TU Delft

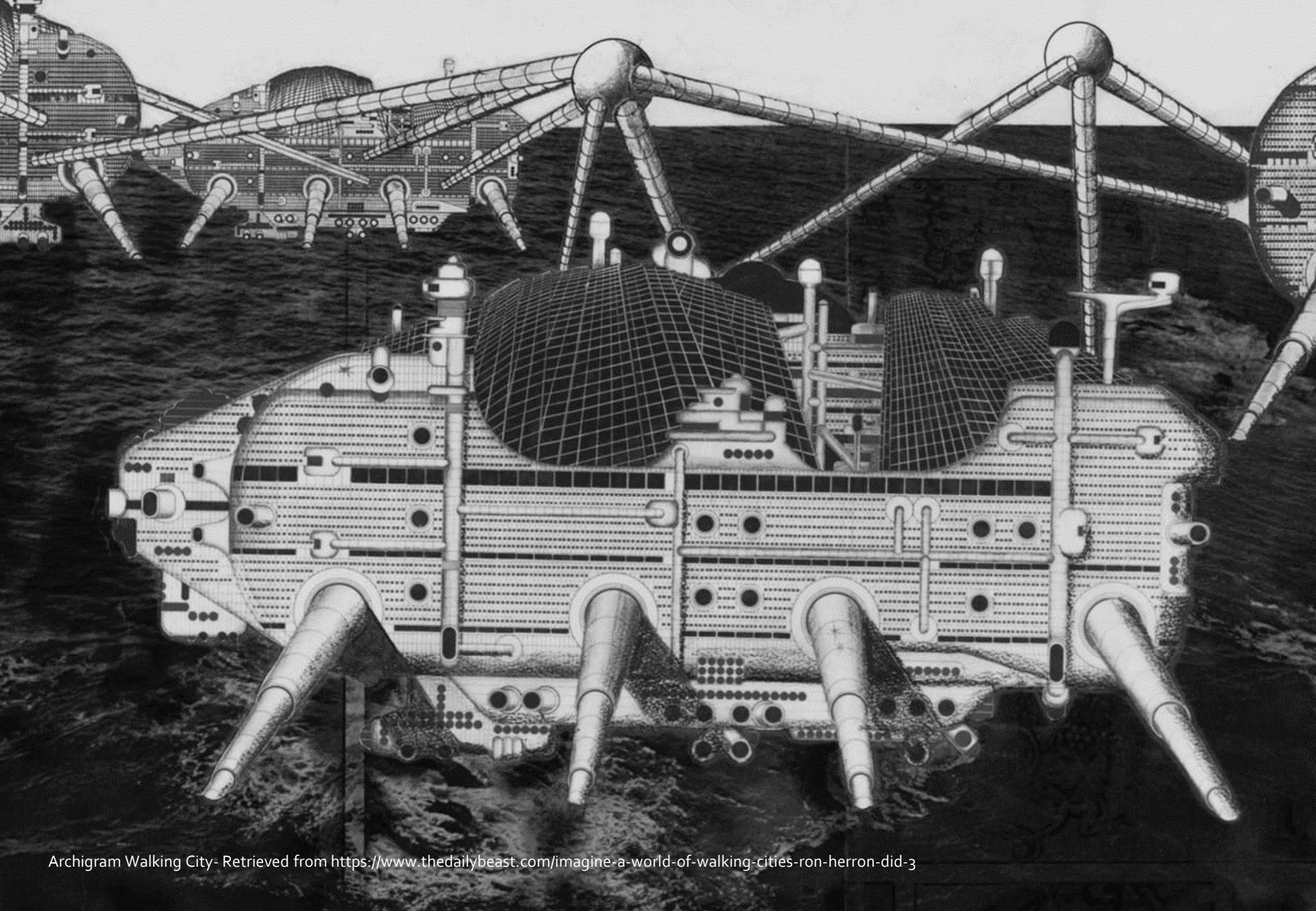
BT Graduation Studio
Master Thesis P5

Spatial Flexibility in Architecture: An Approach to Integrating Intelligent Swarm Robots for User-Centric Autonomous Architectural Layouts

Mentors: Dr. Serdar Asut , Dr. Jordan Boyle. External Advisor: Ir. Leontine de Wit

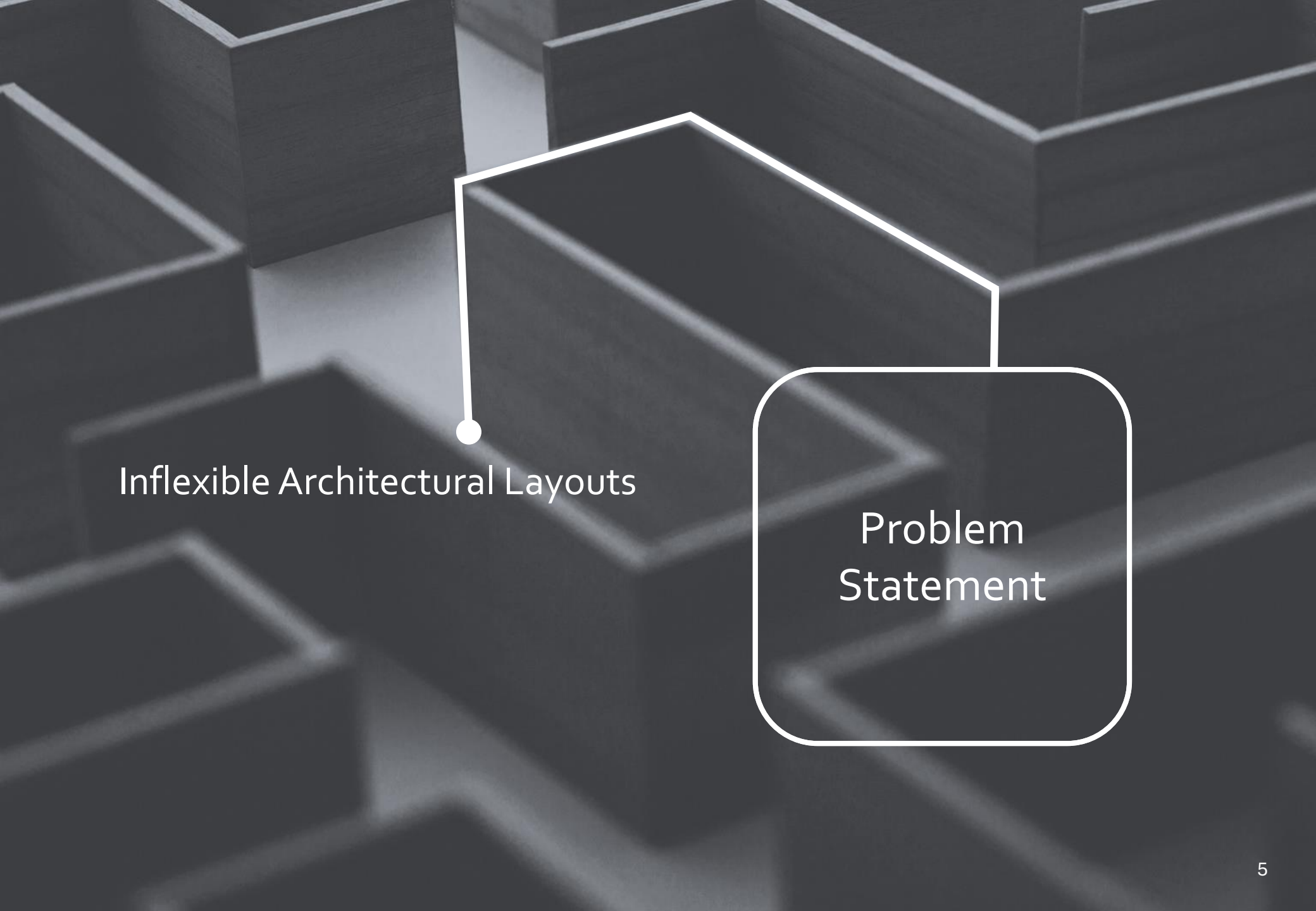
Sareh Yousefi

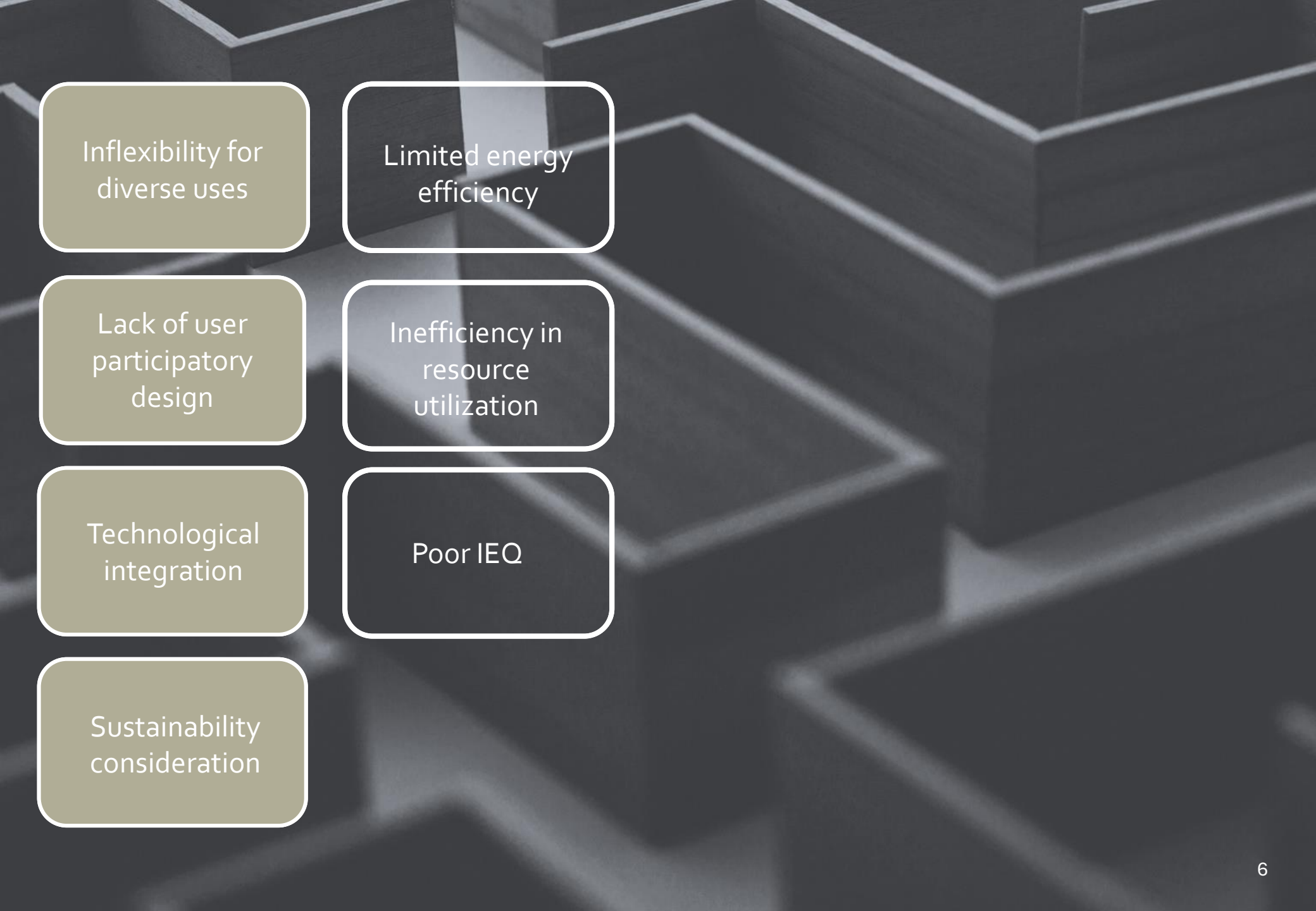
Architecture is not merely the construction of edifices but the crafting of environments that resonate well with the human experience (Alexander, C. et al., 1977).



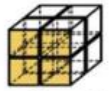
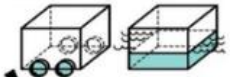
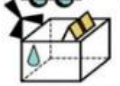
Archigram Walking City- Retrieved from https://www.thedailybeast.com/imagine-a-world-of-walking-cities-ron-herron-did-3

Big Hero 6 Microbots Presentation- Retrieved from https://www.youtube.com/watch?v=fsVJuN75vzEd-3

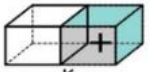
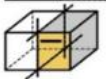
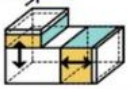

Inflexible Architectural Layouts
Problem Statement


Inflexibility for diverse uses
Limited energy efficiency
Lack of user participatory design
Inefficiency in resource utilization
Technological integration
Poor IEQ
Sustainability consideration

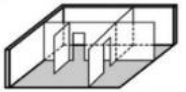
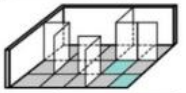
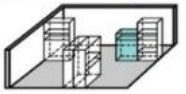
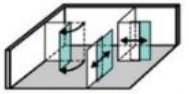
Changeable (Location)

- Modular 
- Portable 
- Mobile 
- Autonomous 

Changeable (Size)

- Expandable 
- Dividable 
- Transformable 

Changeable (Function)

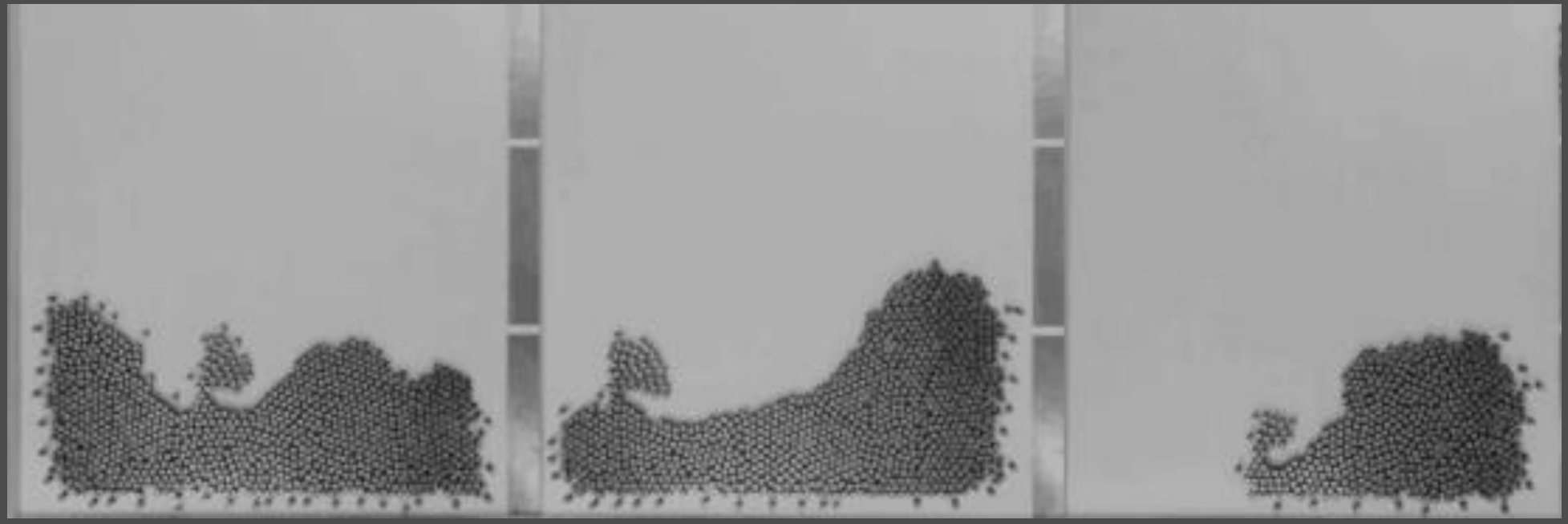
- Rebuildable interior 
- Partitionable interior 
- Divisible interior 
- Convertible interior 
- Multifunctional interior 
- Functionally transformable interior 

Flexibility systematics-types of flexibility depending on the.. .Retrieved from. https://www.researchgate.net/figure/Flexibility-systematics-types-of-flexibility-depending-on-the-nature-and-scale-of-changes_fig1_331314074

Swarm in Nature

Starling Murmuration- Retrieved from https://makeagif.com/gif/starling-murmuration-short-agfSbV

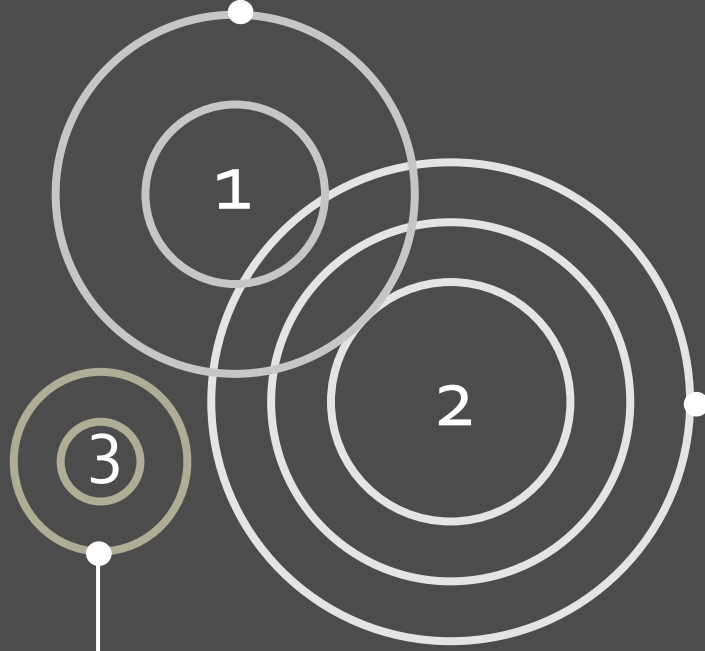
Swarm Robots



Swarm Robots- Retrieved from https://www.wsj.com/articles/harvard-scientists-devise-robot-swarm-that-can-work-together-1408039261

Research Questions

1- What are the key design parameters to achieve spatial flexibility in architectural layout design?

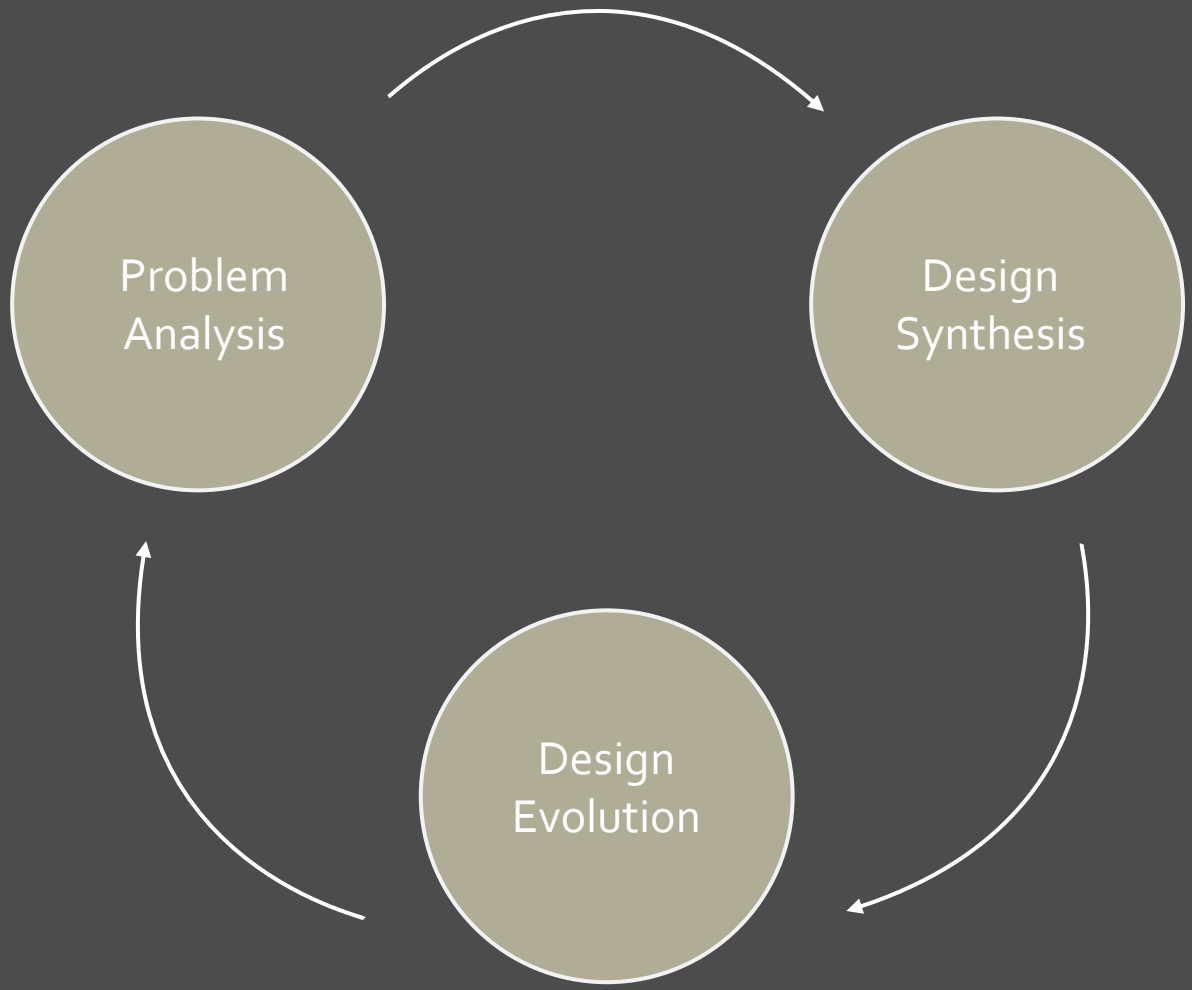


2- What are the most optimal strategies and technological frameworks to efficiently integrate swarm robotics into architectural workflows, which allows for the creation of au*tonomous* layouts that continuously respond to user preferences and evolving spatial requirements?

3- What are the necessary steps to prototype a sample scenario of a robotic swarm configuring a flexible architectural layout**?**

Research Objective

Utilizing Swarm Robotics for Spatial Flexibility in Architecture


Problem Analysis
Design Synthesis
Design Evolution

A system that focuses on user needs to promote productivity and performance and minimize errors (Norman & Draper, 1986)

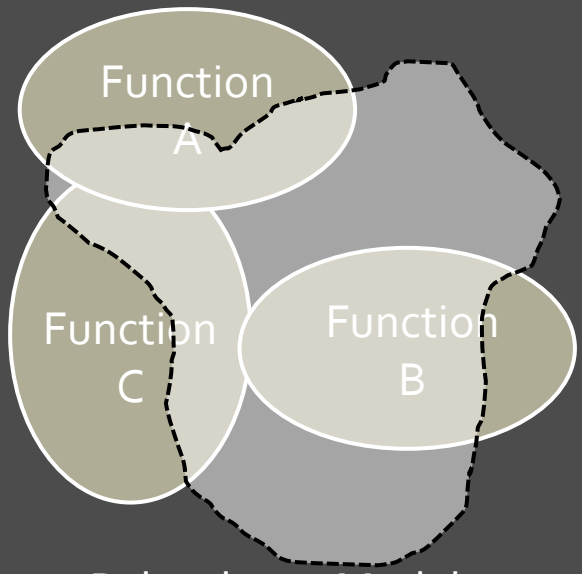
Flexibility and Function

Function A
Or

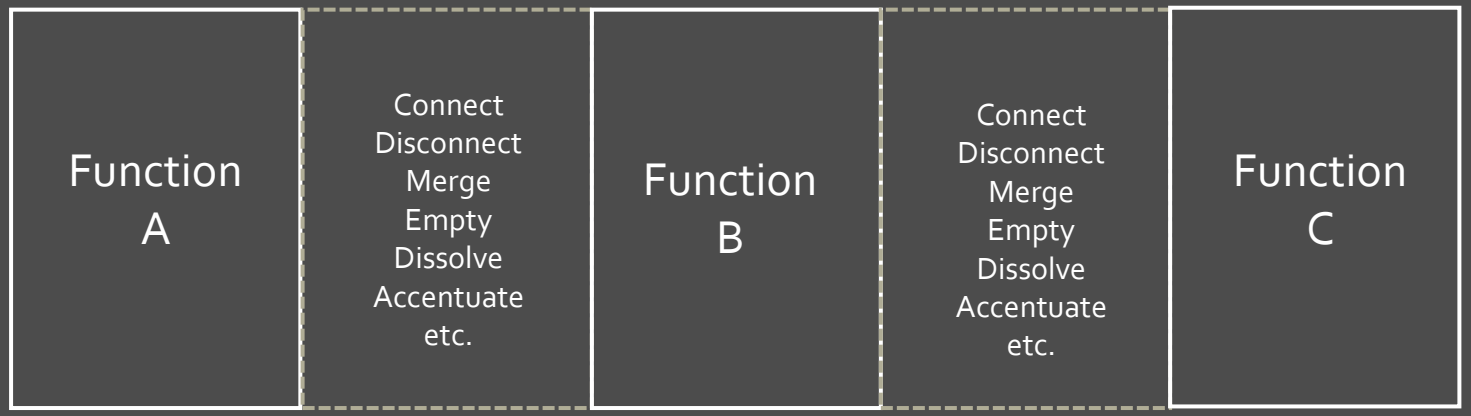
Function B
Or

Function C

Multi-functionality Model



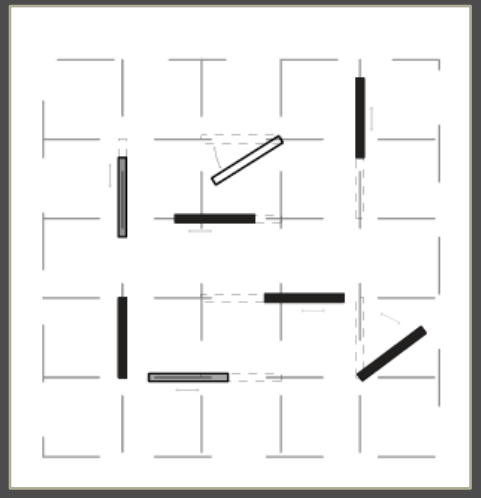
Polyvalence Model



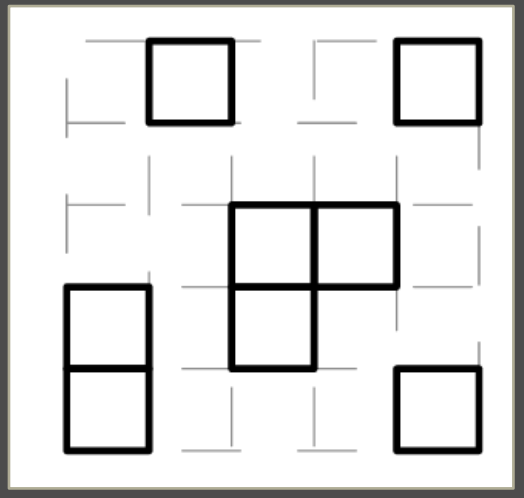
Contextual Relations Model

Strategies to Achieve Flexibility

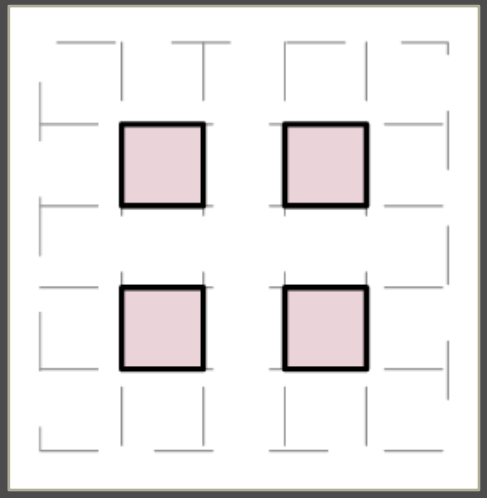
1- Operational Elements



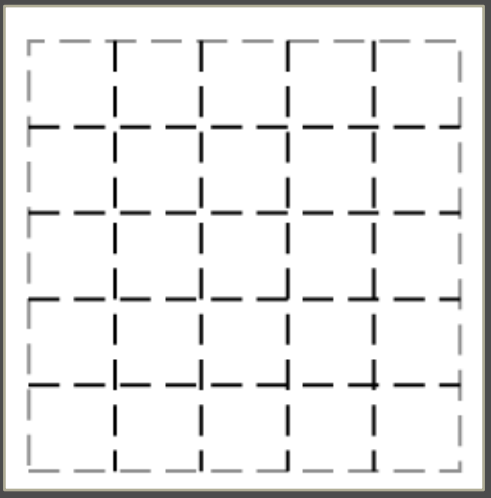
2-Modular Systems



3-Arrangement of Spaces



4-Erasing Programs



Operational elements like sliding walls, partitions, doors, and windows create spatial flexibility. Retrieved from https://www.researchgate.net/publication/264177780_On_Flexibility_in_Architecture_Focused_on_the_Contradiction_in_Designing_Flexible_Space_and_Its_Design_Proposition

Case Studies

Innovation Hubs

Haier Global Creative Research Center -China

Tata innovation Center- New York

Educational Buildings

Echo Building-TU Delft

Pulse Building-TU Delft

A Cultural Center/ Theatre

Amare Theatre- Den Haag

Transparency
Open Plan
Glass

Equal Views and Access
Steps

Glass

Polyvalency
Partition Walls

Non-fixed Furniture

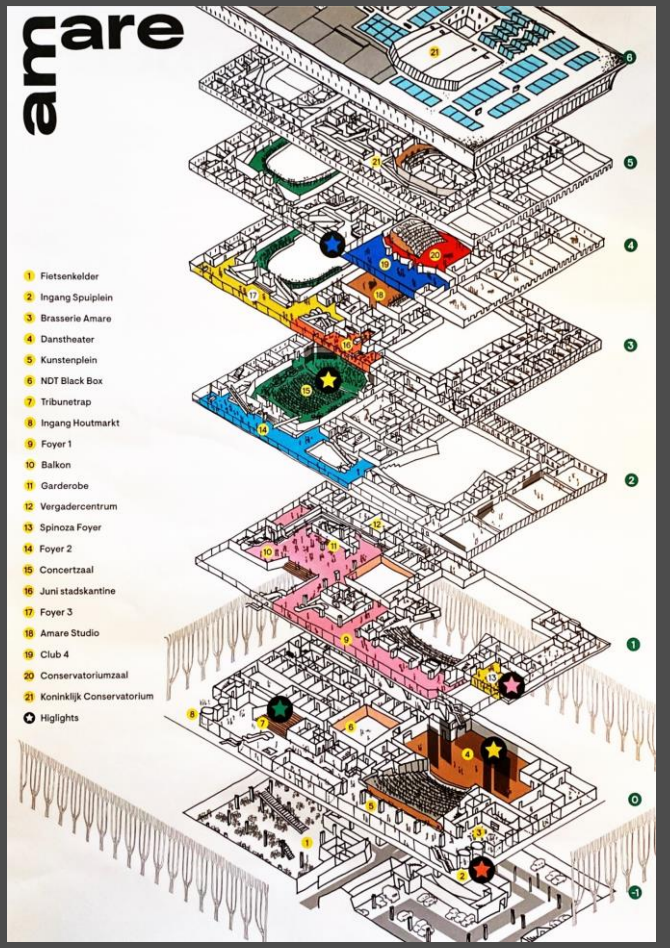
Strategies for design of innovative spaces. Own work created with the assistance of DALL·E 2

Building Programs

Space	Number of Spaces	Area
Research Section	1	835
Exhibition	1	3260
Auditorium	1	990
Gallery	1	390
VR/IMAX	2	1070
Library	1	765
Lobby	3	735
Roof Garden/Courtyard	1	-
Marketing/Business	1	600
Kitchen	1	161
Café	1	700
Technical Rooms	5	4301
Restrooms	32	-
Total		12907

Space	Number of Spaces	Area
Huddle	19	800
Workshops	5	3115
Conference	1	175
Classroom	2	1341
Research Section	27	782
Lab	8	2943
Lobby	2	1341
Roof Garden/Courtyard	1	-
Offices	13	1912
Restrooms	-	2117
Total		14041 sqm

Space	Number of Spaces
Study/Workshops	7
Mixed Didactics	2
Student Teams	1
Teacher Room	1
VMB6	1
Chill Zone	3
Debate Room	1
Seminars	1
Lecture Halls	3
Master Student Room	1
Case Study Rooms	1
Reception	1
Technical Rooms	
Restaurant	1
Restrooms	-
Total Area	8884 sqm

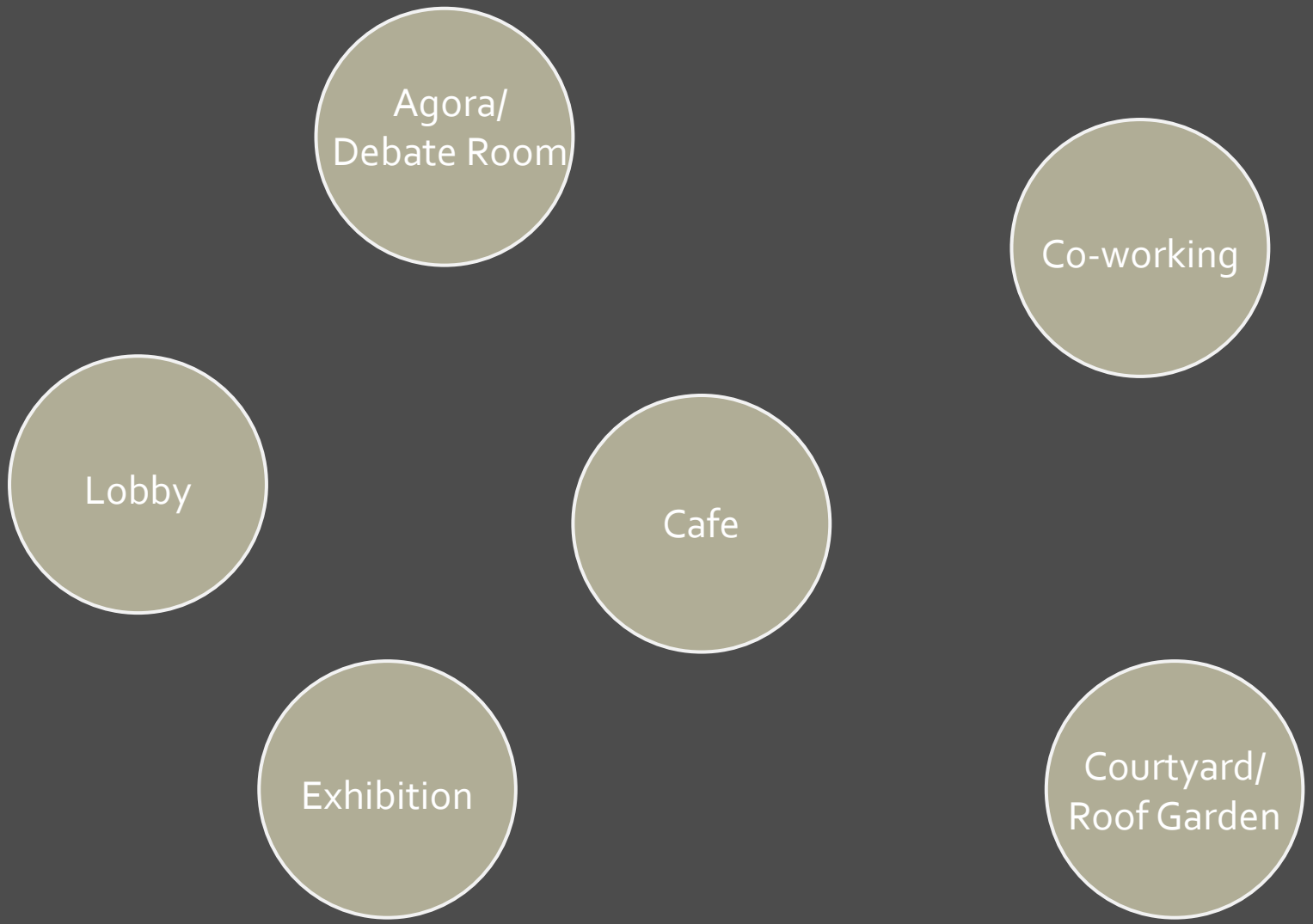


First 4 Case Studies

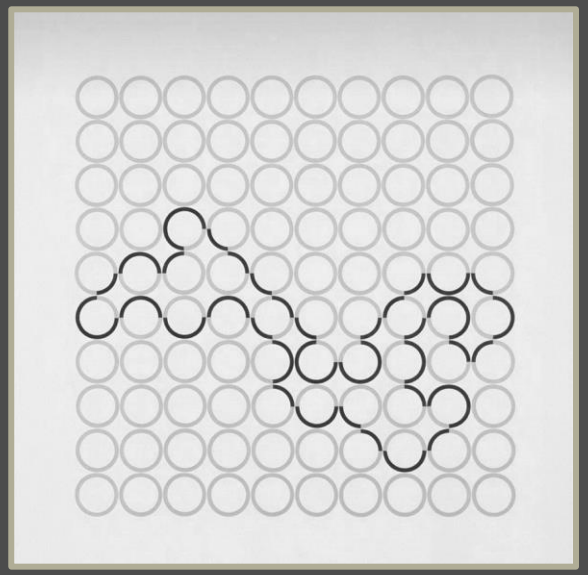
Space
Auditorium
Exhibition
Technical Rooms
Research Section
Library
Co-working/Studio
Workshop
Classroom
Lobby
Café
Offices
Business Section
Gallery
Conference
Agora/ Debate Room
Lab
Roof Garden/Courtyard
Lounge
Restrooms

Amare Theatre

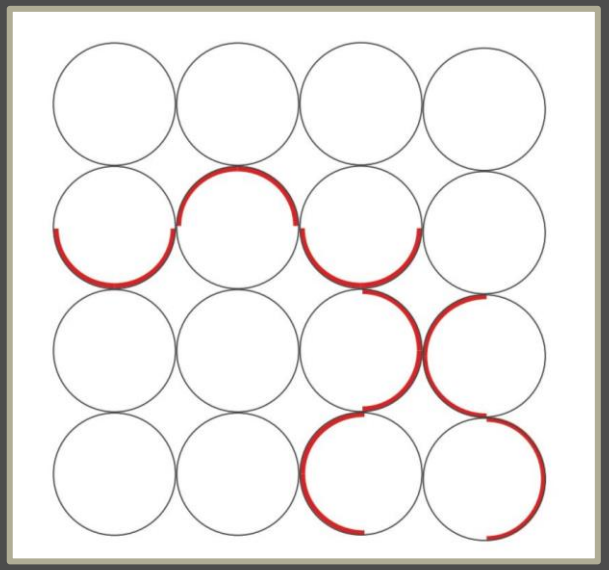
Space
Brasserie Amare
Dance Theatre
Arts Square
NDT Black Box
Grandstand Stairs
Foyer
Balcony
Wardrobe
Meeting centre
Concert Hall
Canteen
Amare Studio
Club
Conservatorium Hall
Royal Conservatory
Offices
Restrooms


Agora/
Debate Room
Co-working
Lobby
Cafe
Exhibition
Courtyard/
Roof Garden

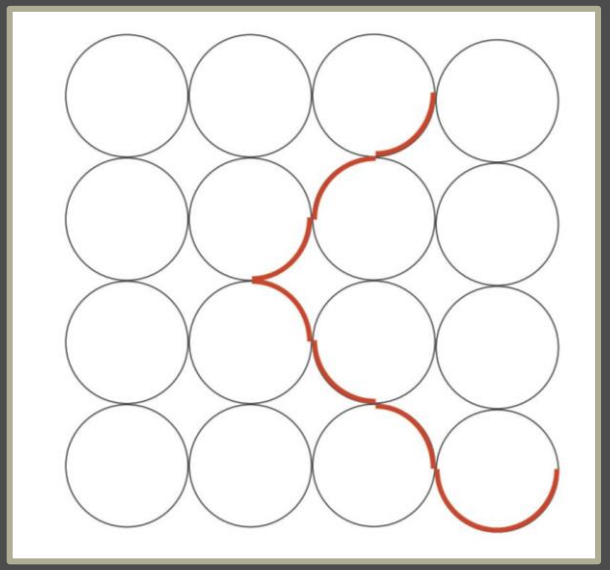
Inspiration



Design

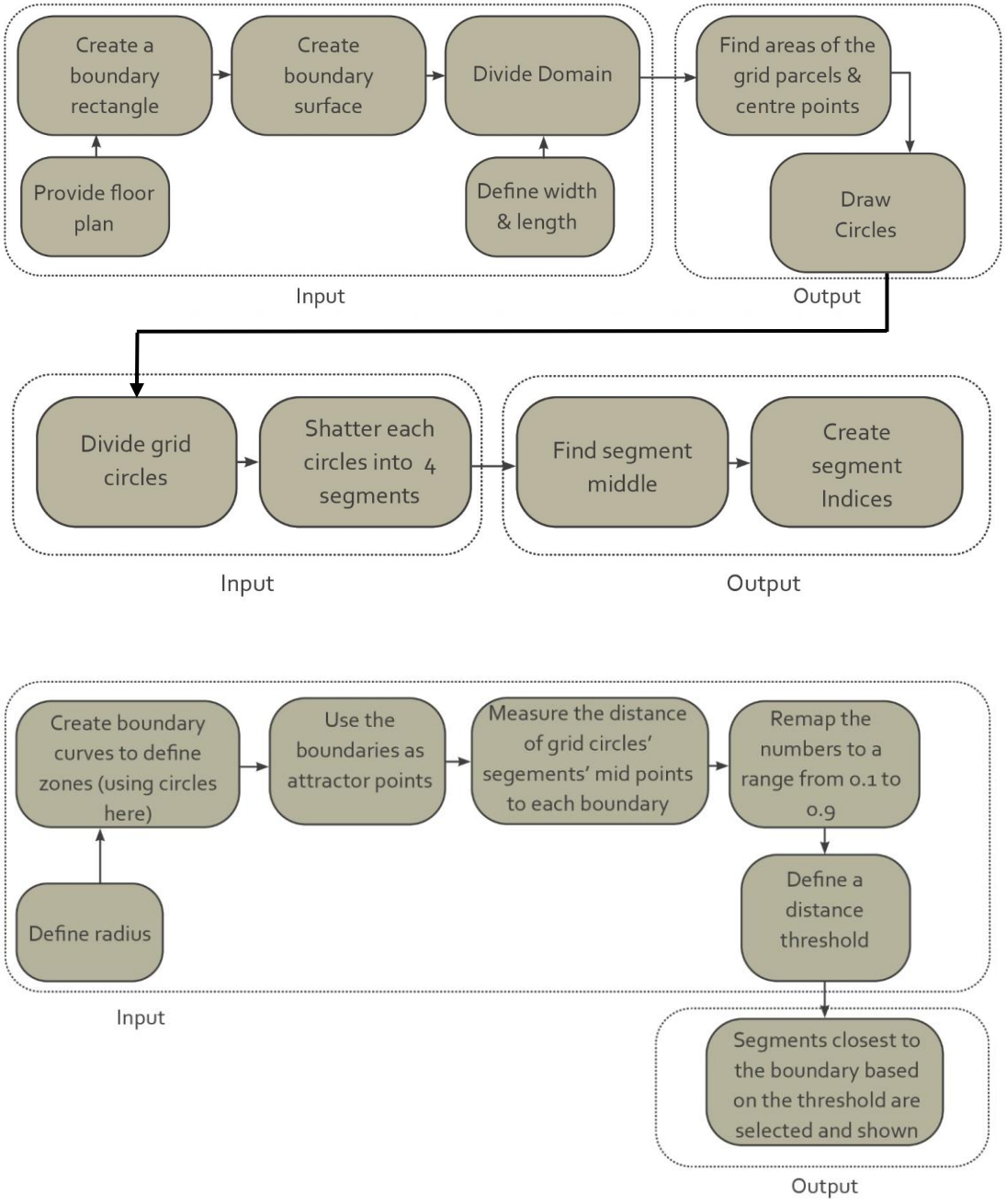


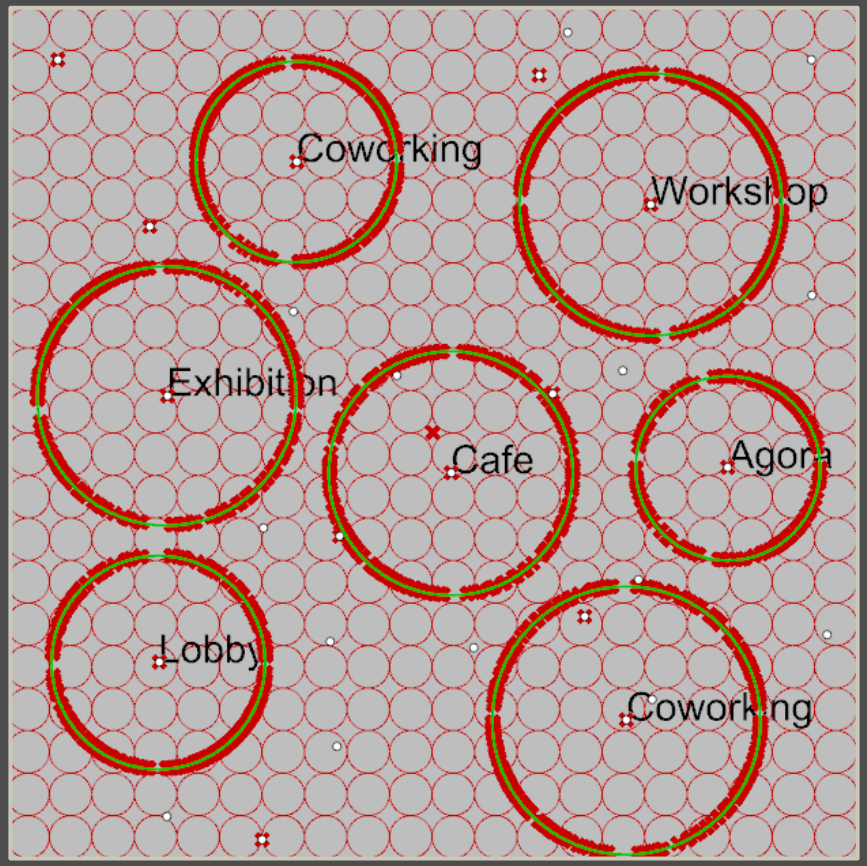
Half Circle Arcs



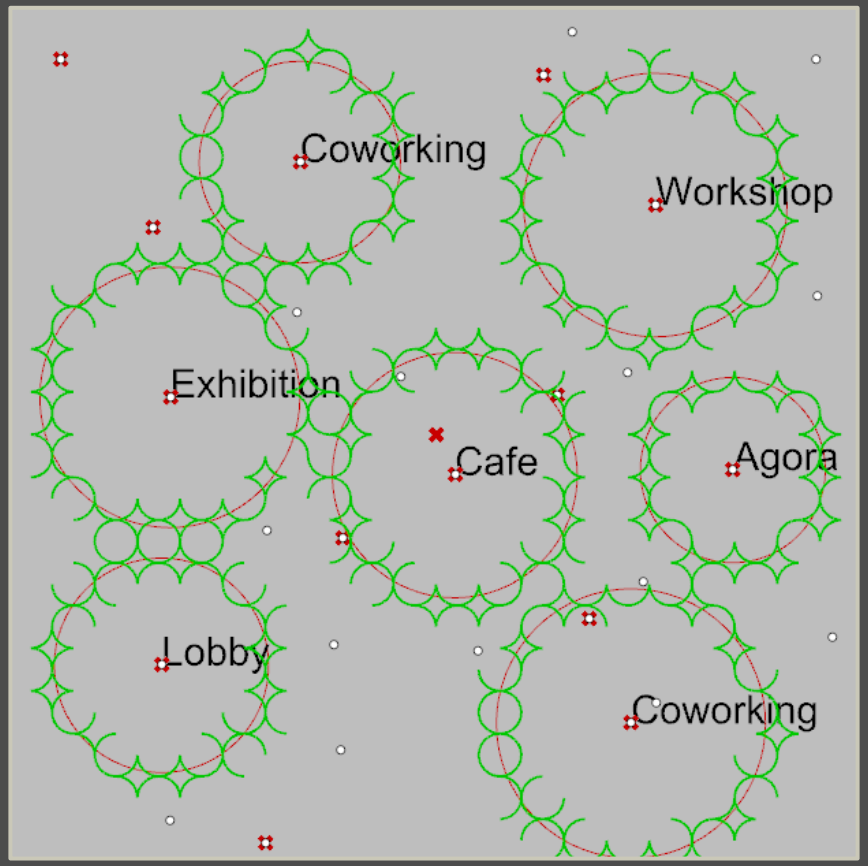
Quarter of Circle Arcs

Geometric pattern. Image as inspiration for the grid and form of robots. Retrieved from https://nl.pinterest.com/pin/760475087075061755/

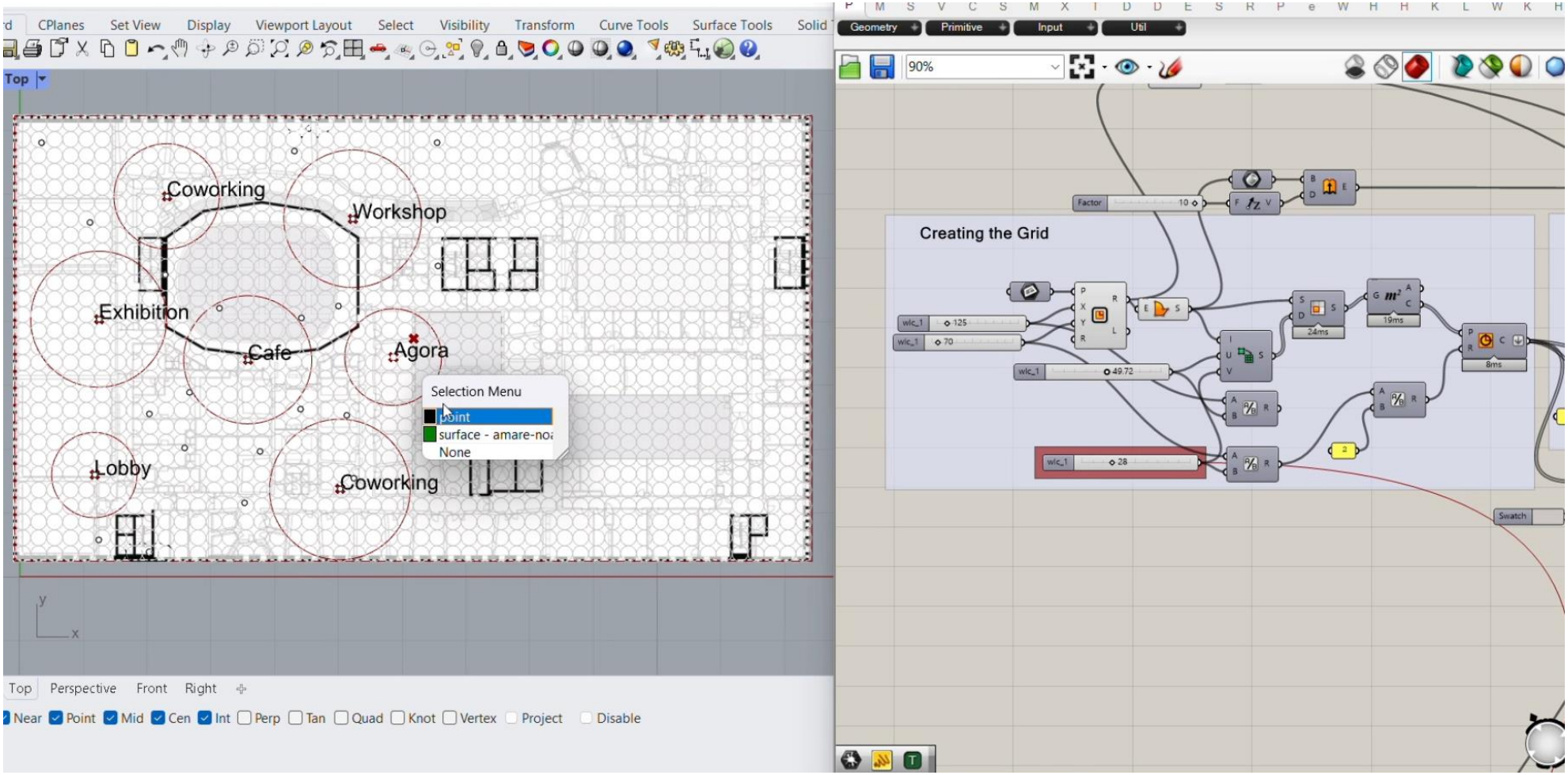

Create a boundary rectangle
Create boundary surface
Divide Domain
Find areas of the grid parcels & centre points
Provide floor plan
Define width & length
Draw Circles
Input
Output
Divide grid circles
Shatter each circles into 4 segments
Find segment middle
Create segment Indices
Input
Output
Create boundary curves to define zones (using circles here)
Use the boundaries as attractor points
Measure the distance of grid circles' segements' mid points to each boundary
Remap the numbers to a range from 0.1 to 0.9
Define radius
Define a distance threshold
Input
Segments closest to the boundary based on the threshold are selected and shown
Output

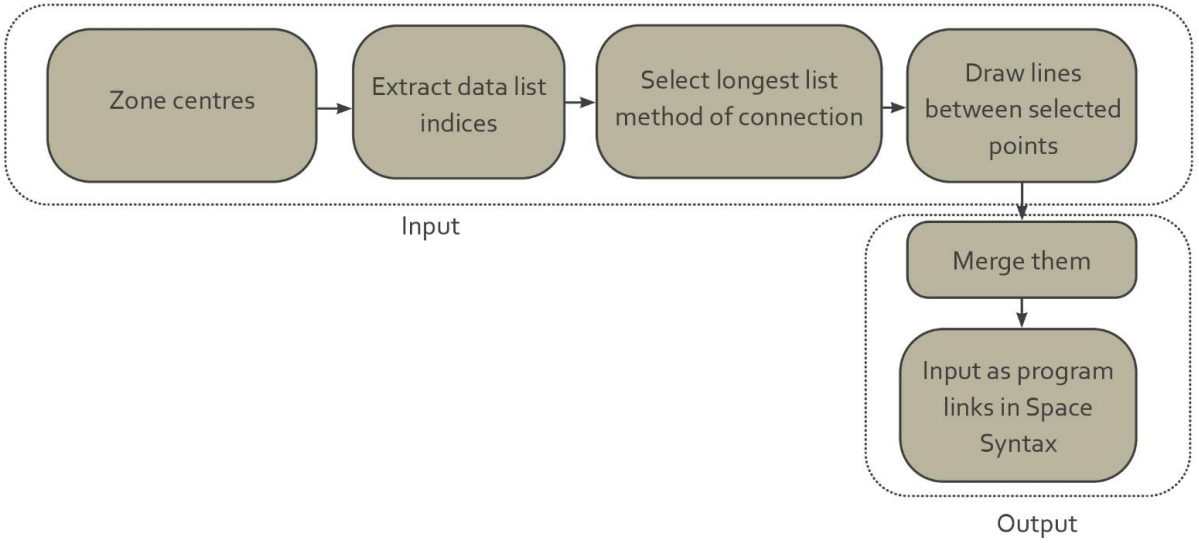


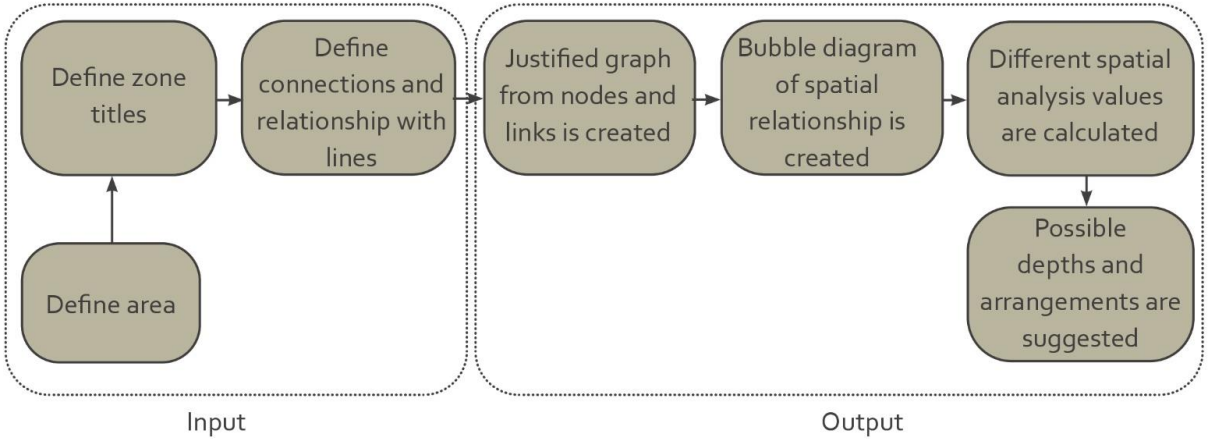
Creating the circular grid and defining program zones with circles

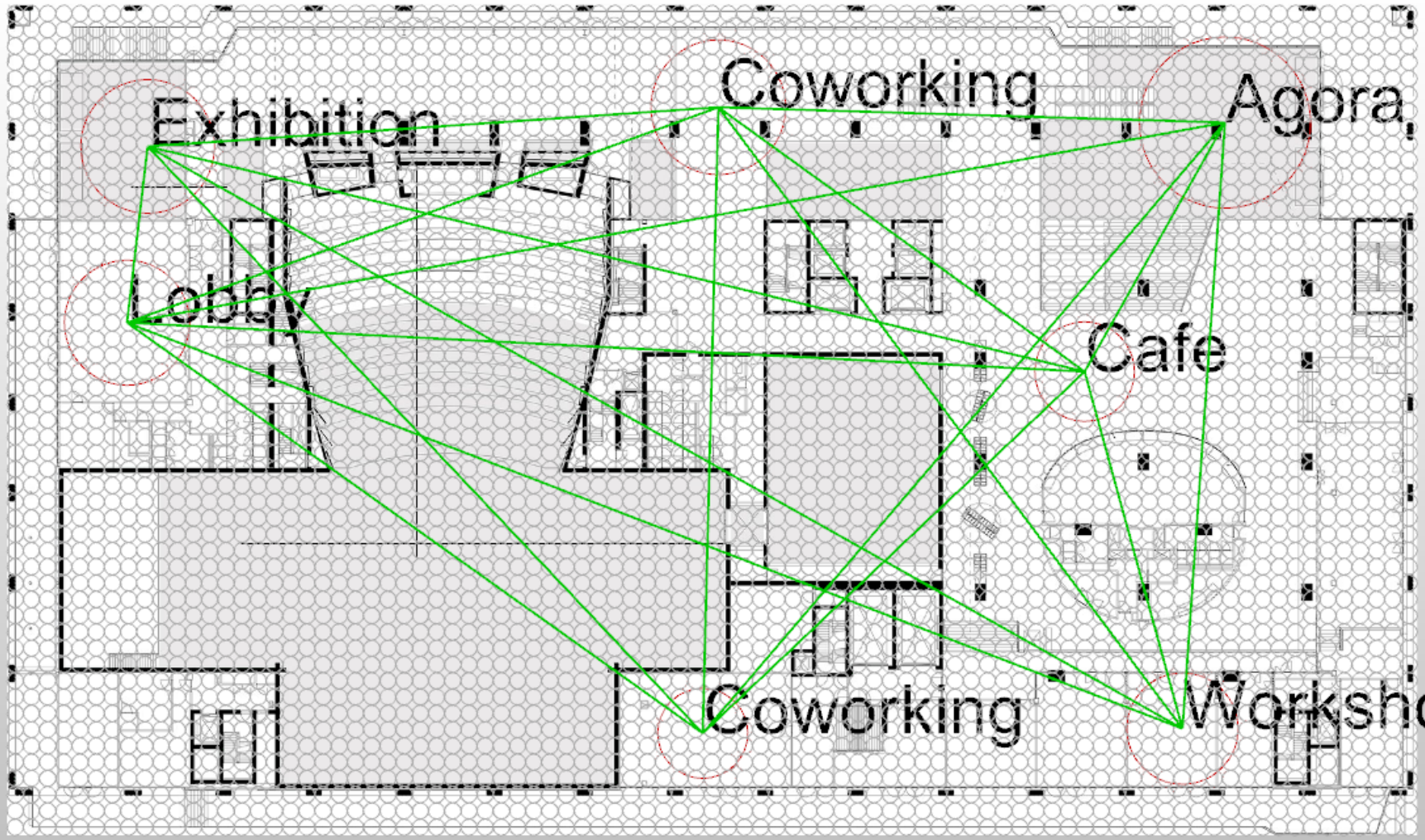


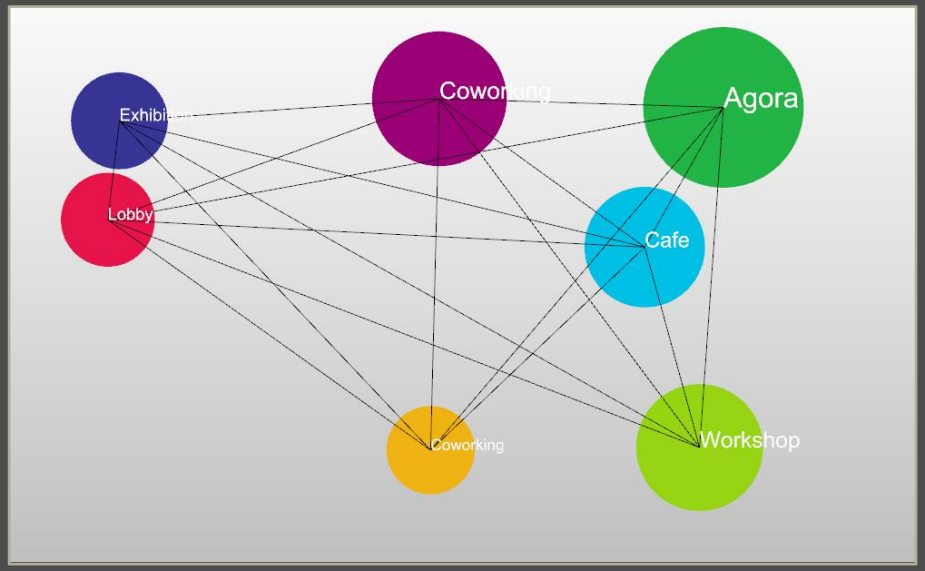
Robots designed as quarter circle arcs with different heights which carry light wood and Shoji paper panels.

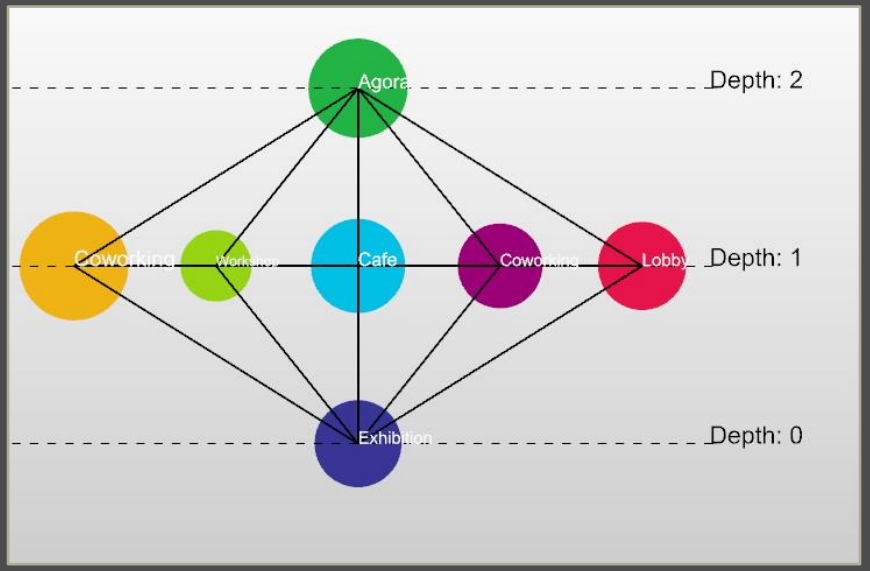

CPlanes
Set View
Display
Viewport Layout
Select
Visibility
Transform
Curve Tools
Surface Tools
Top
Coworking
Workshop
Exhibition
Cafe
Agora
Selection Menu
Point
surface - amare-noa
None
Lobby
Coworking
Top
Perspective
Front
Right
Near
Point
Mid
Cen
Int
Perp
Tan
Quad
Knot
Vertex
Project
Disable
Geometry
Primitive
Input
Util
90%
Creating the Grid
Factor
10
wlc_1
125
wlc_1
70
wlc_1
49.72
wlc_1
28
24ms
19ms
8ms
Swatch

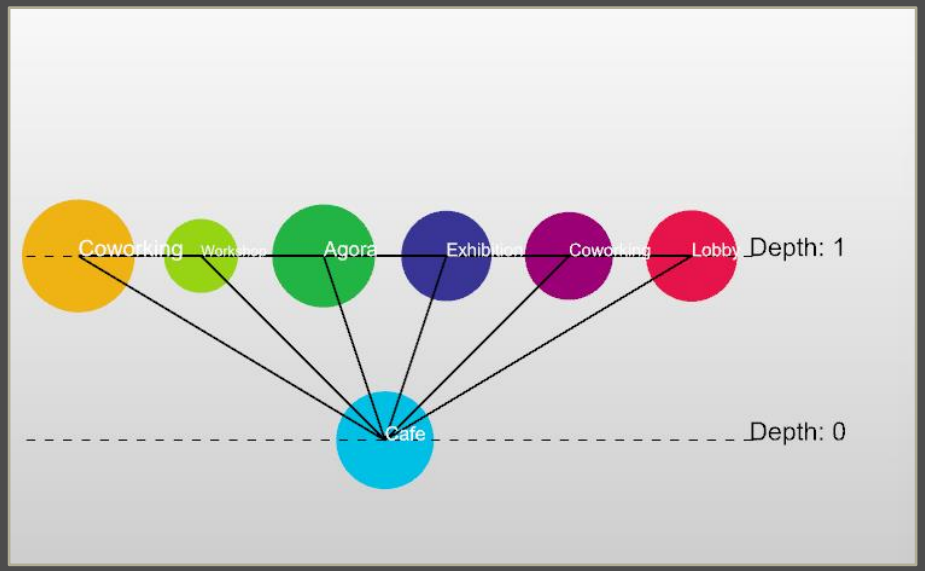

Zone centres
Extract data list indices
Select longest list method of connection
Draw lines between selected points
Input
Merge them
Input as program links in Space Syntax
Output

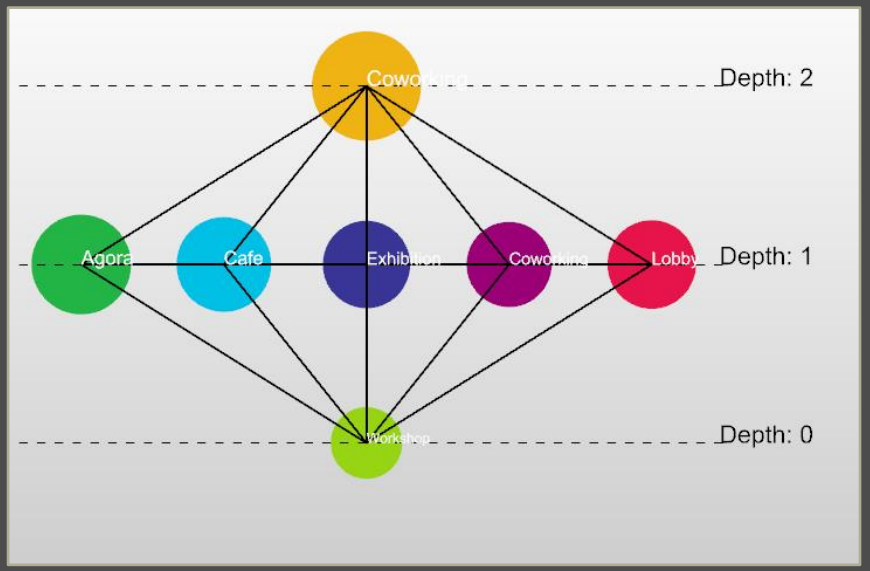

Define zone titles
Define connections and relationship with lines
Define area
Input
Justified graph from nodes and links is created
Bubble diagram of spatial relationship is created
Different spatial analysis values are calculated
Possible depths and arrangements are suggested
Output


Coworking
Agora
Exhibition
Lobby
Cafe
Coworking
Workshop





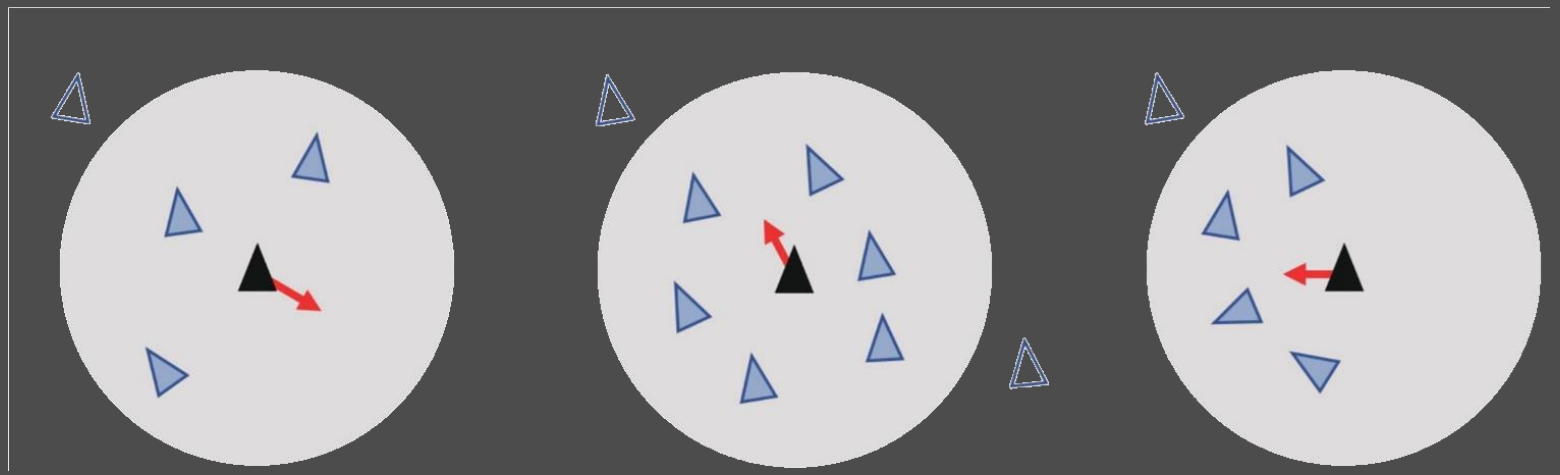




Space Syntax possible depth options and clustering of programs

Biomimetics and Physicomimetics

Flocking

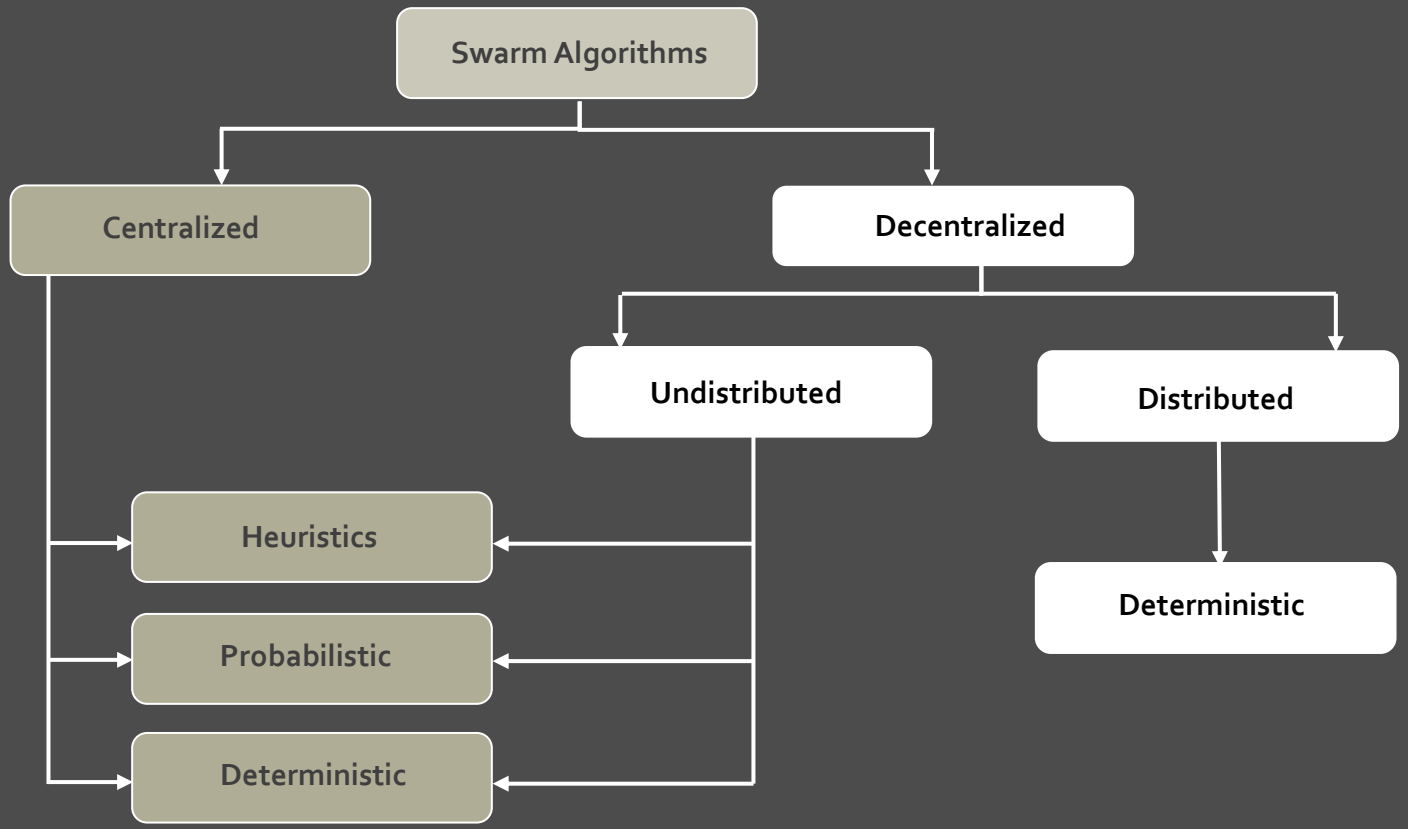


Separation

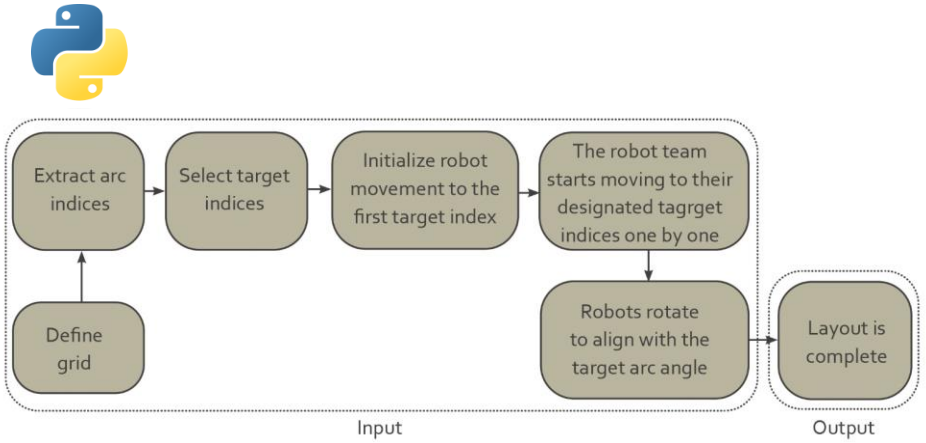
Alignment

Cohesion

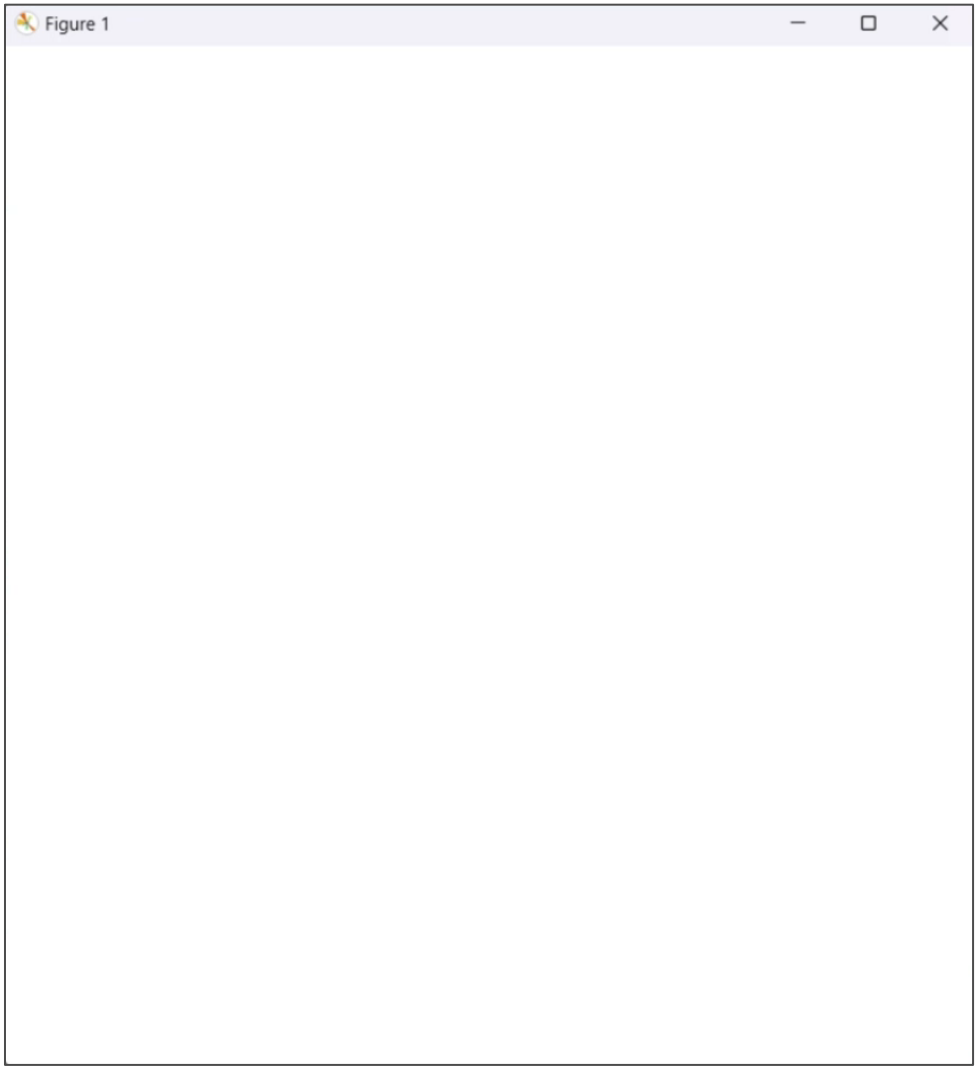
Swarm Intelligence Algorithms



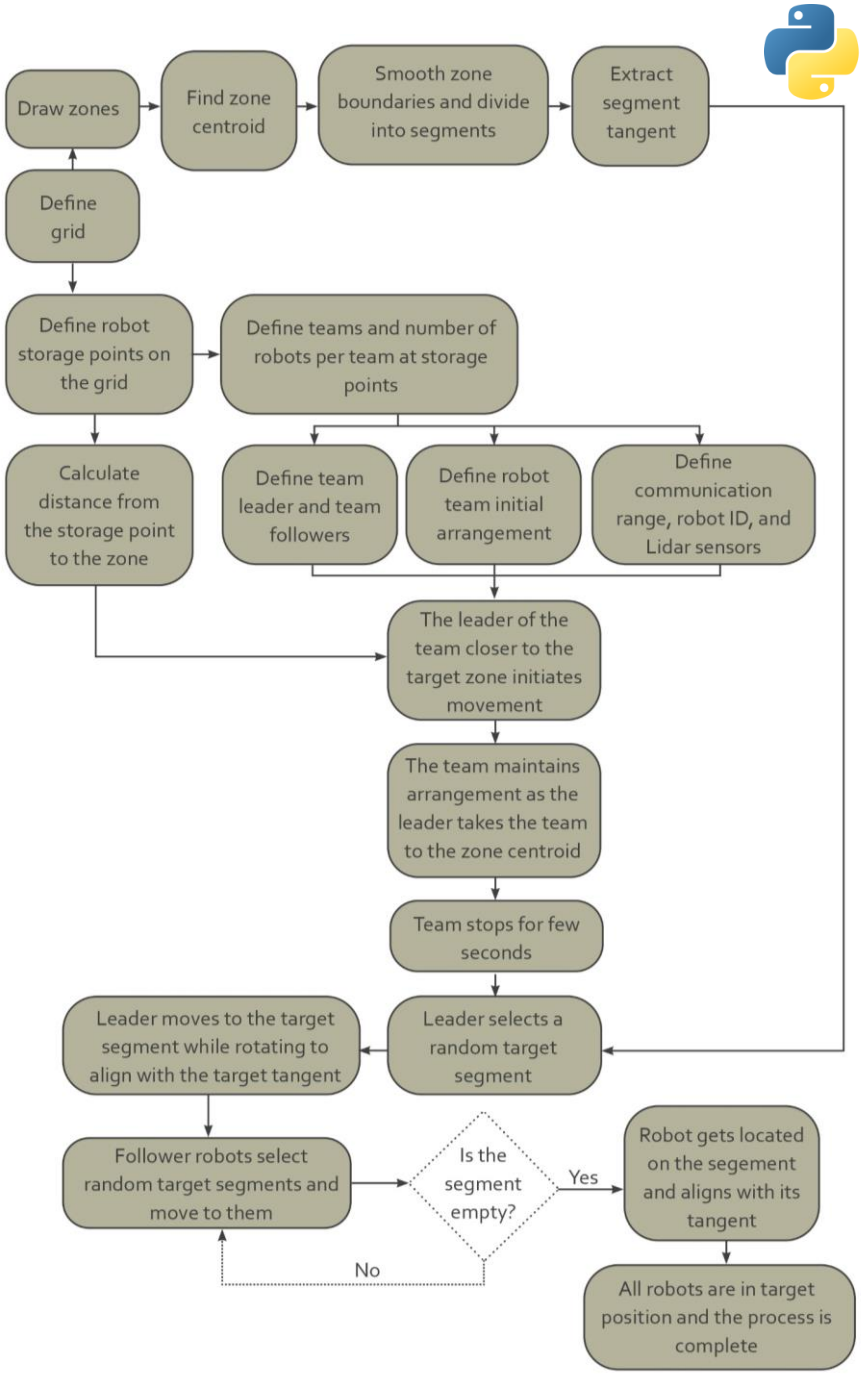
Python Simulation Setup

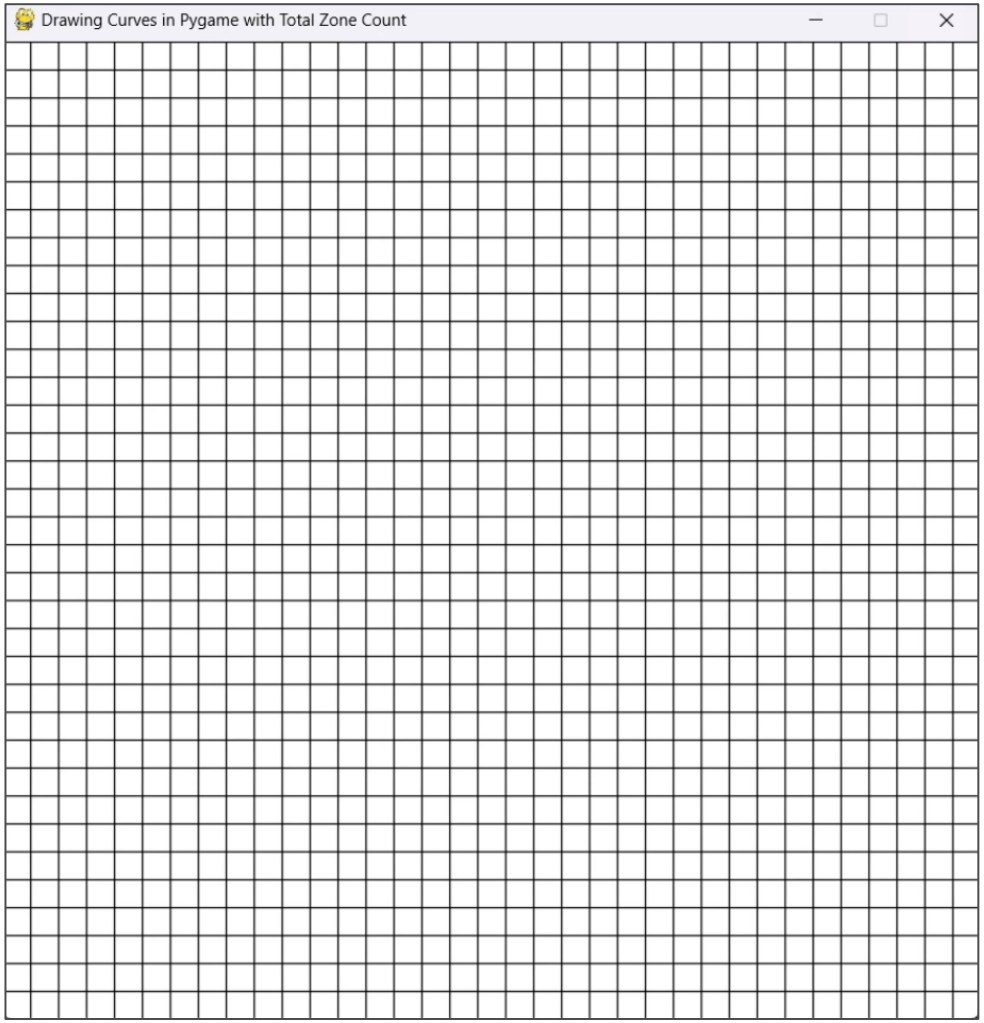


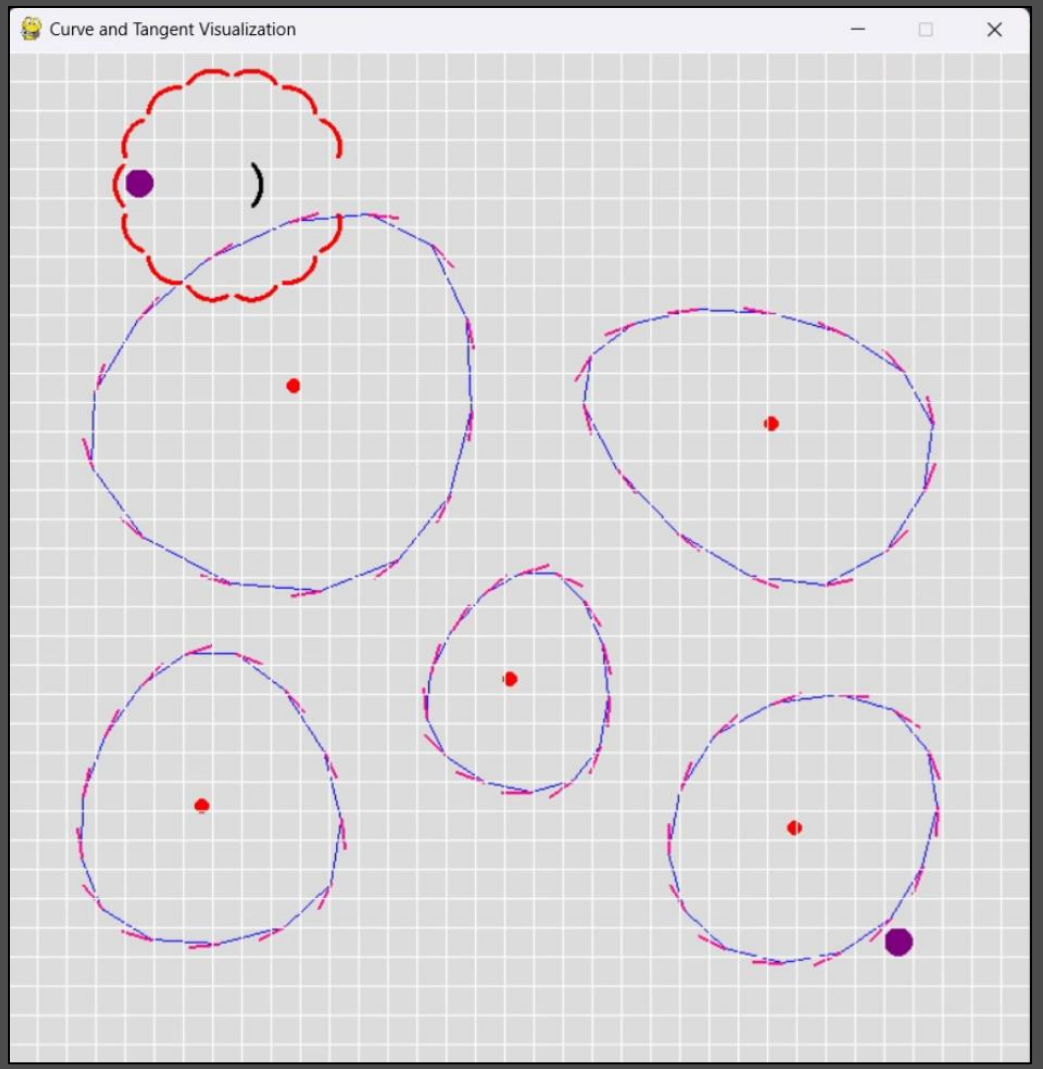
Layout Generation with a Centralized Control Method



Layout Generation with a De-centralized Control Method 1

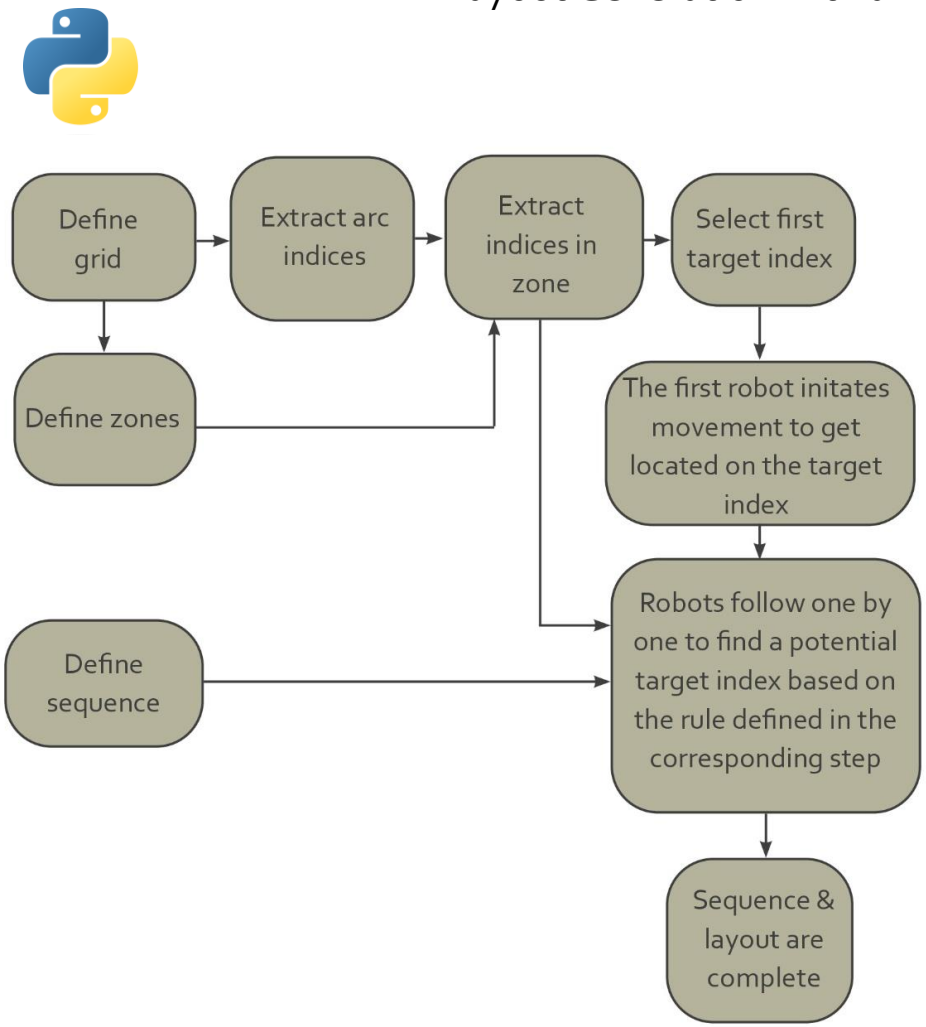


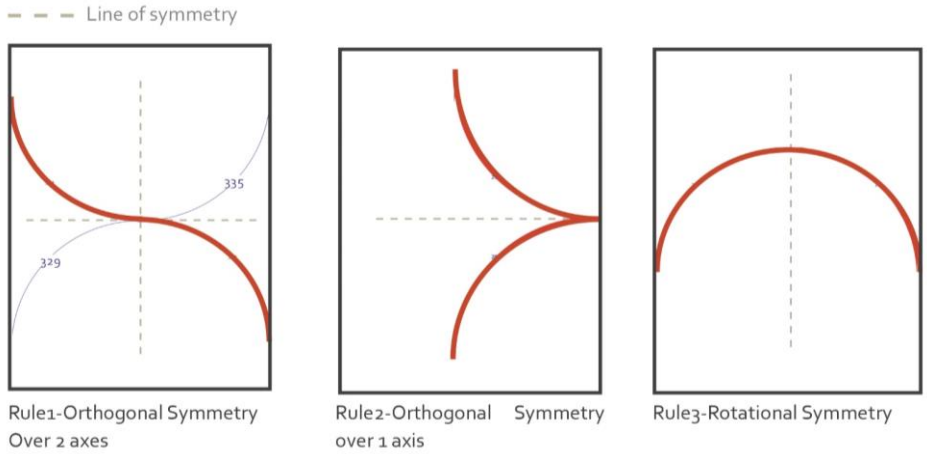




Zones
Segment Tangent
Center Line
Zones' Centroid
Supply Point
Follower Robot
Leader Robot

Layout Generation with a De-centralized Control Method 2

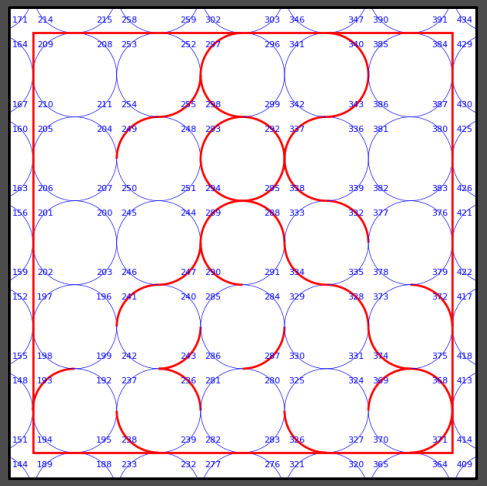


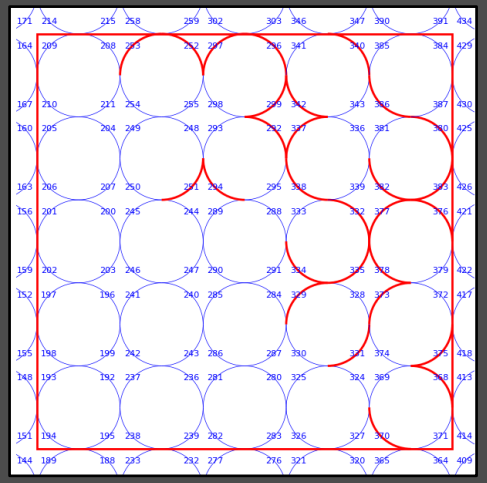


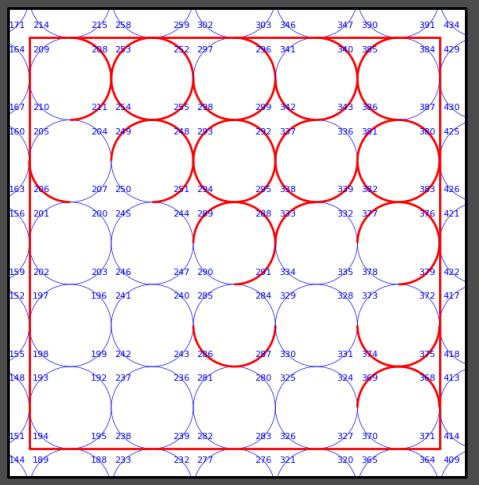
```
# Sequence of rules
s1 = [1, 1, 3, 2, 3, 1, 1, 2, 1, 1, 2, 3, 1, 1, 2, 3, 1, 1, 2, 2, 1, 1]
s2 = [2, 2, 3, 3, 1, 3, 1, 3, 1, 1, 1, 1, 1, 3, 2, 1, 1, 3, 2, 1, 1, 3]
s3 = [3, 1, 3, 1, 1, 2, 1, 3, 1, 2, 1, 2, 1, 1, 3, 1, 2, 1, 2, 3, 1, 3]
s4 = [3, 2, 2, 3, 1, 1, 1, 1, 1, 2, 3, 2, 2, 3, 1, 1, 1, 1, 3, 1, 2, 2]
s5 = [1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 1, 1, 1, 1, 1, 3]
s6 = [2, 2, 2, 2, 2, 2, 2, 3, 2, 2, 2, 1, 1, 2, 2, 1, 1, 2, 2, 1, 1, 2]
s7 = [3, 2, 1, 1, 2, 3, 3, 2, 1, 1, 2, 3, 3, 2, 1, 1, 2, 3, 3, 2, 1, 1]
s8 = [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]
s9 = [3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3]
s10 = [3, 3, 3, 3, 3, 3, 1, 1, 1, 1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 3, 3, 3, 1, 1, 1, 1, 3, 3, 3, 3]
```

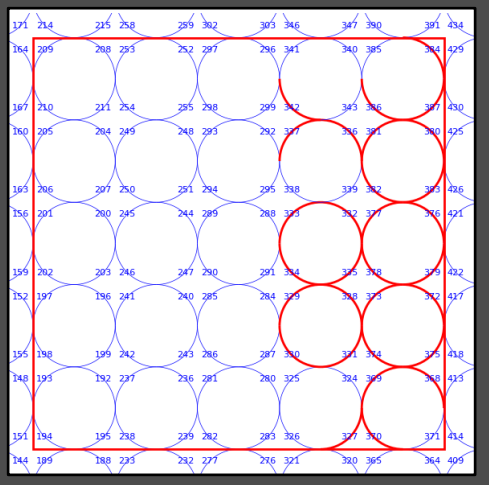
Then 10 sequences defined for this experiment, each made of the symmetry rules of the page before

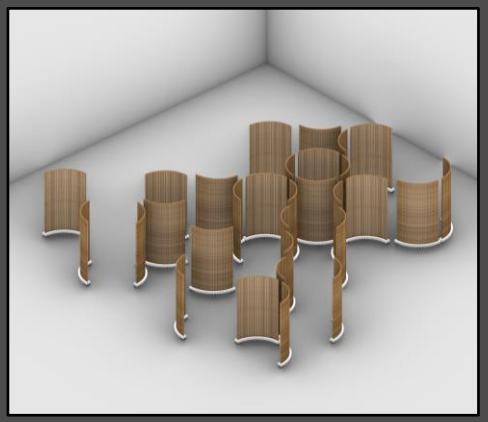

Figure 1

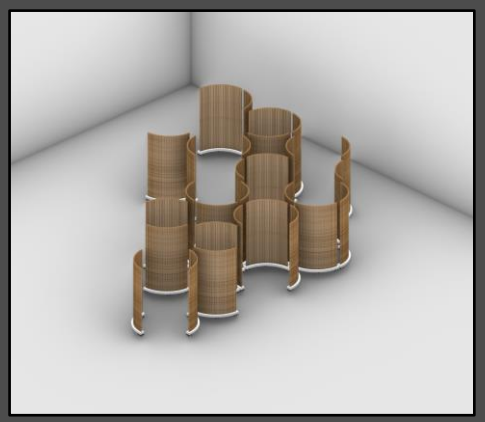


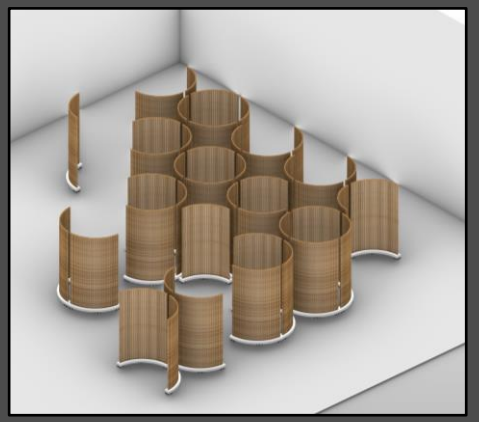


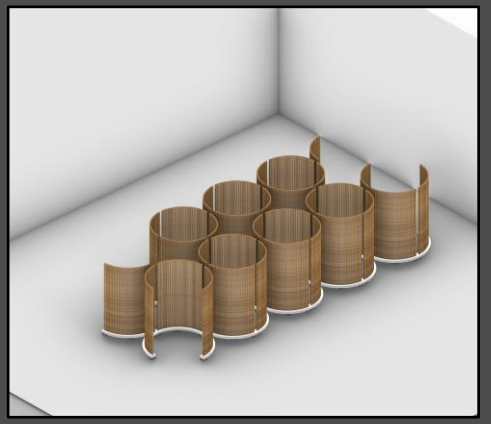












s1 =
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s2 =
[2, 2, 3, 3, 1, 3, 1, 3, 1, 1, 1, 1, 1, 3, 2, 1, 1, 3, 2, 1, 1, 3]

s3 =
[3, 1, 3, 1, 1, 2, 1, 3, 1, 2, 1, 2, 1, 1, 3, 1, 2, 1, 2, 3, 1, 3]

s4 =
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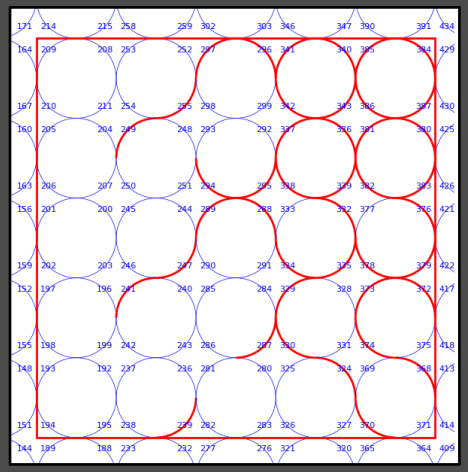
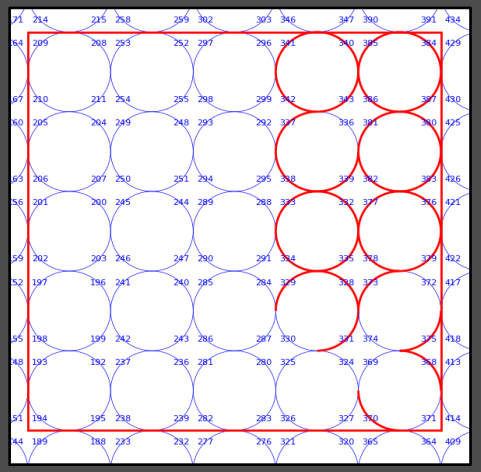
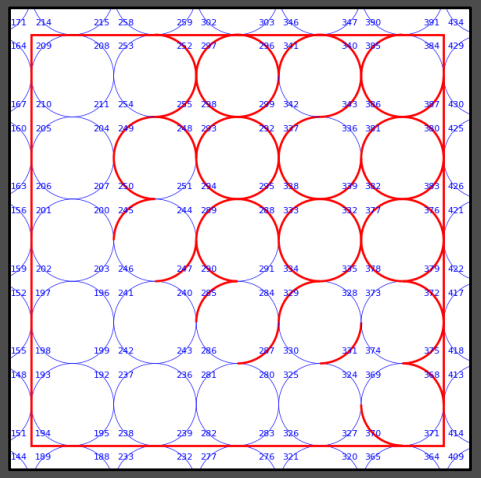
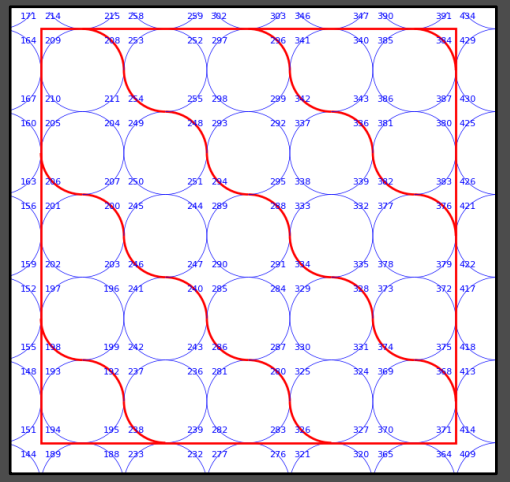
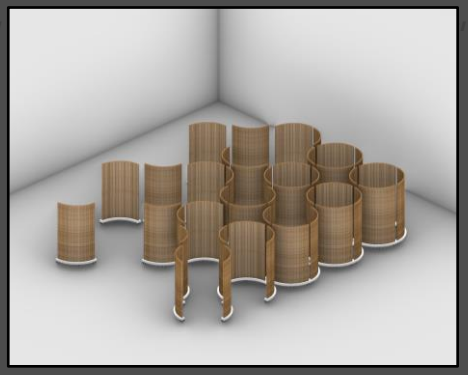
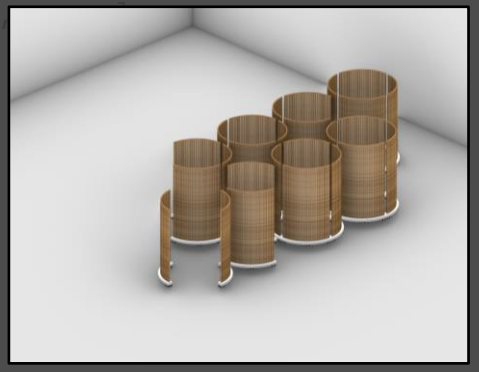


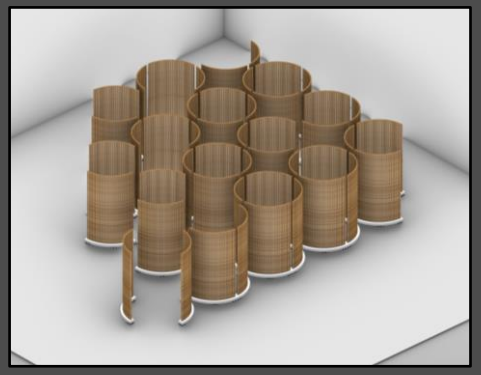


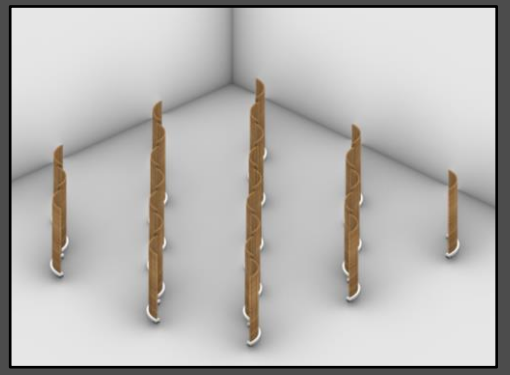










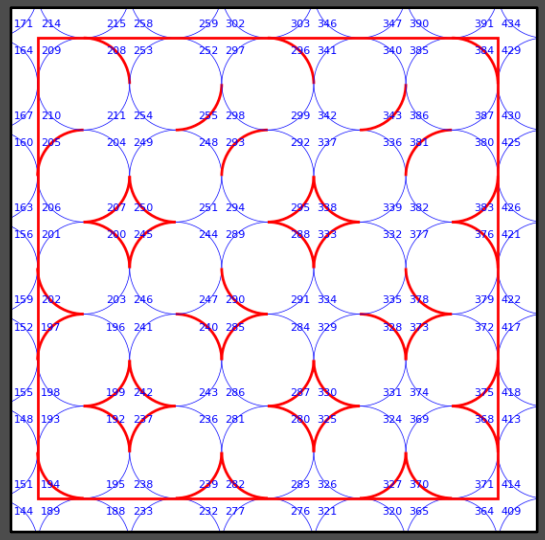


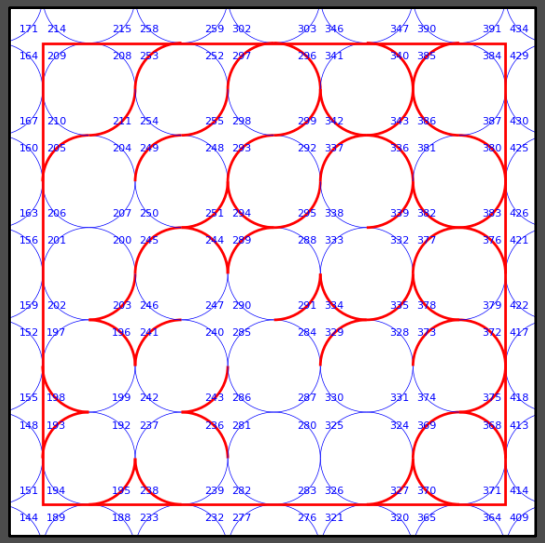
s5 =
[1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 1, 1, 1, 1, 3]

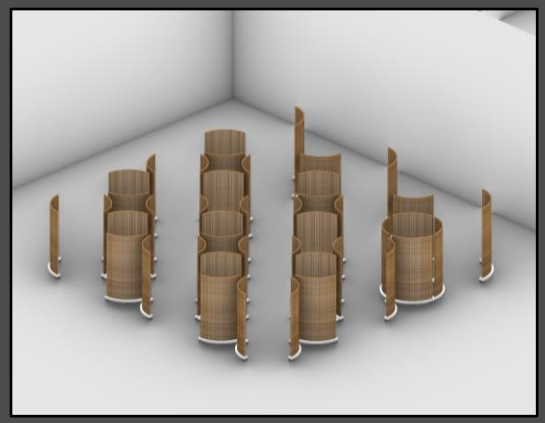
s6 =
[2, 2, 2, 2, 2, 2, 2, 3, 2, 2, 2, 1, 1, 2, 2, 1, 1, 2, 2, 1, 1, 2]

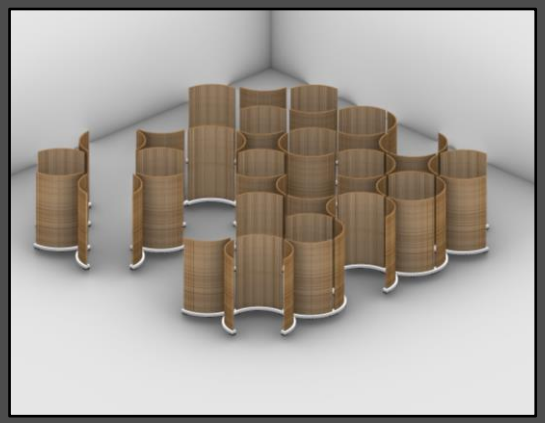
s7 = [3, 2, 1, 1, 2, 3, 3, 2, 1, 1, 2, 3, 3, 2, 1, 1, 2, 3, 3, 2, 1, 1]

s8 = [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]





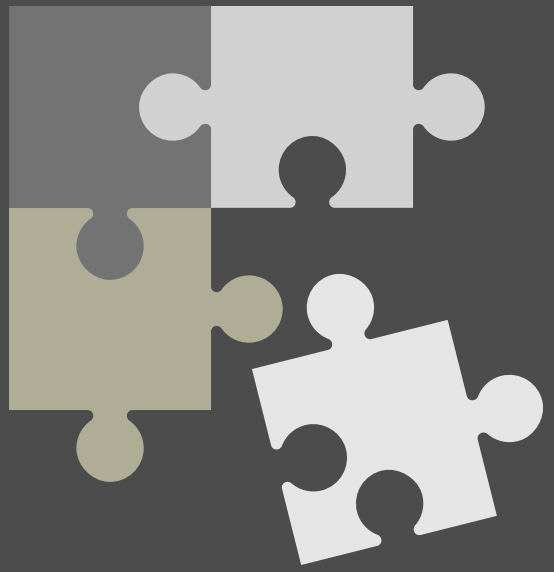




s9 = [3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3]

s10 = [1, 1, 3, 3, 3, 3, 1, 1, 1, 1, 1, 1, 1, 1, 3, 1, 1, 1, 1, 3, 3, 3, 1, 1, 1, 1, 3, 3, 3, 3]

Conclusion

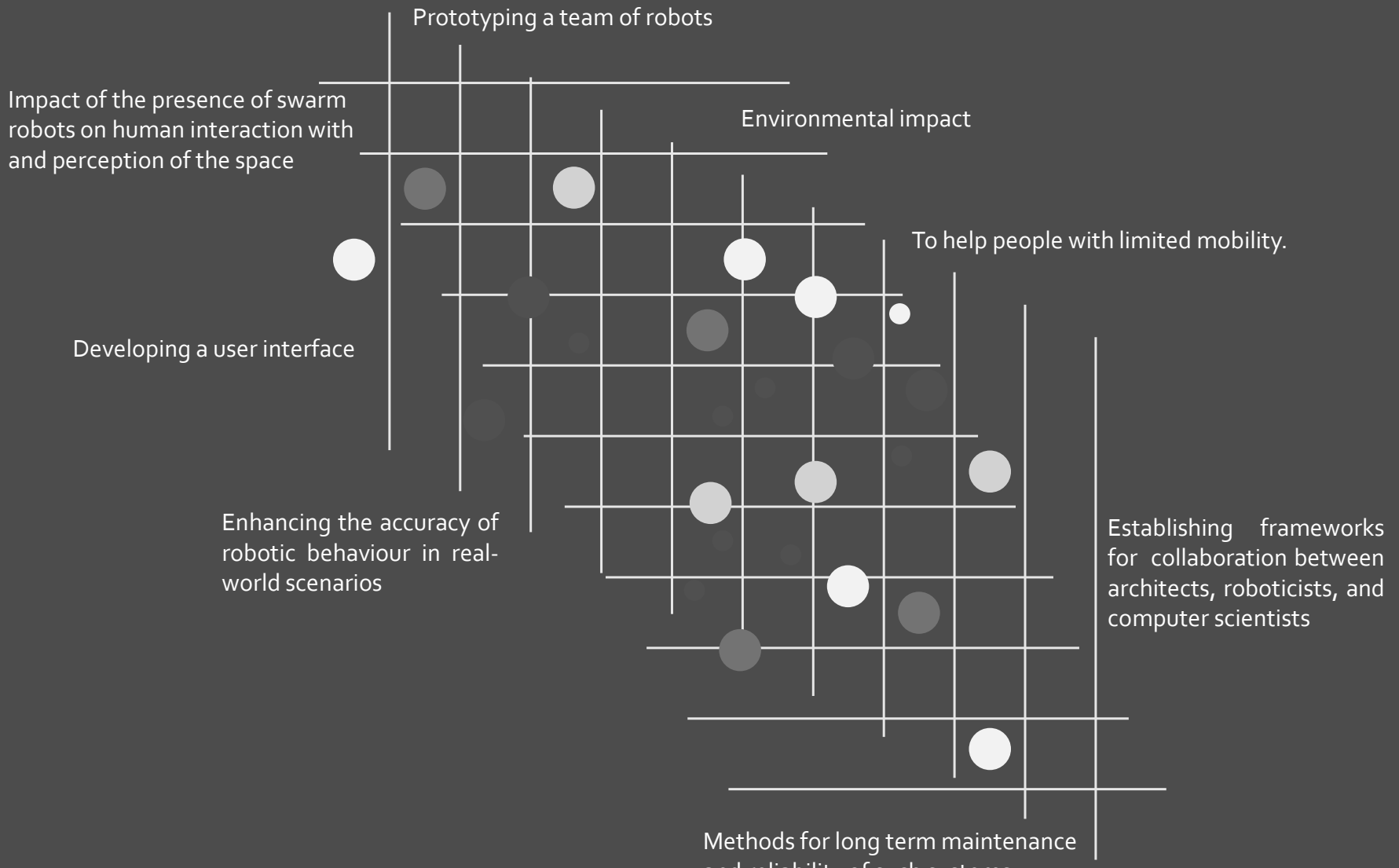


1- What are the key design parameters to achieve spatial flexibility in architectural layout design?

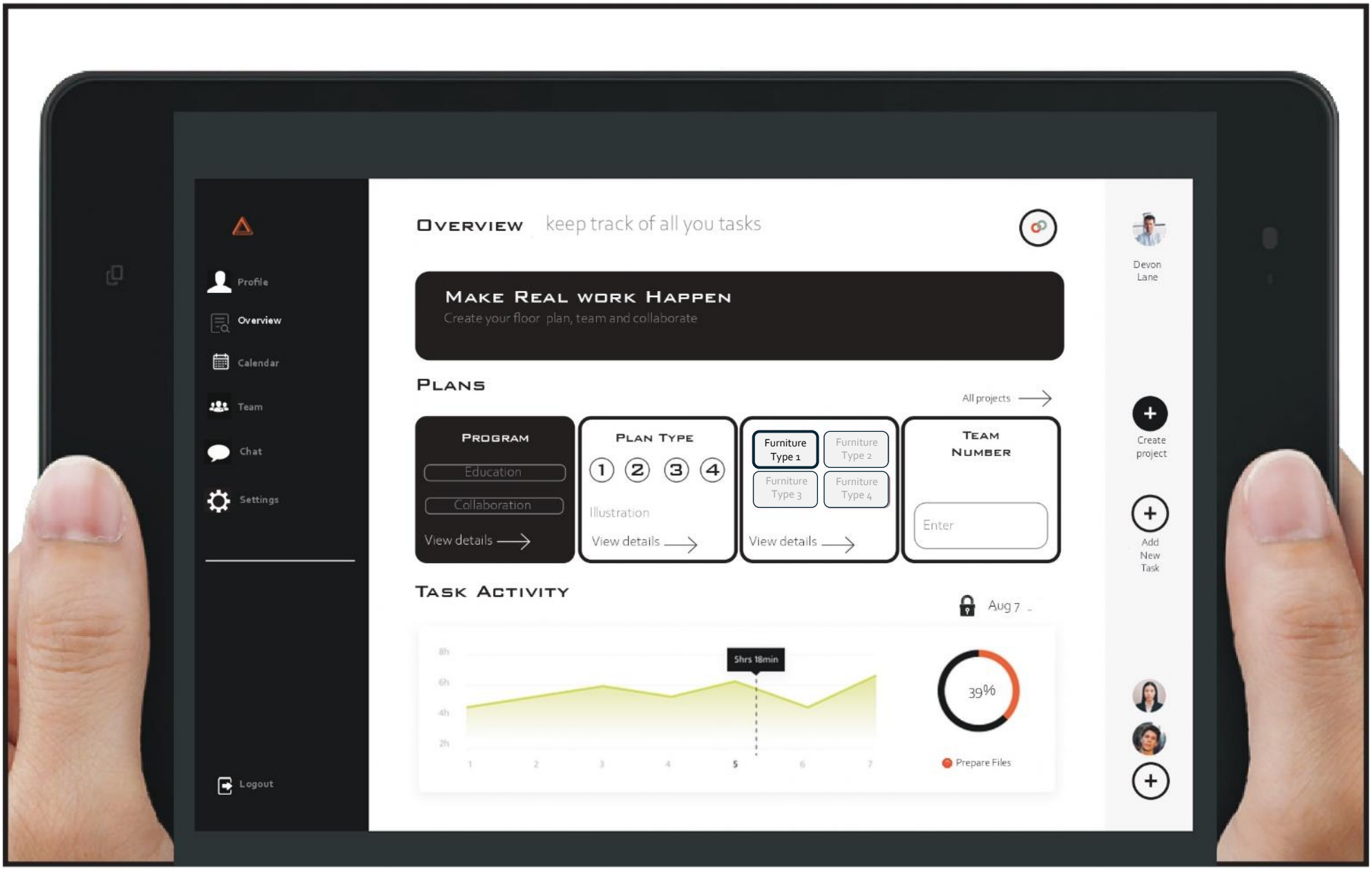
2- What are the most optimal strategies and technological frameworks to efficiently integrate swarm robotics into architectural workflows, which allows for the creation of au*tonomou*s layouts that continuously respond to user preferences and evolving spatial requirements?

3- What are the necessary steps to prototype a sample scenario of a robotic swarm configuring a flexible architectural layout**?**

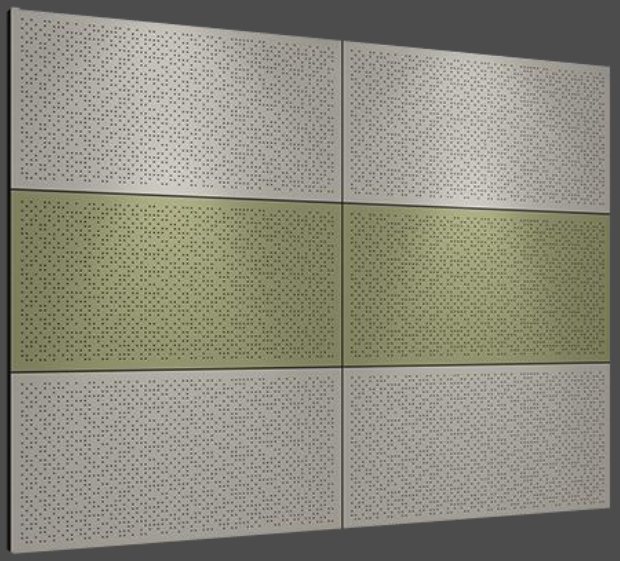
Discussion

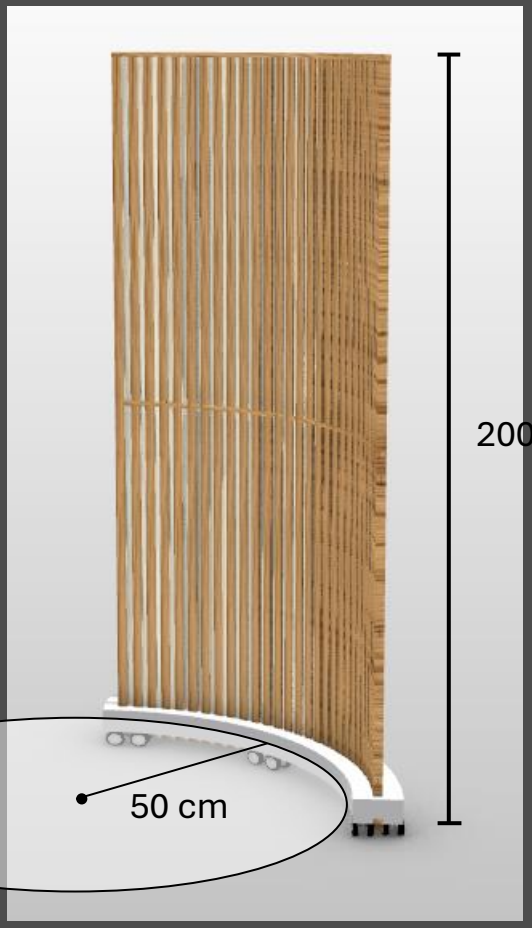

Prototyping a team of robots
Impact of the presence of swarm robots on human interaction with and perception of the space
Environmental impact
To help people with limited mobility.
Developing a user interface
Enhancing the accuracy of robotic behaviour in real-world scenarios
Establishing frameworks for collaboration between architects, roboticists, and computer scientists
Methods for long term maintenance and reliability of such systems

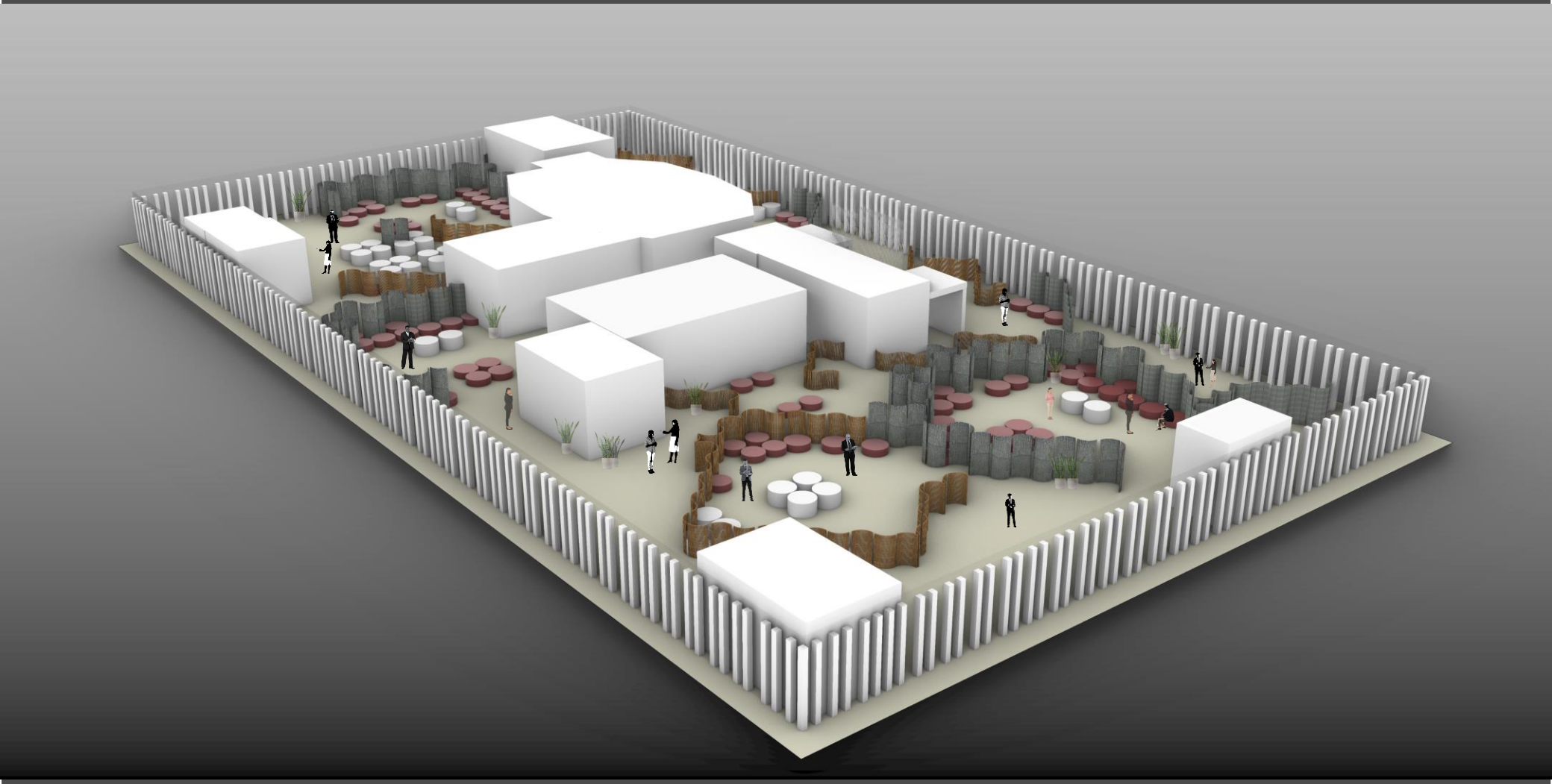

Coworking
Workshop
Agora
Exhibition

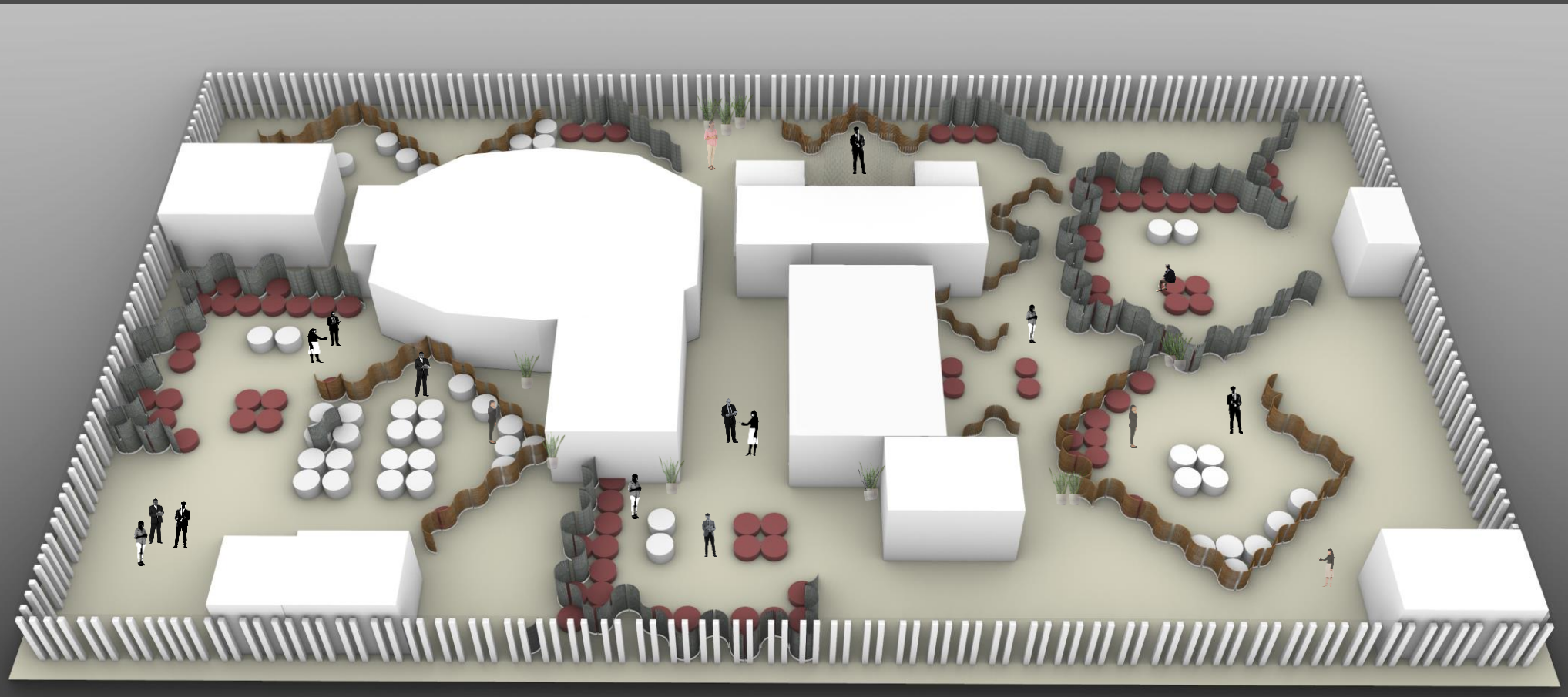

Profile
Overview
Calendar
Team
Chat
Settings
Logout
Overview keep track of all you tasks
Make Real work Happen
Create your floor plan, team and collaborate
Plans
All projects
Program
Education
Collaboration
View details
Plan Type
1 2 3 4
Illustration
View details
Furniture Type 1
Furniture Type 2
Furniture Type 3
Furniture Type 4
View details
Team Number
Enter
Task Activity
Aug 7
5hrs 18min
39%
Prepare Files
Devon Lane
Create project
Add New Task

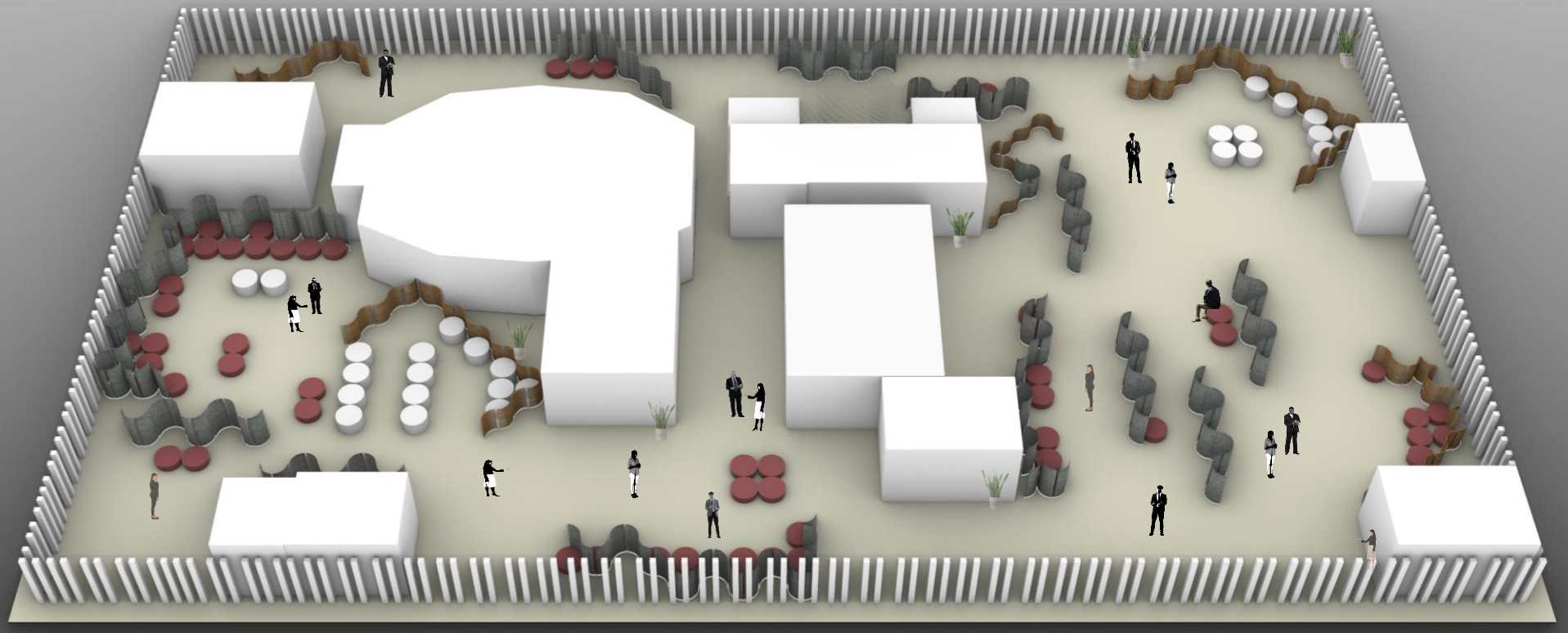
Acoustic Panels

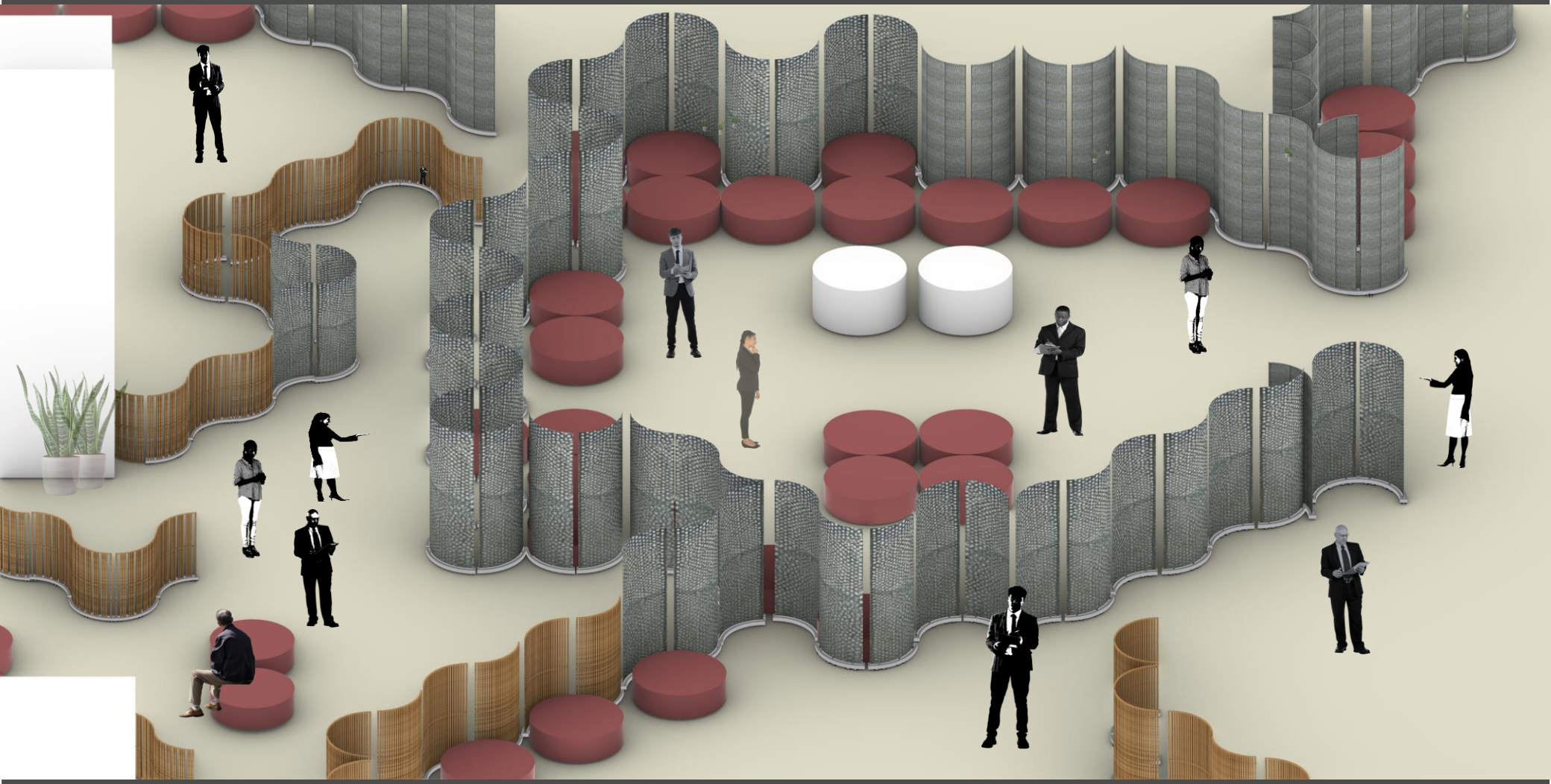












Reflection

1-User well-being

2-Circularity of the design

3- Reducing environmental impact

Thank You

Own Work created using DALL-E