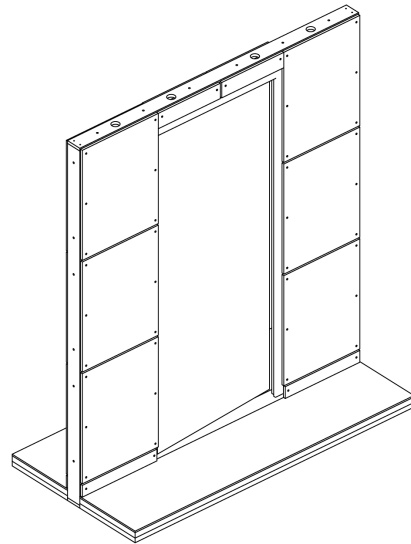


Implement Building Products

Enclosing Frame Wood

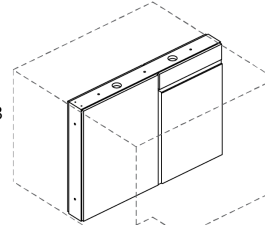


Complex Building Products

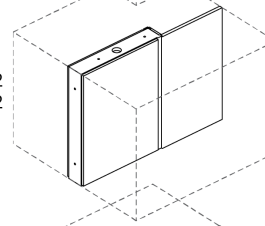


Building Tile **2100**

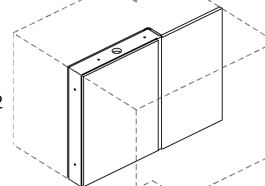
CTile 2103
UQ: 00120011



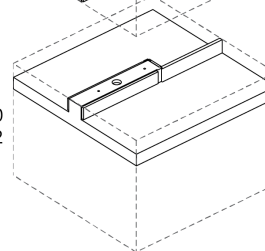
CTile 2102
UQ: 00120012



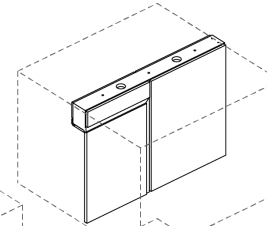
CTile 2101
UQ: 00120012



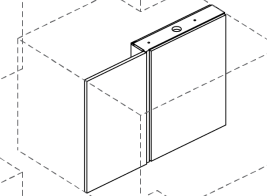
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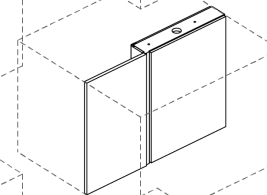
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UQ: 00210011



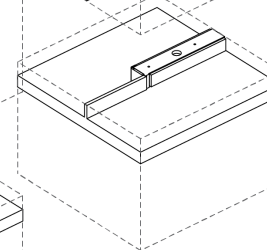
CTile 2105
UQ: 00210021



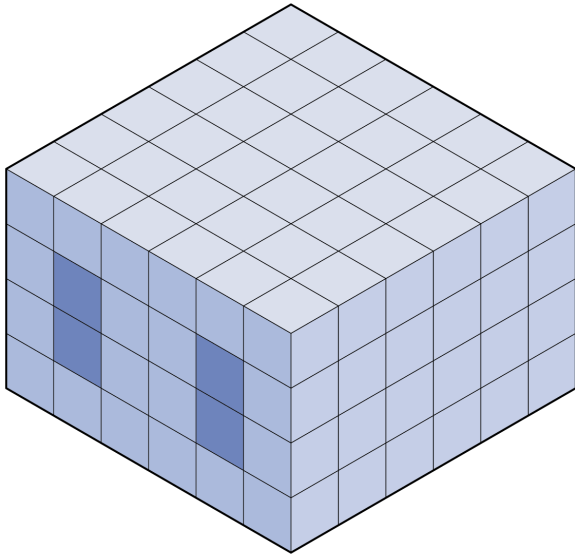
CTile 2106
UQ: 00210021



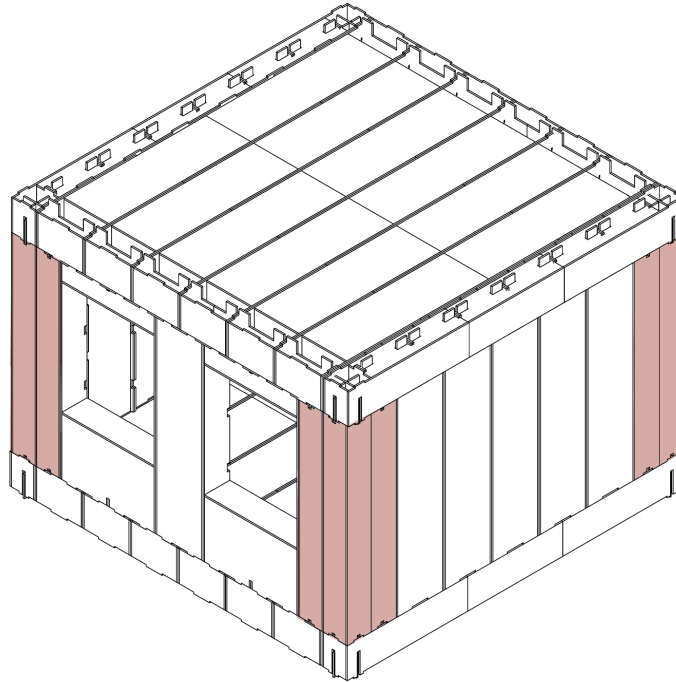
CTile 2107
UQ: 00000021



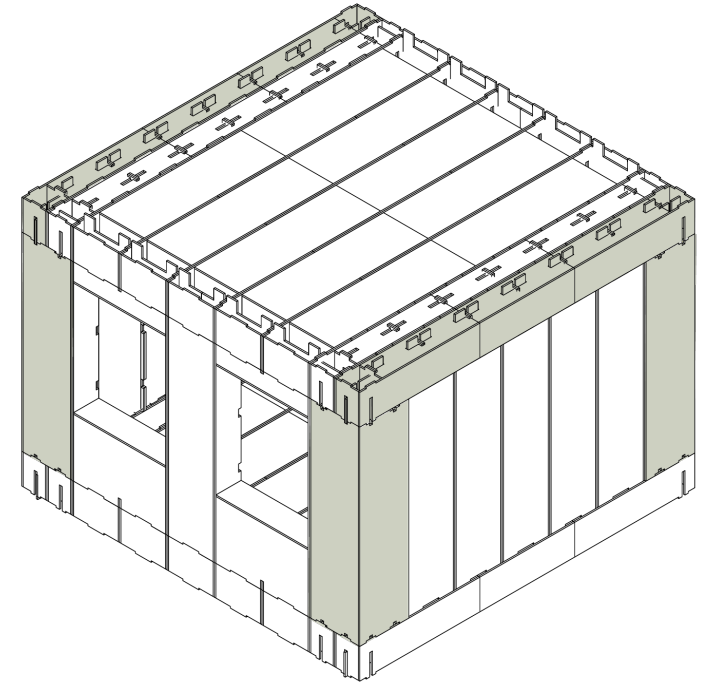
Application on Wikihouse



Voxel Set as Input

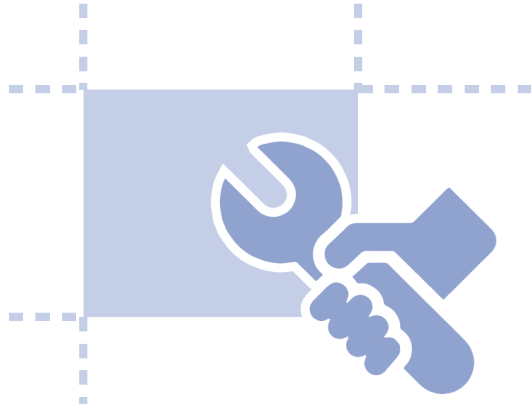


Applied Skylark 250 Blocks (unmodified)



Adjusted Skylark System

Industry Feedback



Potential for deconstruction /
disassembly



Potential for creating
material passports



Construction companies protect
their intellectual property

Design Method Comparison

System Name	Discrete BIM Design Tool	beterBASIShuis	Individualized Design by an Architect
Spatial Individualization	≈ individual configuration and sizing of all rooms (based on grid)	✗ lenght, with and amount of floors adjustable, room configuration fixed	✓ individual configuration and sizing of all rooms (based on grid)
Style / Finishing Option	✓ style options according to tile implementations - theoretically unlimited	≈ only six facade style options	✓ all styles / finishes possible
Industrialization Potential	✓ All Components can be prefabricated	✓ prefabrication in-house	✗ no industrialization potential
Workflow/ Product Monitoring	✓ Data control and construction management through integrated discrete BIM	✓ standartized construction workflow in-house	✗ need to create BIM model or manual monitoring

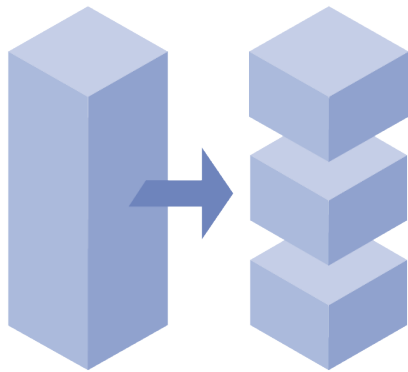
Impact on the Stakeholders

	Architect	House Owner	Engineers / Consultants	Building Product Manufacturer
Participation	 Topological Design  Tile Placement	 Topological Design  Tile Placement	 only read access	 Building Product Design
Added Value	 Simplified / faster Design Process  BIM Monitoring	 Information / Influence on cost, design and performance	 IFC data for all Tiles + Placement	 Simplified product integration
Disadvantages	 Design restrictions to building grid		 Individualized / continuous structures difficult to integrate	

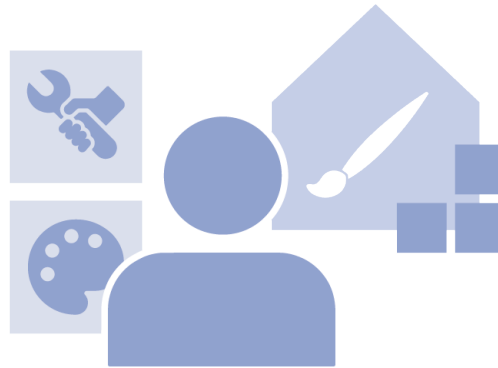
Conclusions



Product



any building product encodable
through computational division

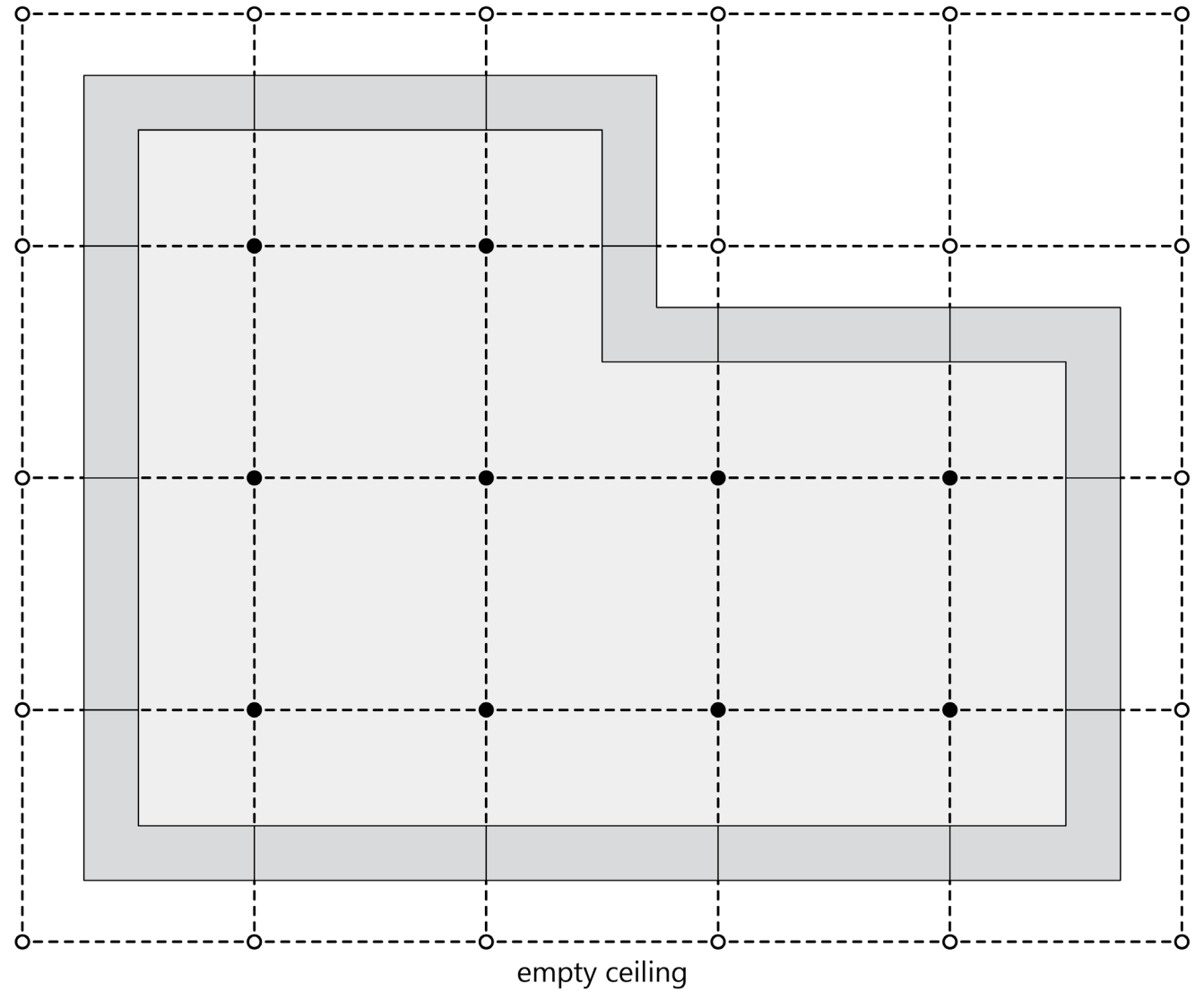
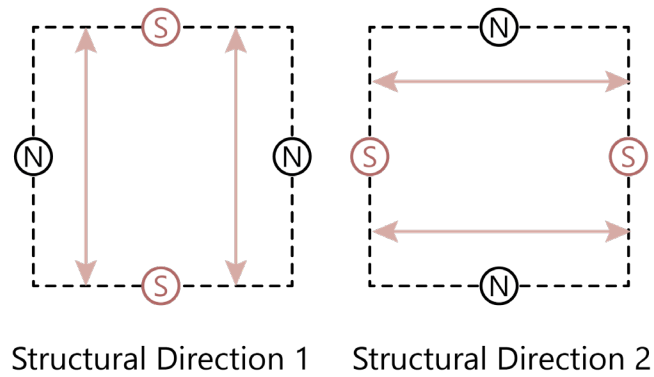


end-user can produce customized
spatial and detail design

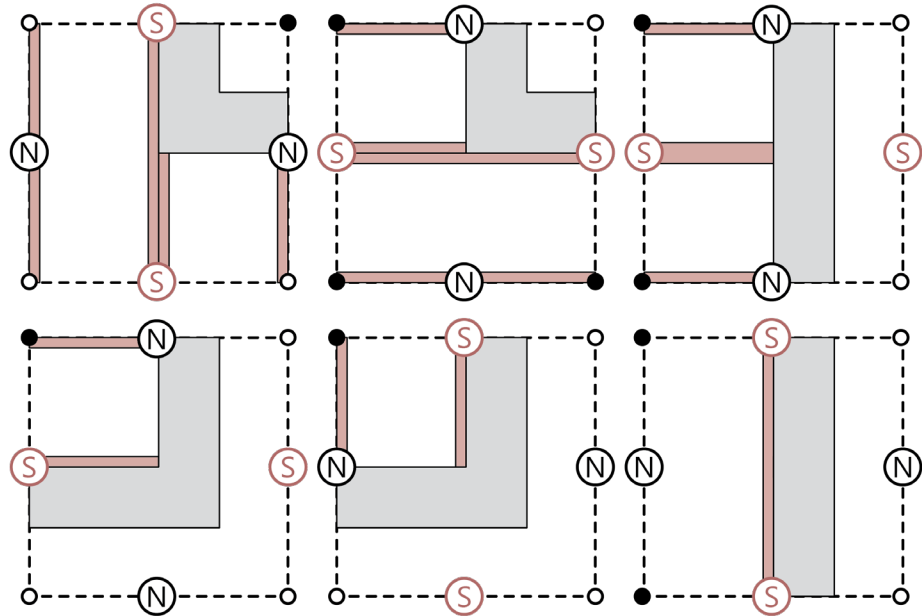


visualization, detail generation
and export

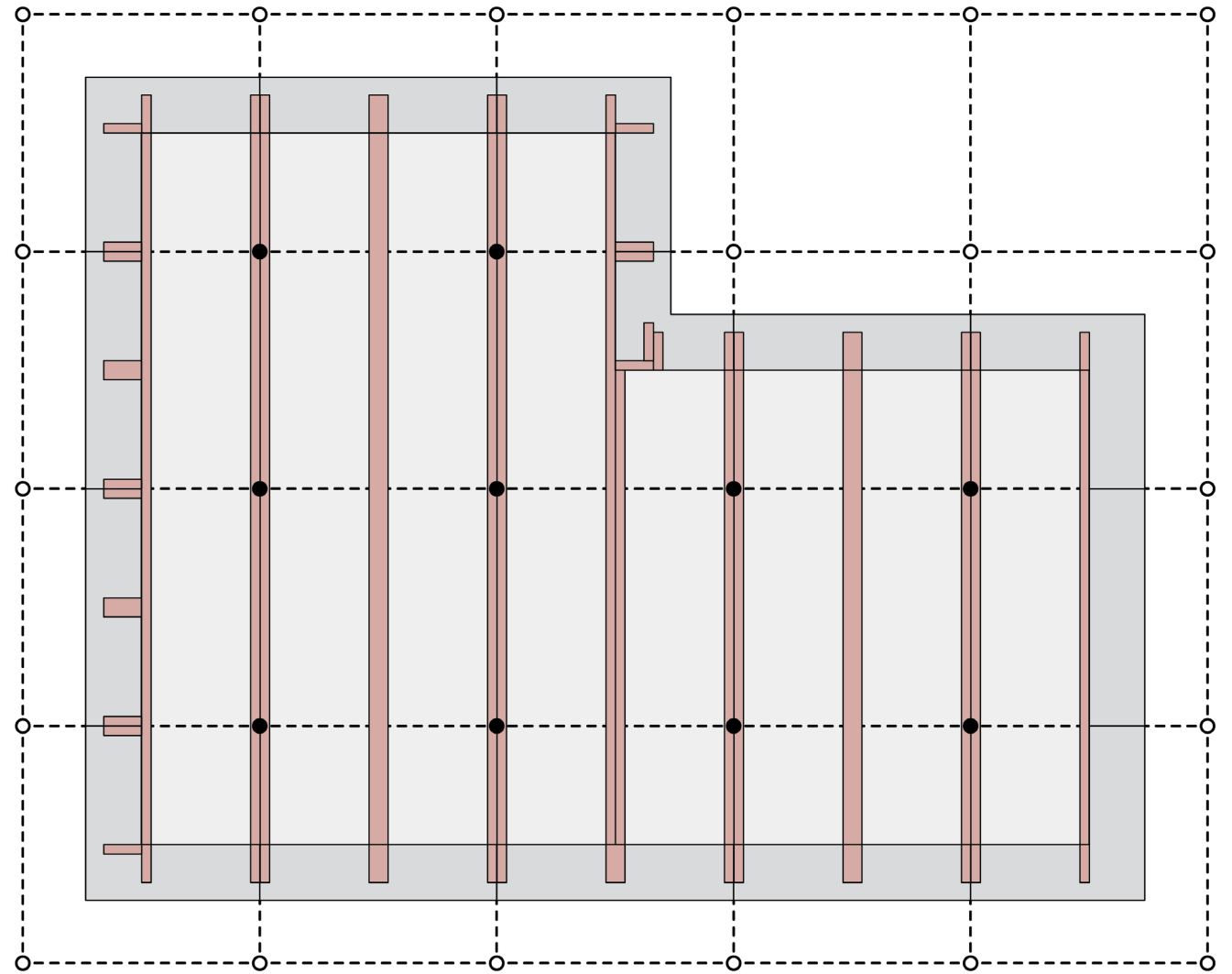
Limitations: Structure



Limitations: Structure

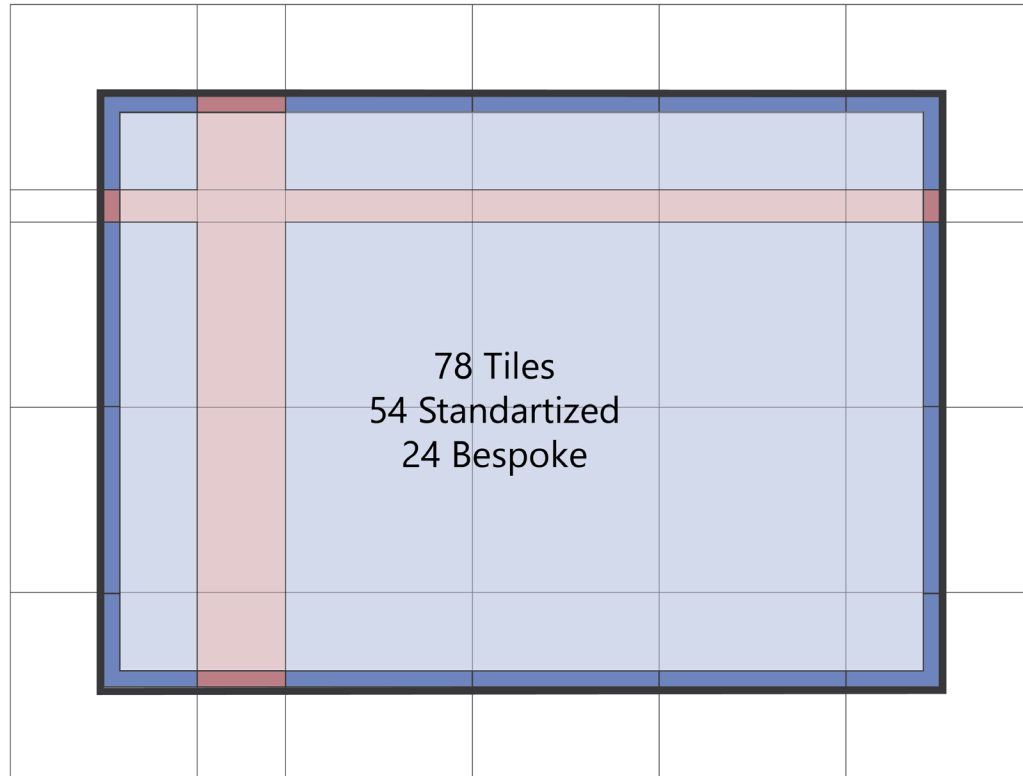


tile options with structural direction

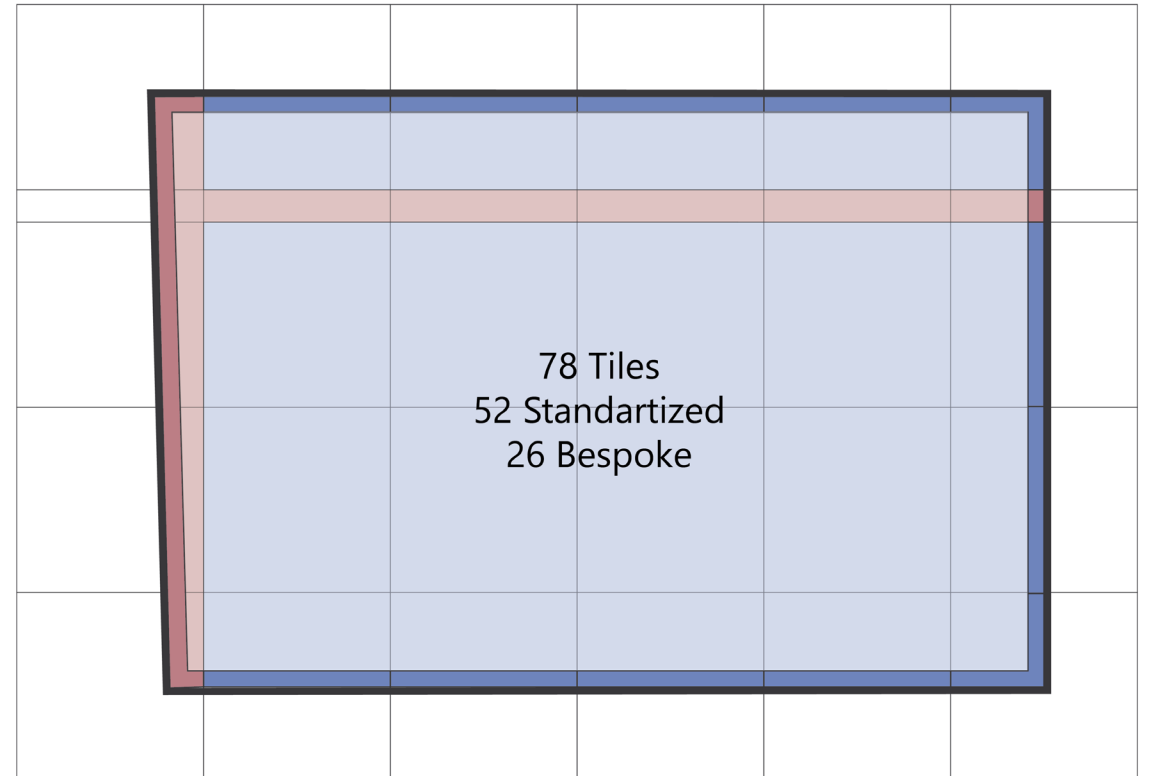


applied structure

Limitations: Bespoke Tiles

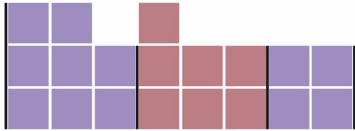


Orthogonal Walls

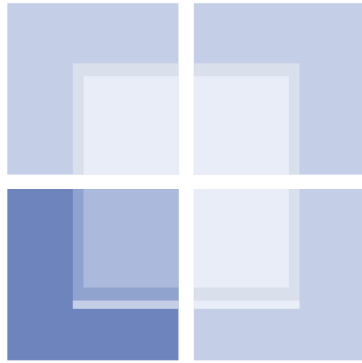


Inclined Wall

Industry Context

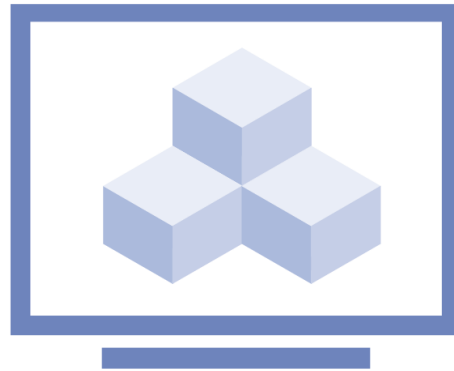
	 Self-Builder	 Development Projects	 Apartment Buildings
Initial Platform Set-Up	 Architect / Client 	 Architect / Investor 	 Architect / Investor 
Topological Design	 unrestricted 	 site-restrictions 	 only interior design 
Tileset Selection	end-user (+architect) 	end-user / investor (+architect)	investor (+architect) 

Future Developments



Automatic Tile Placement

use the WFC to add intelligence to design steps



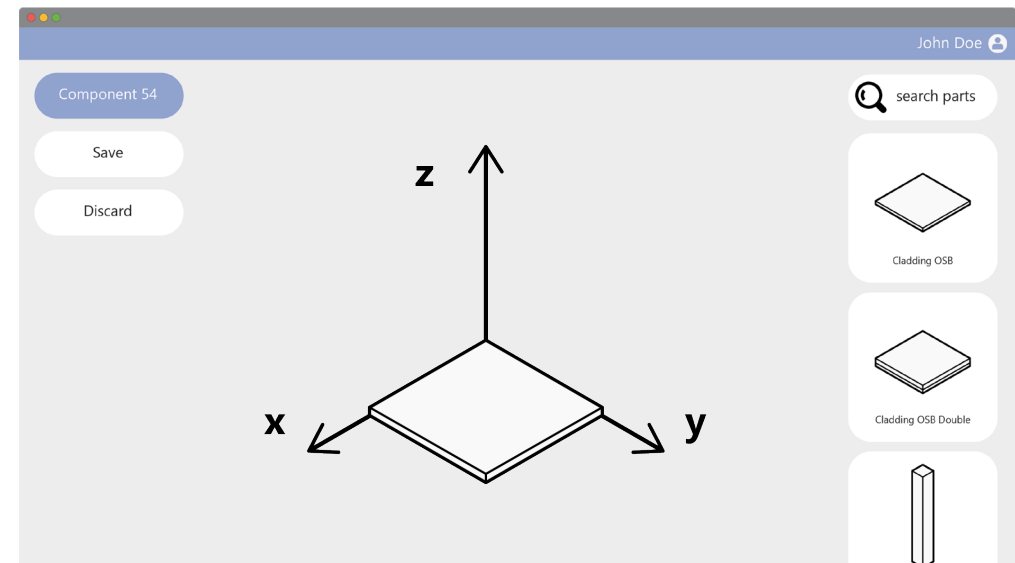
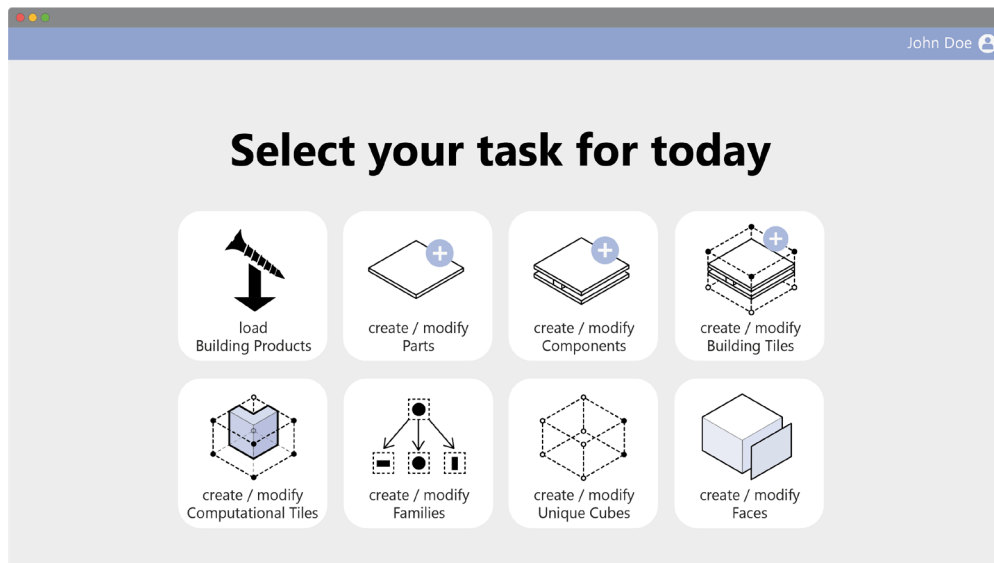
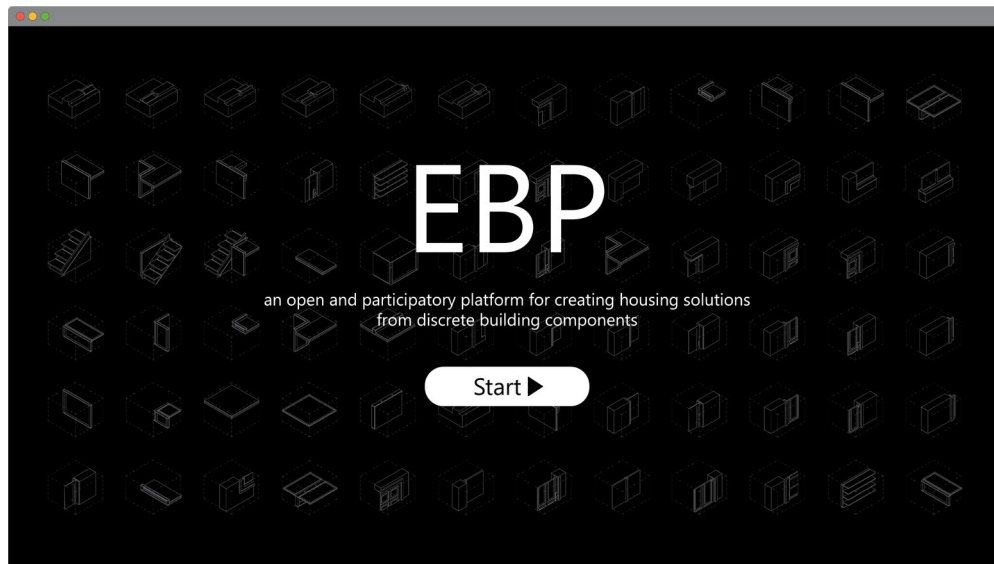
Digital Platform

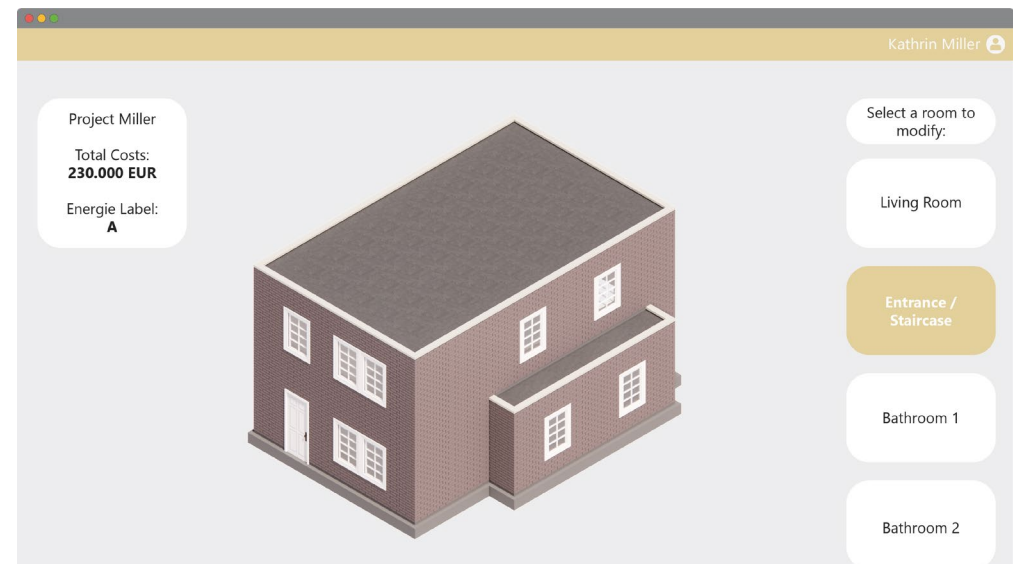
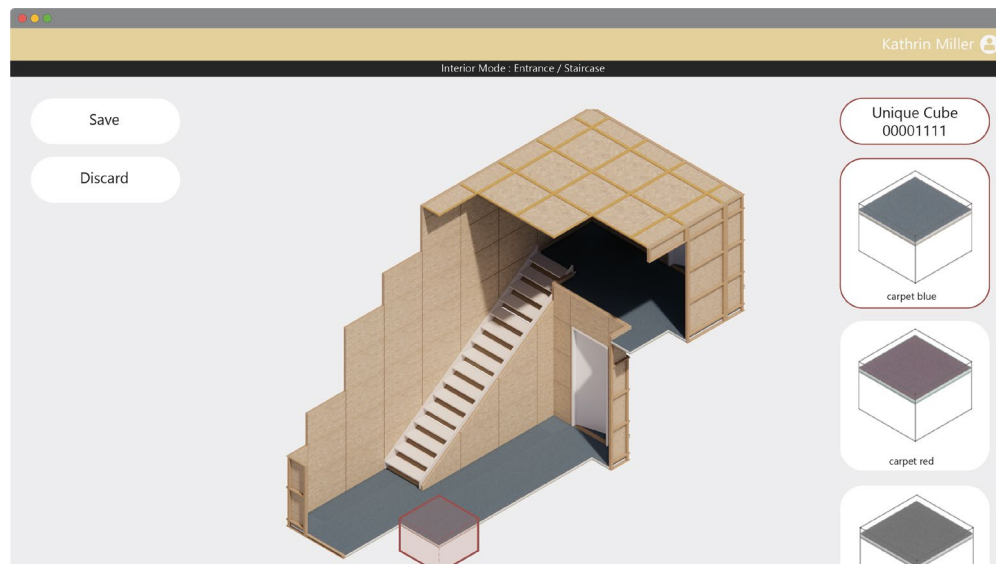
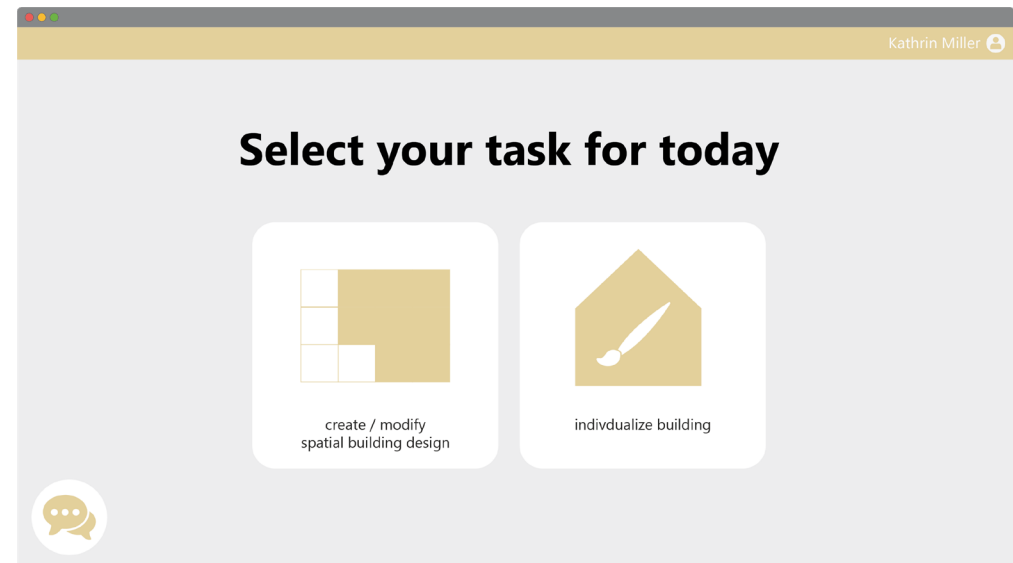
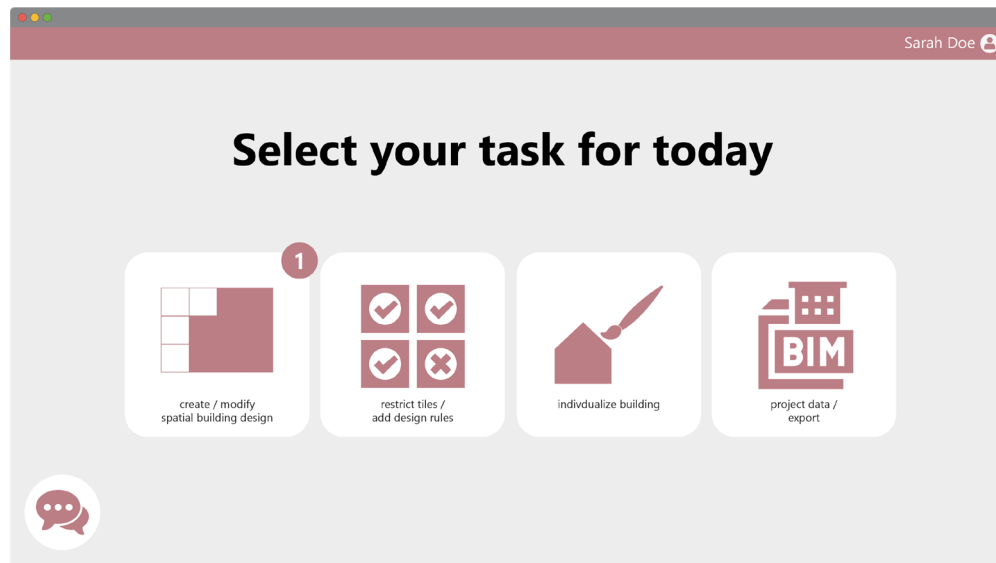
improve usability + cloud-based platform solution



Human-Computer Interaction

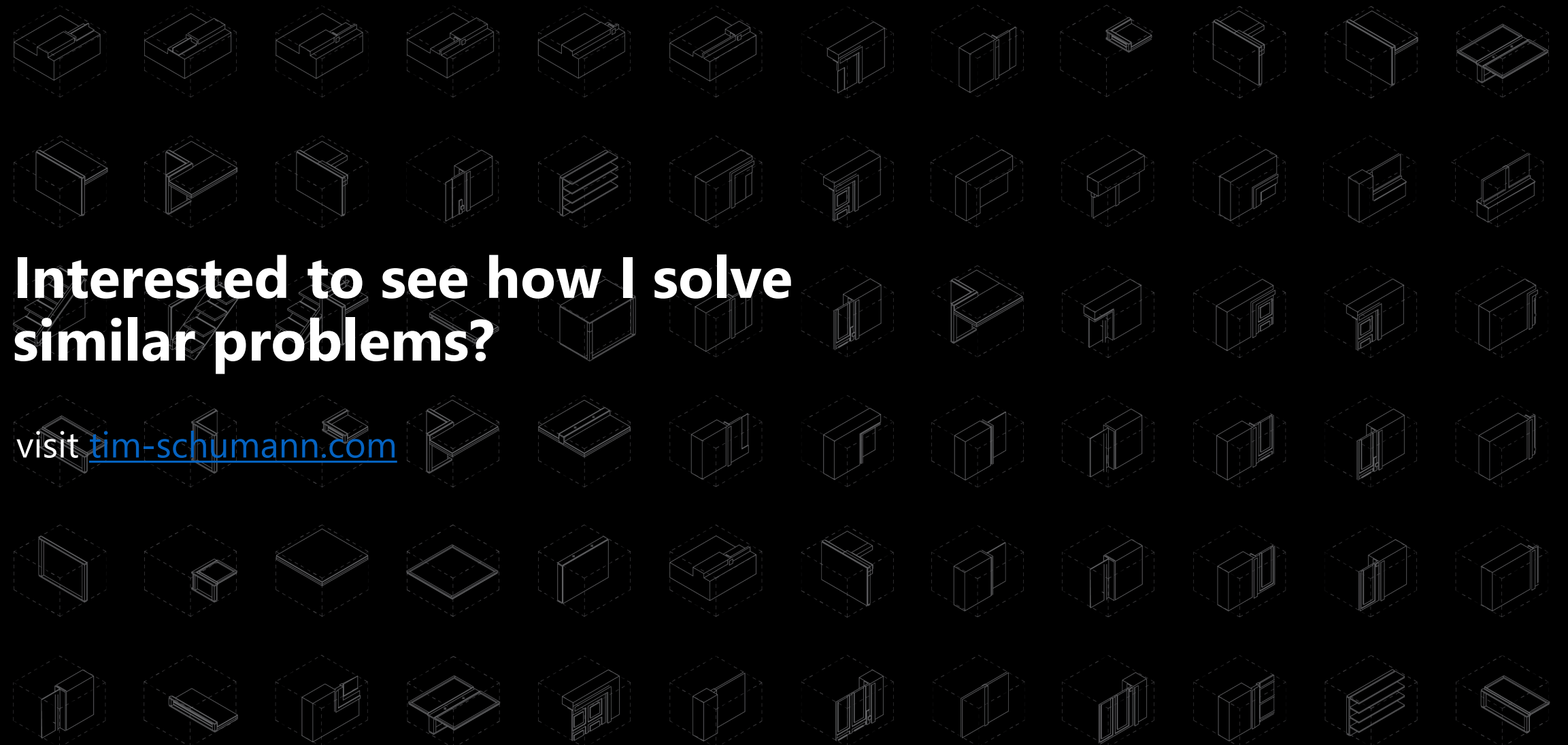
improve interaction through Virtual Reality





External Graphics

- (1) rtl nieuws. (2022) Retrieved from <https://www.rtlnieuws.nl/economie/artikel/5253847/huizenprijzen-stijging-sneller-maandlasten-300-euro-hoger>
- (2) hollandfoto (2019). Retrieved from www.hollandfoto.net/Shutterstock
- (3) TBI Woonlab (2022). Retrieved from <https://www.tbiwoonlab.nl/labels/beterbasishuis/woonplanner-beterbasishuis/#woonplanner>
- (4) The Newmakers (2022). Retrieved from <https://www.uuthuuske.nl/en/design/>
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