REUSING WASTE WOOD

FOR AN EXTERIOR WALL ELEMENT

JOOST VAN EIJK
4222911
BUILDING TECHNOLOGY
08-04-2021

MENTORS:
PIETER STOUTJESDIJK
HANS HOOGENBOOM

DELEGATE BOARD OF EXAMINERS:
HENDRIK PLOEGER

OVERVIEW

- INTRODUCTION TO THE PROBLEM
- DUTCH WASTE WOOD MARKET
- SCOPE OF THIS RESEARCH
- USED DESIGN METHODOLOGY
- FINAL DESIGN
- EXTERIOR WALL ELEMENT TOOL
- CONCLUSIONS AND RECOMMENDATIONS

CHALLENGES

RIJKSOVERHEID, 2018

CHALLENGES

RIJKSOVERHEID, 2018

Grote bouwcoalitie presenteert actieplan voor 1 miljoen woningen in tien jaar

NOS, 2021

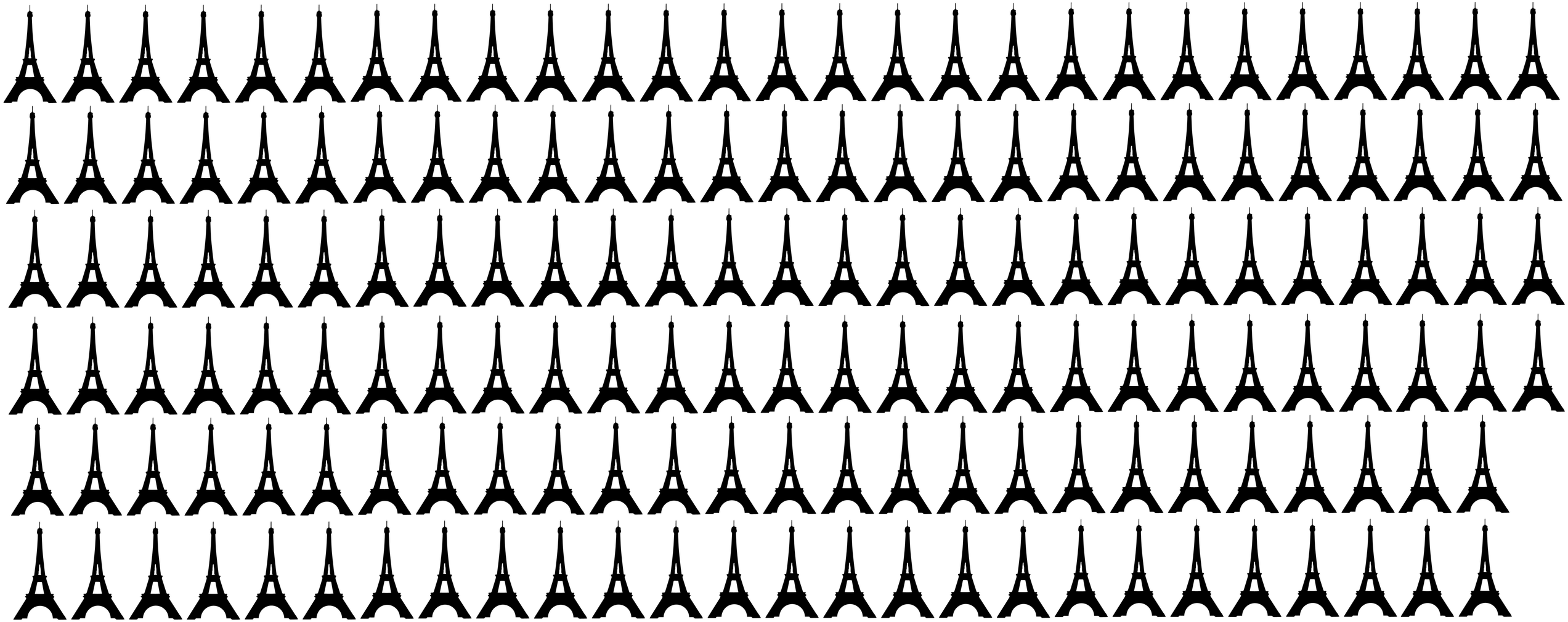
Nog 845 duizend nieuwbouwhuizen te gaan, maar zelfs dat is niet genoeg

VOLKSKRANT, 2020

WASTE PROBLEM

In 2017, 1.610.000.000 kg waste wood.

TAUW, 2017



167 EIFEL TOWERS EVERY YEAR

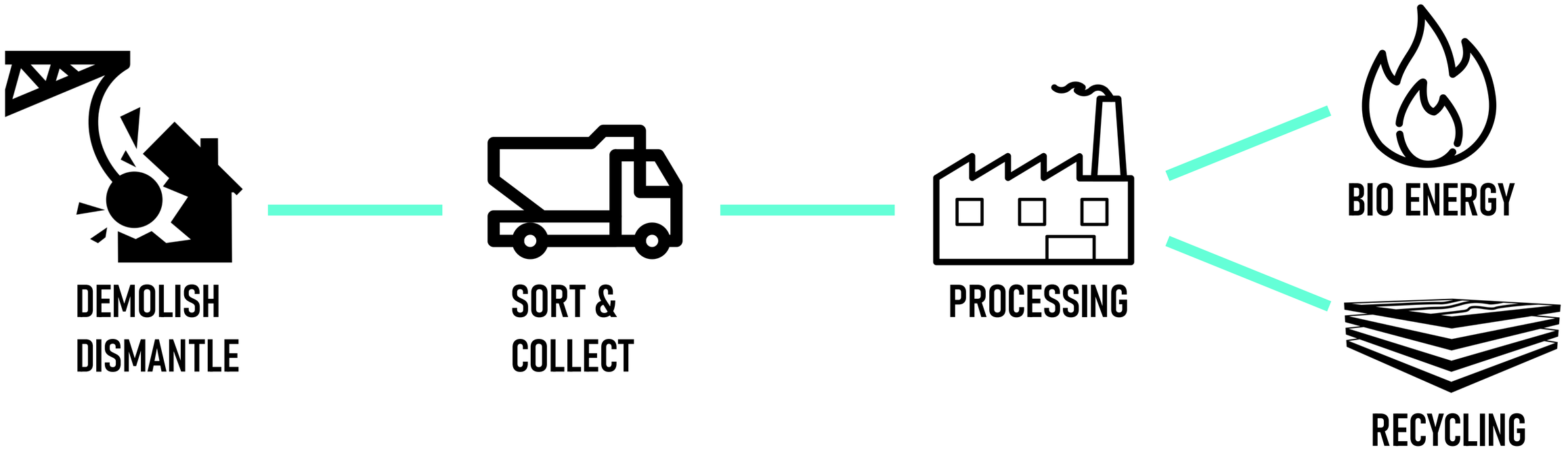
OPPORTUNITY

Nog 845 duizend nieuwbouwhuizen te gaan, maar zelfs dat is niet genoeg

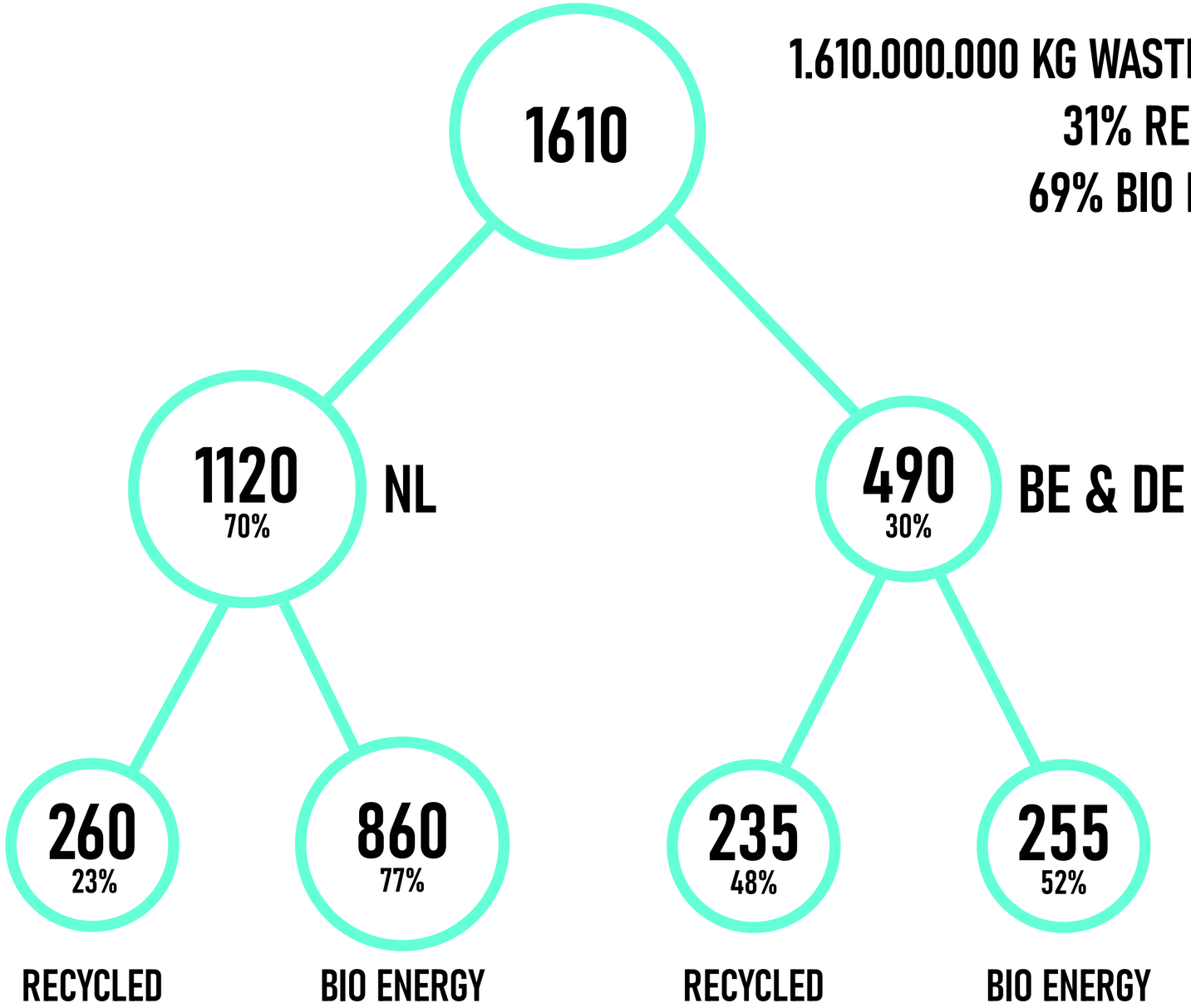
FOCUS

PINTEREST

STAKEHOLDERS



STATISTICS


1610
1.610.000.000 KG WASTE WOOD
31% RECYCLED
69% BIO ENERGY
1120
70%
NL
490
30%
BE & DE
260
23%
860
77%
235
48%
255
52%
RECYCLED
BIO ENERGY
RECYCLED
BIO ENERGY

WASTE WOOD CATEGORIES

A

UNTREATED
NOT PAINTED

B

EVERYTHING THAT IS
NOT A OR C WOOD

C

TREATED
CONTAMINATED

B

SOLID B WOOD

REUSABLE
RECYCLABLE
BIOENERGY

RECYCLABLE
BIOENERGY

GLUED B WOOD
- ENGINEERED BOARDS

BIOENERGY

DOWNCYLCING

RECYCLING = DOWN CYLCING

SOLID B WOOD

SHREDDING

ENGINEERED BOARDS

INCINERATION

B

1.260.000.000 KG

29%

SOLID B-WOOD

PARTLY REUSABLE
RECYCLABLE
BIOENERGY

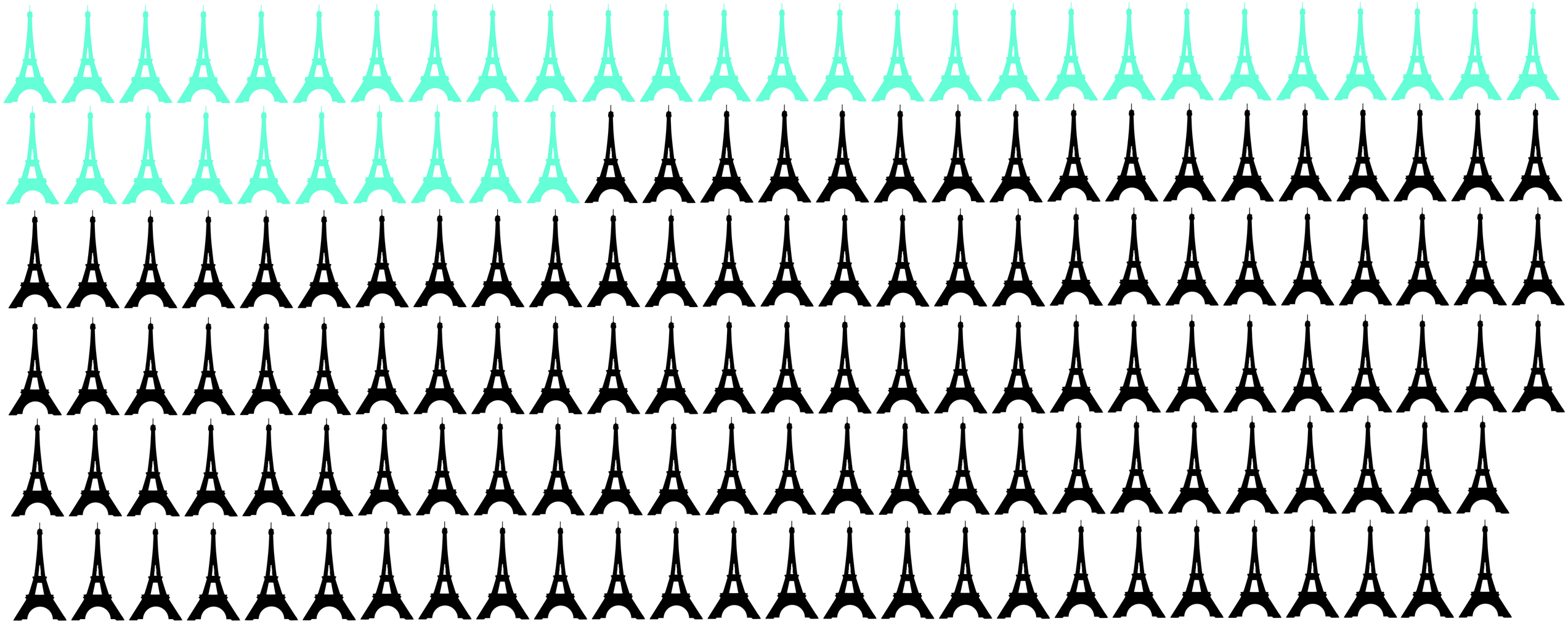
71%

NON SOLID B-WOOD

BIOENERGY

370.000.000 KG HAS THE POTENTIAL TO BE REUSED

SOURCE: TAUW, 2017



37 EIFFEL TOWERS EVERY YEAR

CURRENT PROBLEM

CHANGING DIMENSIONS AND AVAILABILITY

LINDNER

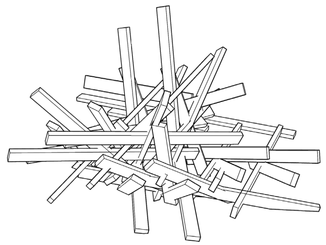
CURRENT PROBLEM

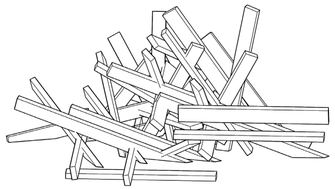
EXPERIENCED CARPENTER IS REQUIRED

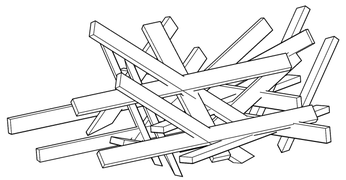
JOBDESCRIPTIONSWIKI

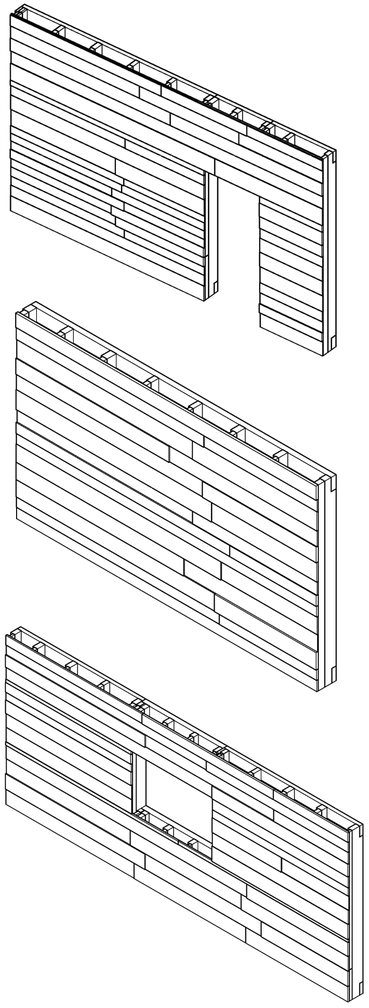
SOLUTION

PARAMETRIC MODEL

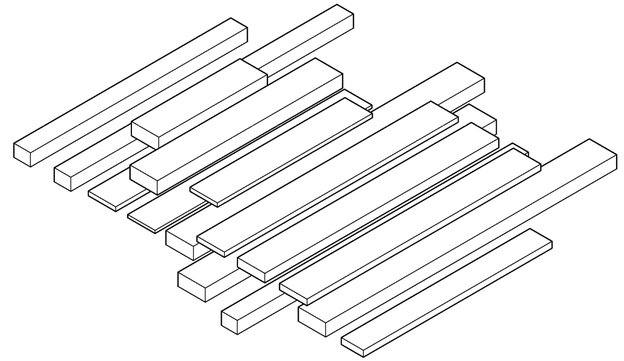






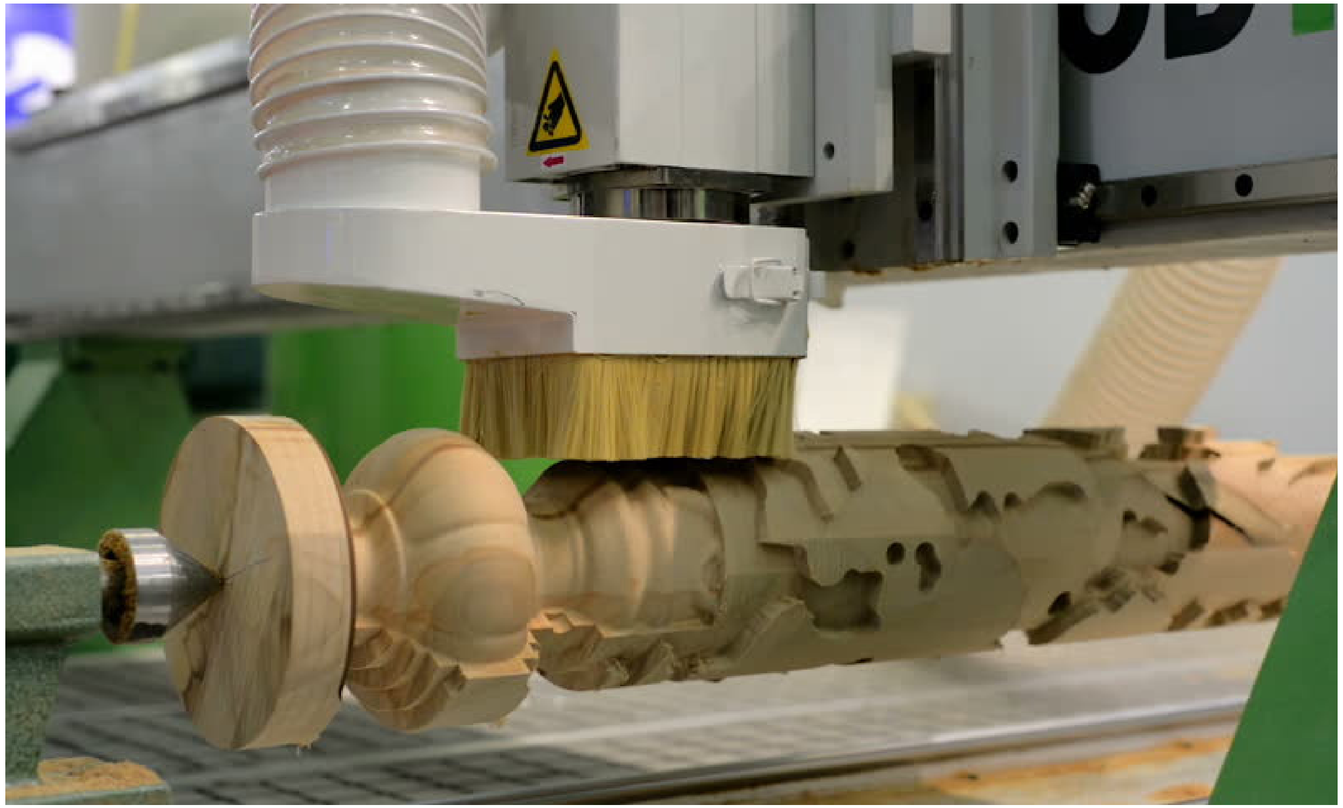


REUSE AFTER END OF LIFE

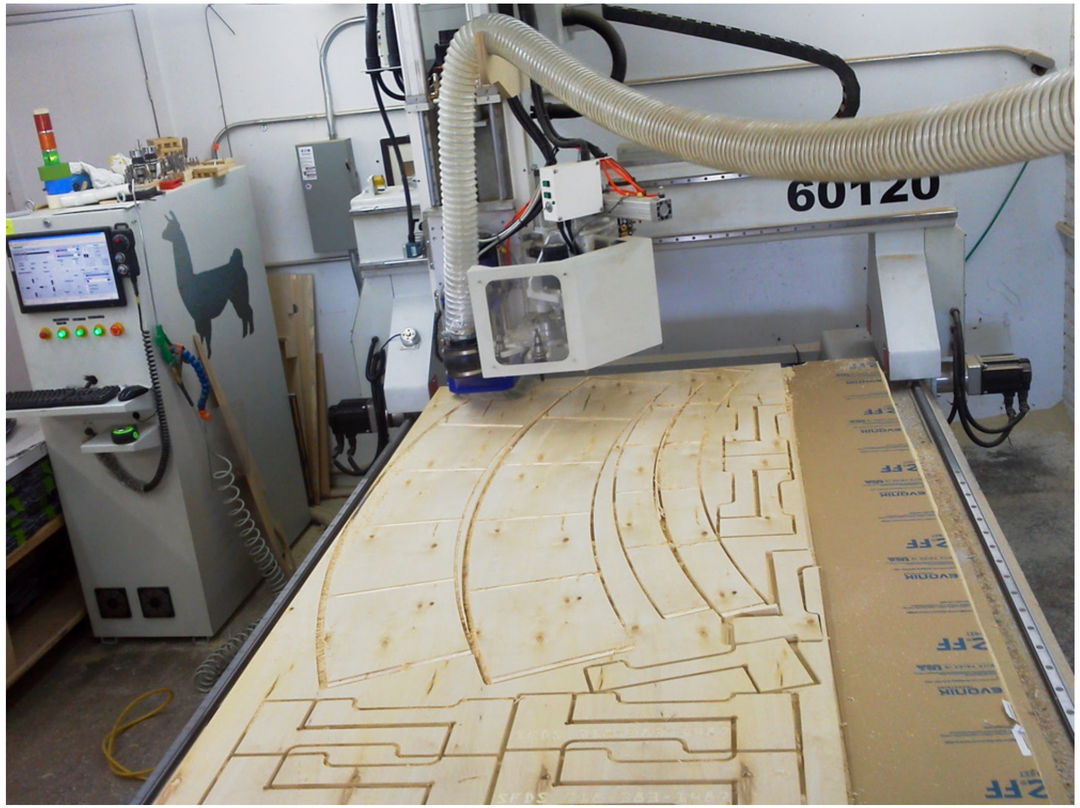


CHANGING DIMENSIONS AND AVAILABILITY

DIGITAL FABRICATION



SHUTTERSTOCK



SFDSHOP

RESEARCH QUESTION

How can a database, a parametric model, and scripting be used to develop an exterior wall element from waste wood that minimizes the material loss and takes full benefit of the waste wood dimensions?

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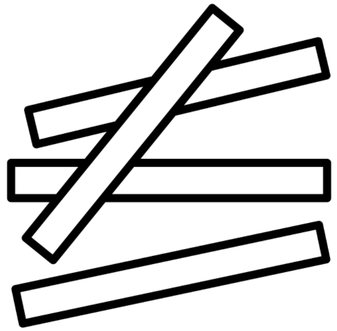
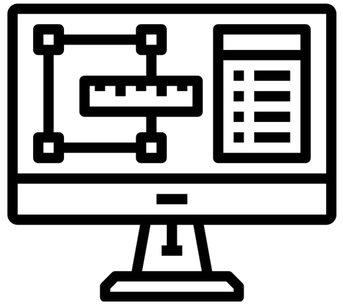


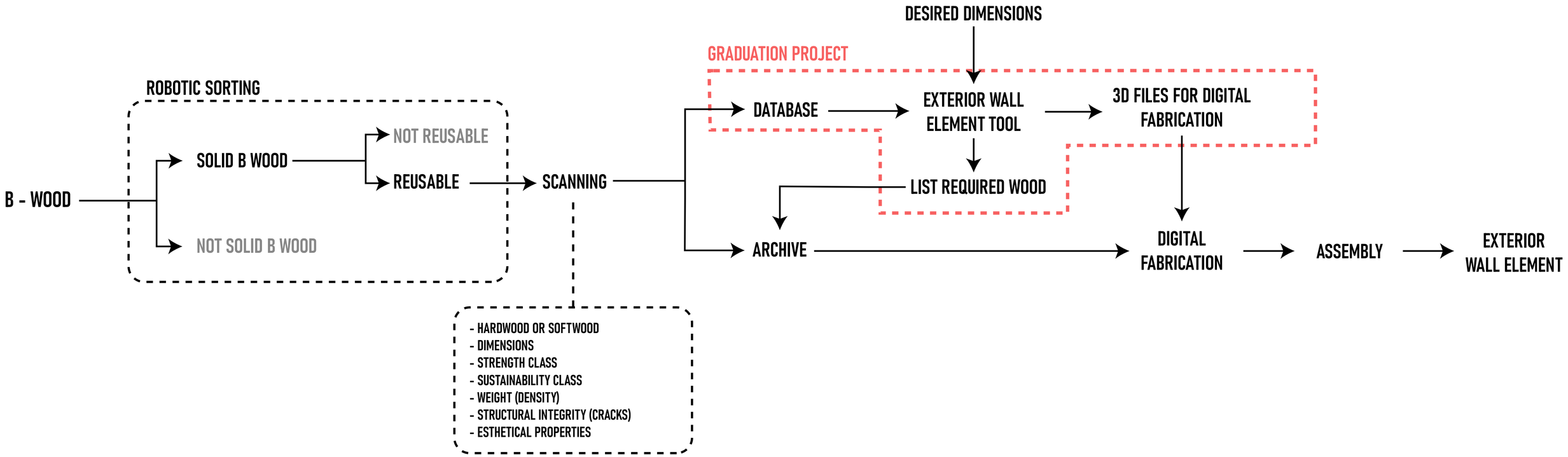
DESIGN OF AN EXTERIOR WALL ELEMENT

DATABASE THAT CAN COMMUNICATE WITH A PARAMETRIC MODEL

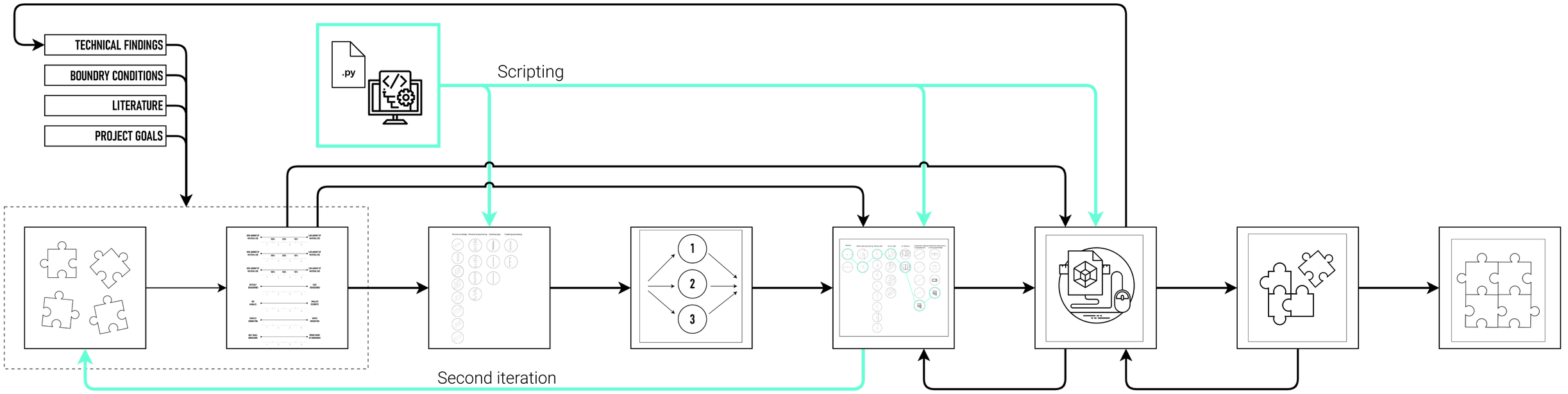


EXTERIOR WALL ELEMENT TOOL

SCOPE OF THESIS

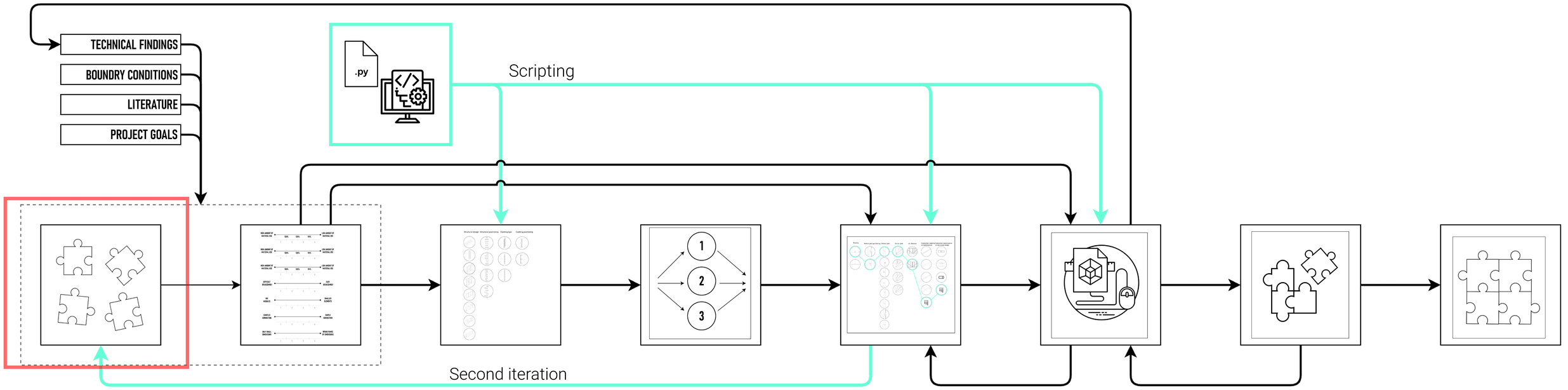


DESIGN METHODOLOGY



A. Design problems B. Criteria C. Alternatives D. Concepts E. Concept analyses F. Prototyping G. Sub-solutions H. Final design

DESIGN METHODOLOGY



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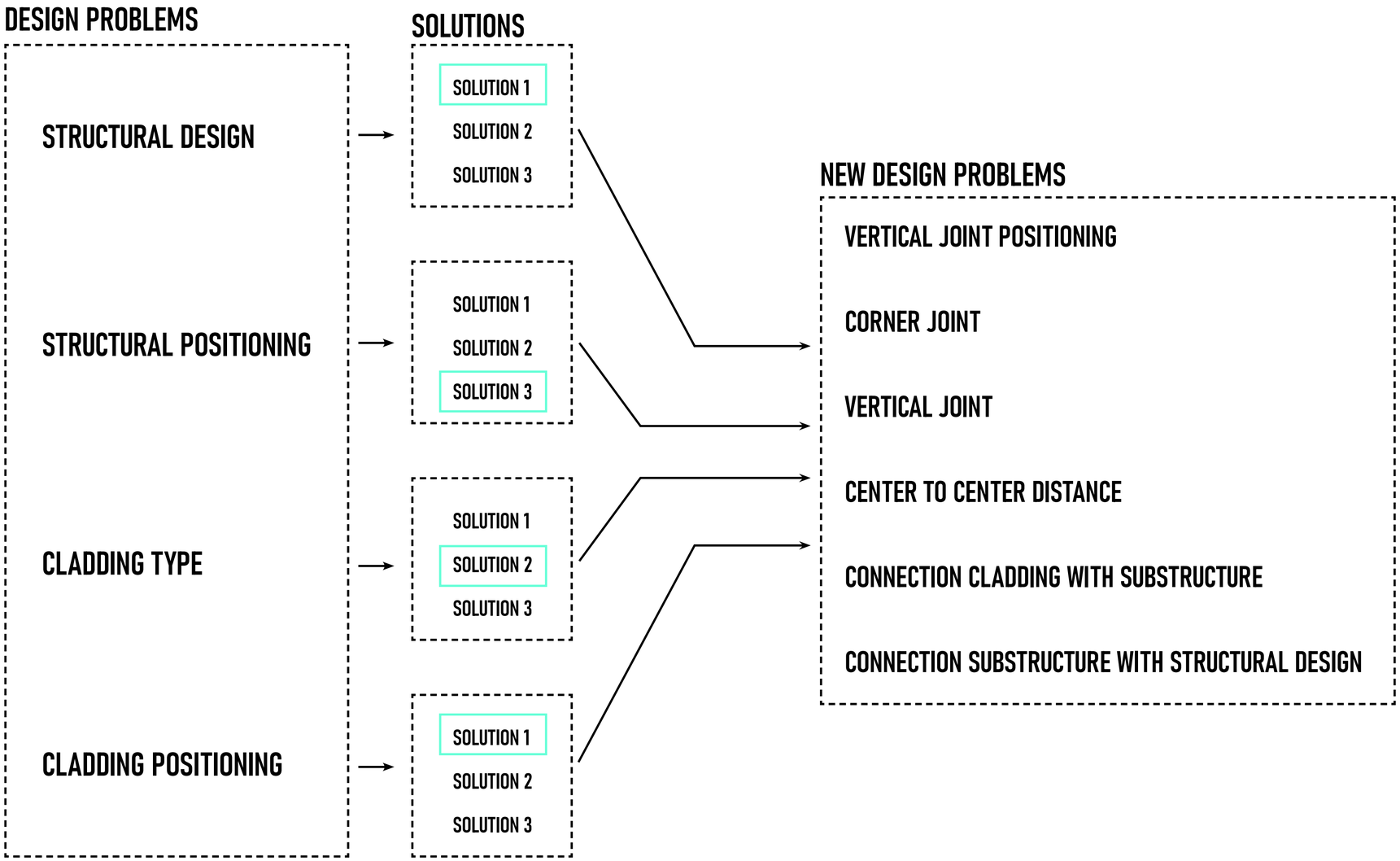
DESIGN PROBLEMS



DESIGN PROBLEMS

DESIGN PROBLEMS

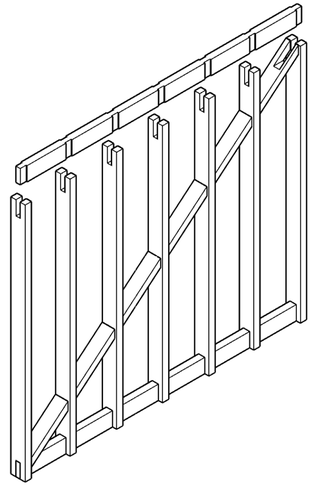
- STRUCTURAL DESIGN
- STRUCTURAL POSITIONING
- CLADDING TYPE
- CLADDING POSITIONING

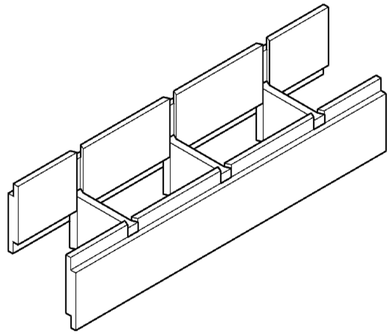
SOLUTIONS

- STRUCTURAL DESIGN: SOLUTION 1, SOLUTION 2, SOLUTION 3
- STRUCTURAL POSITIONING: SOLUTION 1, SOLUTION 2, SOLUTION 3
- CLADDING TYPE: SOLUTION 1, SOLUTION 2, SOLUTION 3
- CLADDING POSITIONING: SOLUTION 1, SOLUTION 2, SOLUTION 3

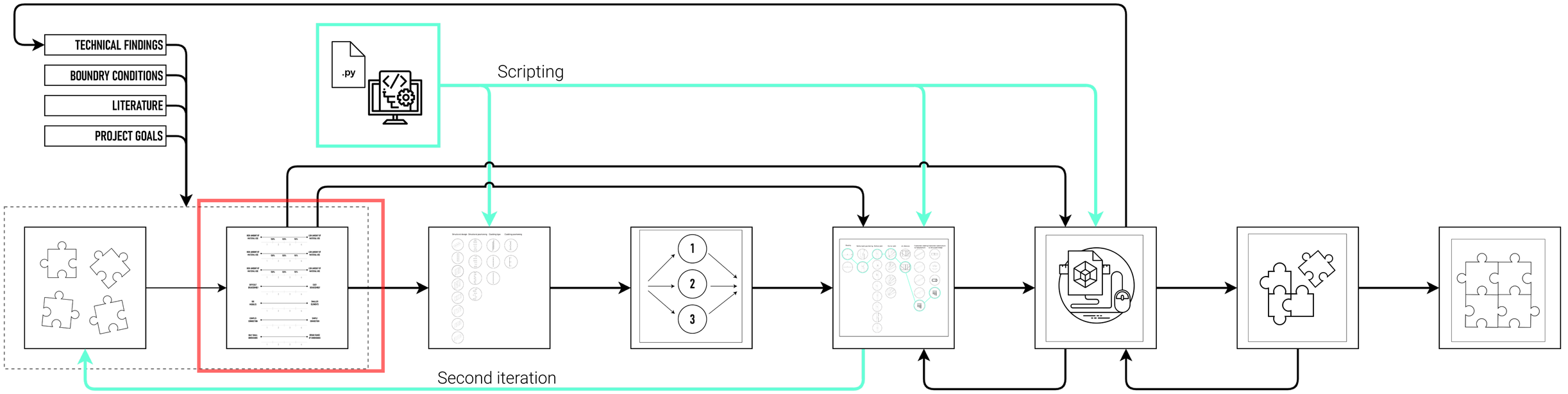
NEW DESIGN PROBLEMS

- VERTICAL JOINT POSITIONING
- CORNER JOINT
- VERTICAL JOINT
- CENTER TO CENTER DISTANCE
- CONNECTION CLADDING WITH SUBSTRUCTURE
- CONNECTION SUBSTRUCTURE WITH STRUCTURAL DESIGN





DESIGN METHODOLOGY



A. Design problems | B. Criteria | C. Alternatives | D. Concepts | E. Concept analyses | F. Prototyping | G. Sub-solutions | H. Final design

CRITERIA

- ALLOW FOR CONSTRUCTING WITH WASTE WOOD
- MINIMIZE ADDITIONAL WASTE AND PREVENT UNNECESSARY CUTS
- REUSABLE AS MUCH AS POSSIBLE AND HAVE AN ENVIRONMENTALLY POSITIVE IMPACT.
- REALISTIC CONSTRUCTION PROCESS.

CRITERIA

MINIMIZING ADDITIONAL WASTE:

WEIGHT

- EXPECTED MATERIAL LOSS ●●●
- FULL LENGTH USAGE ●●●
- FLEXIBILITY OF PIECES ●●●

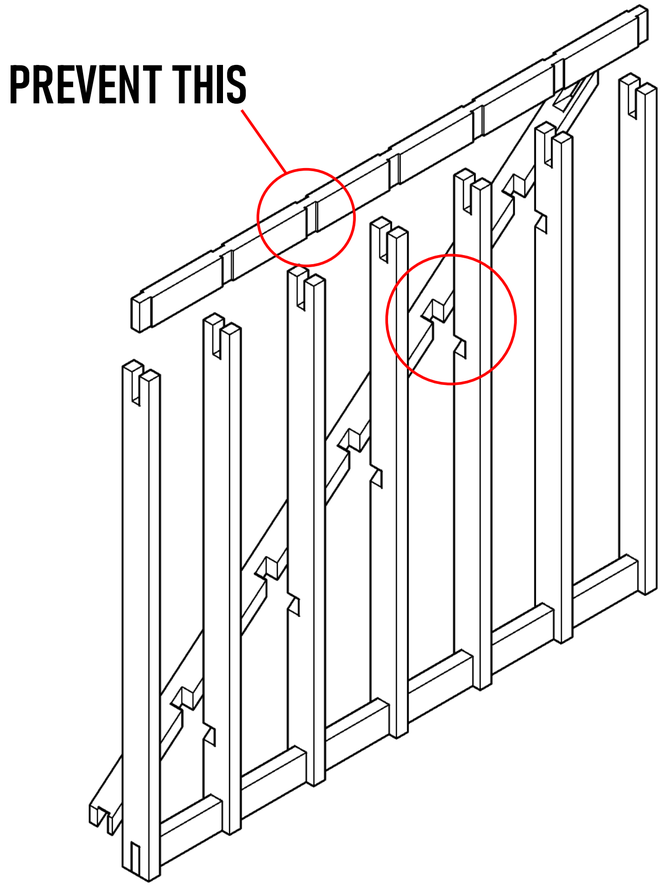
END OF LIFE & ENVIRONMENTAL FRIENDLY:

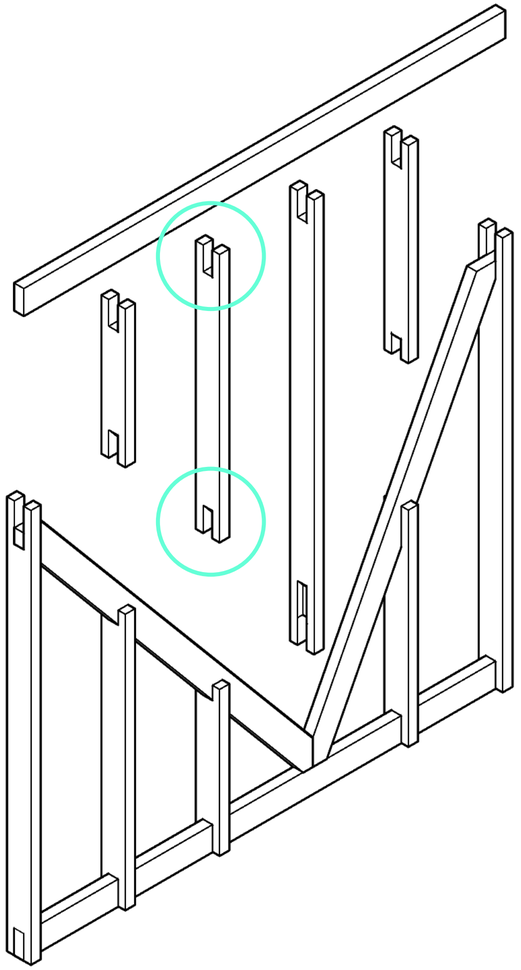
- TOTAL MATERIAL USE ●●●
- DISASSEMBLY ●●
- LOADING EFFICIENCY ●

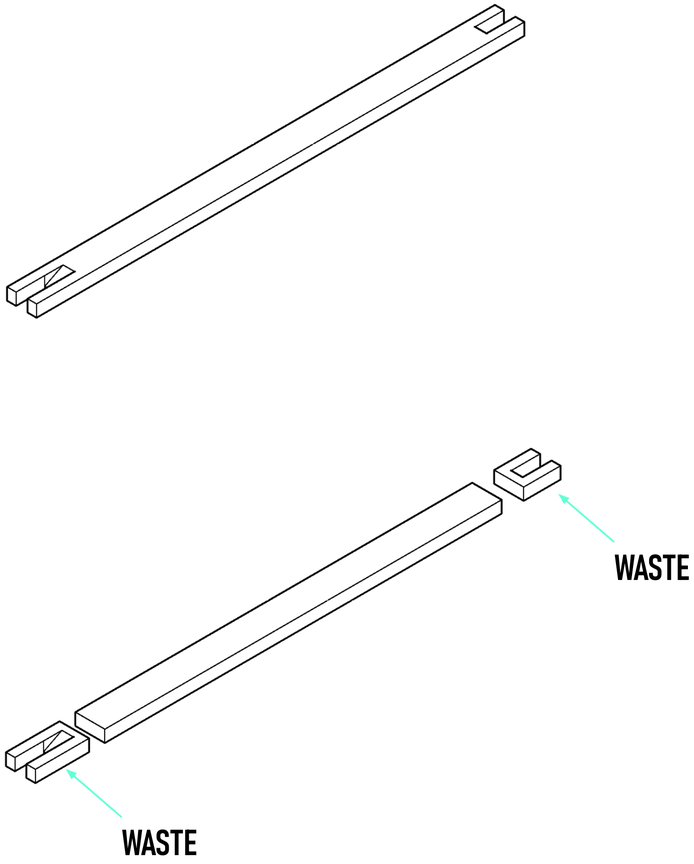
REALISTIC DESIGN:

- ASSEMBLY COMPLEXITY ●●
- ASSEMBLY TIME ●
- MACHINE TIME ●
- MACHINE COMPLEXITY ●
- COMPLEXITY OF CONNECTION ●●

DESIGN PRINCIPLE



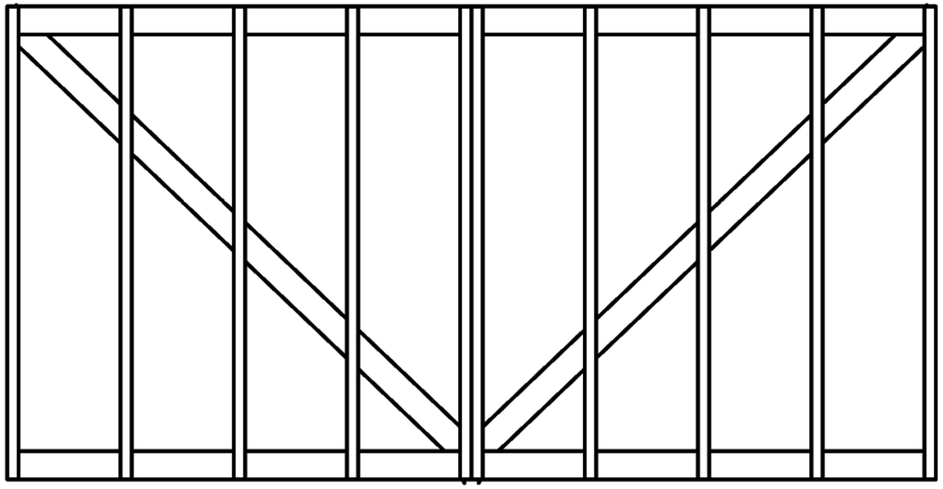


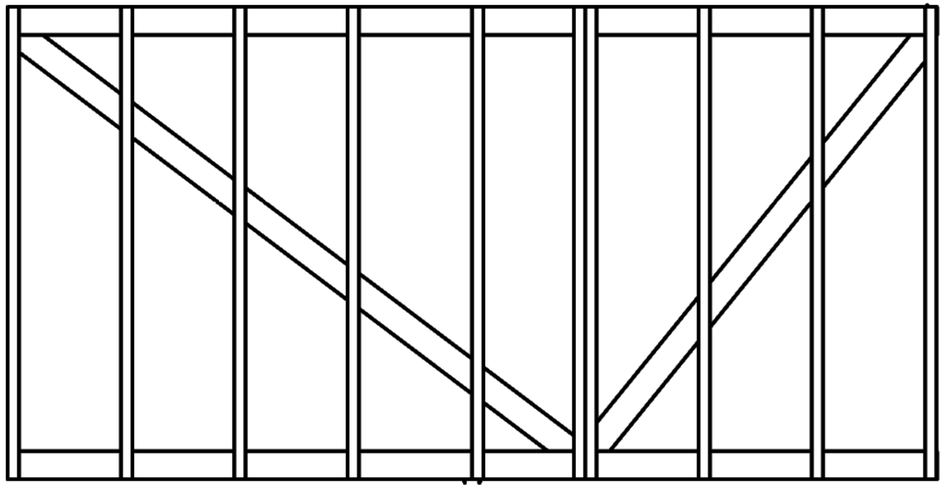


MODIFICATIONS SHOULD BE ON THE OUTSIDE

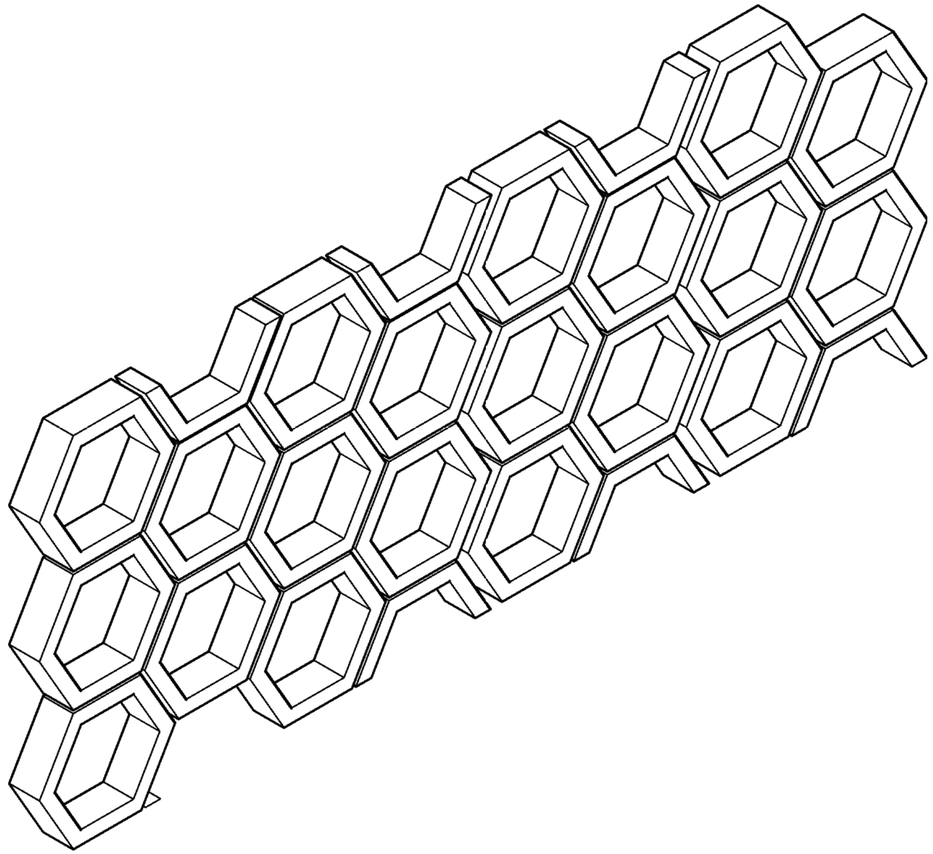
DESIGN PRINCIPLE

AVOID SYMMETRY

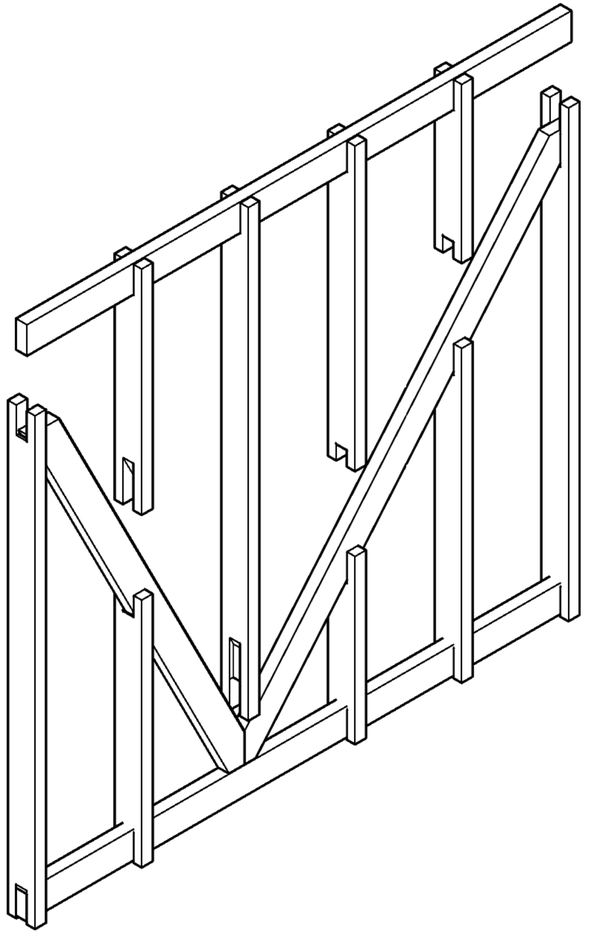




DESIGN PRINCIPLE

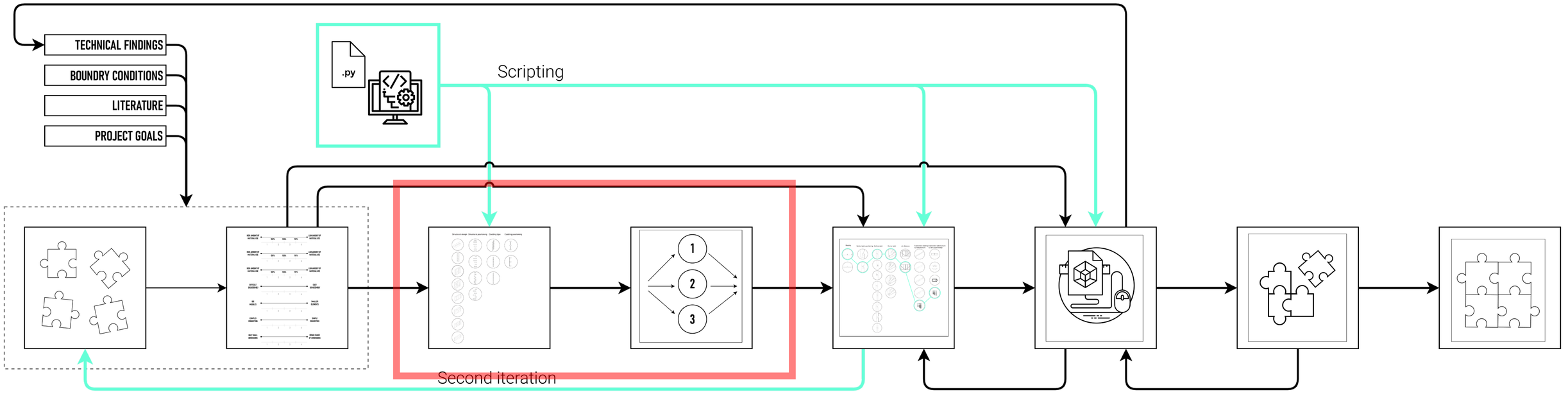


ONE DIMENSION REQUIRED



MULTIPLE DIMENSIONS

DESIGN METHODOLOGY



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ALTERNATIVES

STRUCTURAL DESIGN

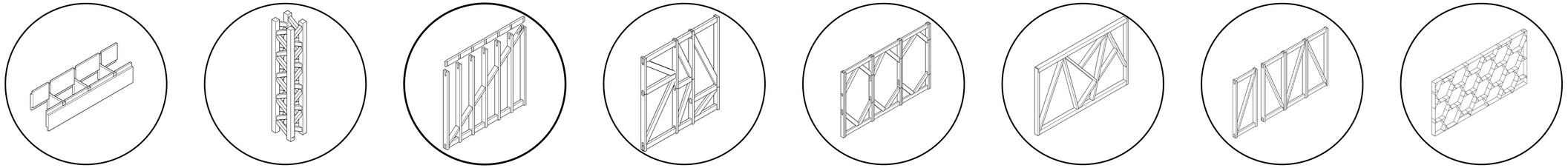
STRUCTURAL POSITIONING

CLADDING TYPE

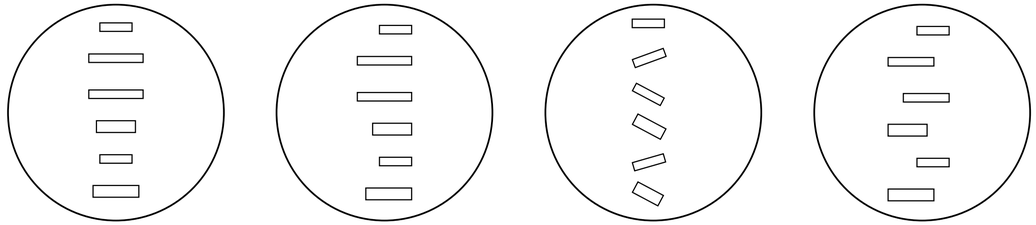
CLADDING POSITIONING

ALTERNATIVES

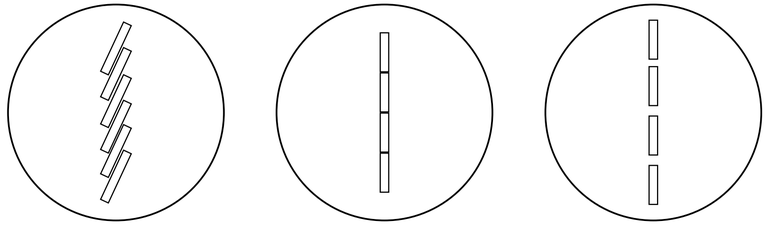
STRUCTURAL DESIGN



STRUCTURAL POSITIONING



CLADDING TYPE



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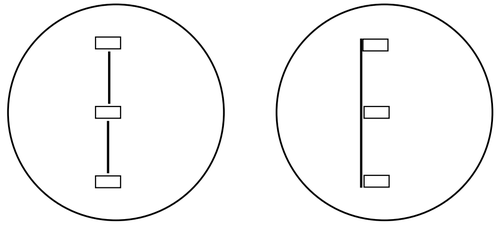
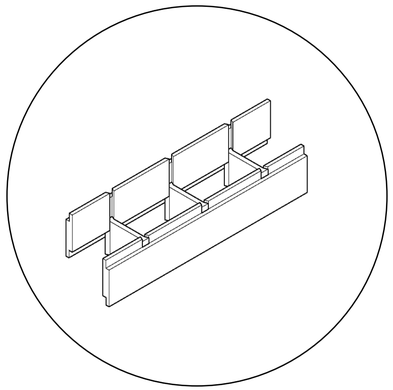
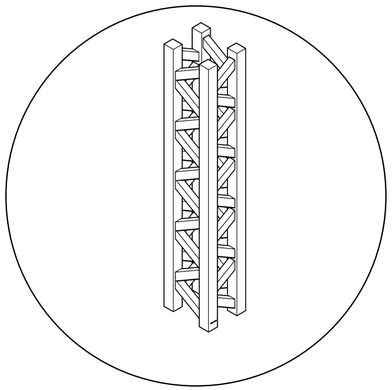
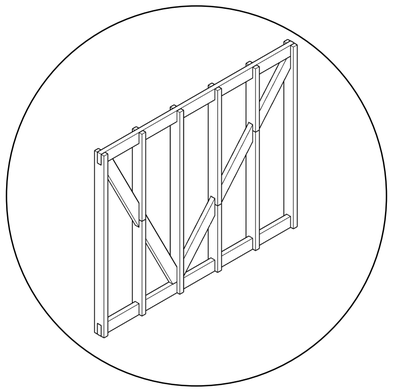
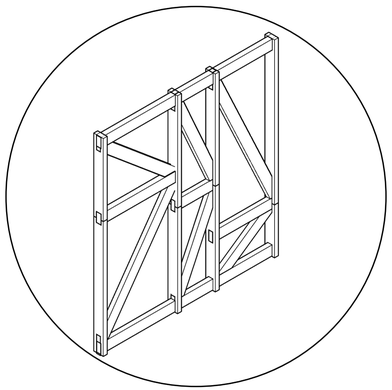
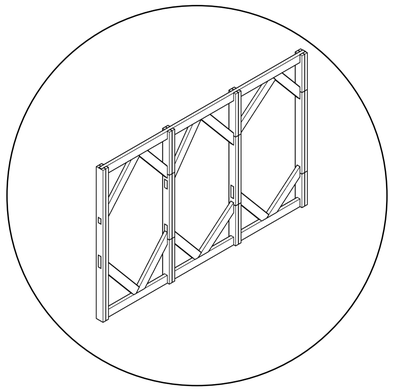
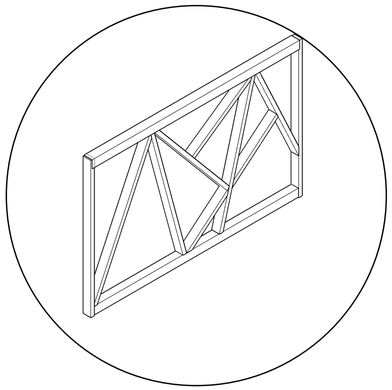
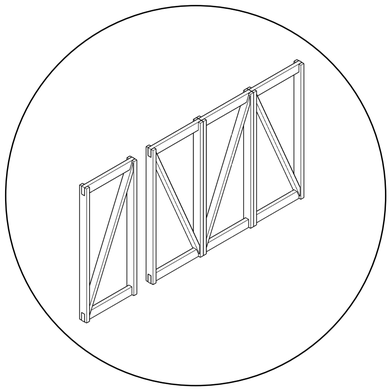
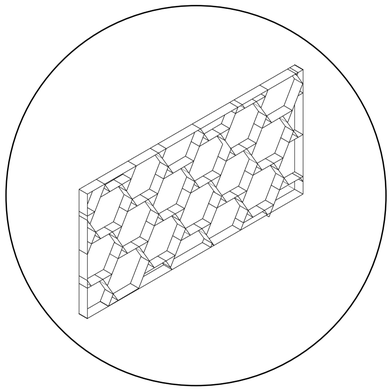
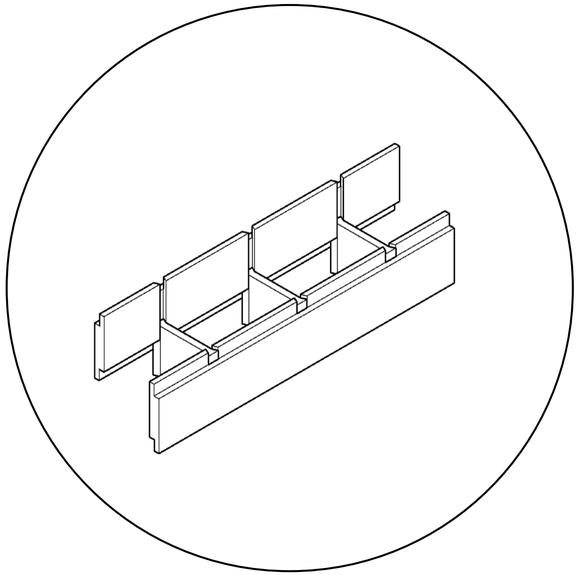


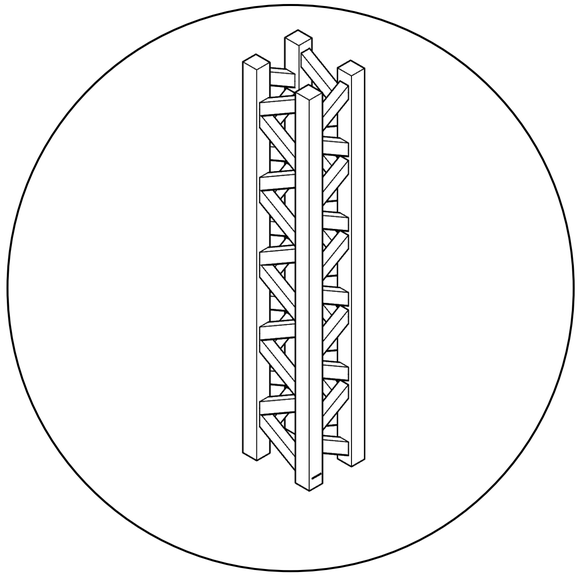
STRUCTURAL DESIGN

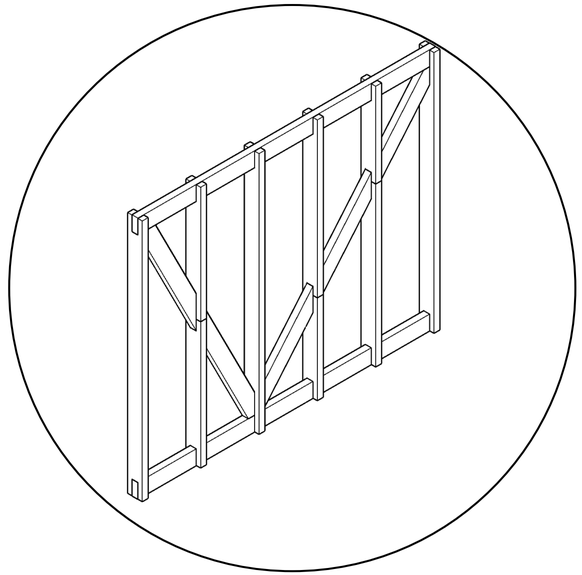
STRUCTURAL DESIGN



+ EASY ASSEMBLY
+ SIMPLE CONNECTION
- HIGH MACHINE TIME
- HIGH ASSEMBLY TIME



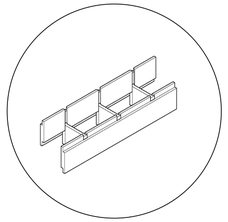
+ EFFICIENT TRANSPORTATION
- LOT OF INDIVIDUAL PIECES
- DIFFICULT TO INTEGRATE INSULATION



+ LOW MATERIAL USE
+ BROAD RANGE OF DIMENSIONS
+ DERIVED FROM EXISTING TFC

STRUCTURAL DESIGN

A



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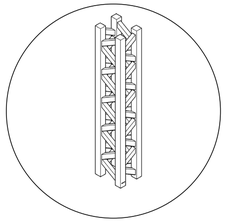

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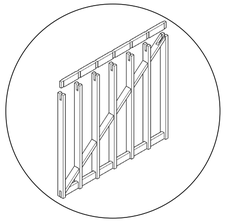

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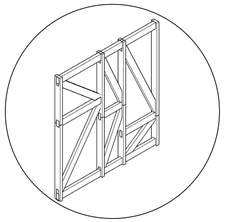

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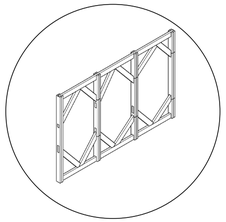

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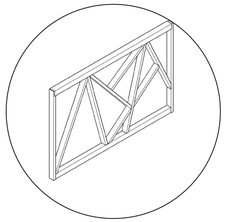

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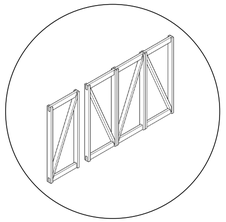

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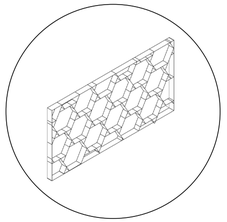
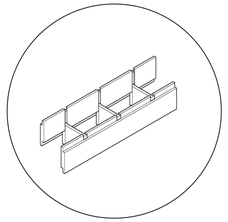


STRUCTURAL INFILL

	A	B	C	D	E	F	G	H	Weight
Expected material loss	3	4	3	3	3	4	3	1	3x
Total material use	1	3	4	1	4	4	4	4	3x
Assembly complexity	4	4	3	2	3	1	4	1	2x
Assembly time	1	1	3	2	3	1	3	1	1x
Machine time	1	1	4	3	4	3	4	1	1x
Flexibility of pieces	4	4	4	4	4	4	4	1	3x
Loading efficiency	4	4	1	1	1	1	3	1	1x
Complexity of connection	4	4	3	1	2	1	4	1	2x
Full length usage	1	4	4	4	4	4	4	1	3x
	49	**67**	**65**	**48**	**63**	**57**	**68**	**19**	

STRUCTURAL DESIGN

A



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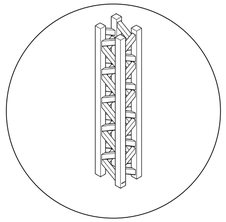

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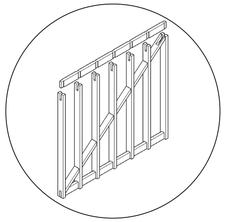

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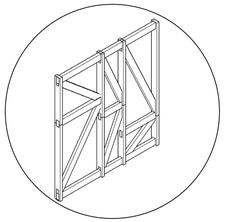

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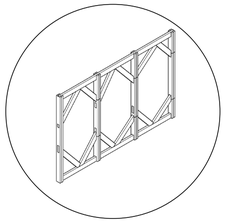

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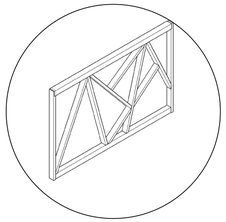

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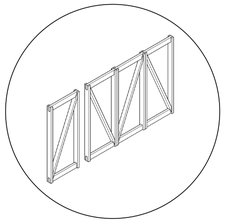

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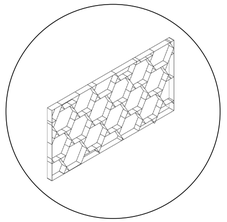

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TOTAL MATERIAL USE

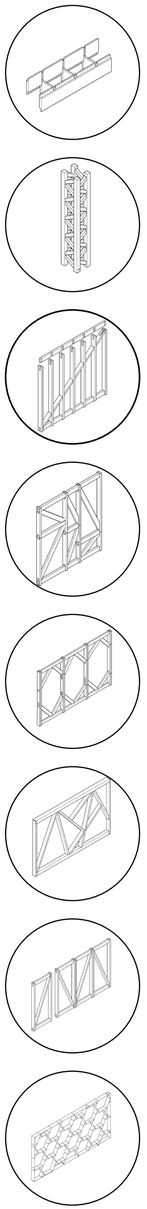
HIGH AMOUNT OF MATERIAL USE

LOW AMOUNT OF MATERIAL USE

SUBJECTIVE SCALE

1 2 3 4

Structural design



TOTAL MATERIAL USE

HIGH AMOUNT OF MATERIAL USE

LOW AMOUNT OF MATERIAL USE

SUBJECTIVE SCALE

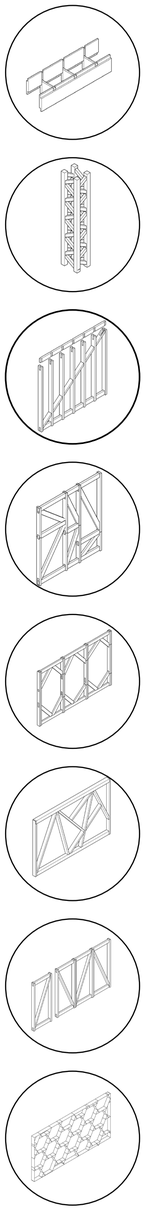
1 2 3 4

OBJECTIVE SCALE

MORE THAN 80m | 80m | 70m | 60m | LESS THAN 60m

1 2 3 4

Structural design



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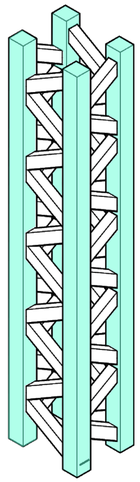
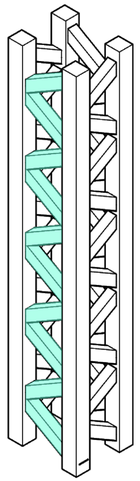
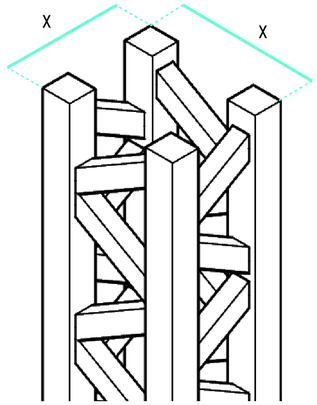


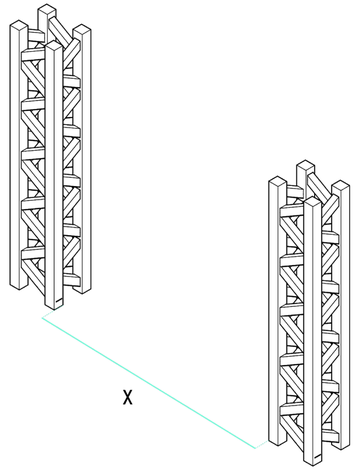
NUMBER OF STUDS



WEBS PER STUD



DISTANCE BETWEEN STUDS

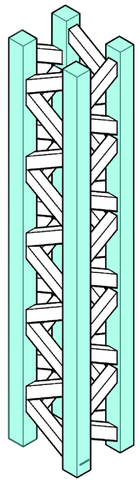


DISTANCE BETWEEN COLUMNS

```python
def truss(height_wall, width_wall, web_connection_per_meter, distance_between_trusses,
          studs_per_truss, distance_between_studs):

    number_trusses = width_wall / distance_between_trusses + 1
    vertical_length = number_trusses * studs_per_truss * height_wall
    height_single_web = 1000 / web_connection_per_meter
    length_single_web = (height_single_web**2 + distance_between_studs**2)**0.5

    total_length_webs = height_wall / height_single_web * length_single_web * studs_per_truss * number_trusses

    total_length = total_length_webs + vertical_length
    total_length = round(total_length / 1000,2)
    print(f'total length = {total_length} meter')

truss(3000, 4800, 3, 3000, 4, 200)
```

```
total length = 67.59 meter
```

SCRIPTING



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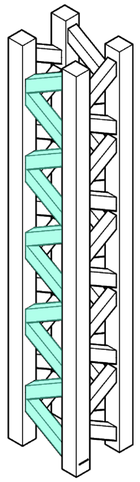
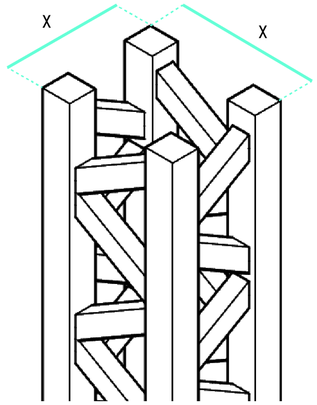
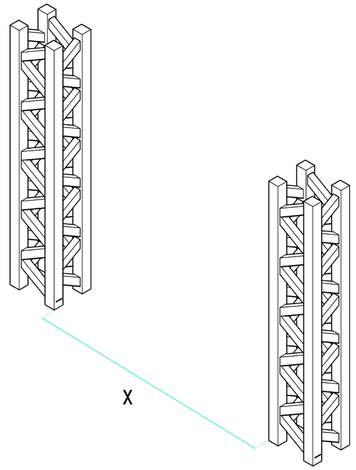


WEBS PER STUD



DISTANCE BETWEEN STUDS



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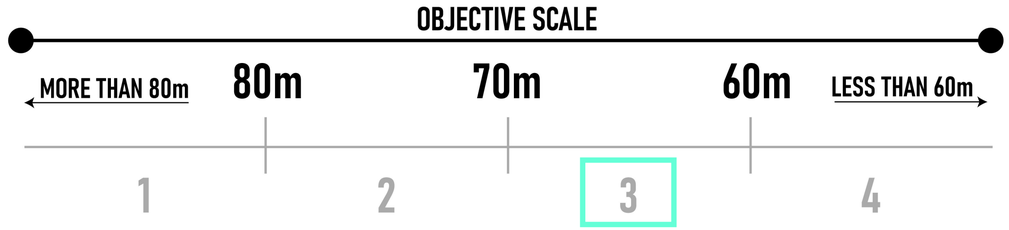
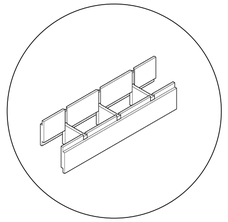


STRUCTURAL DESIGN

A



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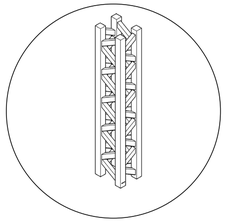

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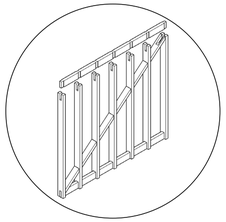

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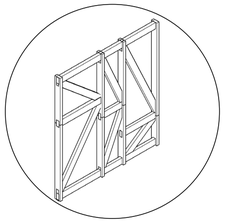

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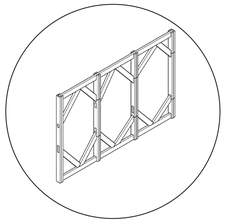

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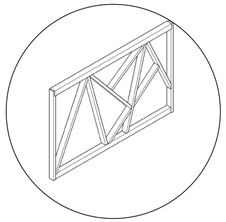

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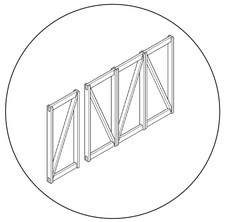

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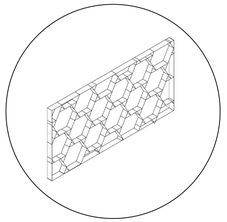

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Loading efficiency	4	4	1	1	1	1	3	1	1x
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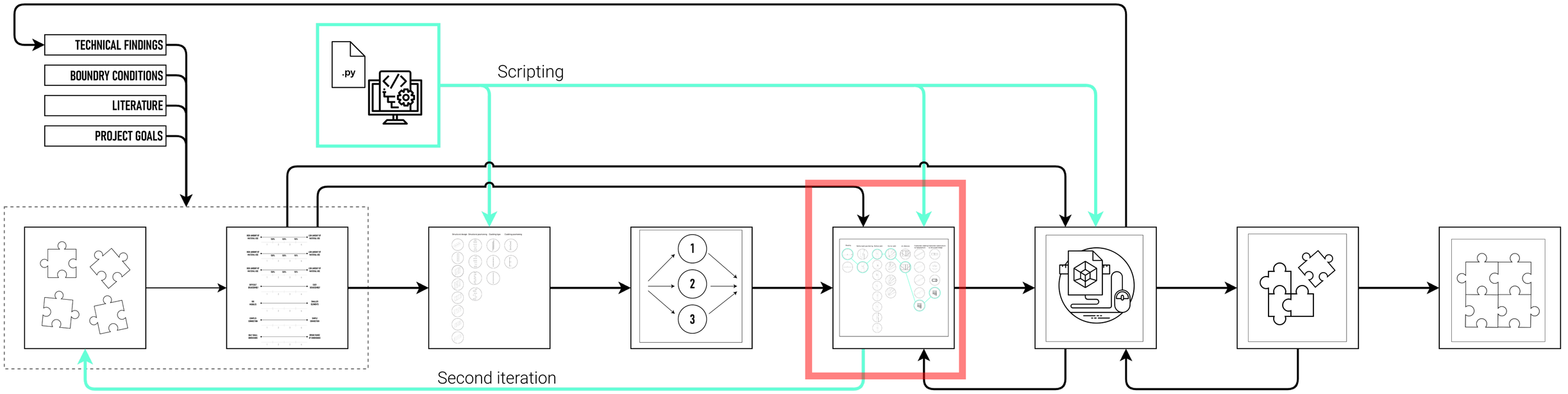
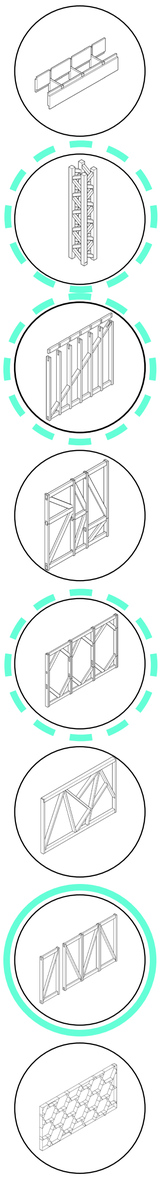
DESIGN METHODOLOGY



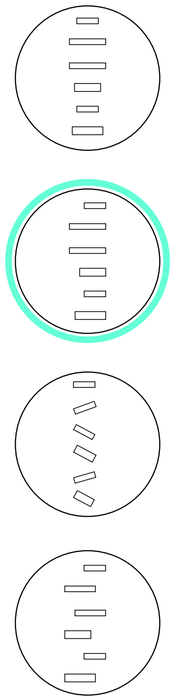
A. Design problems B. Criteria C. Alternatives D. Concepts E. Concept analyses F. Prototyping G. Sub-solutions H. Final design

CONCEPT ANALYSIS

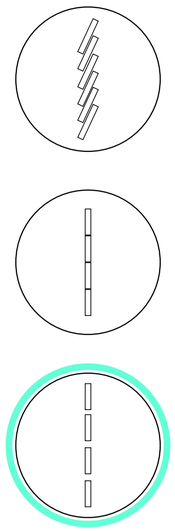
Structural design



Structural positioning



Cladding type



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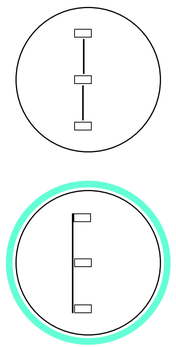

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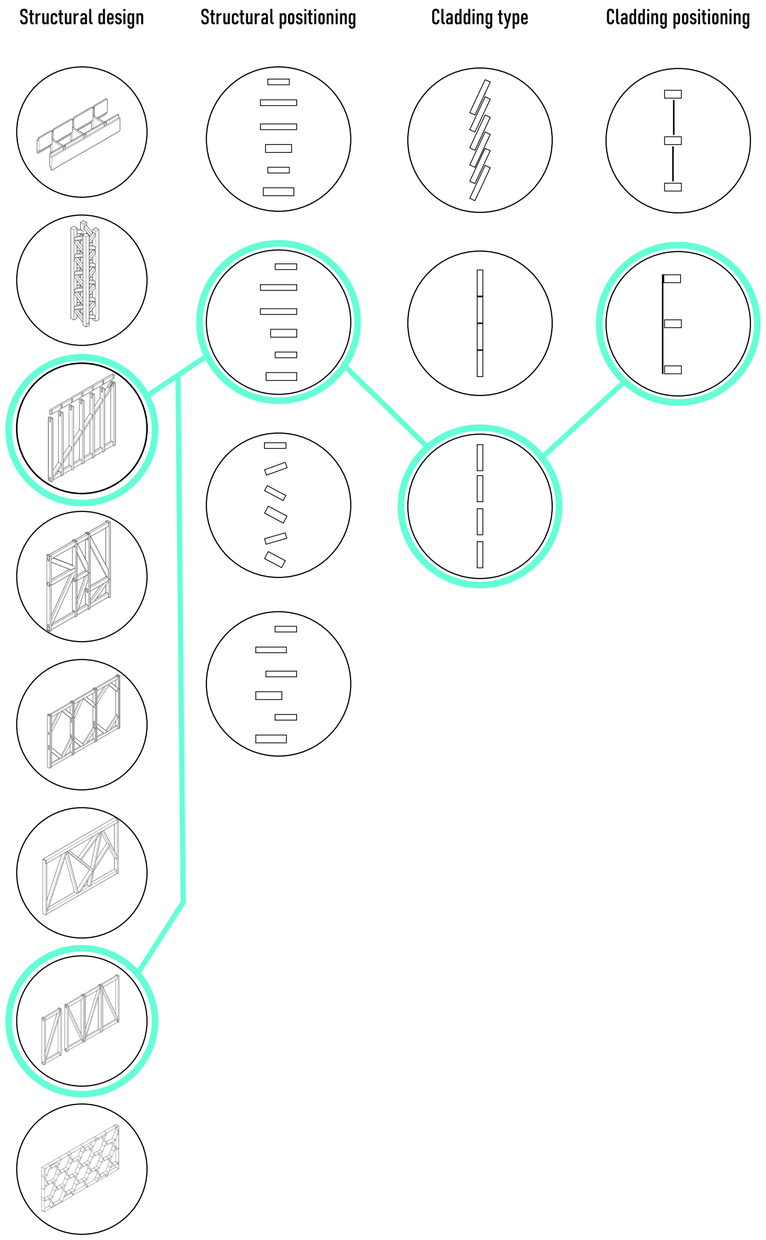
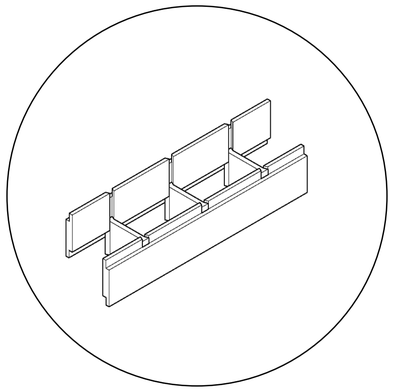
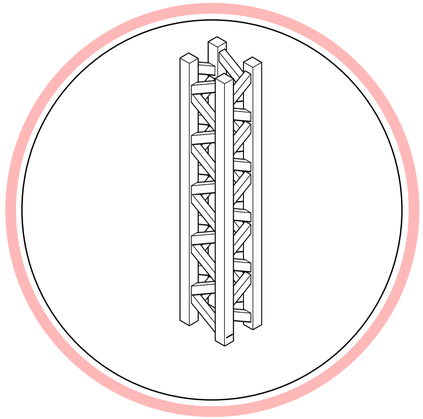
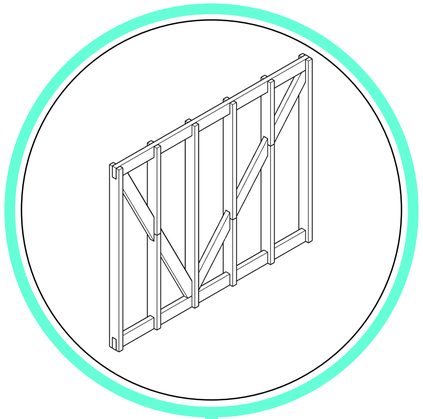
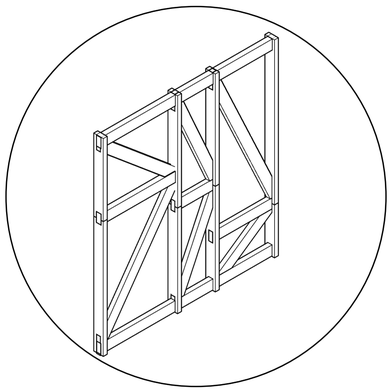
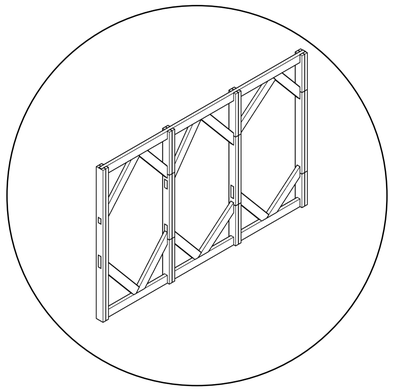
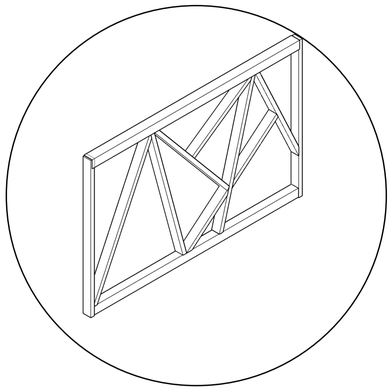
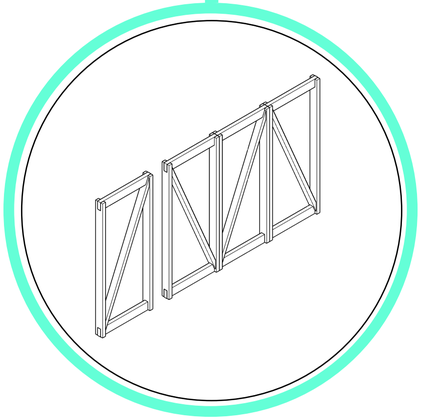
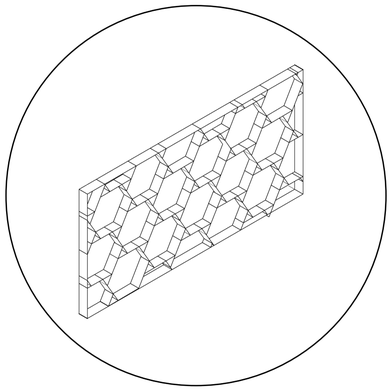
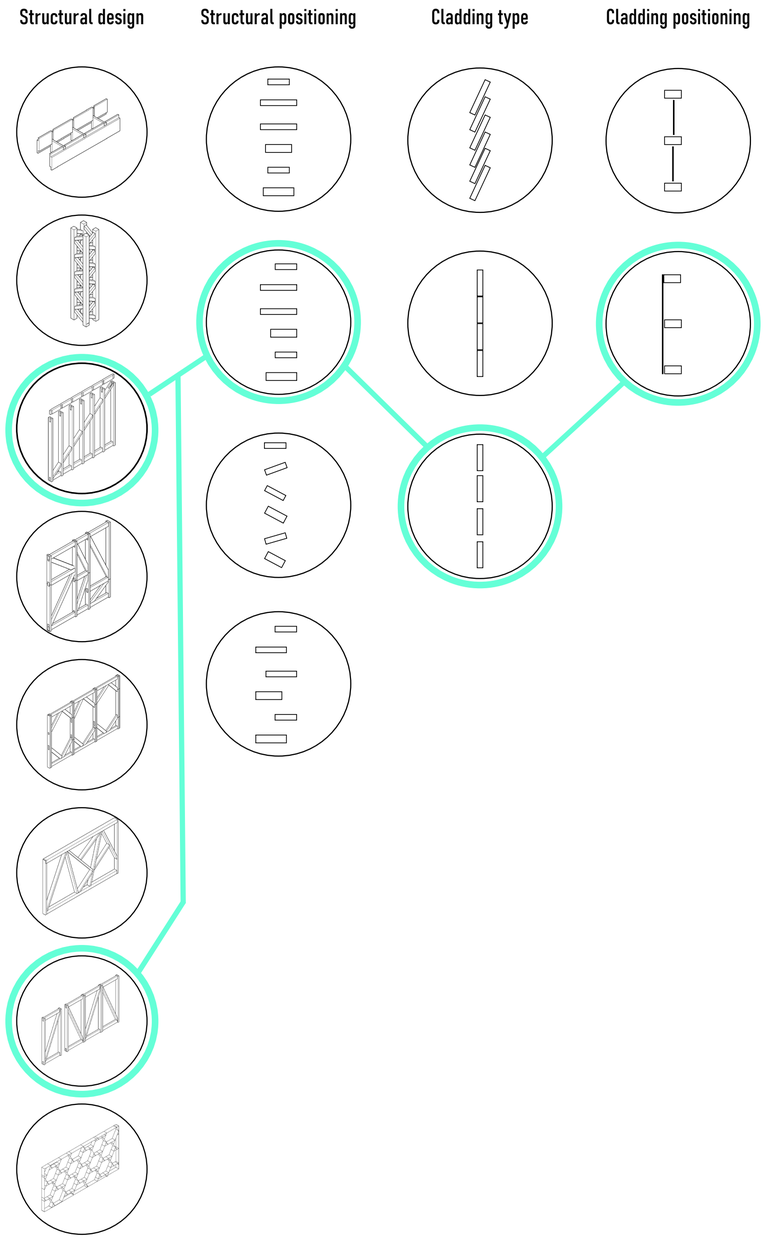
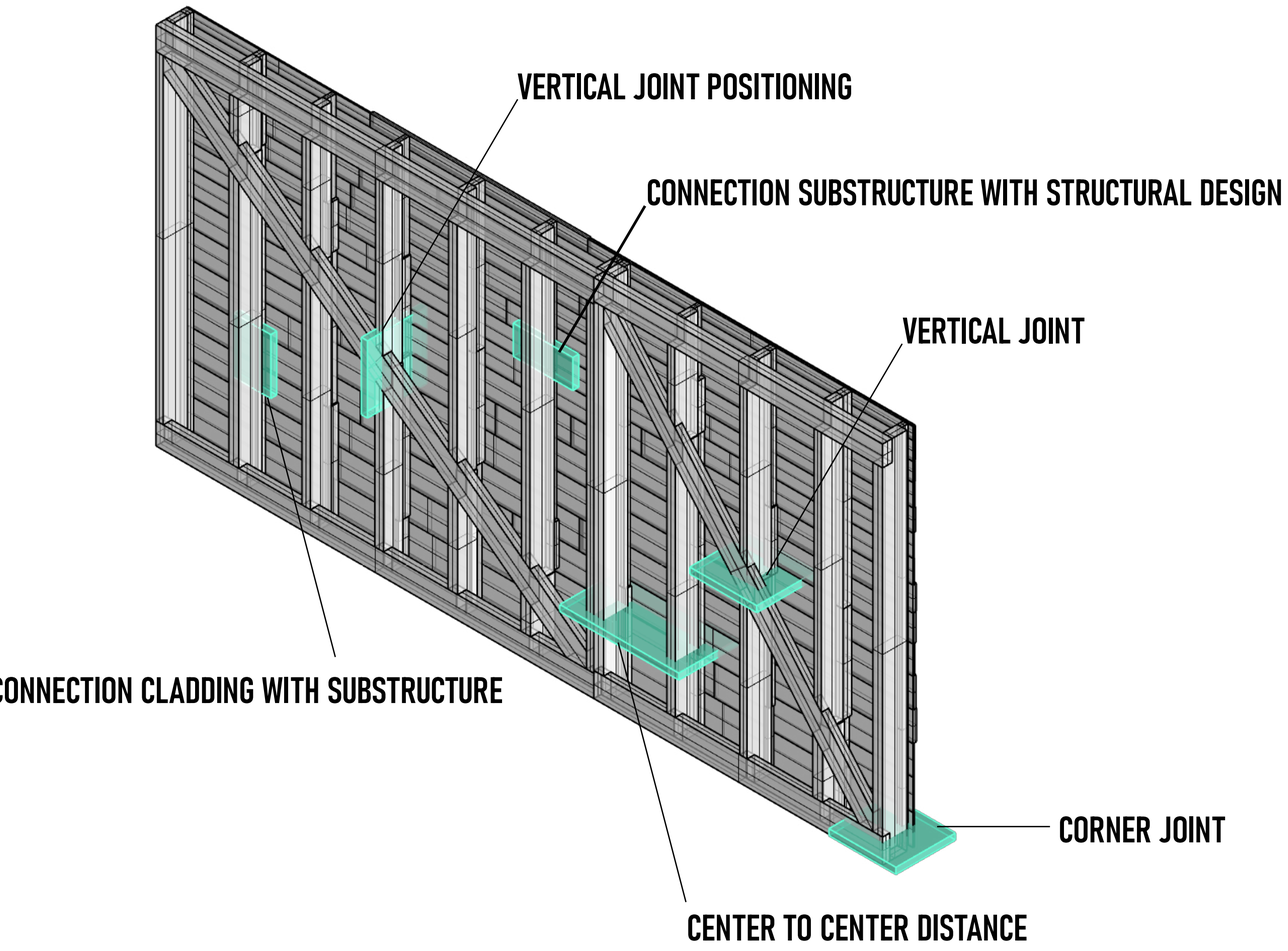


STRUCTURAL DESIGN

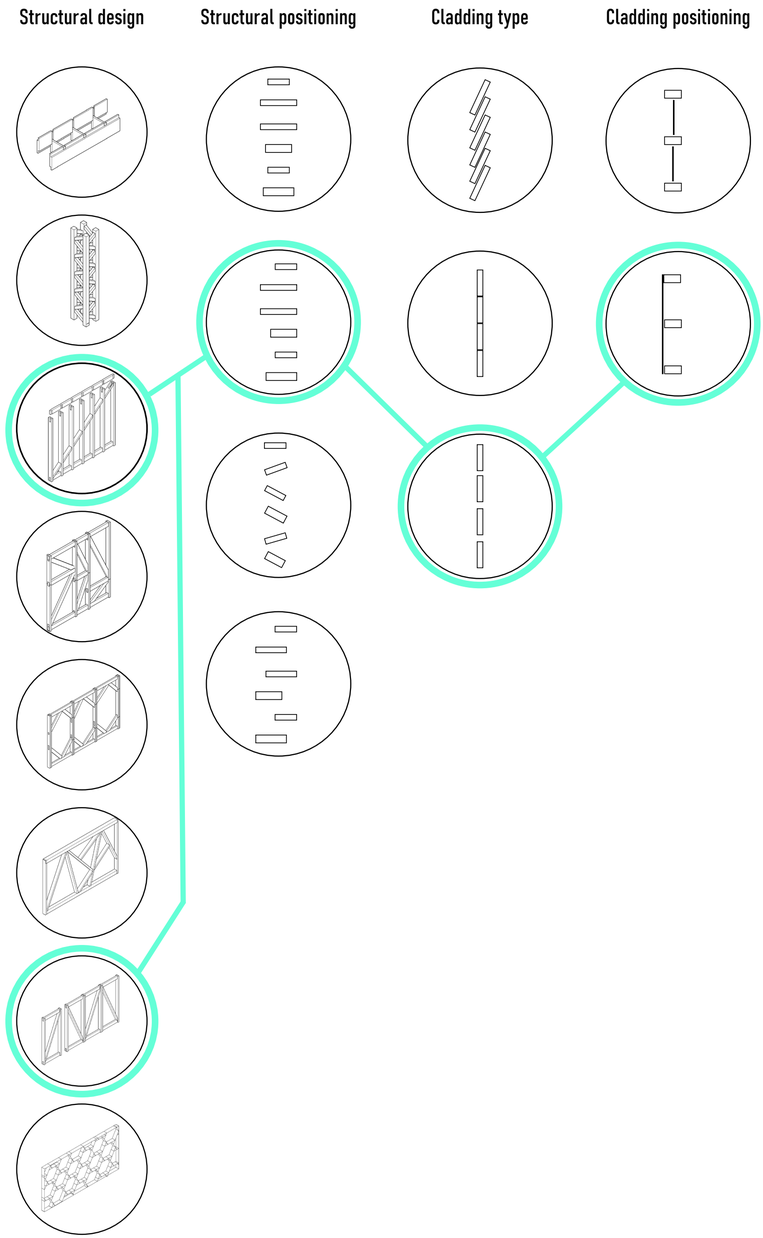









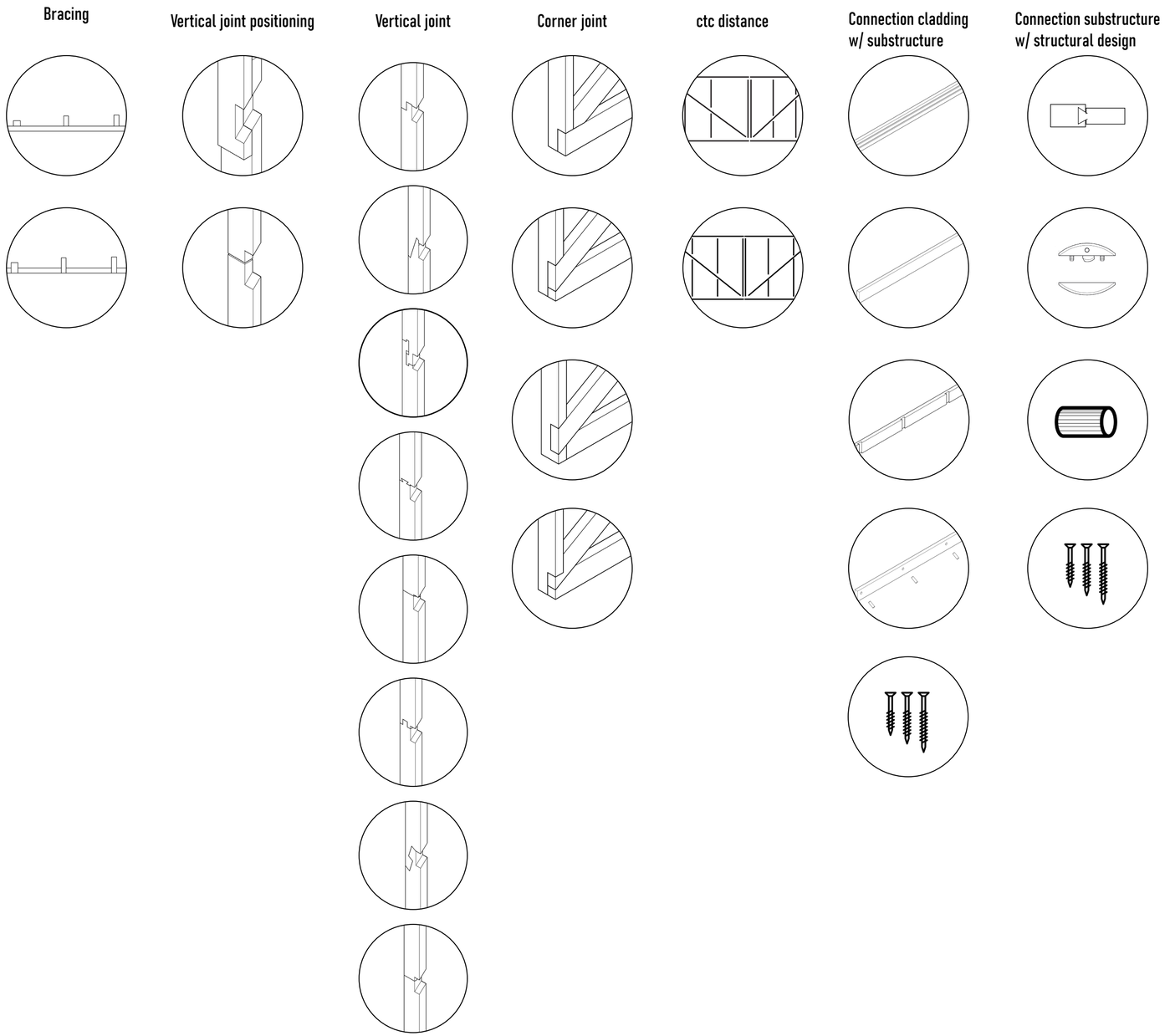
NEW DESIGN PROBLEMS





SECOND ITERATION





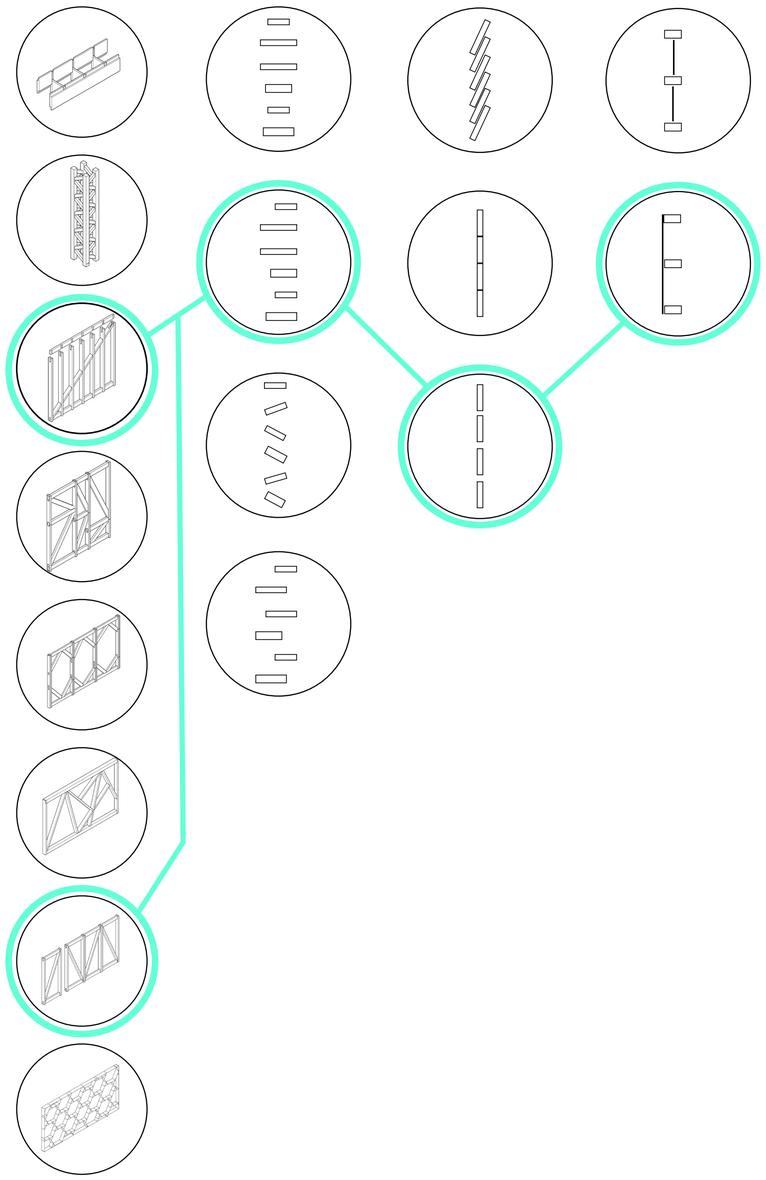
CONCEPT ANALYSIS

Structural design

Structural positioning

Cladding type

Cladding positioning



Bracing

Vertical joint positioning

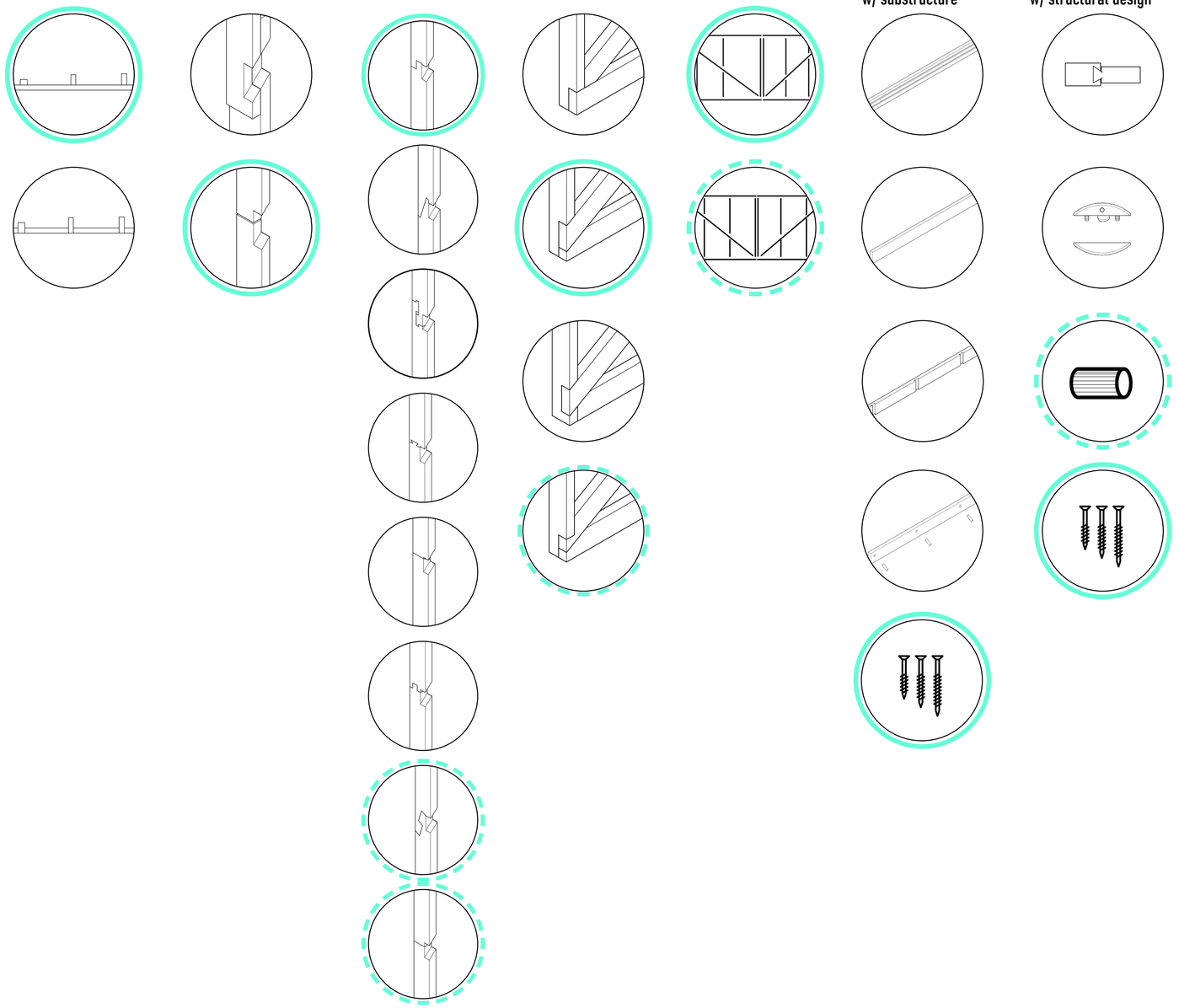
Vertical joint

Corner joint

ctc distance

Connection cladding w/ substructure

Connection substructure w/ structural design



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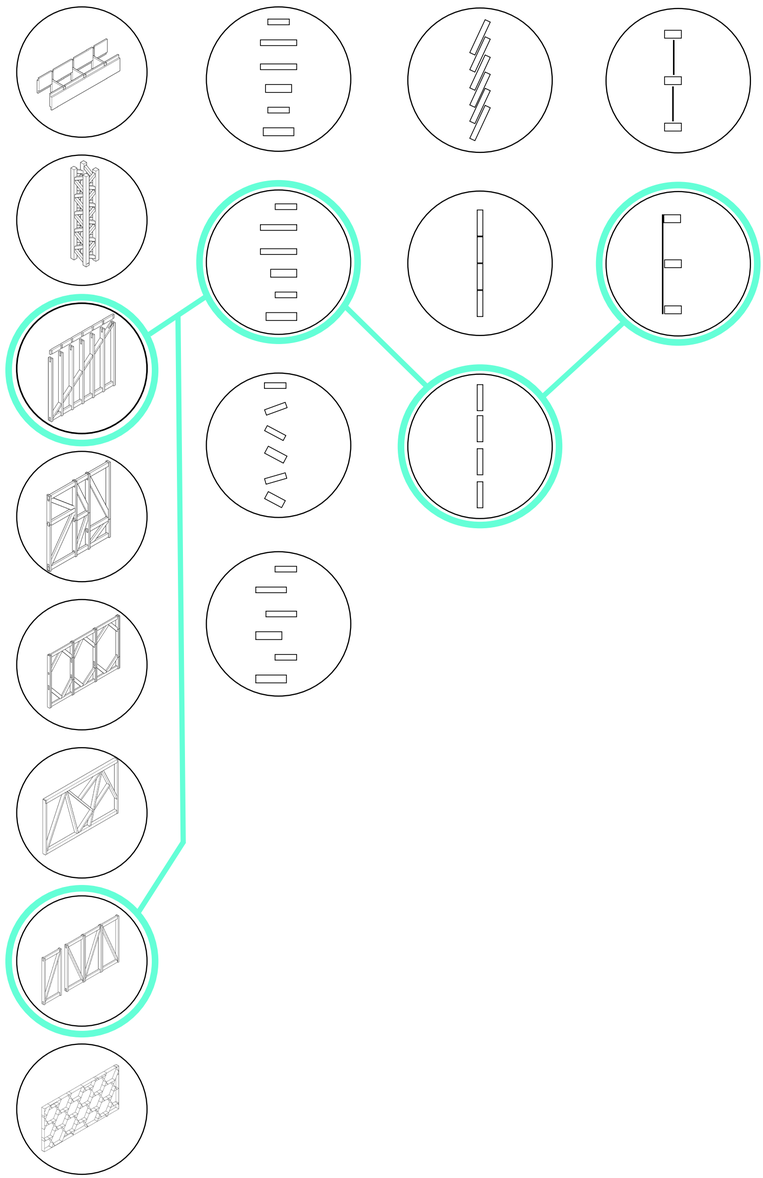

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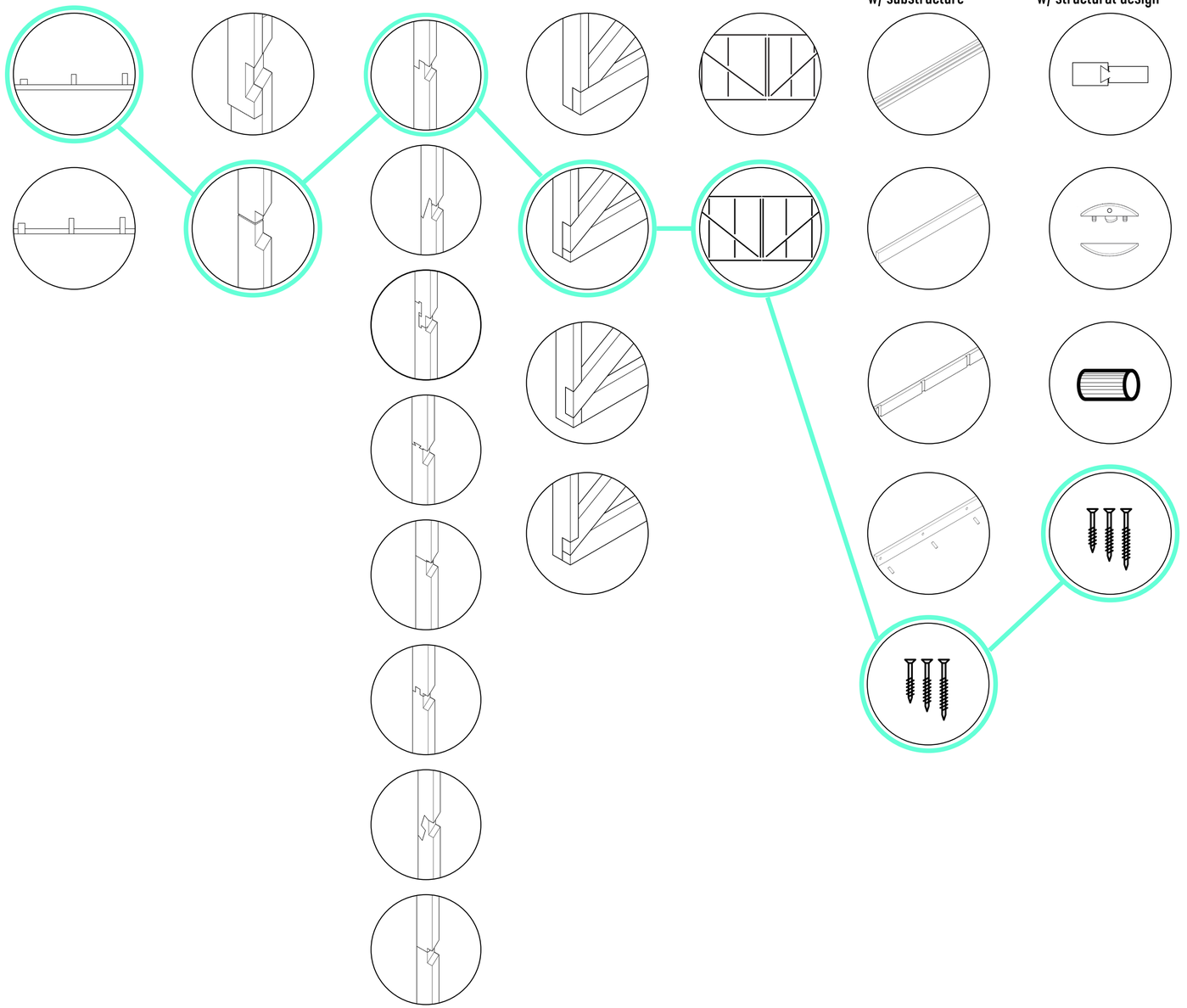
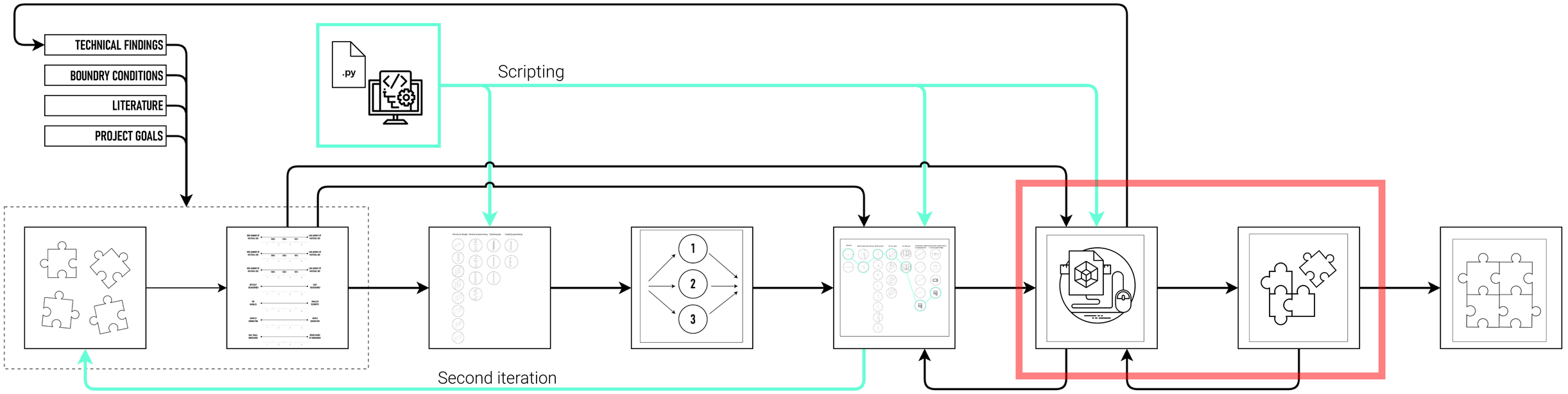
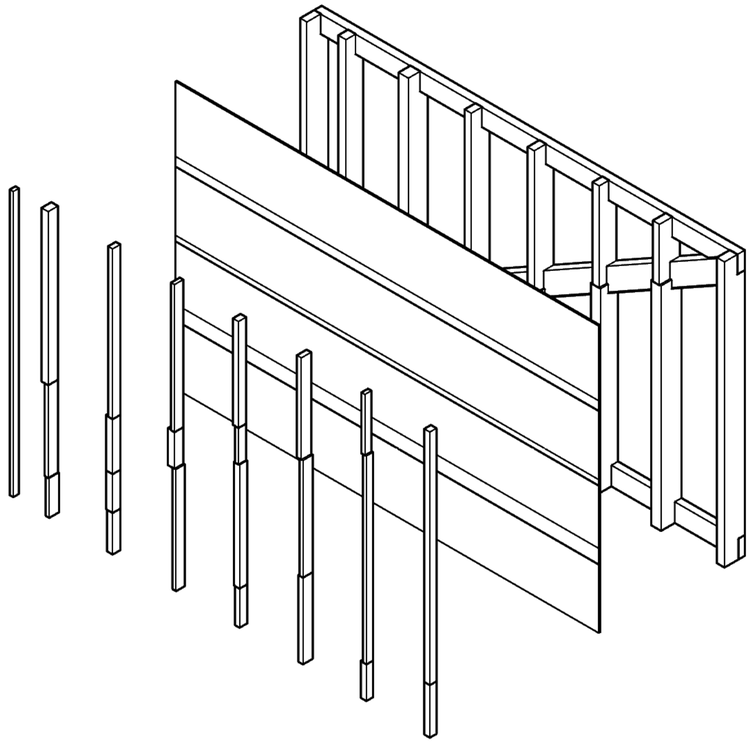


DESIGN METHODOLOGY

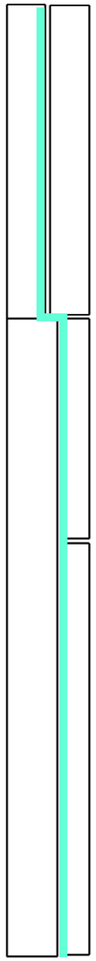


A. Design problems | B. Criteria | C. Alternatives | D. Concepts | E. Concept analyses | F. Prototyping | G. Sub-solutions | H. Final design

WATER BARRIER FOIL

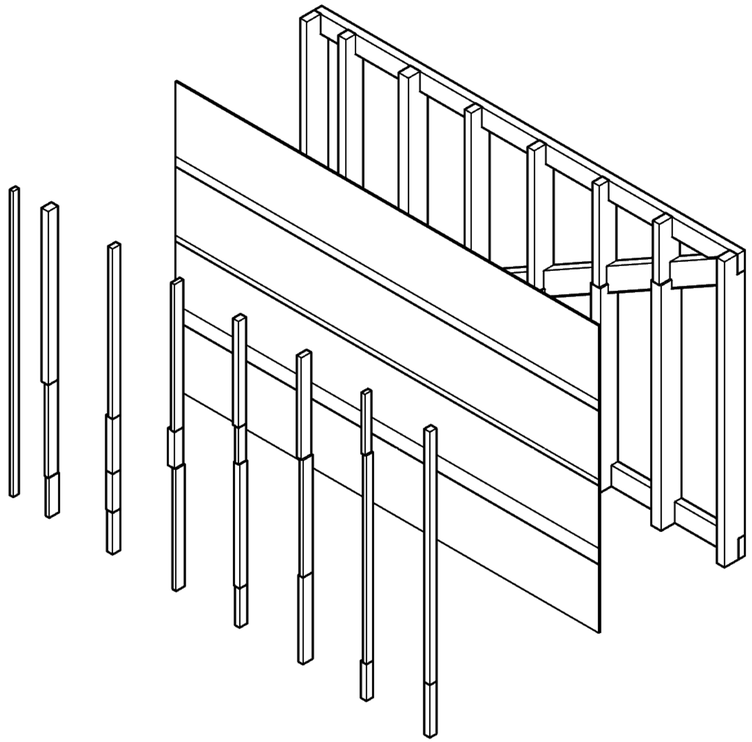


STUD

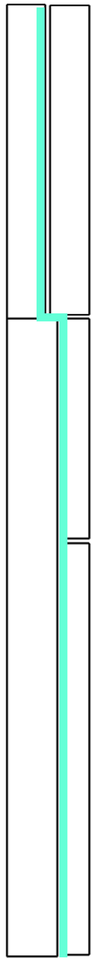


SUBSTRUCTURE

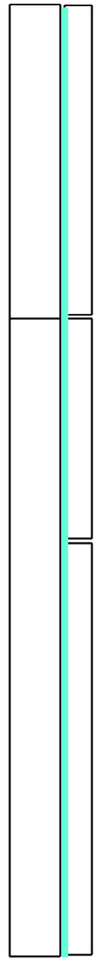
WATER BARRIER FOIL



STUD

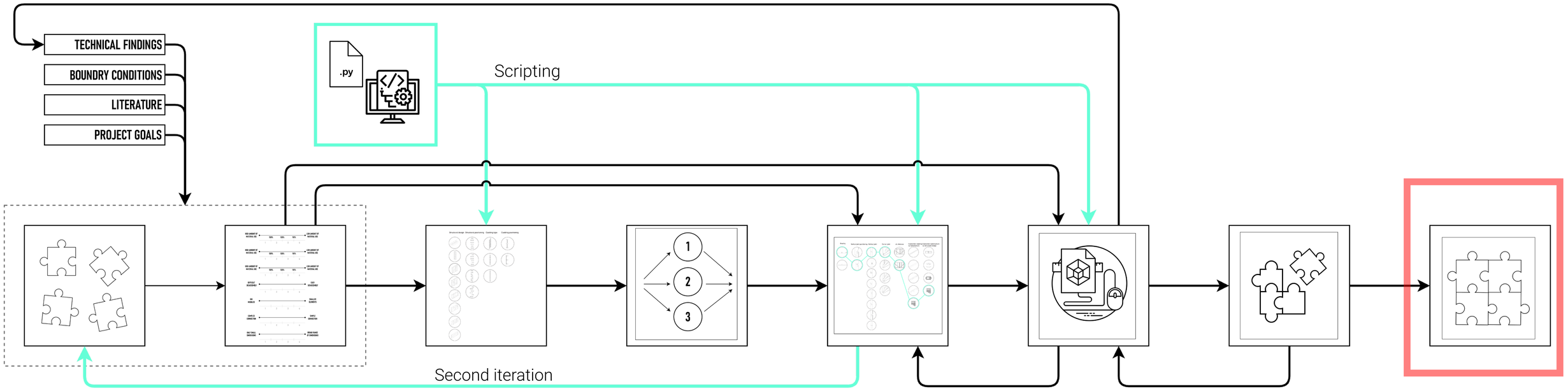


SUBSTRUCTURE



WASTE INCREASE OF 0.5%

DESIGN METHODOLOGY



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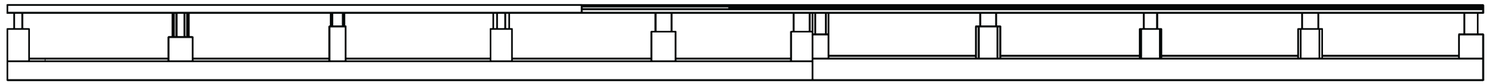
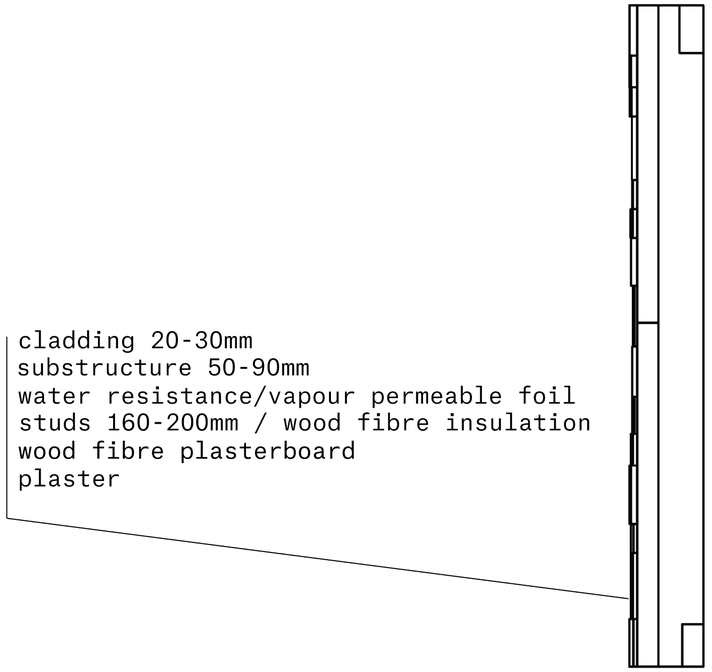
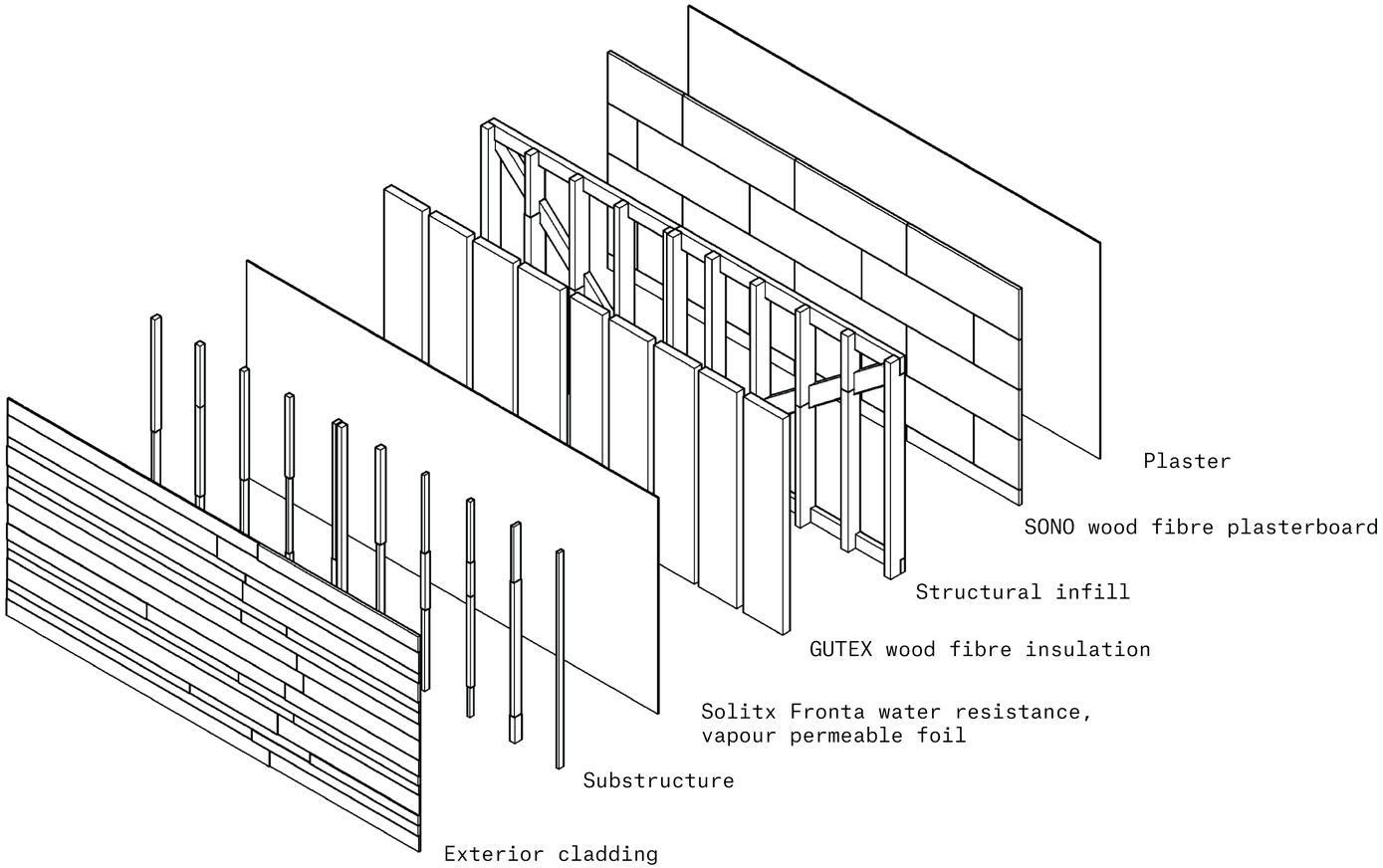
FINAL DESIGN

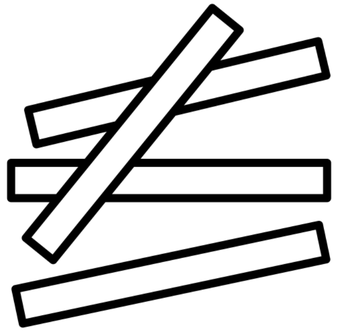




cladding 20-30mm
substructure 50-90mm
water resistance/vapour permeable foil
studs 160-200mm / wood fibre insulation
wood fibre plasterboard
plaster

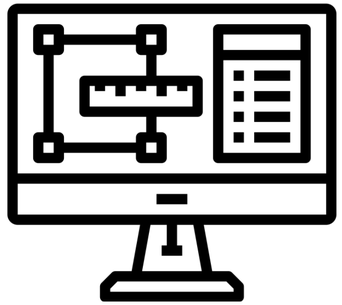


How can a database, a parametric model, and scripting be used to develop an exterior wall element from waste wood that minimizes the material loss and takes full benefit of the waste wood dimensions?



DESIGN OF AN EXTERIOR WALL ELEMENT

DATABASE THAT CAN COMMUNICATE WITH A PARAMETRIC MODEL



EXTERIOR WALL ELEMENT TOOL

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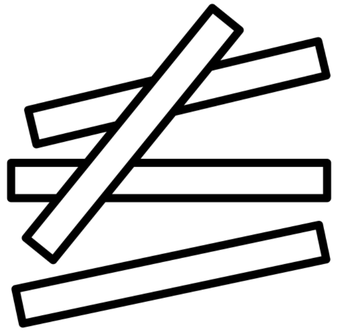

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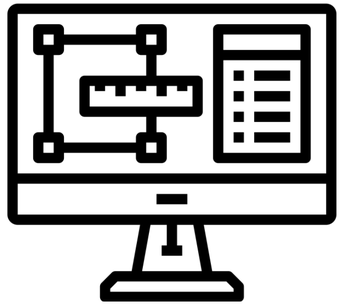

EXTERIOR WALL ELEMENT TOOL

DATABASE

DATABASE WITH WASTE WOOD PROPERTIES DOES NOT YET EXIST

- ID NUMBER
- LENGTH IN MM
- DEPTH IN MM
- WIDTH IN MM
- STRENGTH CLASS
- WEIGHT IN KG
- TYPE OF WOOD
- STRUCTURAL INTEGRITY
- PAINTED
- DENSITY
- VOLUME
- ARCHIVED ON
- SUSTAINABILITY CLASS
- SELLER ID

waste_wood/postgres@PostgreSQL 12

Query Editor | Query History

```
1  SELECT * FROM waste_wood
```

Data Output | Explain | Messages | Notifications

	wood_id [PK] integer	wood_length_mm numeric	wood_depth_mm numeric	wood_width_mm numeric	strength_class character varyin	wood_weight_kg numeric	wood_type character varying	structural_integrity boolean	painted boolean	density_kgm3 numeric (10,2)	volume_dm3 numeric (10,2)	archived_on timestamp with	sustainability_class integer	seller_id integer
45	45	2627	117	70	C22	16.459	Cedar	false	false	765.00	21.52	2021-02-12 ...	5	2
46	46	1496	146	74	C20	8.178	Douglas Fir	false	true	505.98	16.16	2021-02-12 ...	2	2
47	47	763	176	29	C18	2.302	Oak	false	true	591.11	3.89	2021-02-12 ...	2	1
48	48	1081	111	72	D30	4.976	Oak	true	false	575.97	8.64	2021-02-12 ...	5	2
49	49	2260	109	44	D18	5.875	Douglas Fir	true	false	542.03	10.84	2021-02-12 ...	5	5
50	50	3137	171	53	C18	14.471	Douglas Fir	true	false	508.99	28.43	2021-02-12 ...	3	2
51	51	273	198	73	D18	2.77	Cedar	true	false	701.99	3.95	2021-02-12 ...	4	5
52	52	1831	193	62	C22	15.446	Douglas Fir	false	false	704.98	21.91	2021-02-12 ...	1	2
53	53	3493	61	84	D30	10.13	Poplar	true	true	565.98	17.90	2021-02-12 ...	1	4
54	54	2008	126	27	C20	5.199	Pine	true	true	761.07	6.83	2021-02-12 ...	2	4
55	55	514	134	79	C22	3.912	Douglas Fir	false	false	718.96	5.44	2021-02-12 ...	3	4
56	56	2290	108	53	D24	8.612	Cedar	true	false	657.01	13.11	2021-02-12 ...	2	4
57	57	2999	97	57	C20	9.667	Poplar	true	false	583.00	16.58	2021-02-12 ...	2	2
58	58	2004	168	27	C20	5.936	Poplar	false	false	653.01	9.09	2021-02-12 ...	3	2
59	59	1671	174	21	D18	3.657	Pine	false	false	598.94	6.11	2021-02-12 ...	1	6
60	60	1365	199	44	C18	7.207	Spruce	false	true	603.00	11.95	2021-02-12 ...	1	2
61	61	1773	75	50	C18	4.288	Douglas Fir	false	true	644.93	6.65	2021-02-12 ...	5	6

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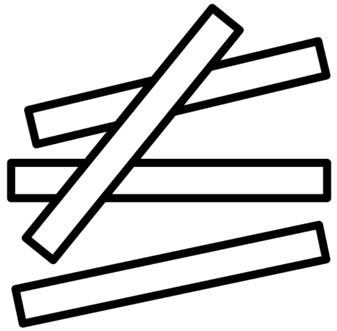

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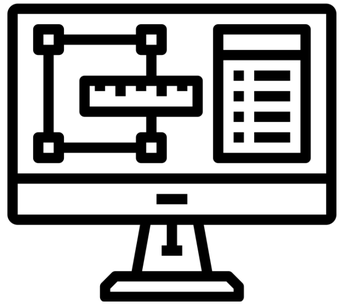
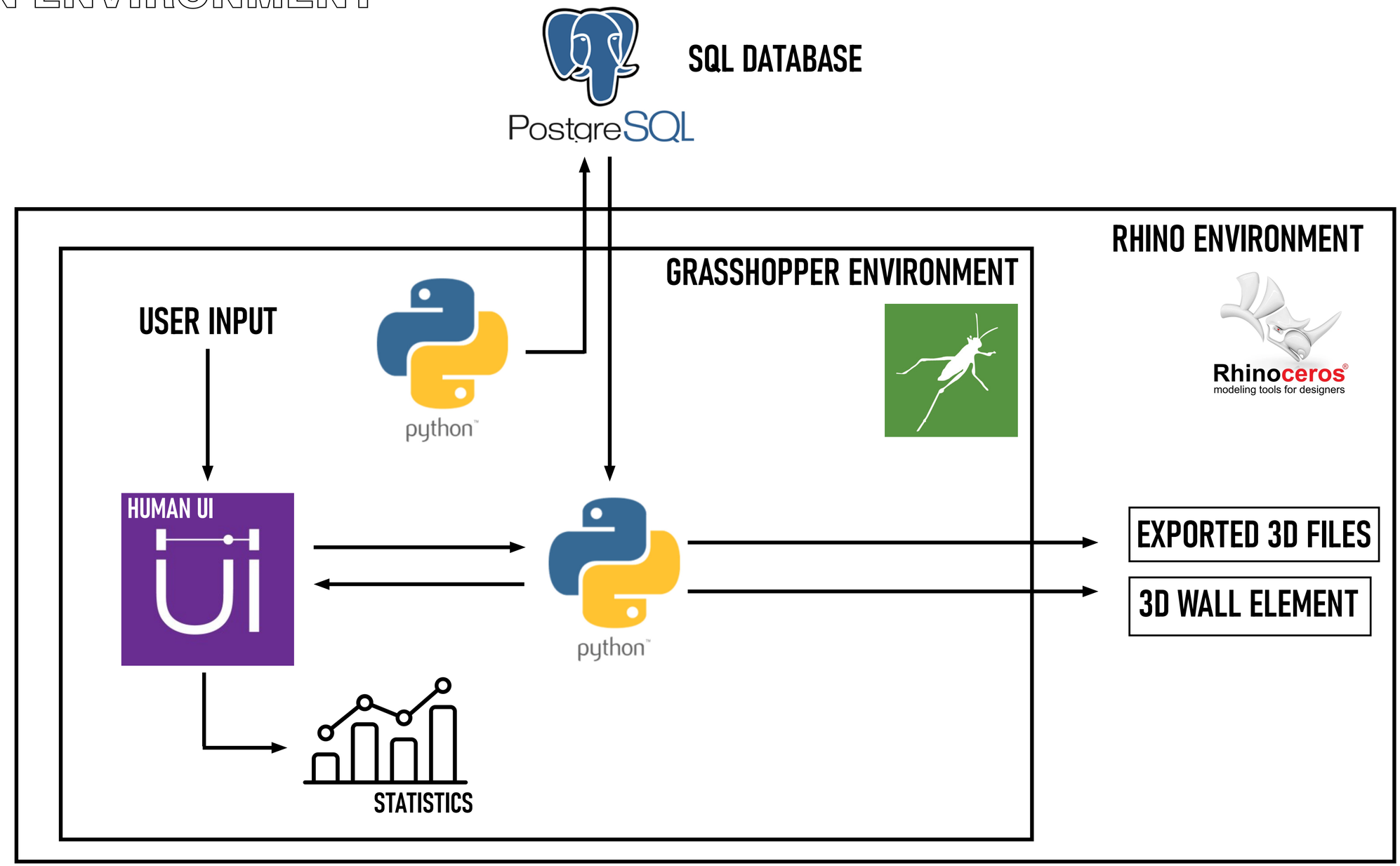
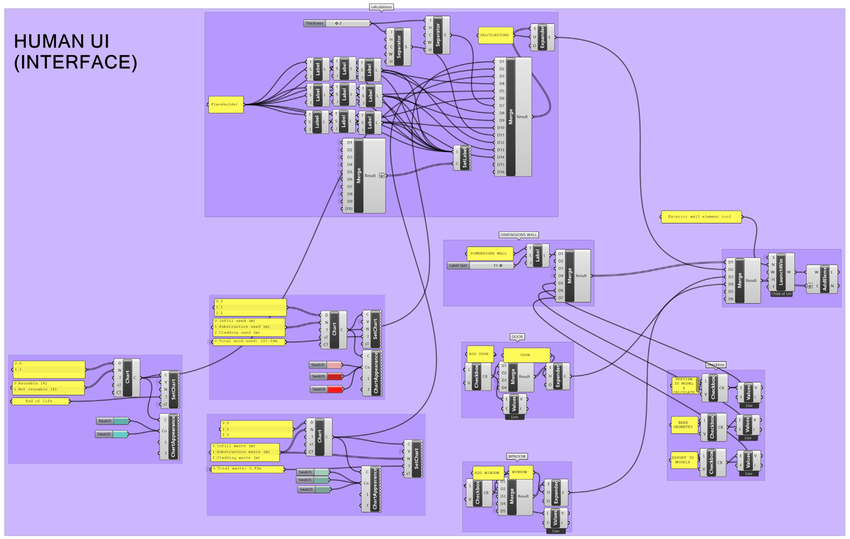


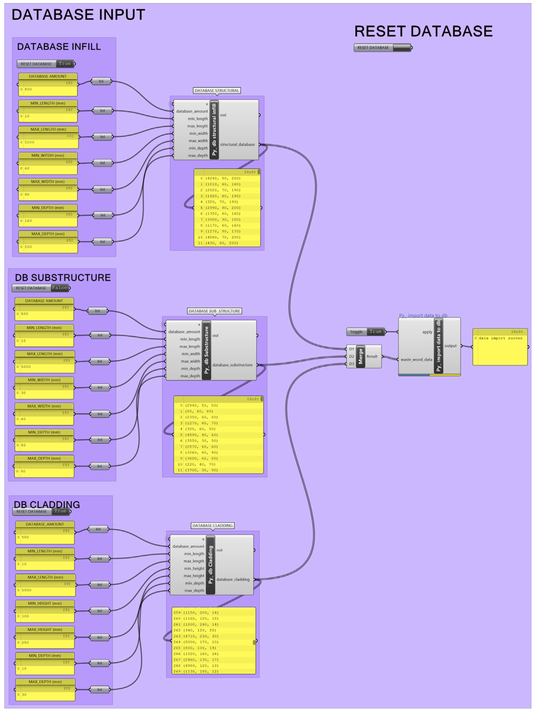
EXTERIOR WALL ELEMENT TOOL

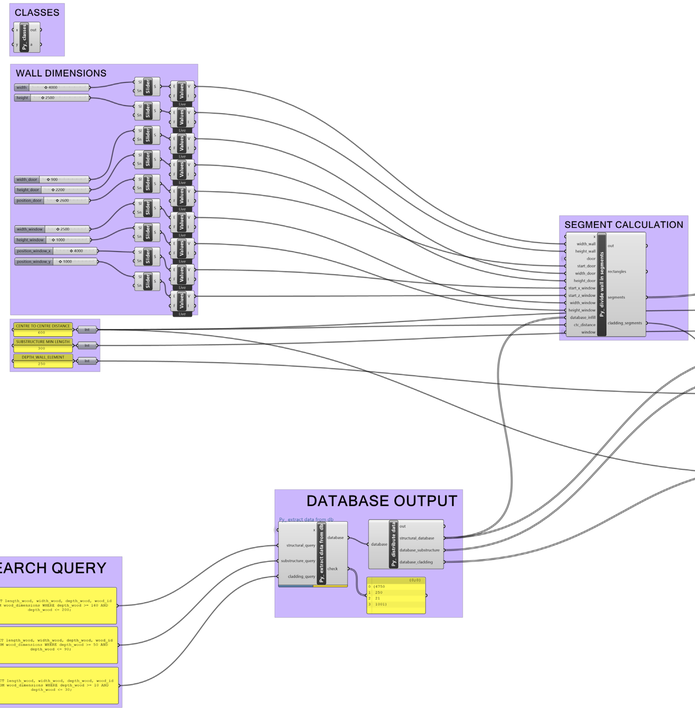
DESIGN ENVIRONMENT



GRASSHOPPER

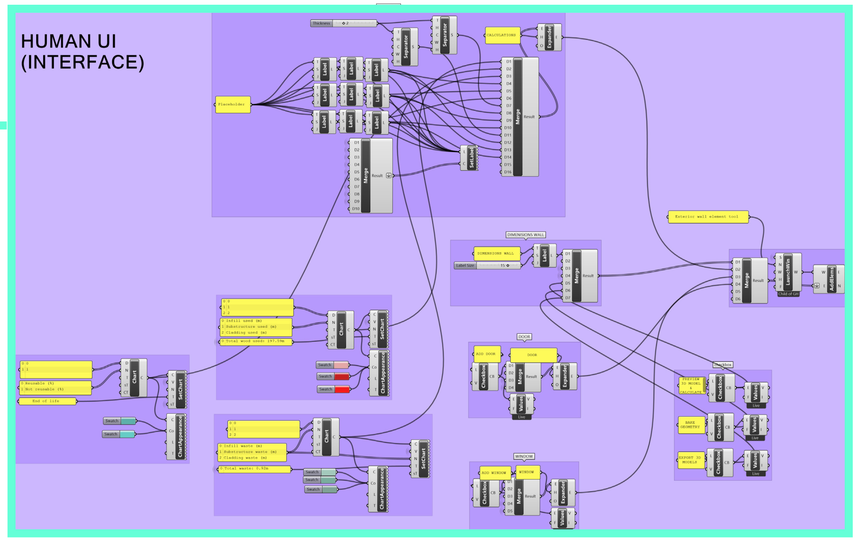






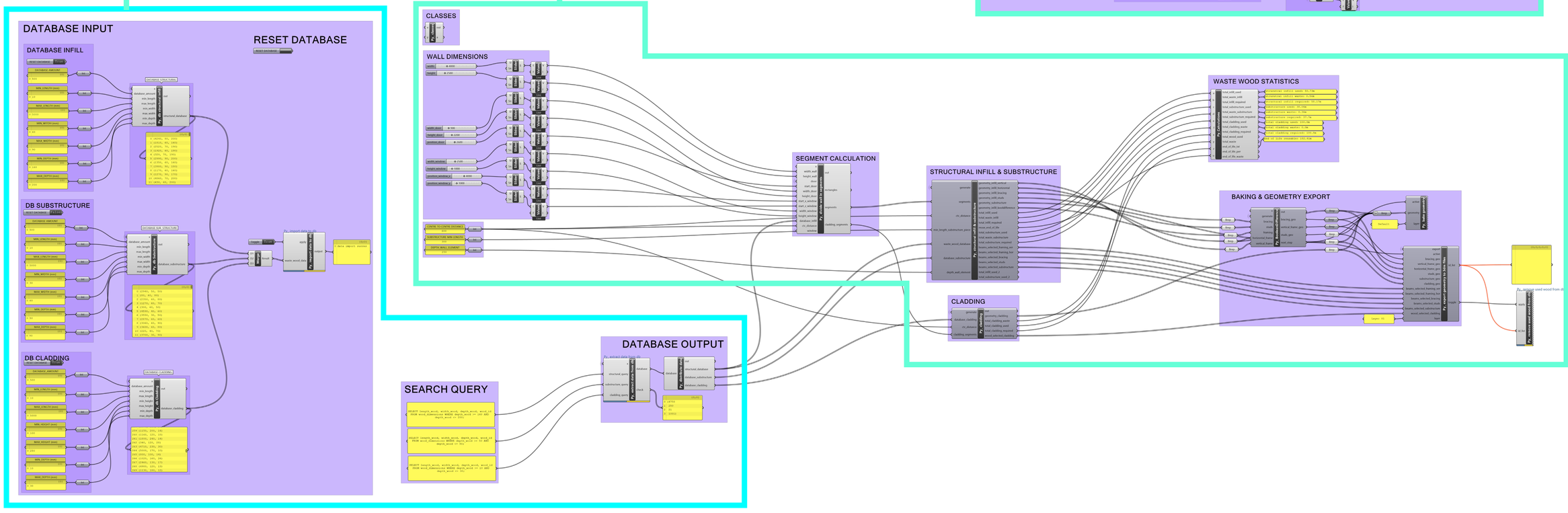
GRASSHOPPER

HUMAN UI

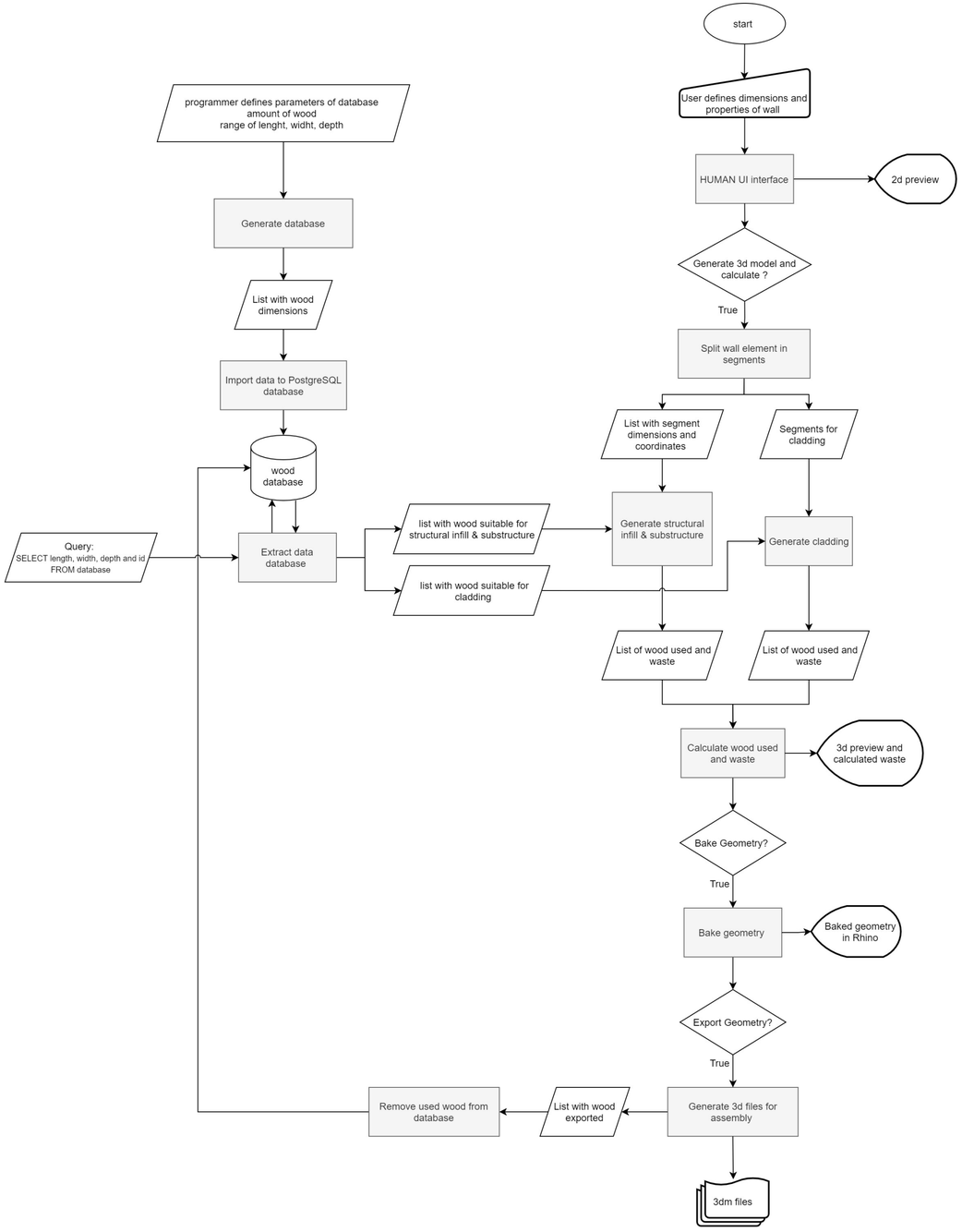


PostgreSQL

python™

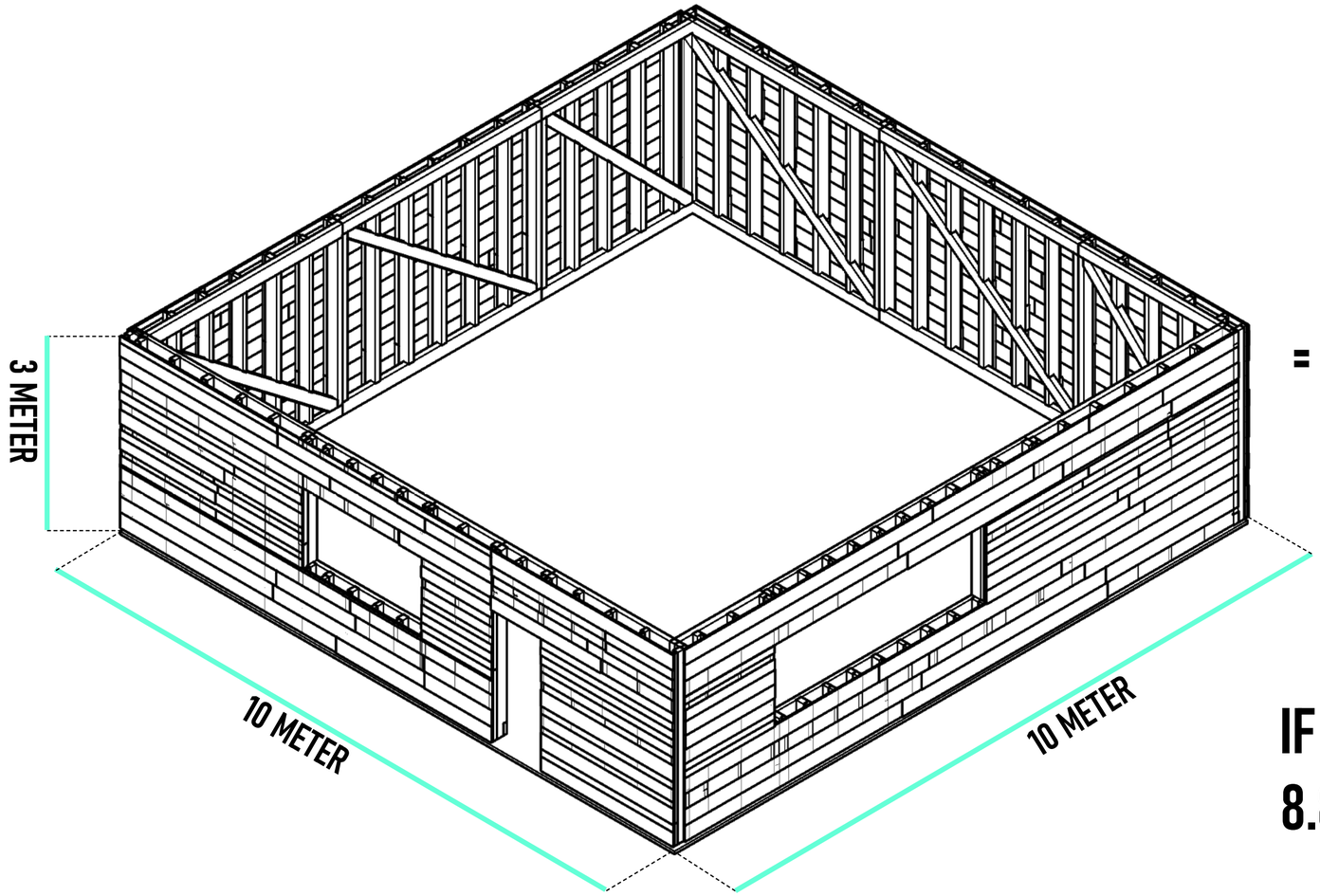


FLOWCHART


start
User defines dimensions and properties of wall
HUMAN UI interface
2d preview
Generate 3d model and calculate ?
True
Split wall element in segments
List with segment dimensions and coordinates
Segments for cladding
programmer defines parameters of database
amount of wood
range of lenght, widht, depth
Generate database
List with wood dimensions
Import data to PostgreSQL database
wood database
Query:
SELECT length, width, depth and id
FROM database
Extract data database
list with wood suitable for structural infill & substructure
list with wood suitable for cladding
Generate structural infill & substructure
Generate cladding
List of wood used and waste
List of wood used and waste
Calculate wood used and waste
3d preview and calculated waste
Bake Geometry?
True
Bake geometry
Baked geometry in Rhino
Export Geometry?
True
Generate 3d files for assembly
List with wood exported
Remove used wood from database
3dm files

VIDEO

CALCULATION

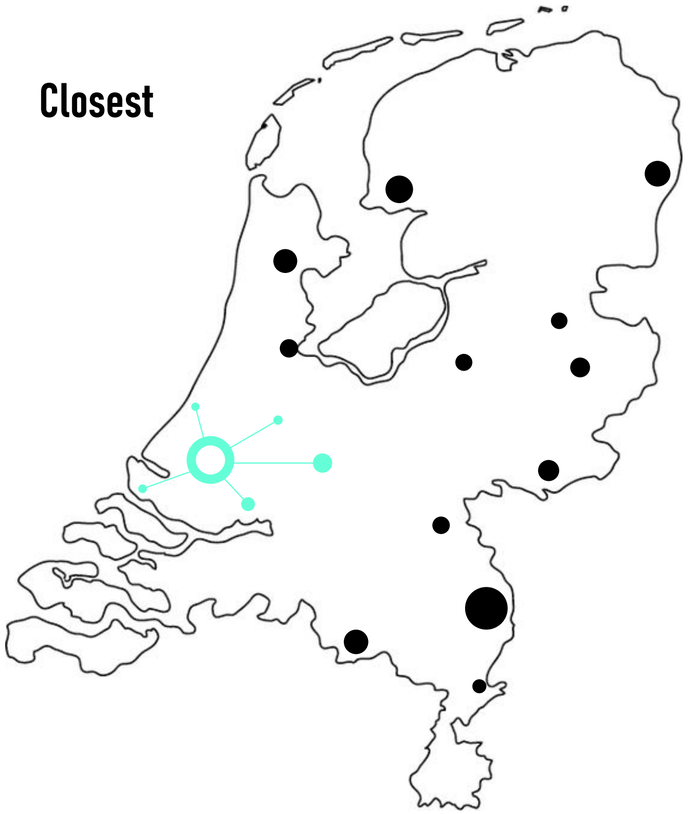


= 120M2 EXTERIOR WALL WHICH WEIGHS 4.192 KG.

IF 10% OF THE SOLID B-WOOD CAN BE REUSED, 8.826 HOUSES CAN BE CONSTRUCTED EVERY YEAR.

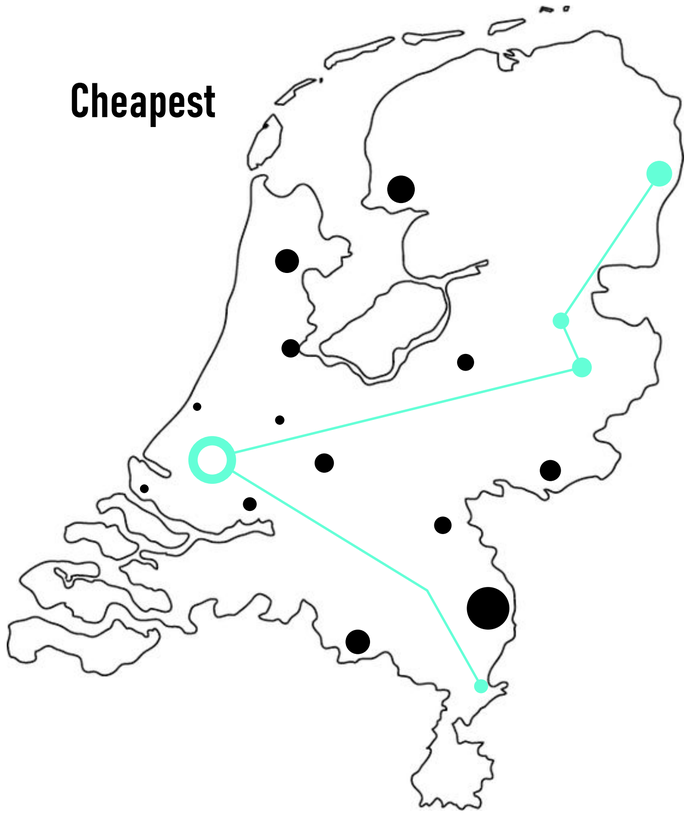
IMPLEMENTATION

Closest



One supplier

Cheapest



CONCLUSION

RIJKSOVERHEID, 2018

Grote bouwcoalitie presenteert actieplan voor 1 miljoen woningen in tien jaar

NOS, 2021

Nog 845 duizend nieuwbouwhuizen te gaan, maar zelfs dat is niet genoeg

VOLKSKRANT, 2020

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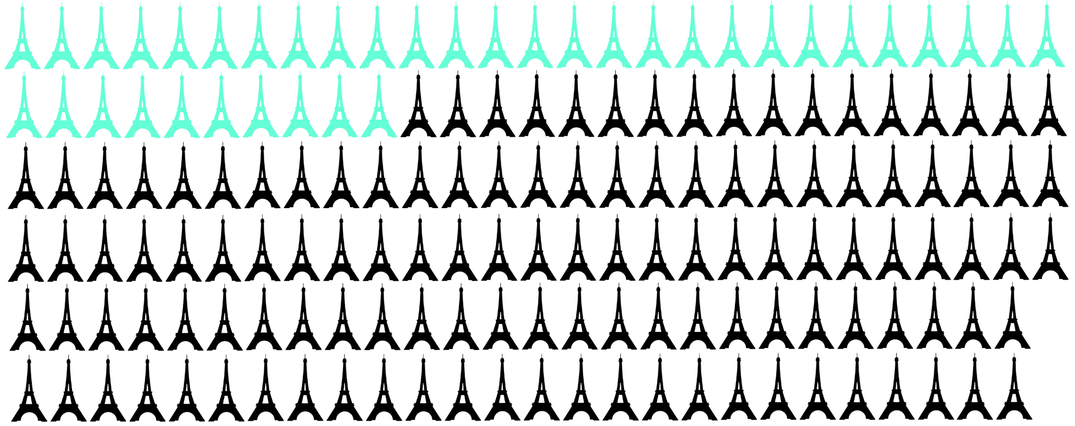

370.000.000 KG HAS THE POTENTIAL TO BE REUSED

SOURCE: TAUW, 2017

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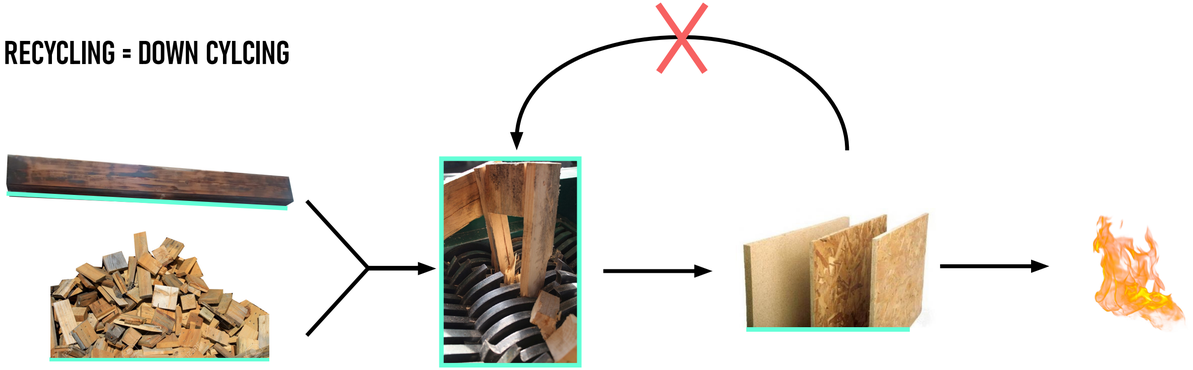
SOURCE: TAUW, 2017

RECYCLING = DOWN CYLCING



SOLID B WOOD | SHREDDING | ENGINEERED BOARDS | INCINERATION

CONCLUSION

RIJKSOVERHEID, 2018

Grote bouwcoalitie presenteert actieplan voor 1 miljoen woningen in tien jaar

NOS, 2021

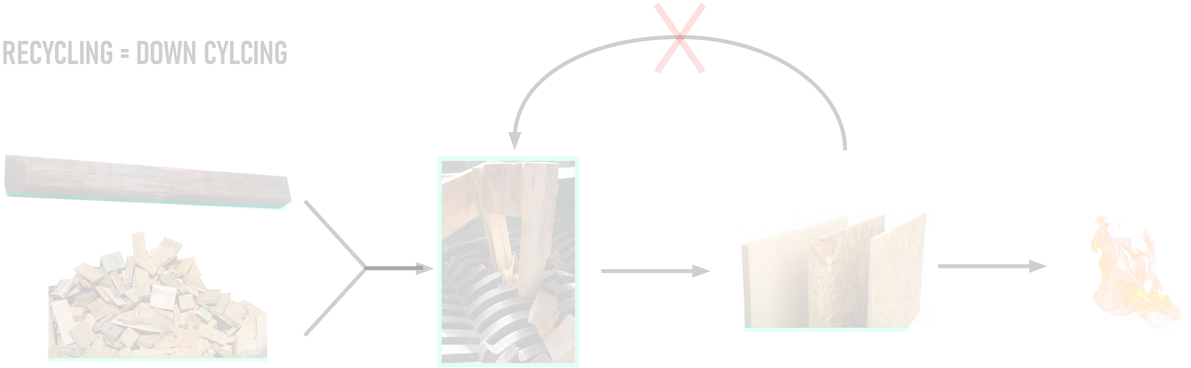
Nog 845 duizend nieuwbouwhuizen te gaan, maar zelfs dat is niet genoeg

VOLKSKRANT, 2020

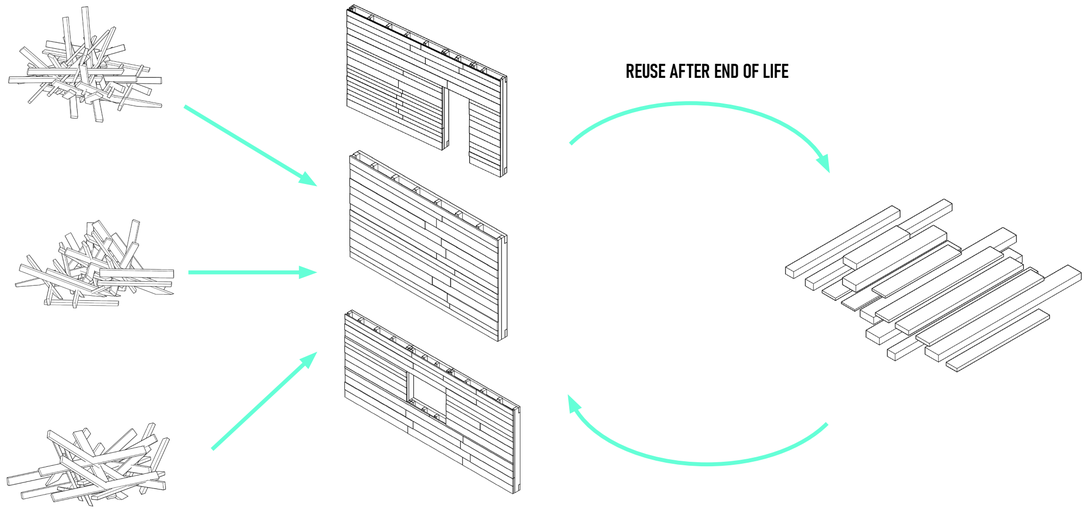
370.000.000 KG HAS THE POTENTIAL TO BE REUSED

SOURCE: TAUW, 2017

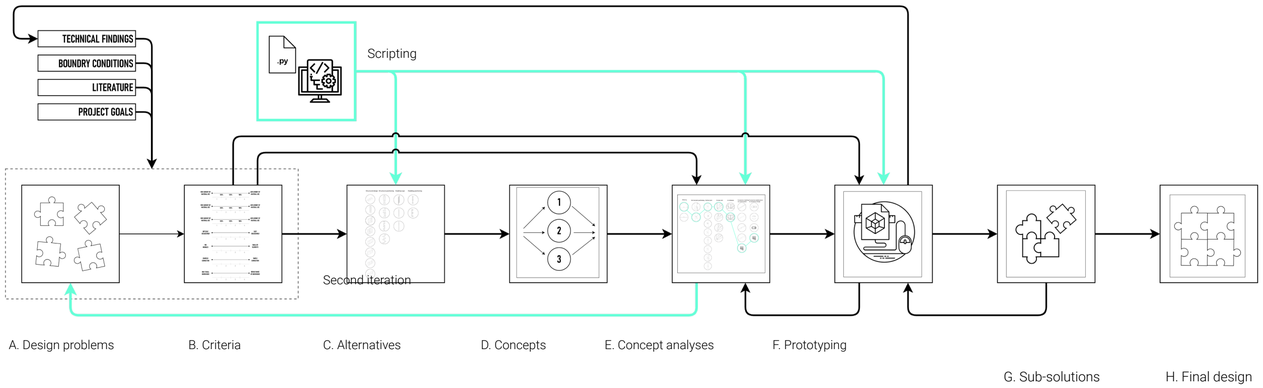
RECYCLING = DOWN CYLCING



SOLID B WOOD | SHREDDING | ENGINEERED BOARDS | INCINERATION



CONCLUSION


TECHNICAL FINDINGS
BOUNDRY CONDITIONS
LITERATURE
PROJECT GOALS
.PY
Scripting
Second iteration
A. Design problems
B. Criteria
C. Alternatives
D. Concepts
E. Concept analyses
F. Prototyping
G. Sub-solutions
H. Final design

CONCLUSION

TECHNICAL FINDINGS
BOUNDRY CONDITIONS
LITERATURE
PROJECT GOALS
.py
Scripting
Second iteration
1
2
3
A. Design problems
B. Criteria
C. Alternatives
D. Concepts
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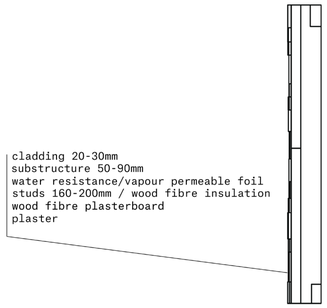
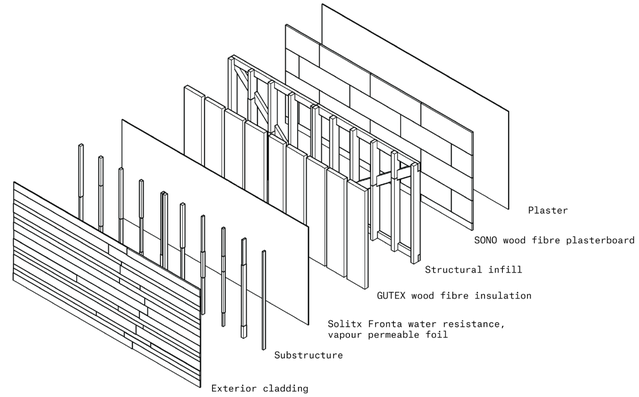
G. Sub-solutions
H. Final design


cladding 20-30mm
substructure 50-90mm
water resistance/vapour permeable foil
studs 160-200mm / wood fibre insulation
wood fibre plasterboard
plaster


Plaster
SONO wood fibre plasterboard
Structural infill
GUTEX wood fibre insulation
Solitx Fronta water resistance,
vapour permeable foil
Substructure
Exterior cladding

CONCLUSION

TECHNICAL FINDINGS
BOUNDRY CONDITIONS
LITERATURE
PROJECT GOALS
.PY
Scripting
1
2
3
Second iteration
A. Design problems
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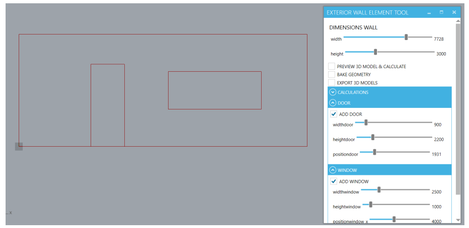
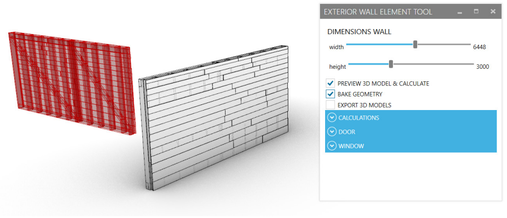
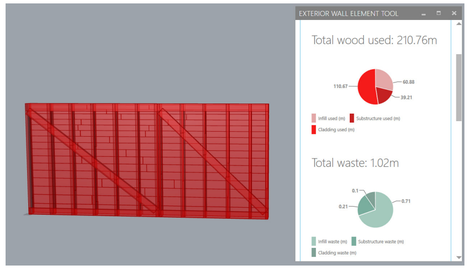
H. Final design

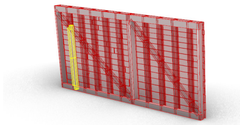
cladding 20-30mm
substructure 50-90mm
water resistance/vapour permeable foil
studs 160-200mm / wood fibre insulation
wood fibre plasterboard
plaster
Plaster
SONO wood fibre plasterboard
Structural infill
GUTEX wood fibre insulation
Solitx Fronta water resistance, vapour permeable foil
Substructure
Exterior cladding

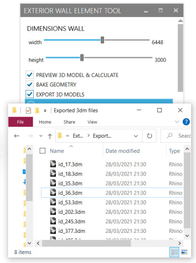

EXTERIOR WALL ELEMENT TOOL
DIMENSIONS WALL
width
height
PREVIEW 3D MODEL & CALCULATE
BAKE GEOMETRY
EXPORT 3D MODELS
CALCULATIONS
DOOR
WINDOW

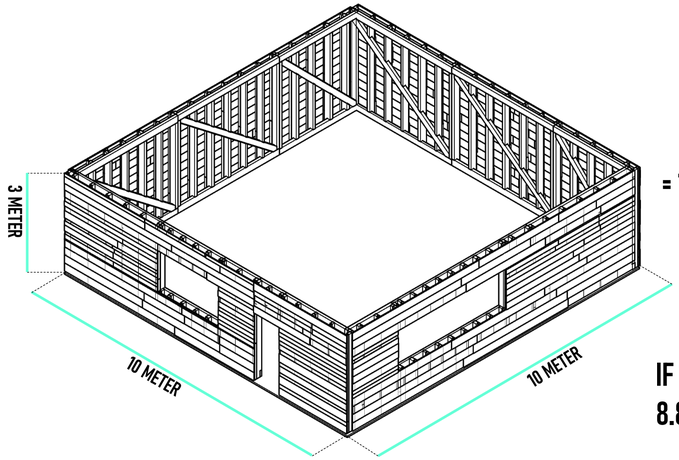


EXTERIOR WALL ELEMENT TOOL
DIMENSIONS WALL
width
6448
height
3000
PREVIEW 3D MODEL & CALCULATE
BAKE GEOMETRY
EXPORT 3D MODELS
CALCULATIONS
DOOR
WINDOW


EXTERIOR WALL ELEMENT TOOL
Total wood used: 210.76m
Total waste: 1.02m



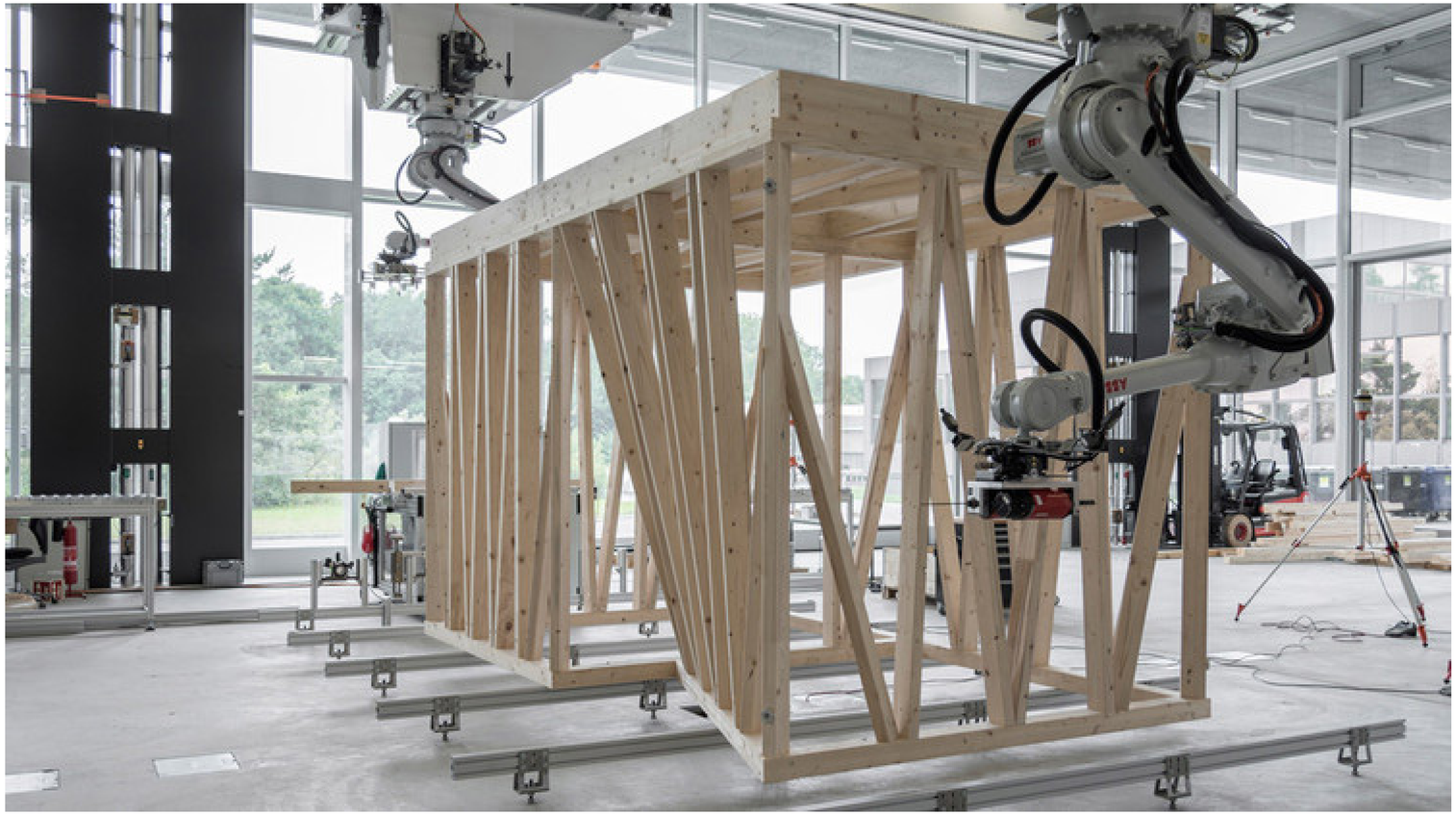

EXTERIOR WALL ELEMENT TOOL
DIMENSIONS WALL
width
6448
height
3000
PREVIEW 3D MODEL & CALCULATE
BAKE GEOMETRY
EXPORT 3D MODELS
Exported 3dm files
File
Home
Share
View
Name
Date modified
Type
id_17.3dm
id_18.3dm
id_35.3dm
id_36.3dm
id_53.3dm
id_202.3dm
id_245.3dm
id_377.3dm
8 items



= 120M2 EXTERIOR WALL WHICH WEIGHS 4.192 KG.

IF 10% OF THE SOLID B-WOOD CAN BE REUSED,
8.826 HOUSES CAN BE CONSTRUCTED EVERY YEAR.

RECOMMENDATION



ETH, ZURICH

FOCUS ON FACADE DESIGN

ROBOTIC ASSEMBLY

QUESTIONS?