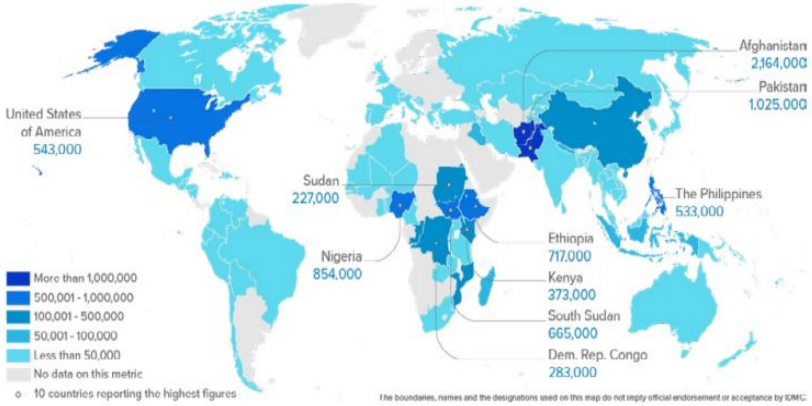
HOMECRAFT

Making shelter design and construction accessible
to non-experts through CNC-aided design and Makerspaces.

Master Thesis P5 - Elisa van Klink

Contents

Many people are in need of shelter

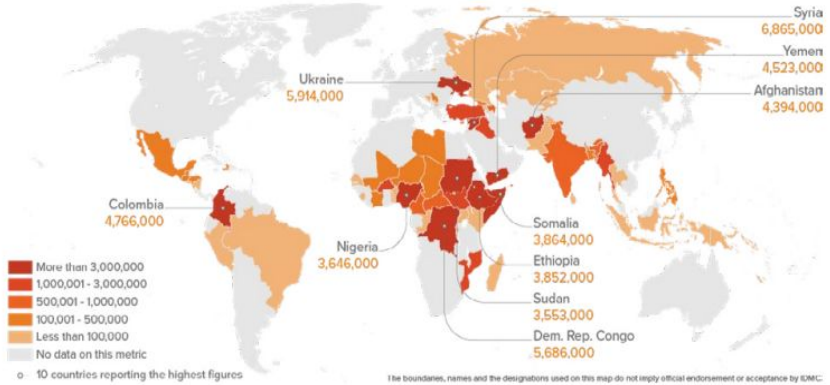


8.7 million

Internally displaced people as a result of disasters in 88 countries and territories as of 31 December 2022

45%

Increase in the number of people internally displaced by disasters since 2021



62.5 million

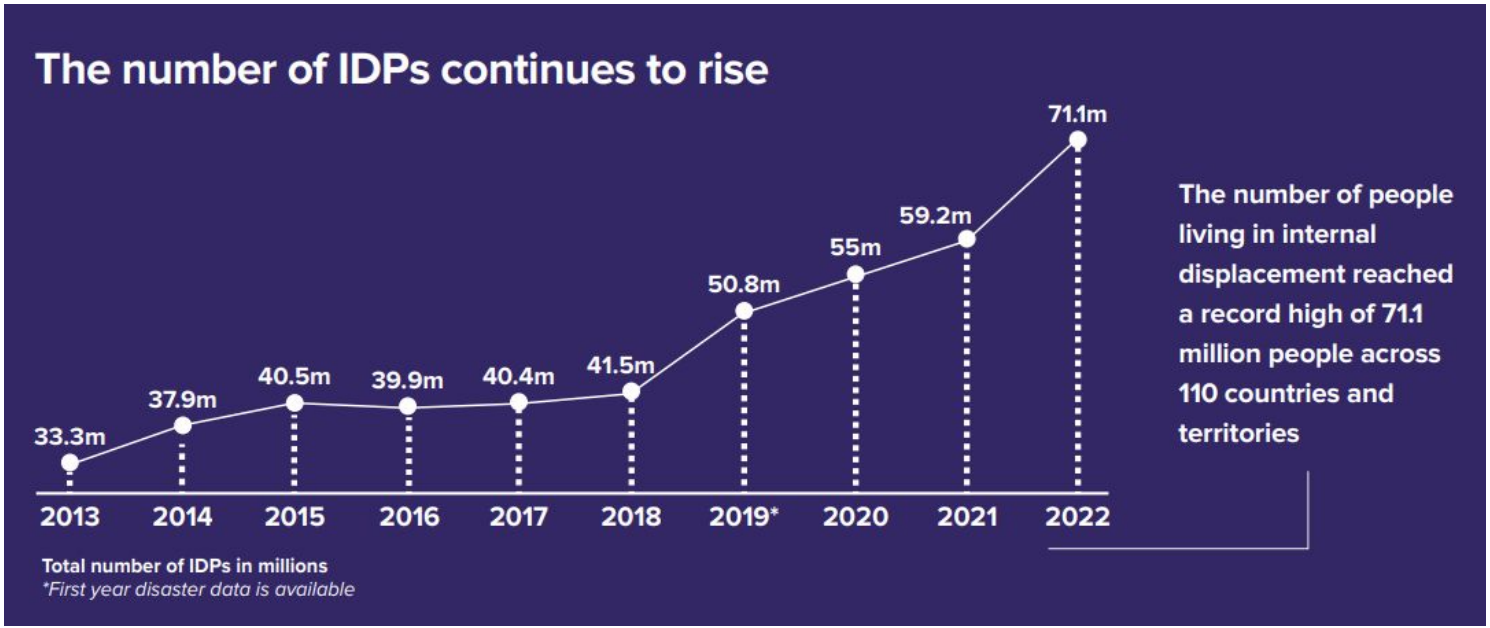
Internally displaced people as a result of conflict and violence in 65 countries and territories as of 31 December 2022

17%

Increase in the number of people internally displaced by conflict and violence since 2021

IDMC. (2023)

The numbers keep rising



IDMC. (2023)

So how do we decrease this number?

Erdelj et al. (2017) and Wikipedia contributors (2024)

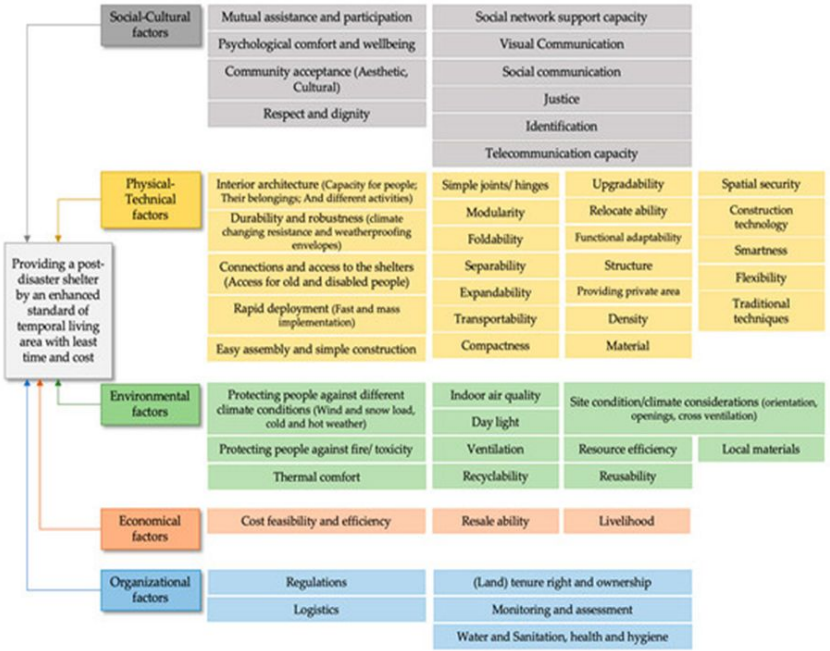
What is a proper ‘shelter’?

“...more than four walls and a roof.”
- Sphere

A complex process

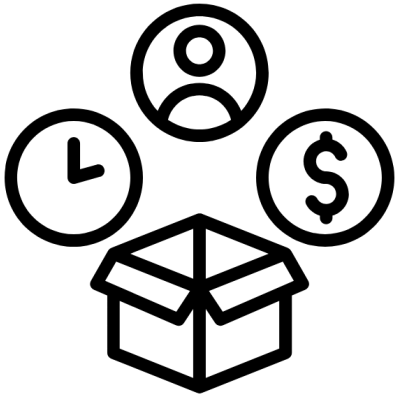
Key design points:

- Design with the community
- Minimize risk
- Design for climate
- Building materials
- Construction

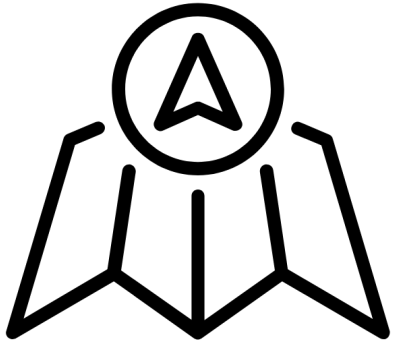


Karimi et al. (2023)

Challenges in shelter design



Limited resources



Remote/ hard to reach areas

What are the implications?

A focus on:

Transportability, costs and speed of construction

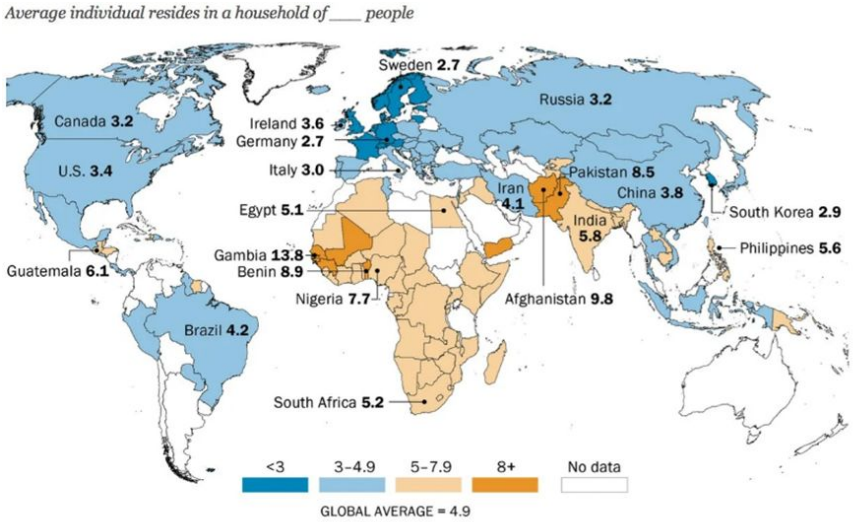
Over the costs of:

Habitability, sustainability, social-cultural, and environmental needs

Social cultural inadequacy: Lack of area

"At least 70% had built an extension or enclosed the space between their caravan units creating shaded makeshift courtyards."

- Albadra et al. (2018)



PEW (2019)

Social cultural inadequacy: Lack of privacy

Collective shelters in Myanmar

Environmental and economical sustainability

- Transport, costs and locality or globallity of materials
- Recyclability and sustainability
- Indoor environment

Transport costs and locality or globality of materials

Kenya-Dadaab 2009 core shelter

Indonesia-Aceh 2004 traditional home (left) vs newer shelter (right)

UN-Habitat (2021), Sahputra et al. (2023) and Ashmore et al. (2008)

Recyclability and sustainability

Jordan 2013 T-shelters

- Carbon intensive materials
- No end of life strategy

“Once they reach the end of their lives, these materials often end up as waste.”

- Montalbano and Santi (2023)

Poor indoor environment

- To hot in the summer, to cold in the winter
- Too noisy

Lack of long-term viability

"In post-disaster and post-conflict (PDPC) situations, it usually takes two to fifteen years to resolve land rights."
- Alshawawreh et al. (2020)

People after Pohang earthquake in a gymnasium

Korea JoongAng Daily (2017)

Standardization

"No single design is suitable for all responses."

- IFRC & RCS (2013)

UNHCR
RHU (Refugee housing unit)

UNHCR (2016)

What happens when shelter is not adequate?

People take matters into their own hands

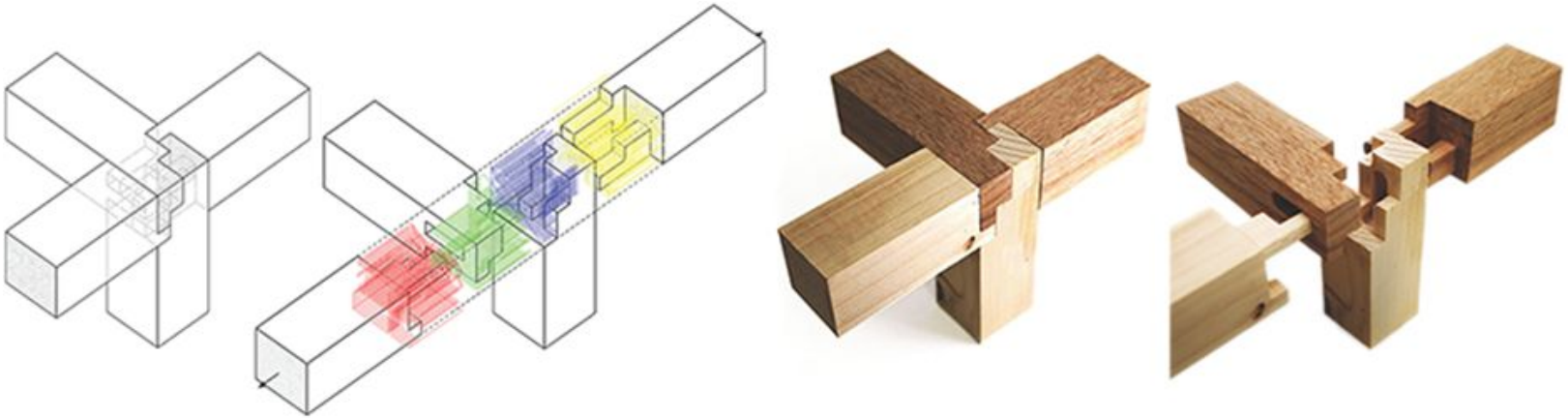
- Aceh
- Canaan

Ashmore et al. (2008) and Ott (2016)

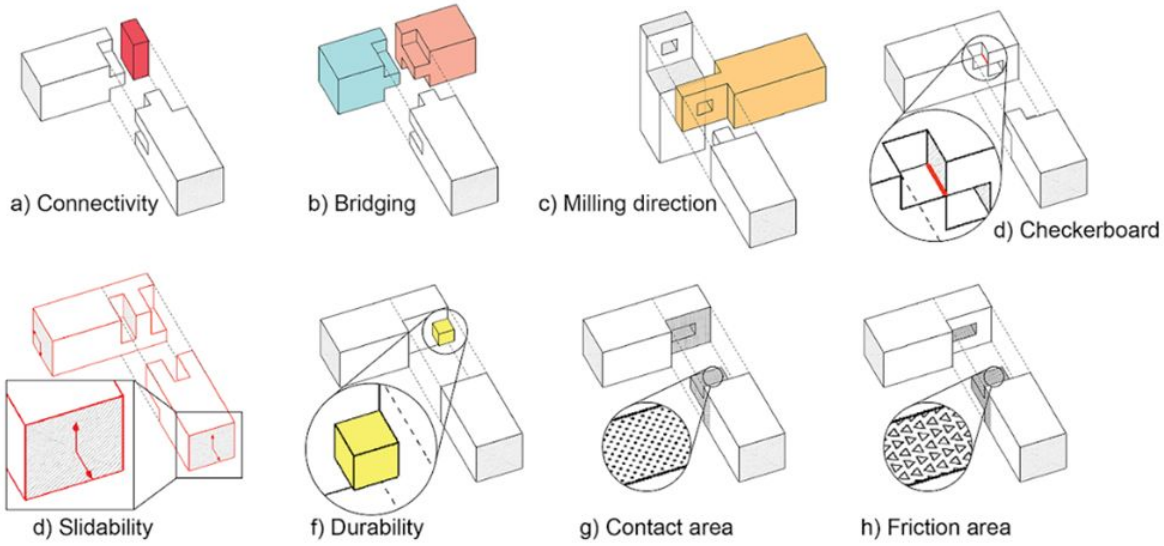
I say let them (with a bit of guidance)

Can we create an environment that empowers the community to build their own shelter without the need of experts?

Technological participatory solutions

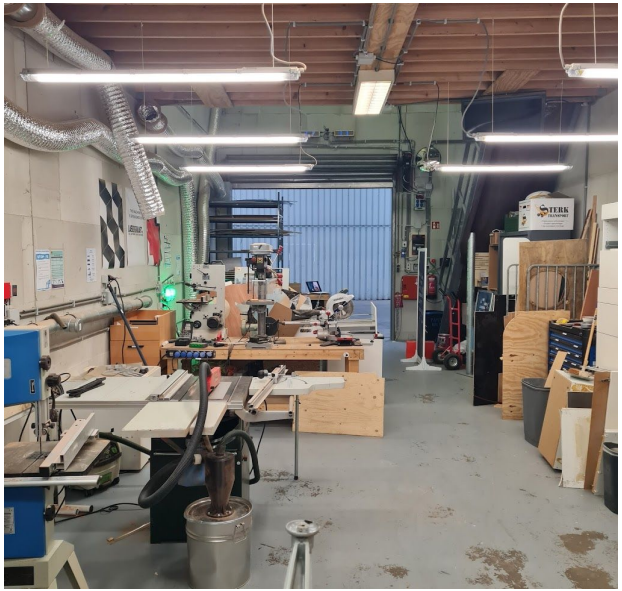


Technological participatory solutions



. Larsson et al. (2020)

The role of Makerspaces



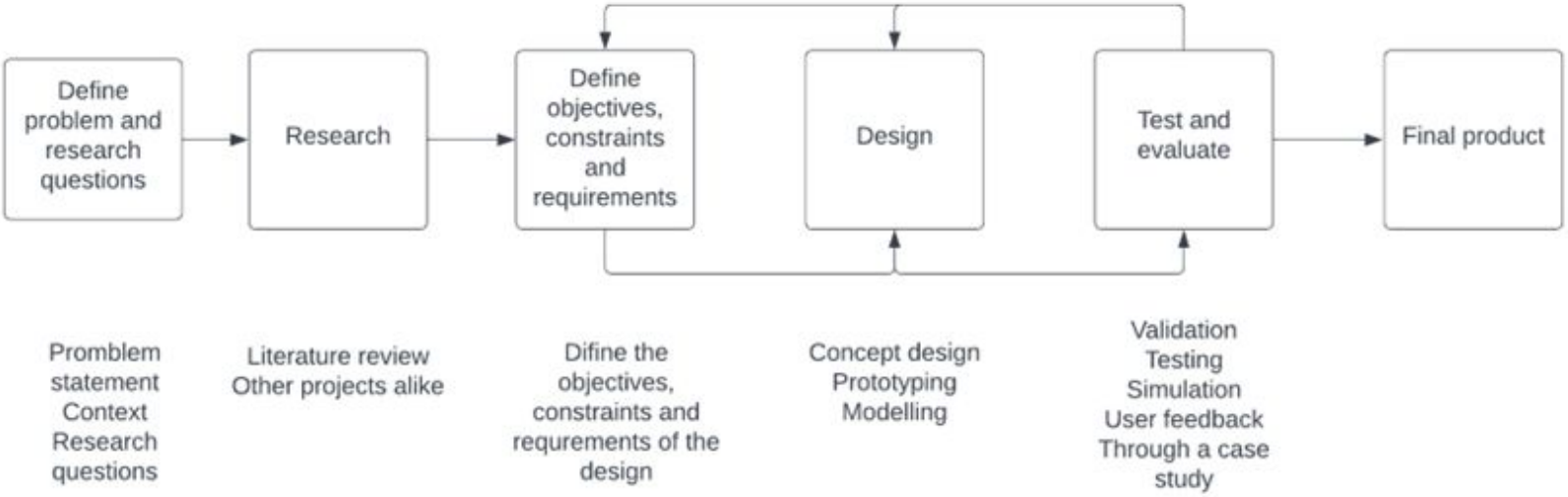
Main research question

How can CNC-routing and computational tools facilitate the design and local production of customizable wood-based shelters by non-experts in post-disaster contexts?

Scope and focus

- 3 axis CNC routing
- Single (at max. or two story) buildings
- Eurocode 5
- Rigid joints
- Cases: Türkiye - Istanbul, The Netherlands - Delft

Methodology



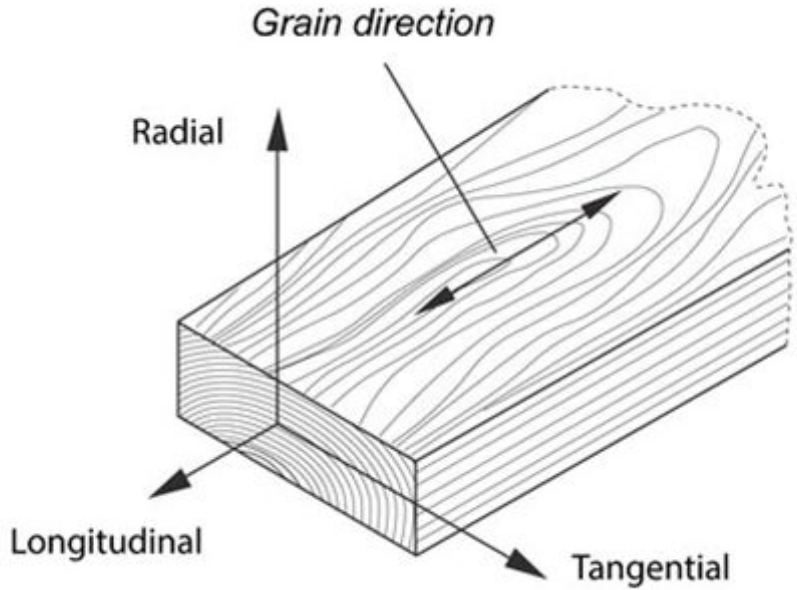
Research framework

Literature study

- Temporary shelter design (standards regulations, types, prior research etc.)
- Structural timber design in the context of CNC

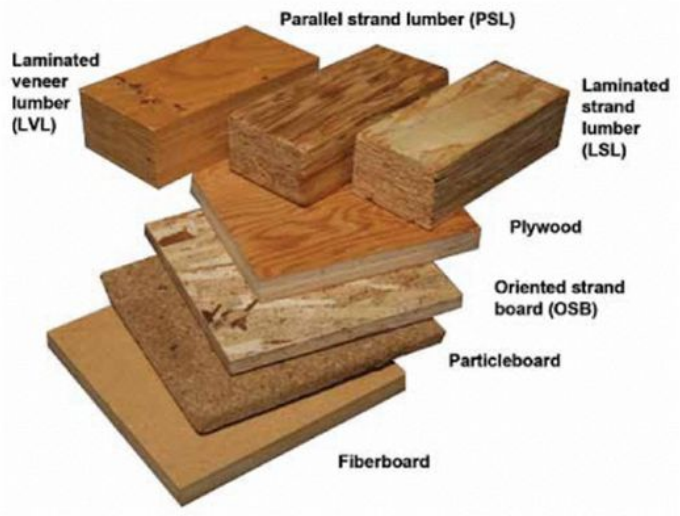
Structural design in timber

- Anisotropic
- Moisture
- Creep



Fragkia and Foged (2020)

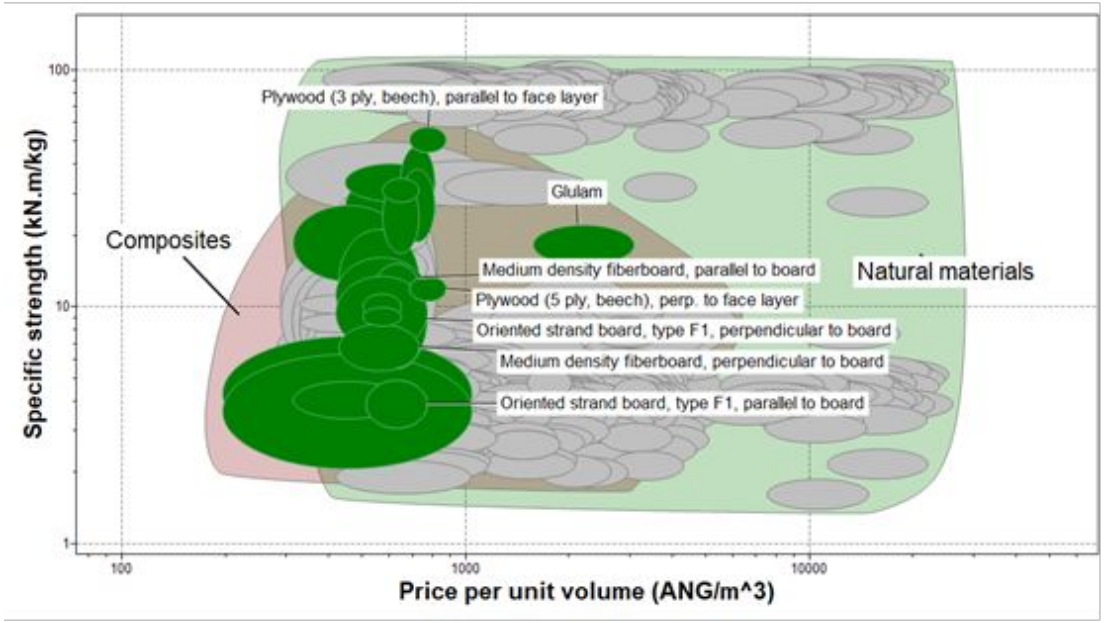
Engineered timber products



Timber Elements \ Fibre Orientation	Parallel	Perpendicular	Random
Boards	Glulam	CLT	
Thin veneers	LVL	Plywood	
Particles & chopped fibres			OSB, Particle board

USDA (2021), Overend (2022)

Price vs strength



Interlocking joinery: Traditional joints

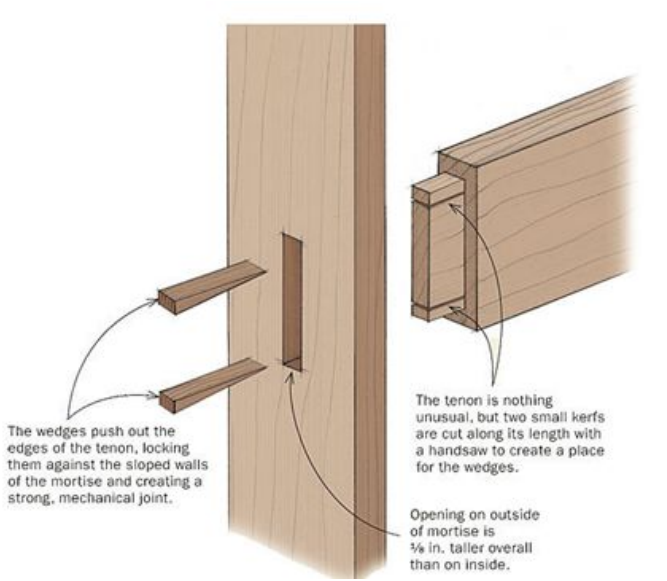
Mortise and tenon

Scarf

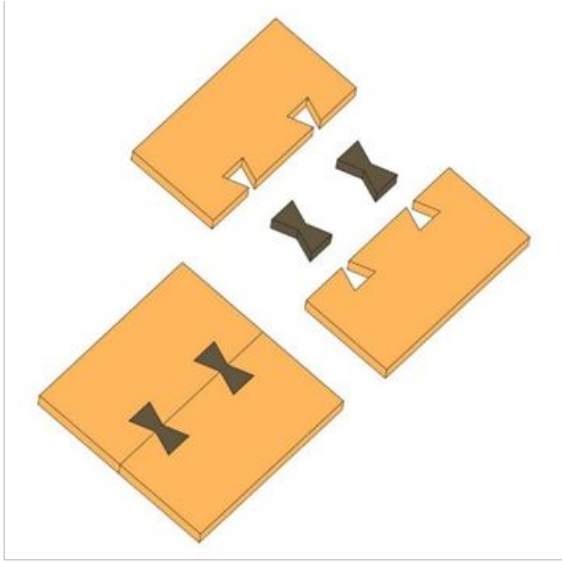
Dovetail

WOOD (2021), Keller (2x, 2024)

Interlocking joinery: With an extra step



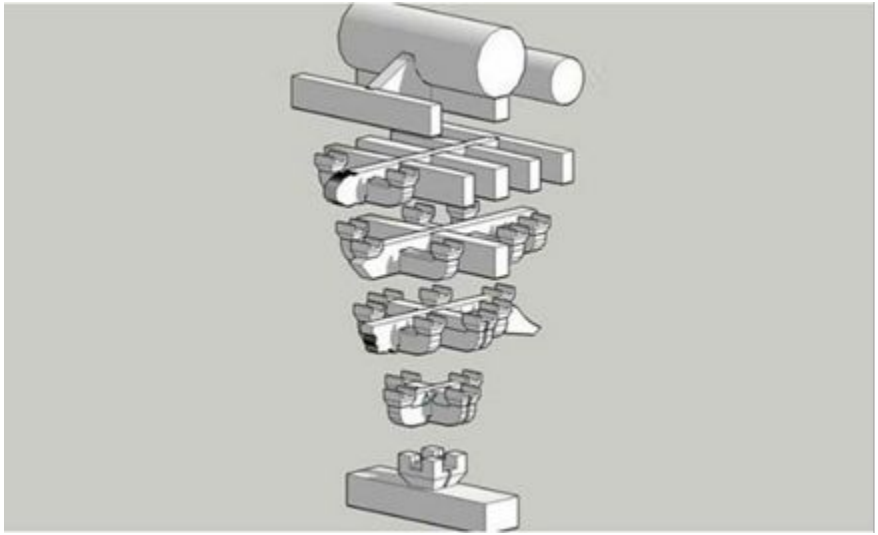
Wedged joint



Key joint

Becksvoort (2012), Craftmanspace (2024)

Interlocking joinery: With many more steps

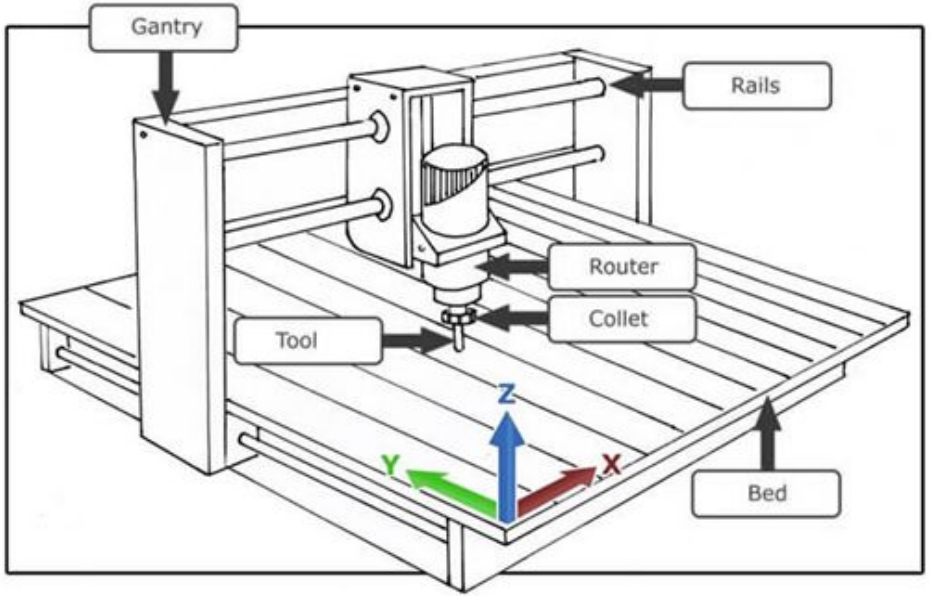


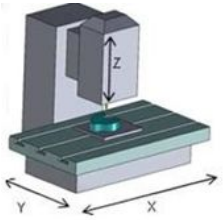
Dougong joint

Dougong joint in a temple

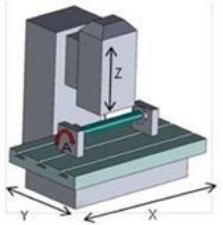
Noe (2017)

CNC (computer numerical control)

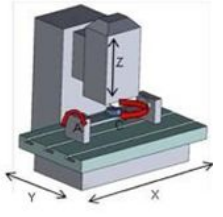




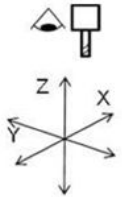
3-Axis



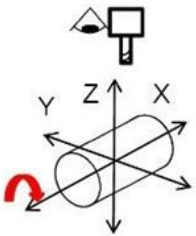
4-Axis



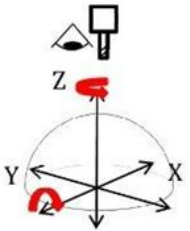
5-Axis



Cartesian
3-Axis



Cylindrical
4-Axis



Hemispherical
5-Axis

Literature study

Claire (2024), Stevens (2024)

CNC-routing vs -milling

CNC-router

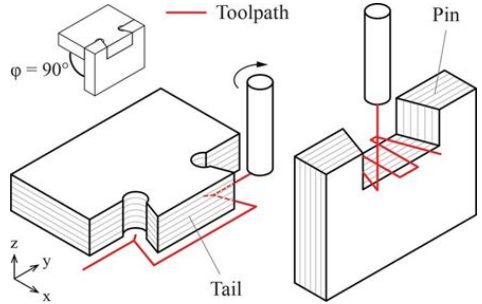
CNC-mill

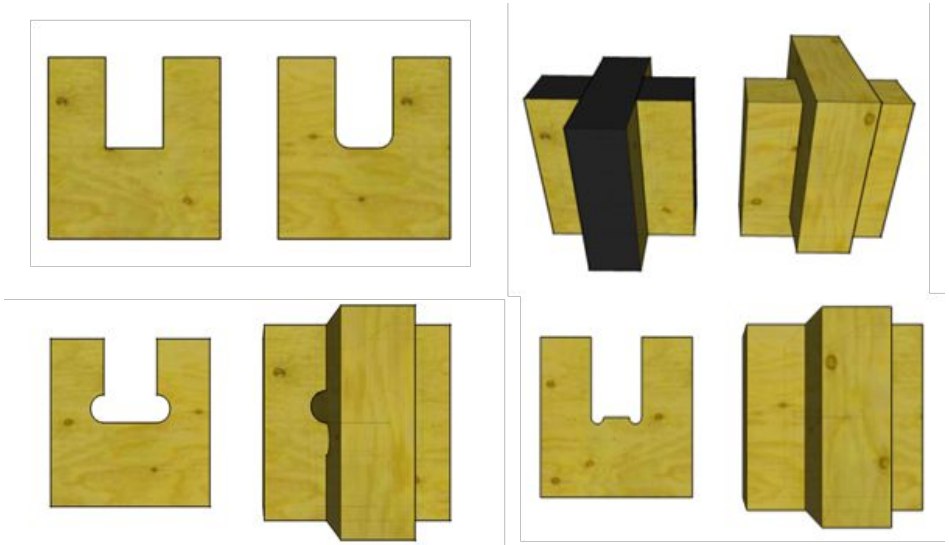
Literature study

Raptor Technologies (2021), Pedregosa (2022)

Key design considerations with CNC

- Machinery
- Toolpath
- Nesting
- Material behaviour





Robeller and Weinand (2016) and Ragan (2014)

Example projects

Literature study

Pieter stoutjesdijk (2012) IMBY (2023)
WikiHouseNL (2024), WikiHouse (2024)

Main pros and cons

Pros:

- Easy and quick assembly
- Passive climate design
- Digital platform
- Sustainable materials

Cons:

- Expensive
- Not upgradable/ extendable

Context: Delft Netherlands vs Istanbul Türkiye

Concept design

Google Maps (2024)

Context: Delft Netherlands vs Istanbul Türkiye

- Climate: Maritime
- Terrain: Open flat river delta
- Main challenges: Flooding, wind, humidity
- Social cultural: Compact living, small households, open
- Resources:Mostly import, machinery and techniques available, high disposable income
- Urban context: Residential, family housing, gallery flats, apartments formal, open streets

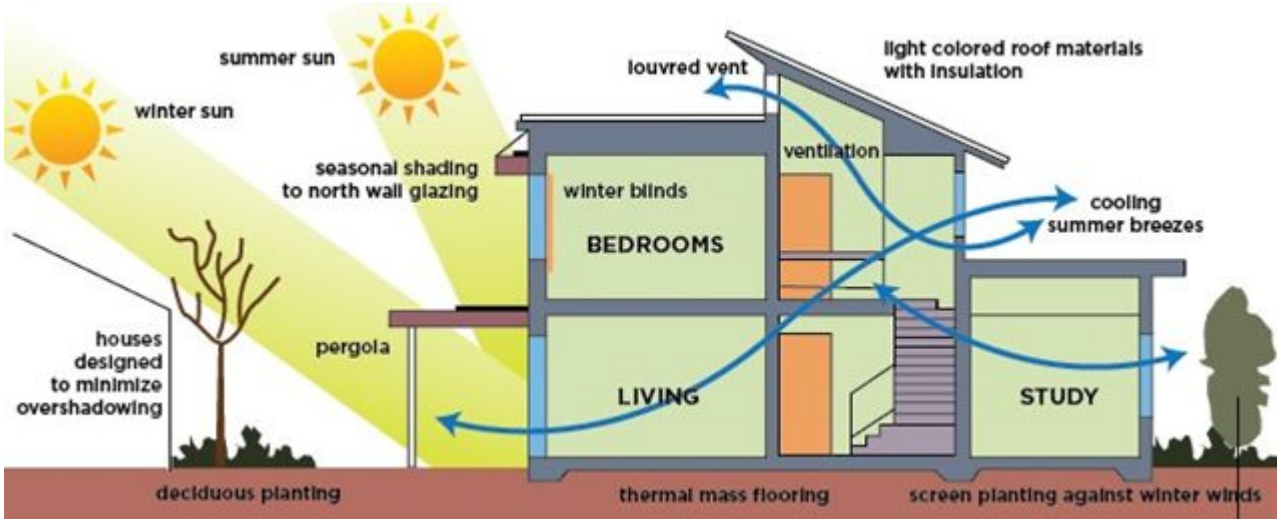
- Climate: Mediterranean
- Terrain: Hilly
- Main challenges: Seismic activity, floods, landslides, wind, humidity
- Social cultural: Gender separation, privacy, religion
- Resources:A lot of production but PLY and OSB mostly imported, machinery and techniques not really available, low disposable income
- Urban context:
  Residential, mid to high rise, closely knit

Google Maps (2024)

Context: Design implications - wind, rain and snow

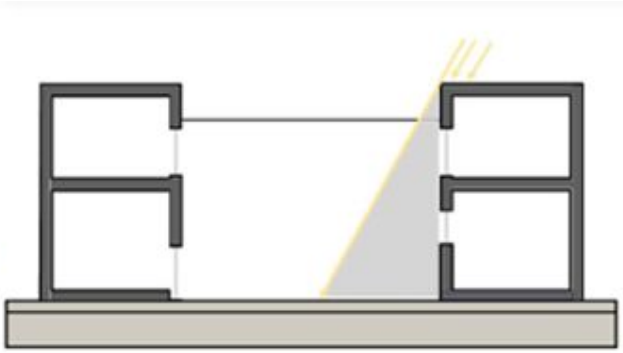
Google Maps (2024)

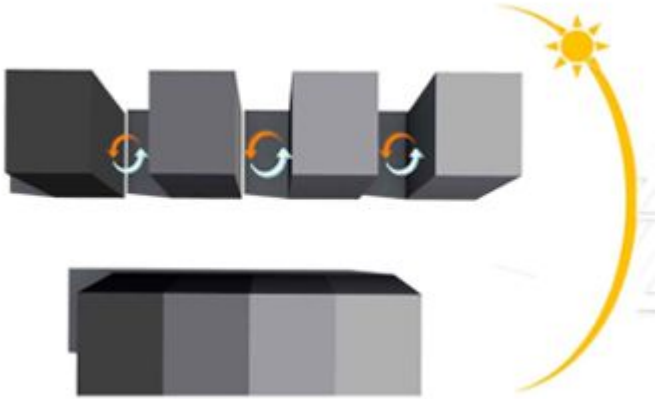
Context: Design implications - Passive design



Google Maps (2024)

Context: Design implications - Urban context



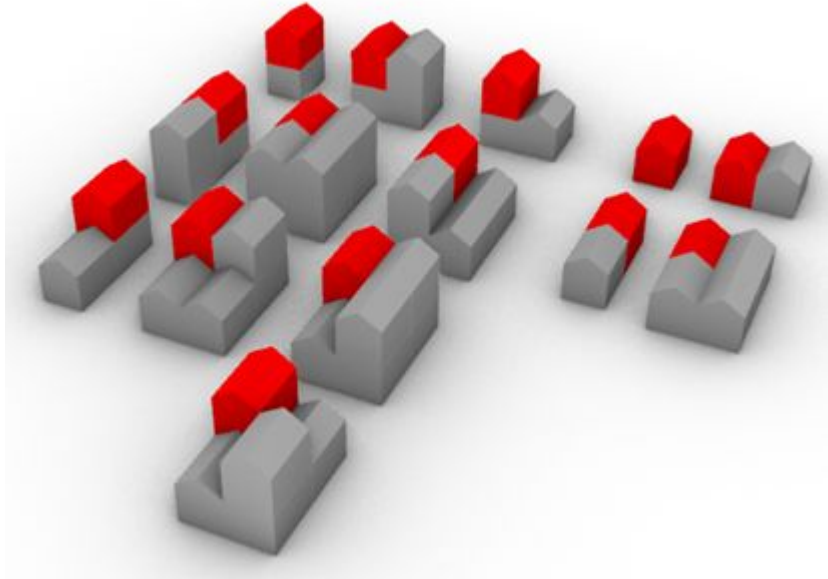


Google Maps (2024)

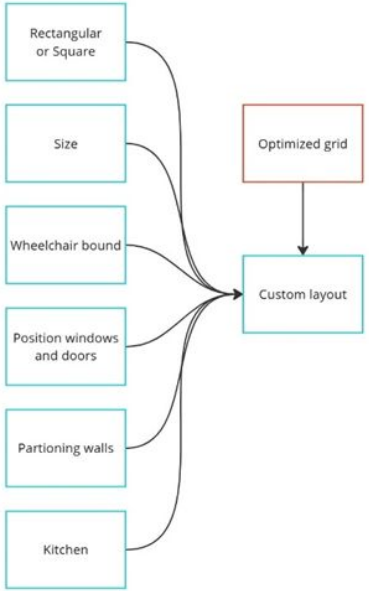
Key design requirements

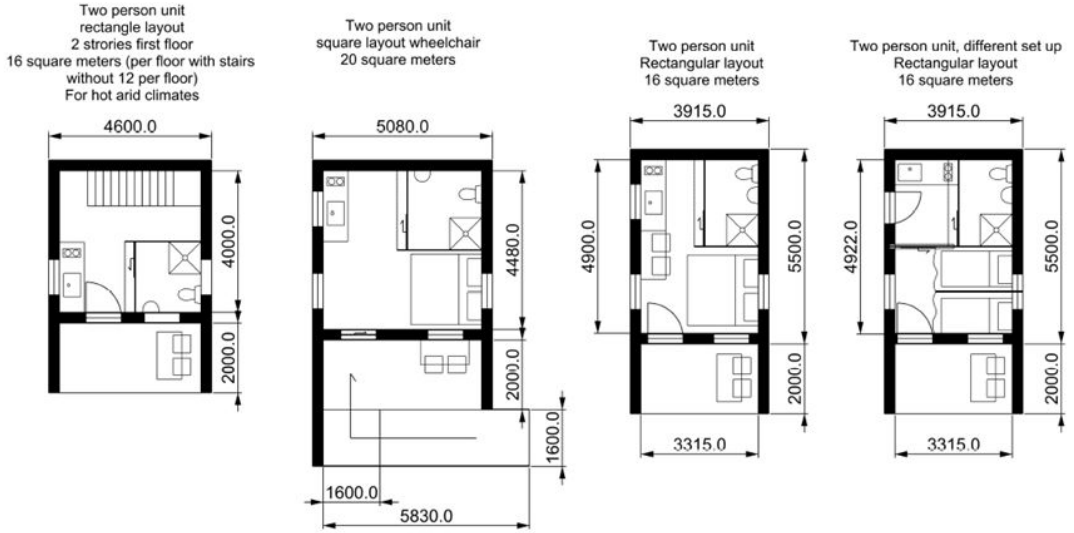
- Modular and expandable design
- Structural Materials: Plywood or OSB (type and species based on what is available)
- Customizable Layouts
- Sustainability and local adaptability (climate)
- Ease of assembly and production
- Structural stability according to Eurocode 5
- Natural ventilation and daylight.
- Low costs and material use (as low as possible)
- Thermal Performance: Insulation materials can be added to walls and roofs to enhance thermal comfort, particularly in extreme climates.
- Cultural and aesthetic Flexibility: fitting with the community.

Concept: Geometry, modularity and expandability

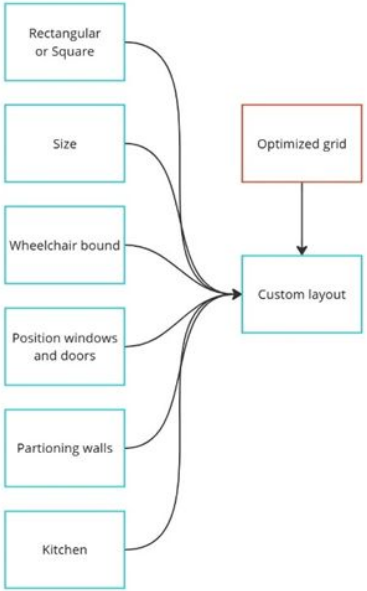


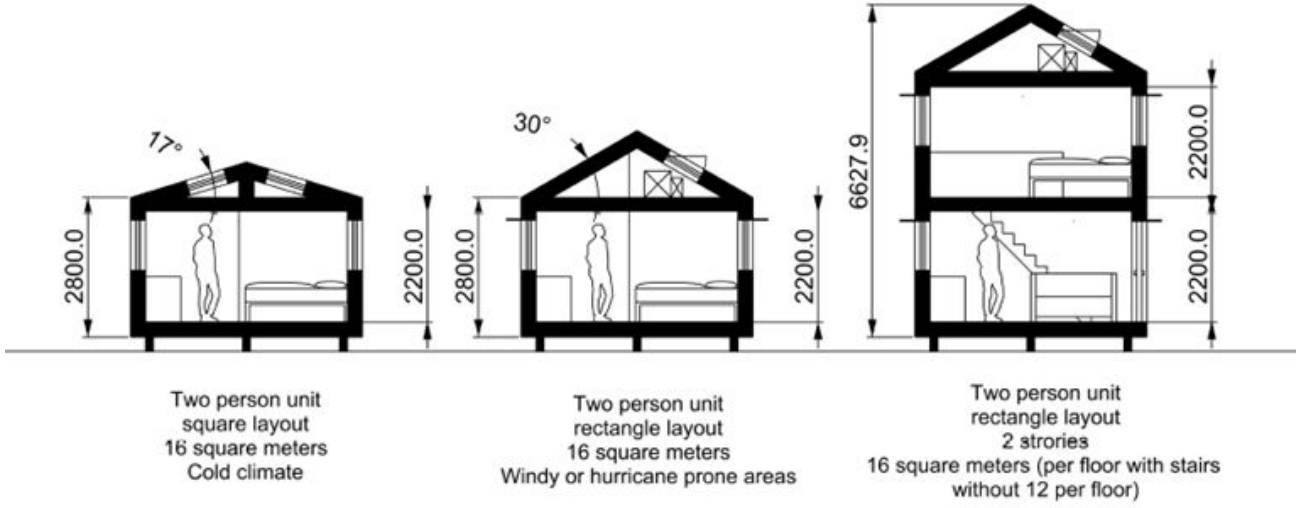
Concept: Custom layout



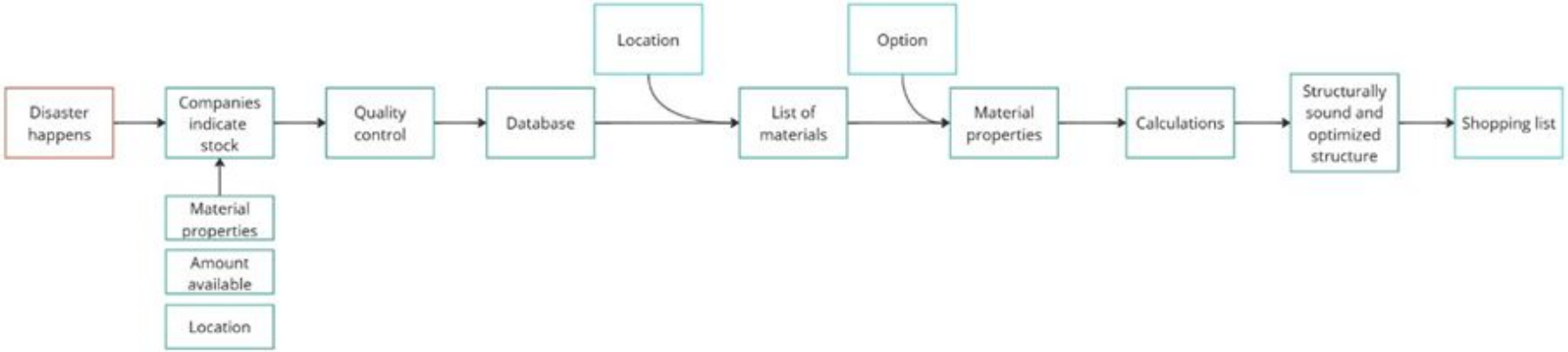


Concept: Custom layout

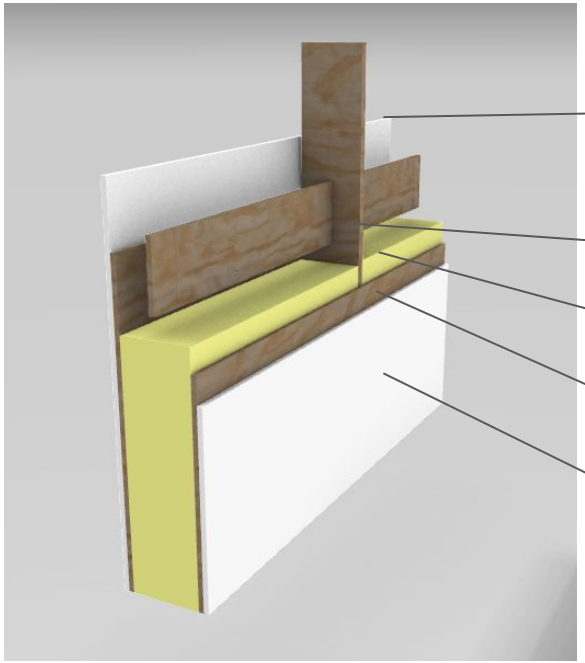




Concept: Materiality



Concept: Materiality - template



Outside finishing layer

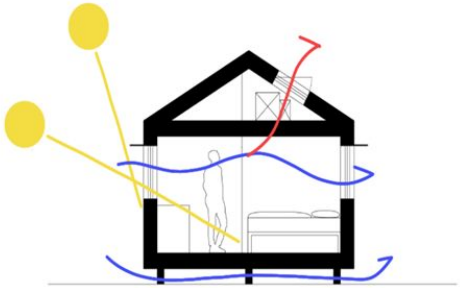
Structural frame
(main and secondary)

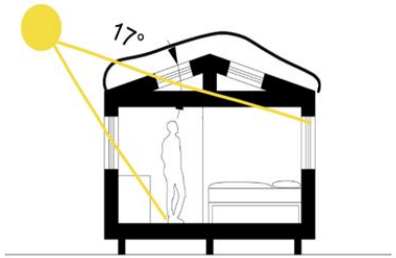
Insultation

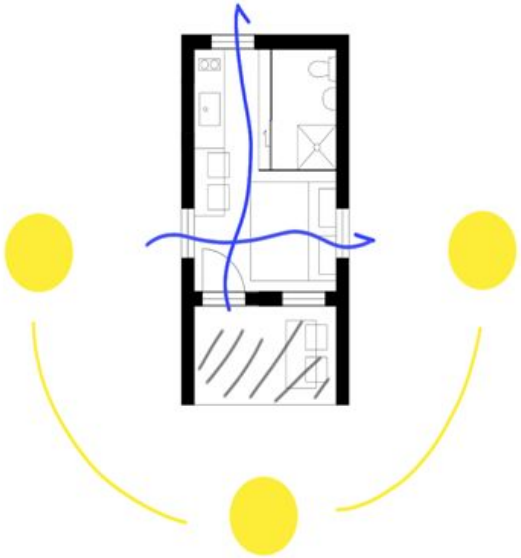
Structural sheets

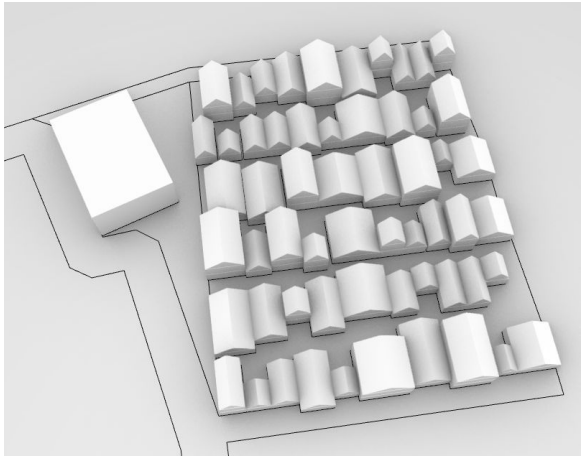
Inside finishing layer

Climate

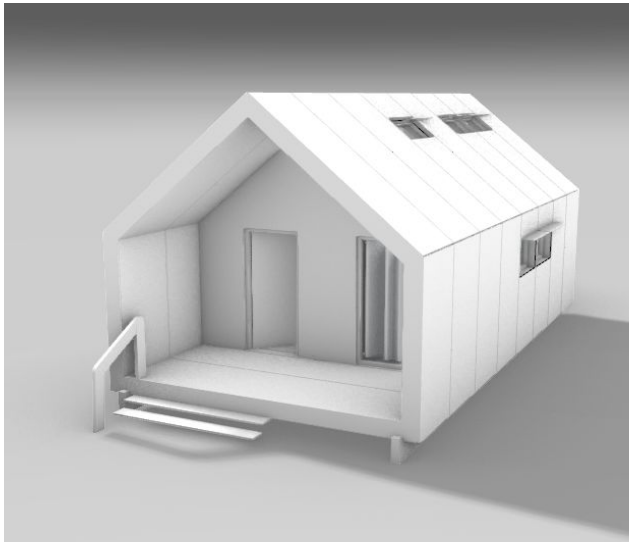


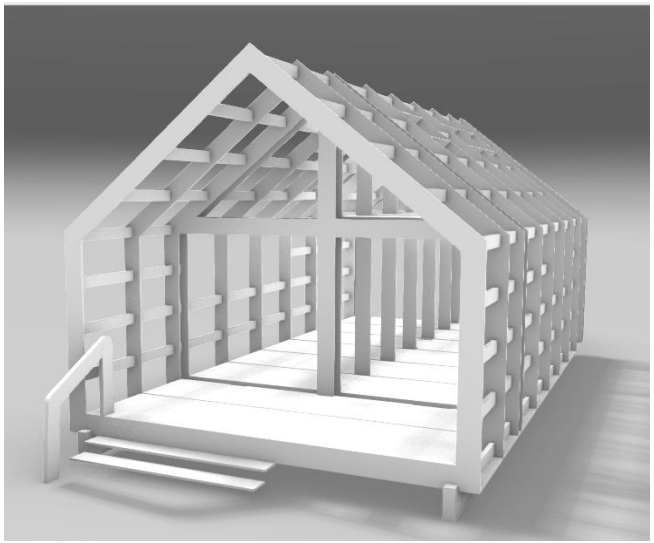






Results





Four person unit rectangular layout (4 by 8m)

The options are endless

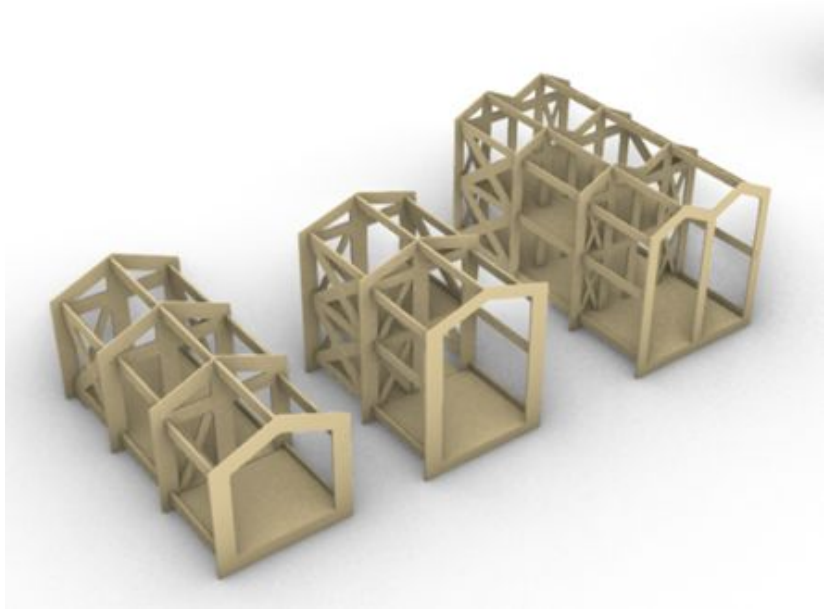
Multiple options even in the same layout

Enjoy the renders :D

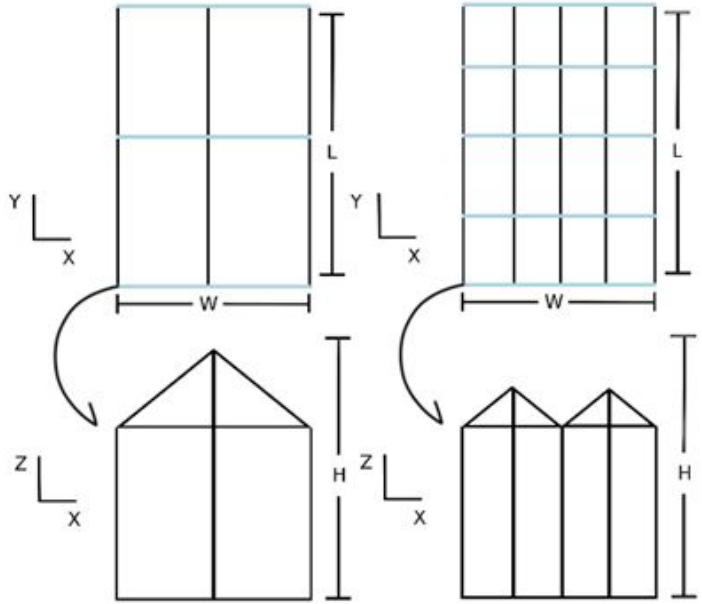




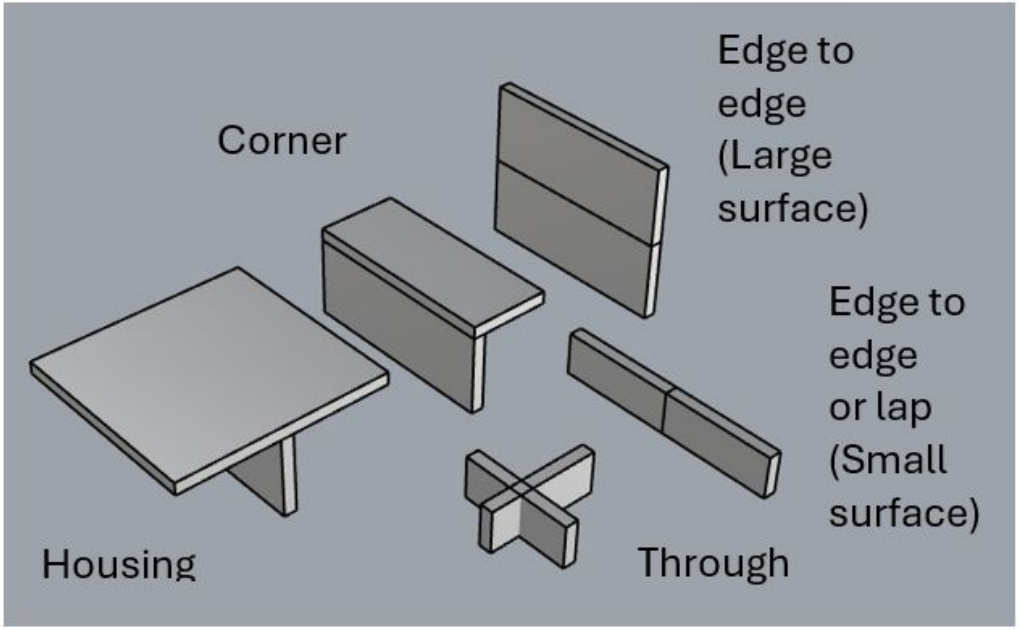
Principles of structural design



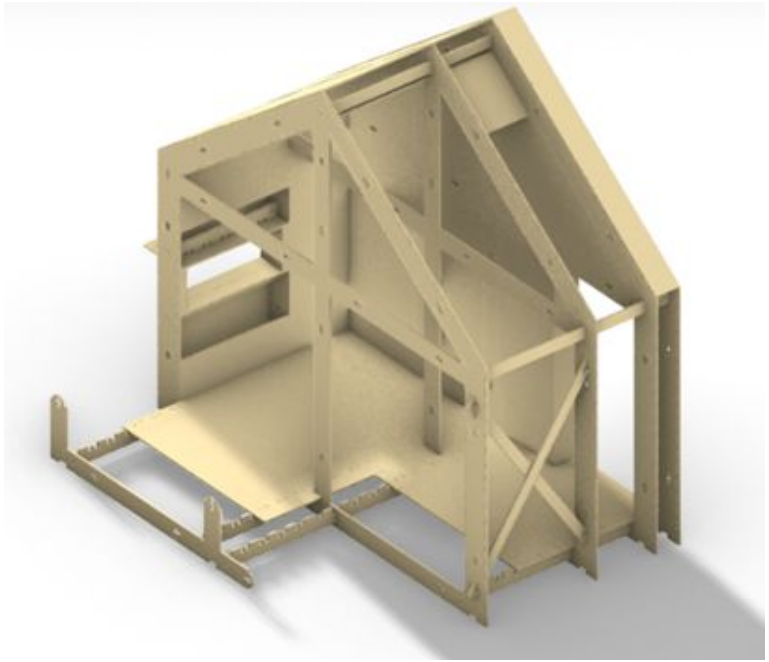
Optimization

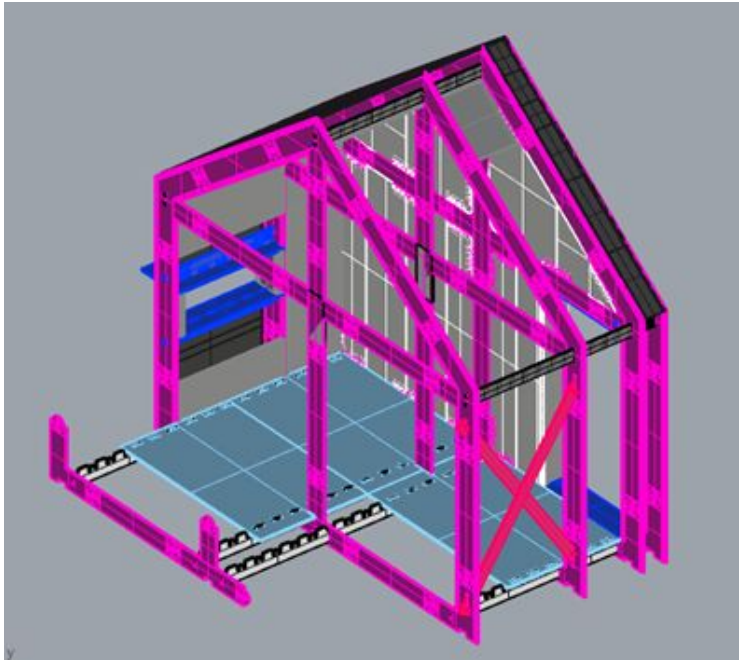


Joinery: Categories



Joinery: Overall concept

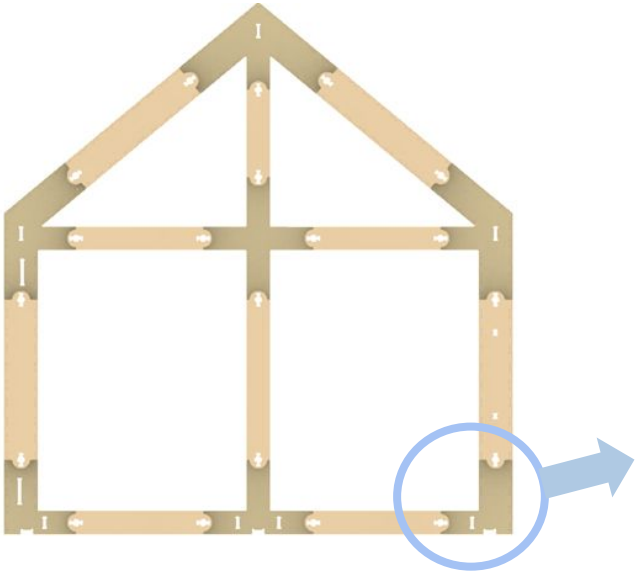


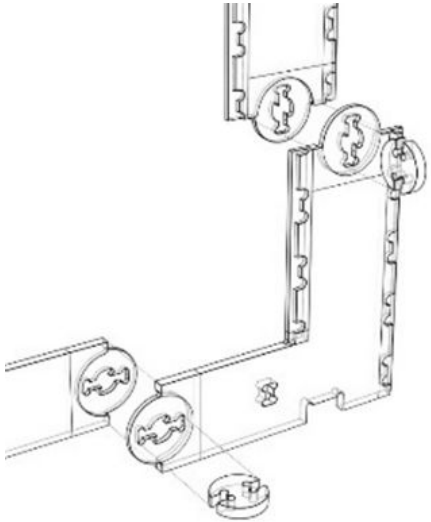


Structural design

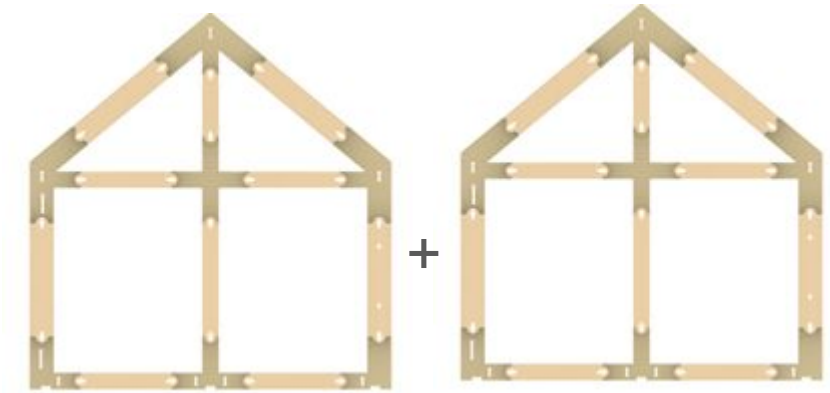
Digital fabrication designers (2014)

Joinery: Frame key connections

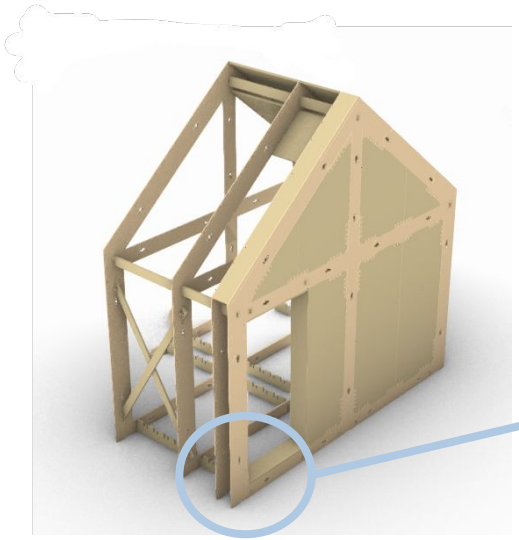


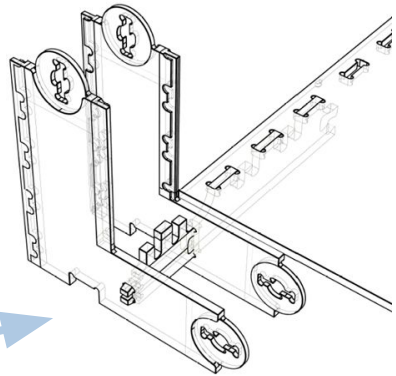


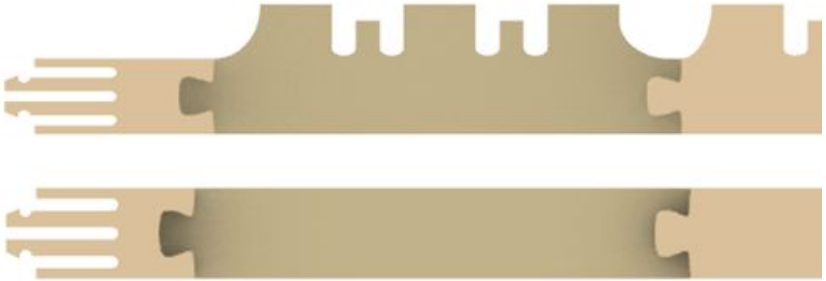
Joinery: Frame upgradability x-axis



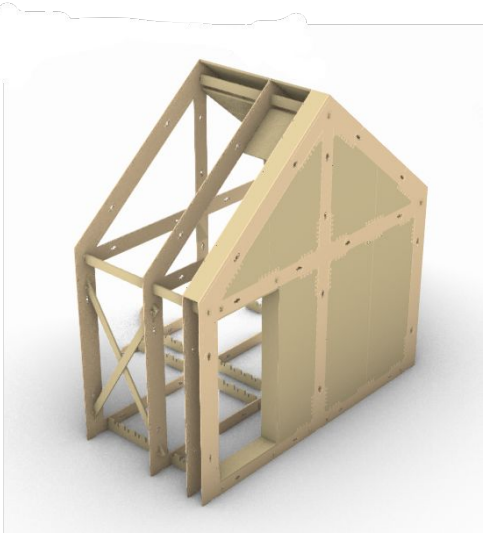
Joinery: Joining frames and floors

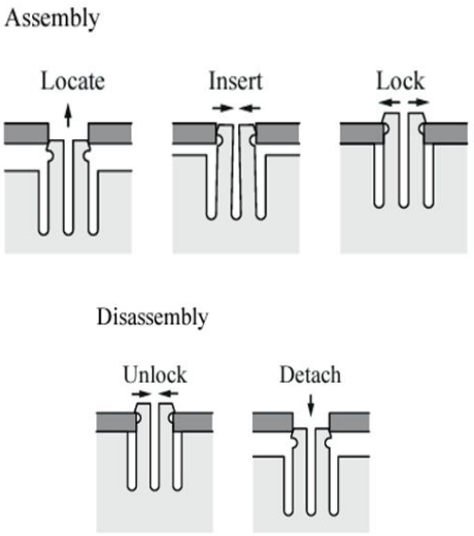


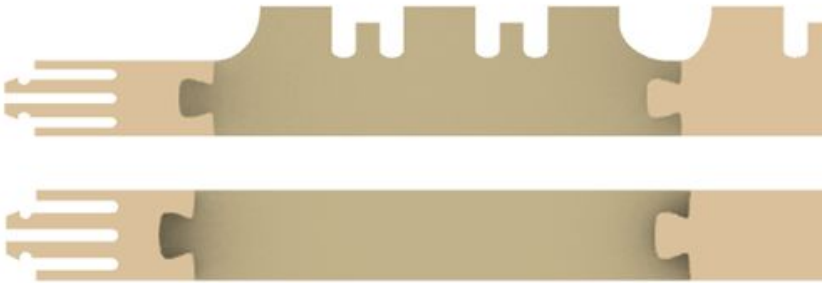




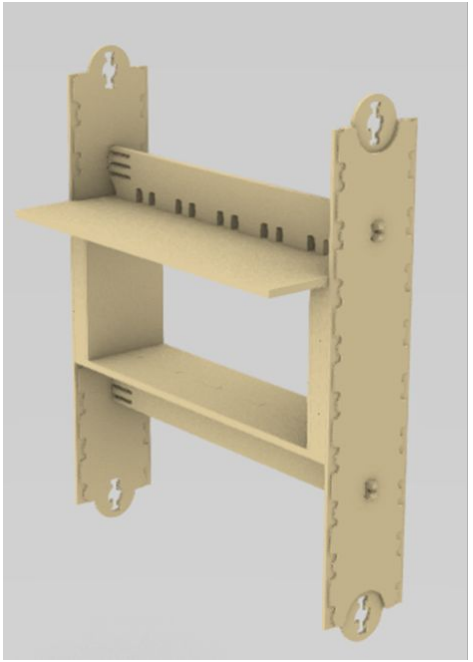
Joinery: Snap-fit and upgradability in y axis

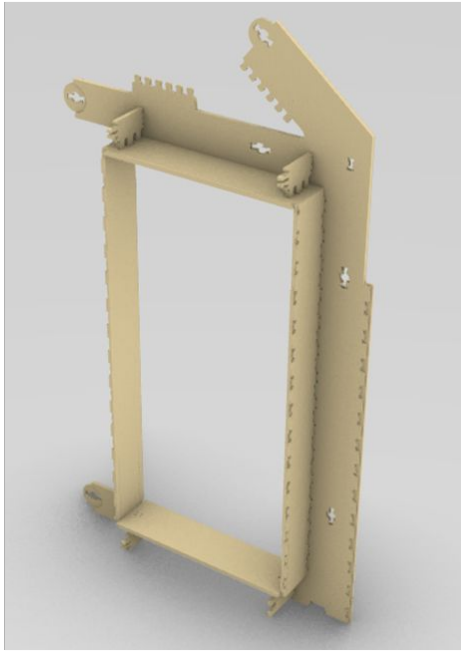




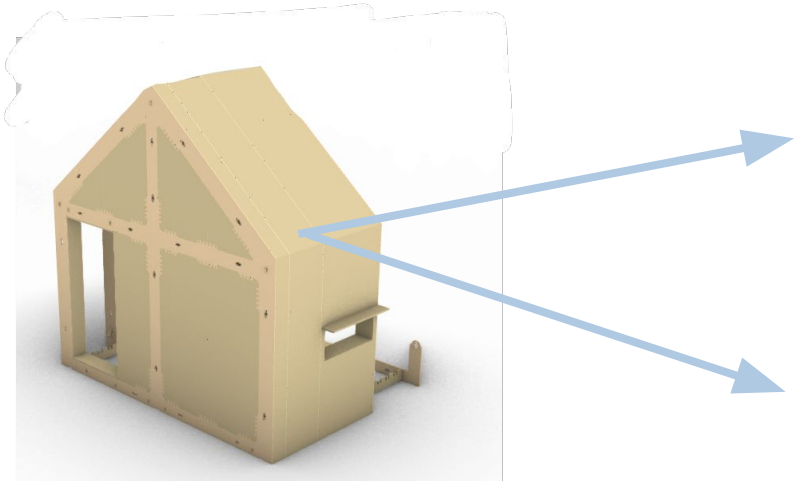


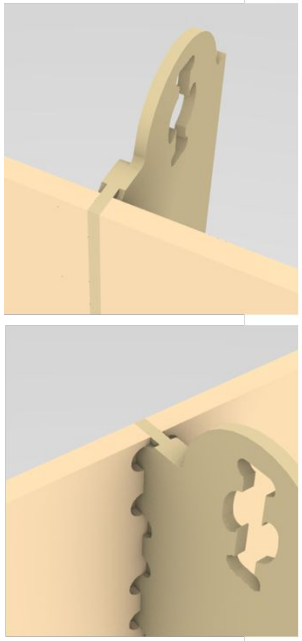
Joinery: Snap-fit and upgradability in y axis

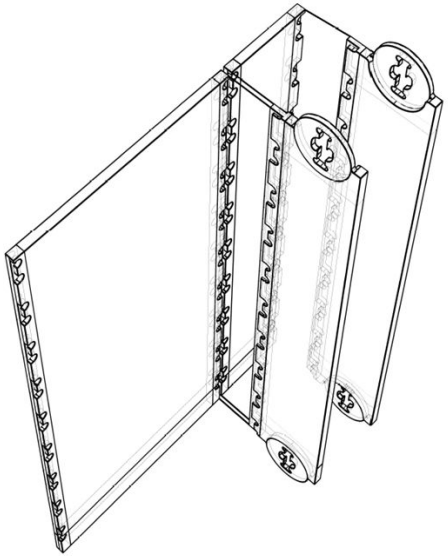




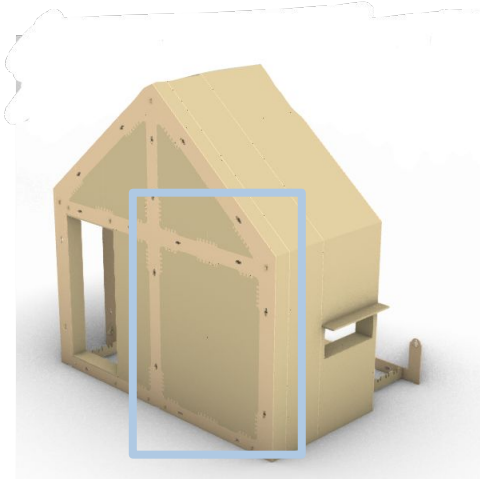
Joinery: Wall to frame angled

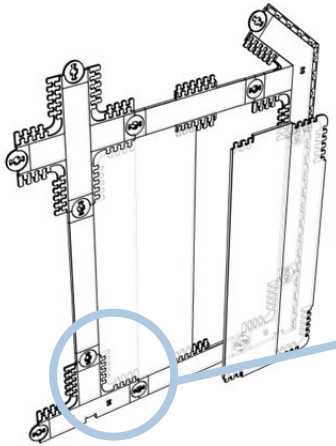


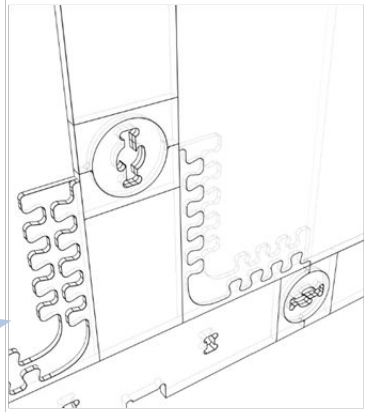


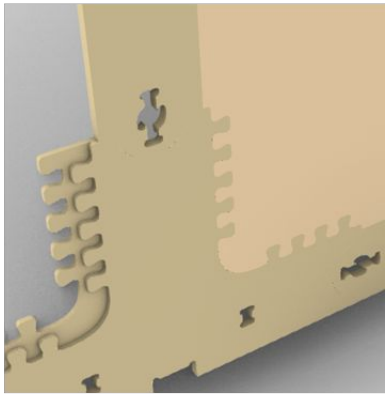


Joinery: Wall to frame angled

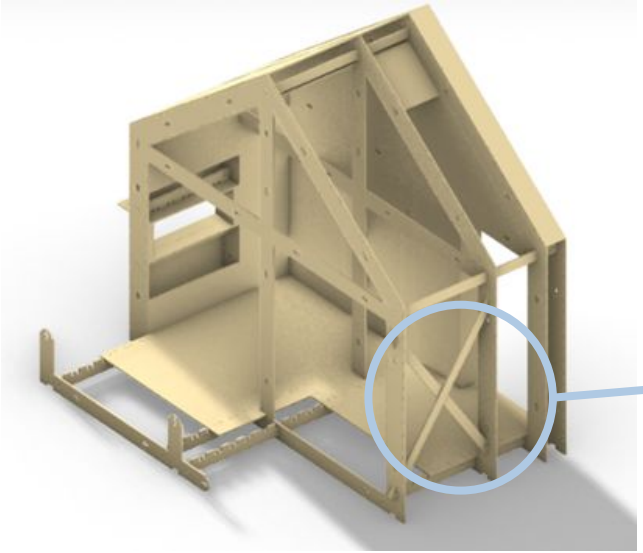


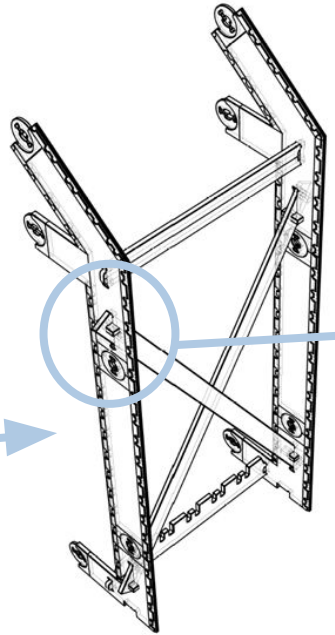


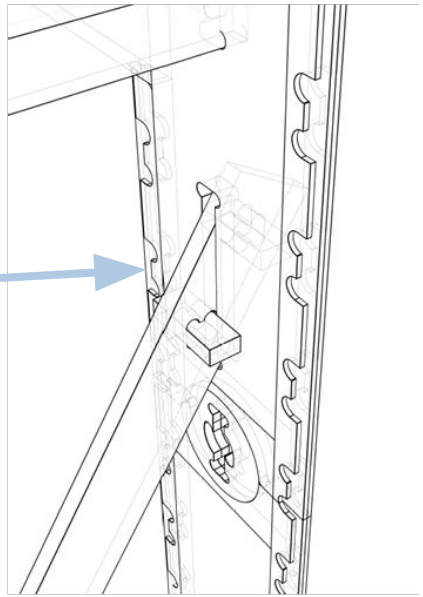




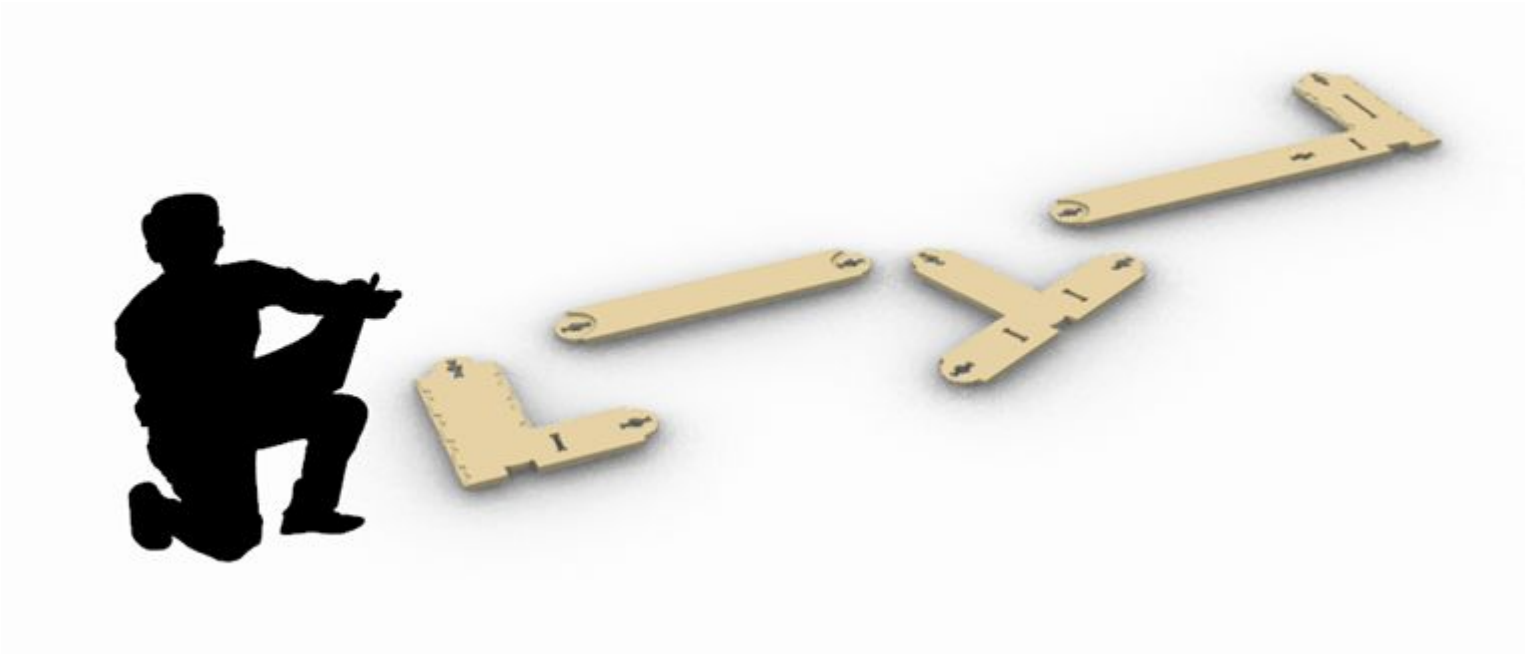
Joinery: Bracing



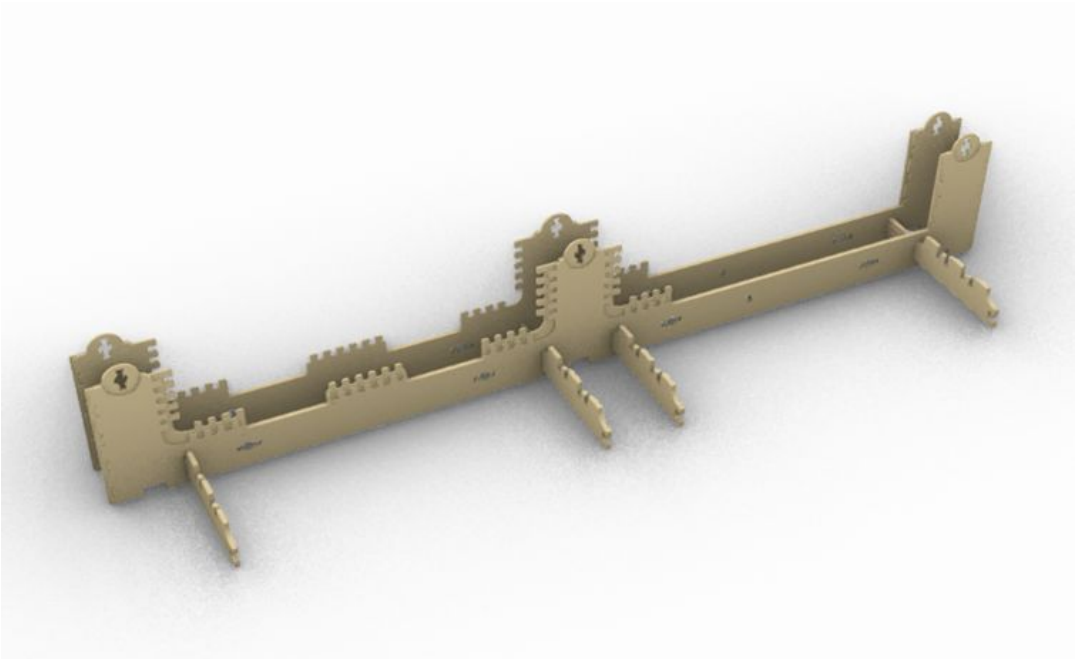




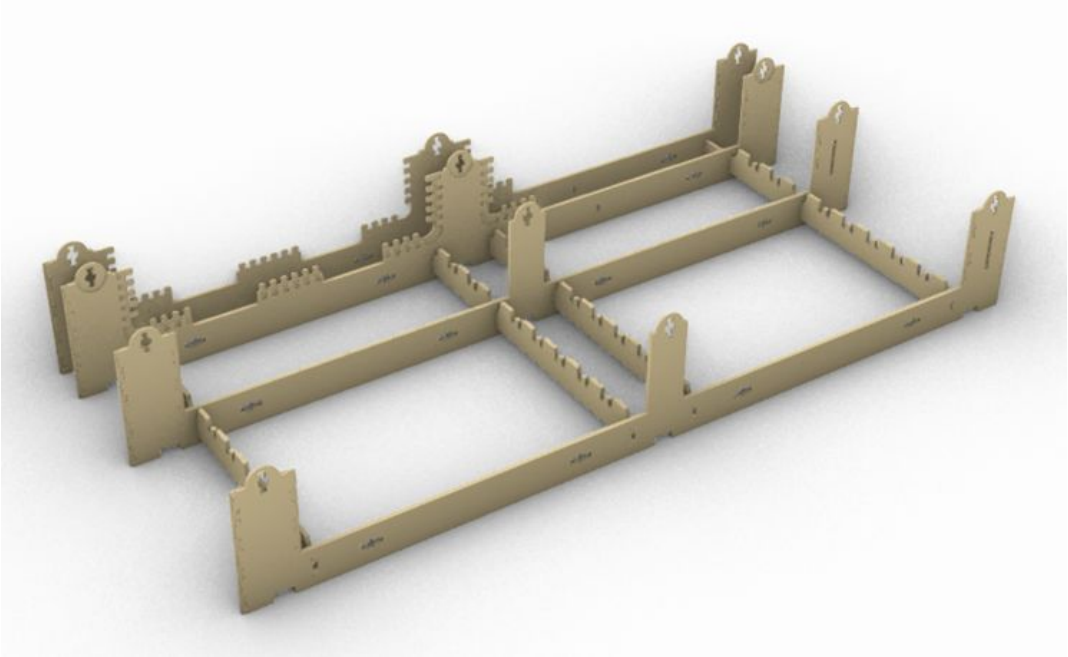
Building sequence



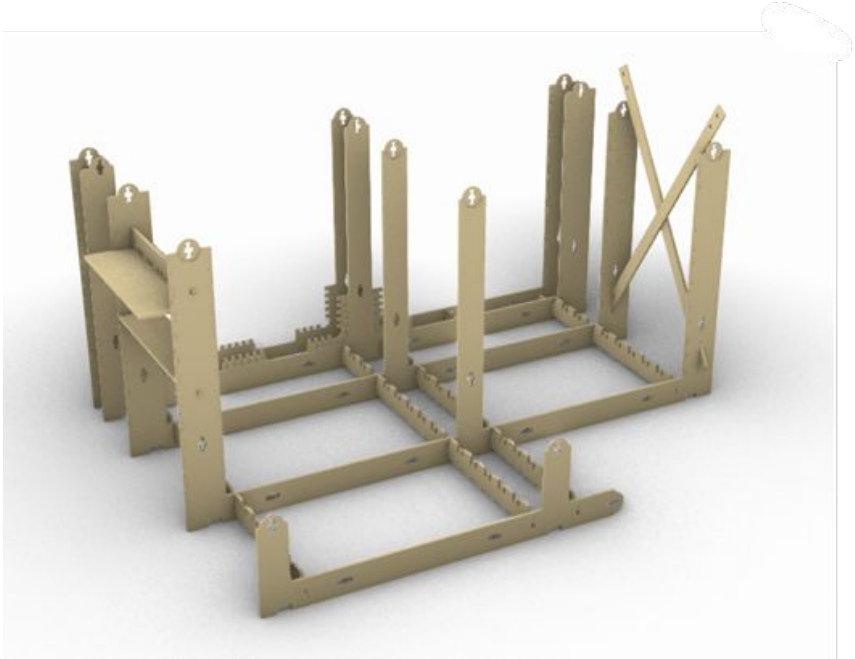
Building sequence



Building sequence

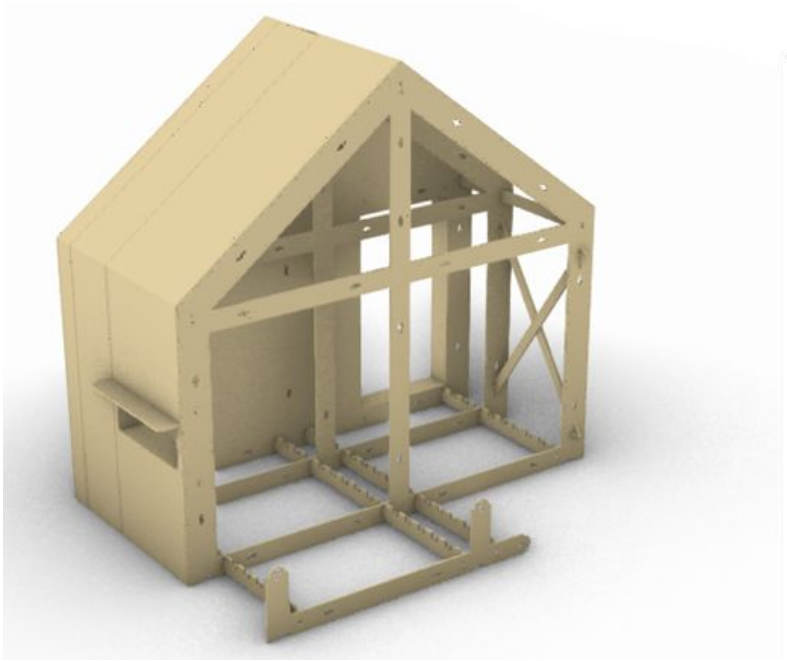


Building sequence



Building sequence

Building sequence



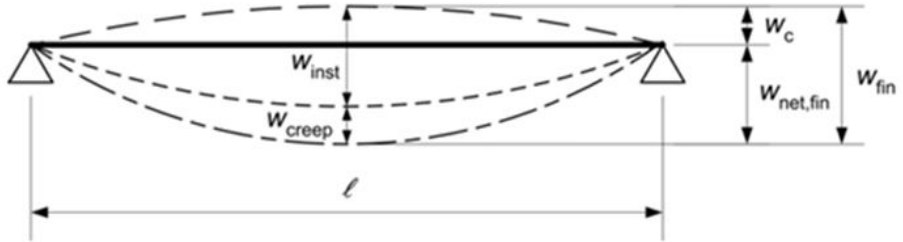
Building sequence

Structural design

:

Ensuring structural integrity: Failure criteria

1. Utilisation: (ULS - Ultimate limit state)
   a. Elastic behaviour
2. Serviceability: (SLS - Serviceability limit state)
   a. Plastic behaviour



EN 1995-1-1 figure 1.7

:

Optimization

$$\sigma_{t,0,d} \leq f_{t,0,d}$$

$$\sigma_{c,90,d} \leq k_{c,90} f_{c,90,d}$$

$$\sigma_{c,0,d} \leq f_{c,0,d}$$

Tensile and compressive stresses

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

$$k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

Bending stresses

$$\tau_d \leq f_{v,d}$$

Shear stresses

:

Optimization

Goal:

- Getting as close as possible to the ULS and SLS = 1, with as little material as possible

Parameters:

- Height cross section
- Number of frames
- Number of columns

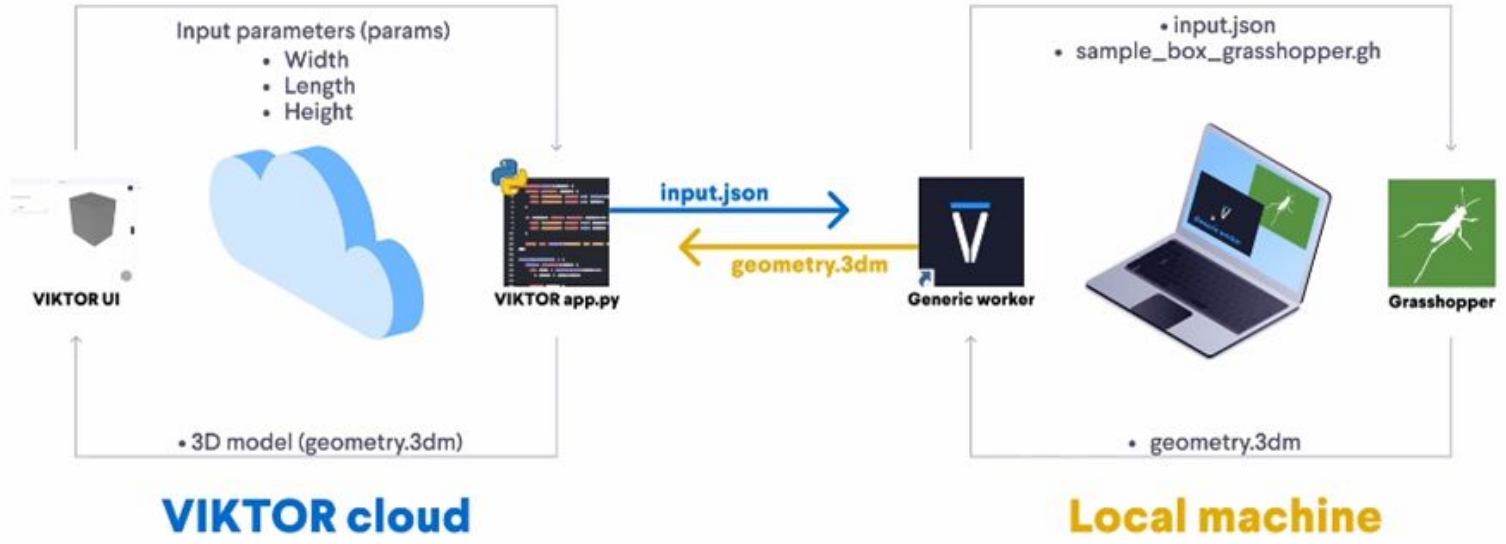
:

What to use to create the digital design?

- Parametric model: Rhino/ Grasshopper/ Python
- Calculation of the loads: Karamba/ Ladybug/Excel
- Fail checks: Grasshopper/ Python
- CNC preparation: OpenNest
- UI: VIKTOR/ Python
- Testing: FEM-model software/ prototyping

:

VIKTOR: How does it work? (locally)



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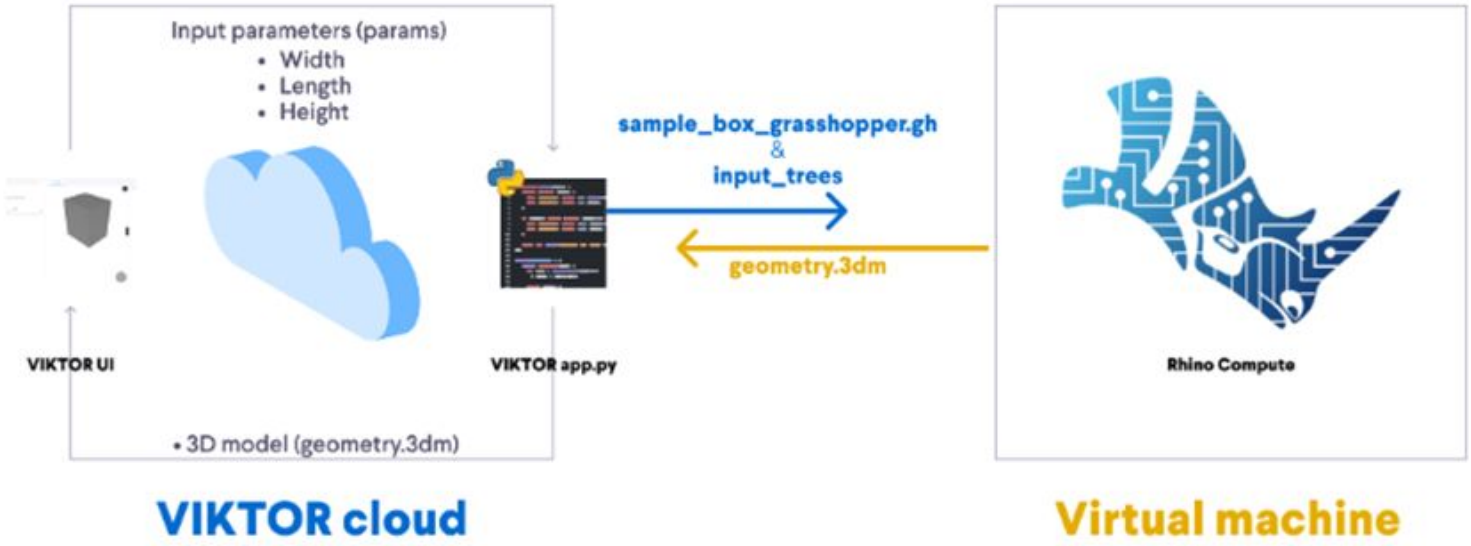
VIKTOR: How does it work? (Virtually)



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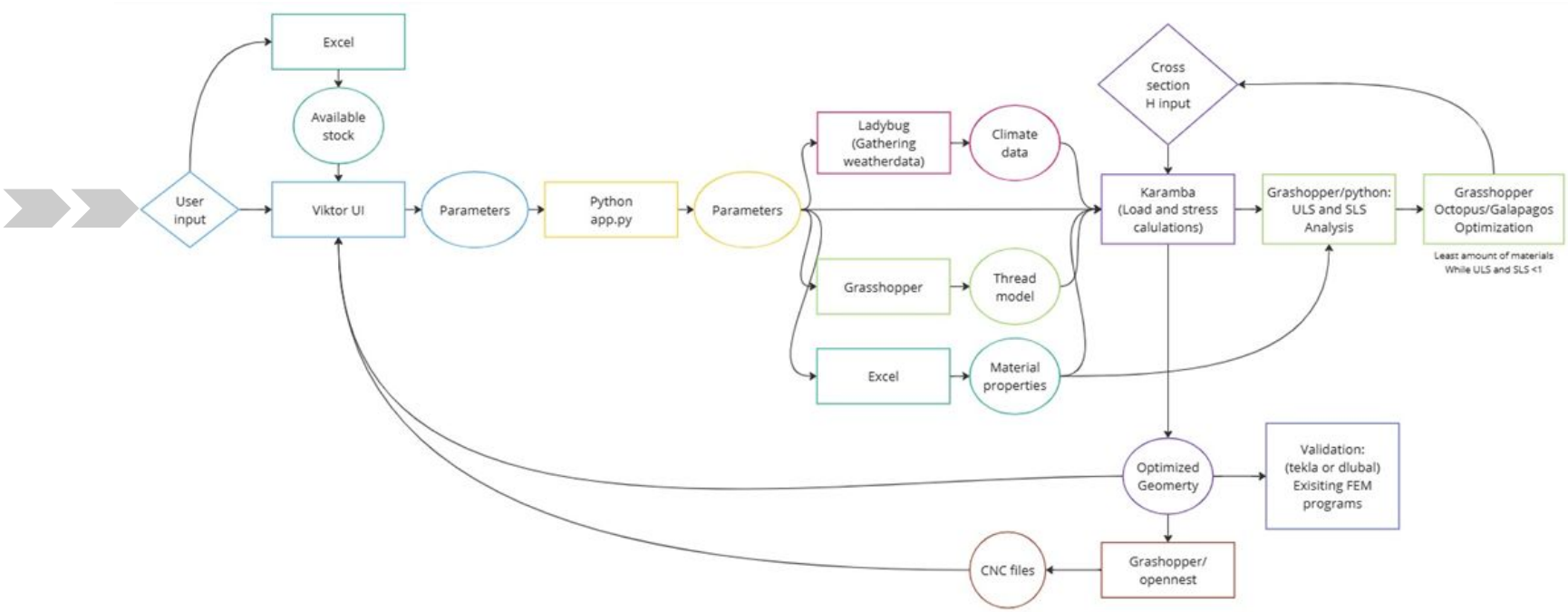
Digital design concept overview



:

User inputs: Location

Input:

- Location
  (longitude, latitude)
- Land, city
  (str)

Output

- Weather data
  (eg. Vm, humidity etc.)
- Available stock
  (resources and machines)
- Factors for loads according to regulations

:

User inputs: Layout

Input:

- Size (min 16 square meters, max 96 square meters in steps of 8): int from 1 to 12
- Type of floor plan (rectangular or square): int 1 or 2
- Position bracing: int 1 to 10
- Position windows: int 1 to 10
- Position doors: int 1 to 10
- If they are wheelchair dependent: bool True or False
- Stories: Int 1 or 2

:

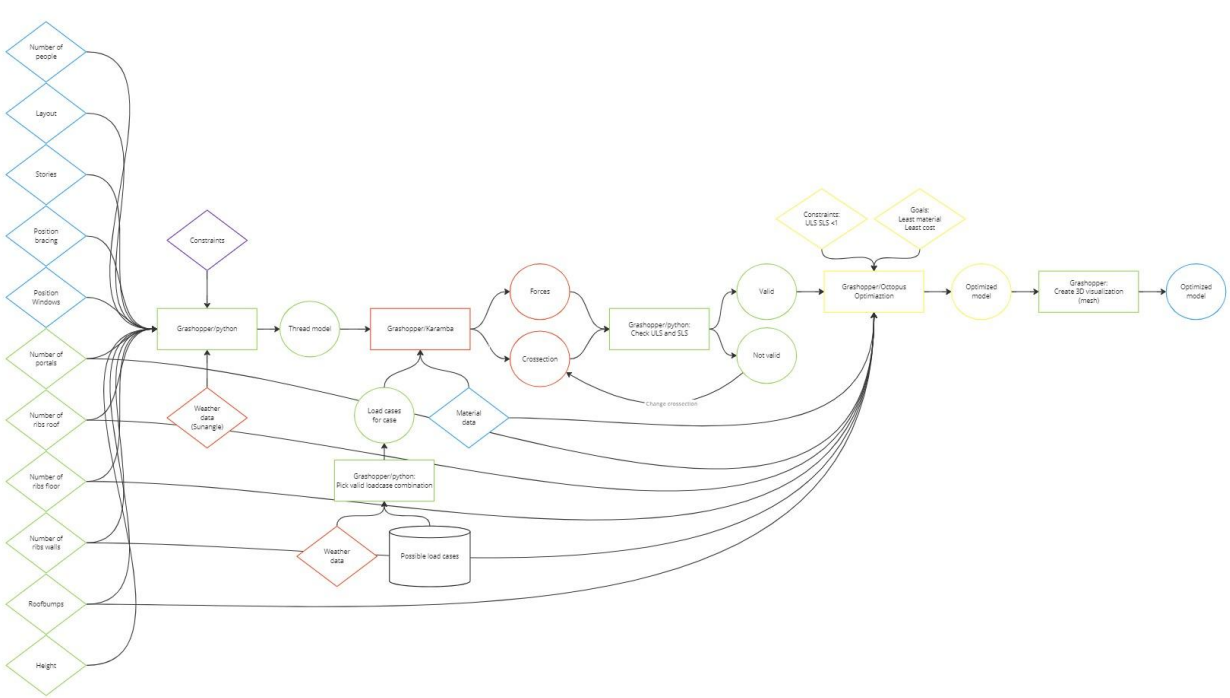
Optimizable parameters

Optimizable parameters

- Cross Section height: int between 200 and 500 in mm
- Number of frames: int 1 to 10
- Number of columns: int 1 to 10

:

Workflow: Parametric model



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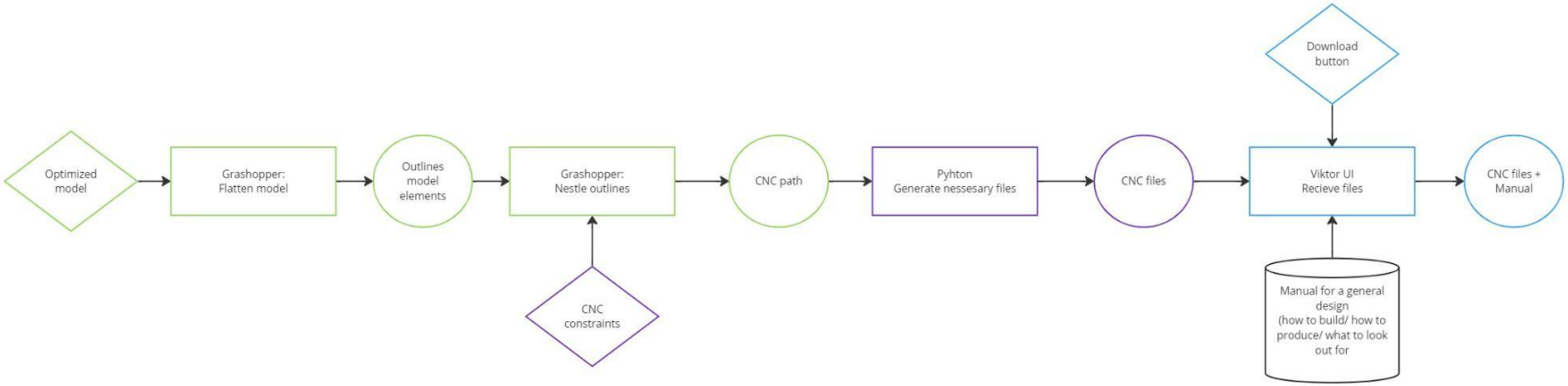
Workflow: CNC-routing preparation



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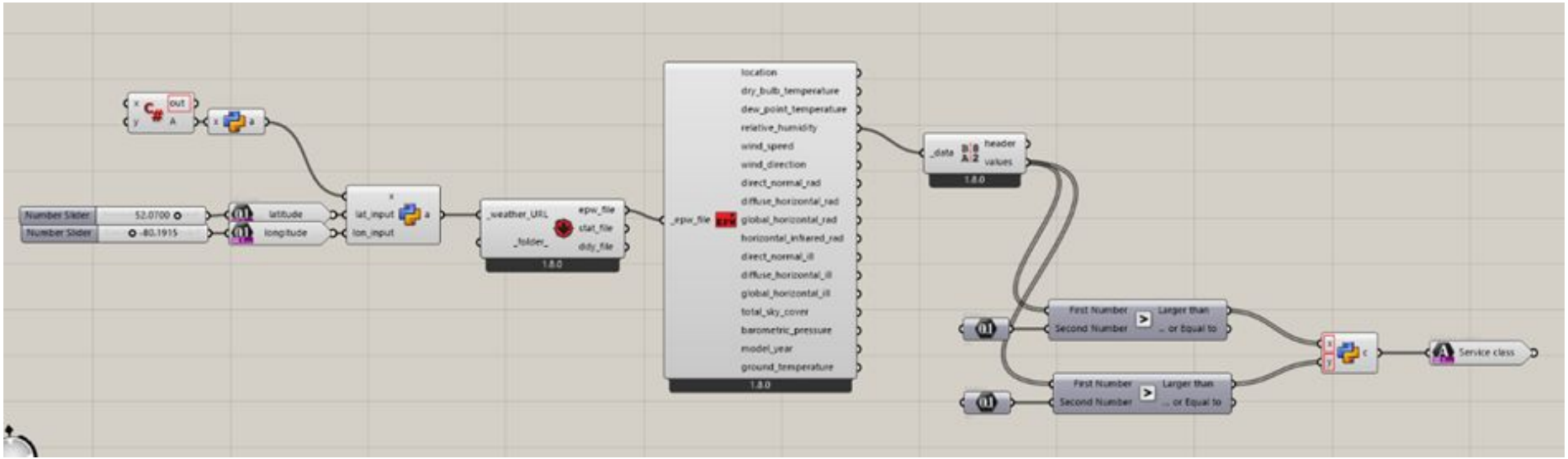
Current results: Weather data



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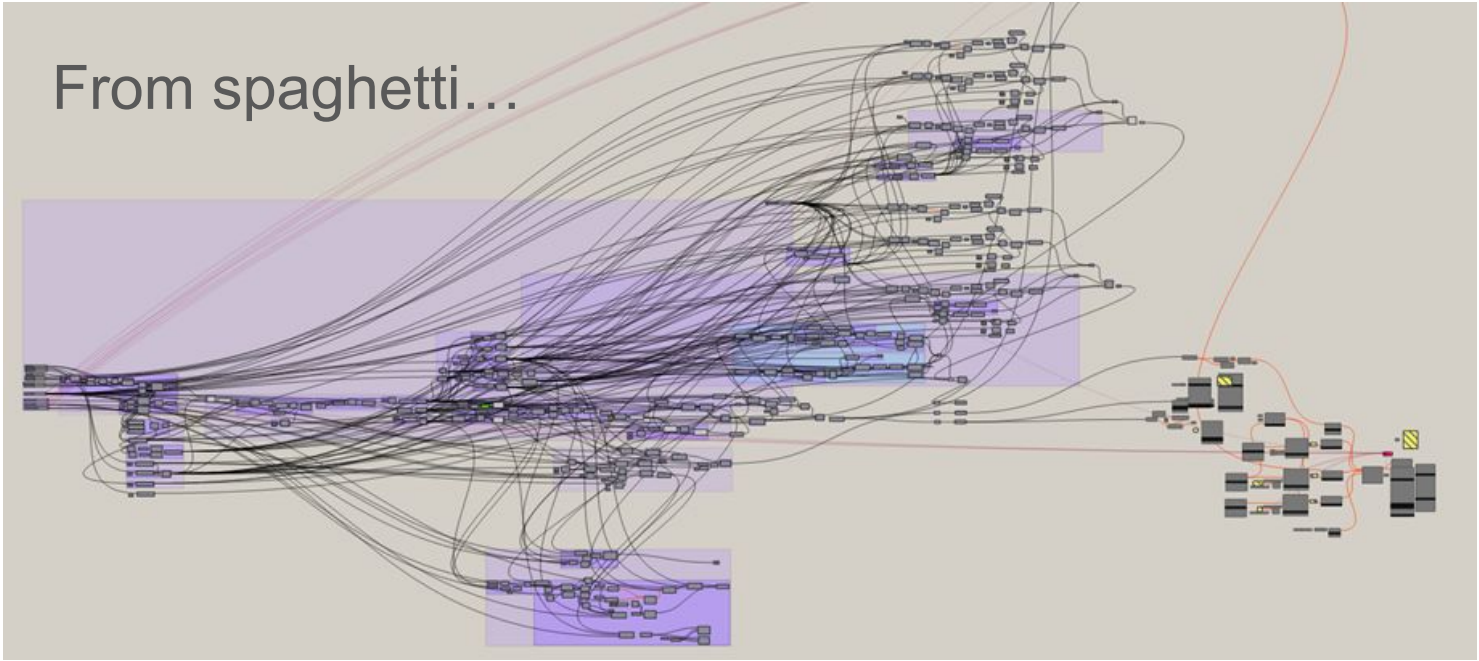
Current results: Parametric thread model



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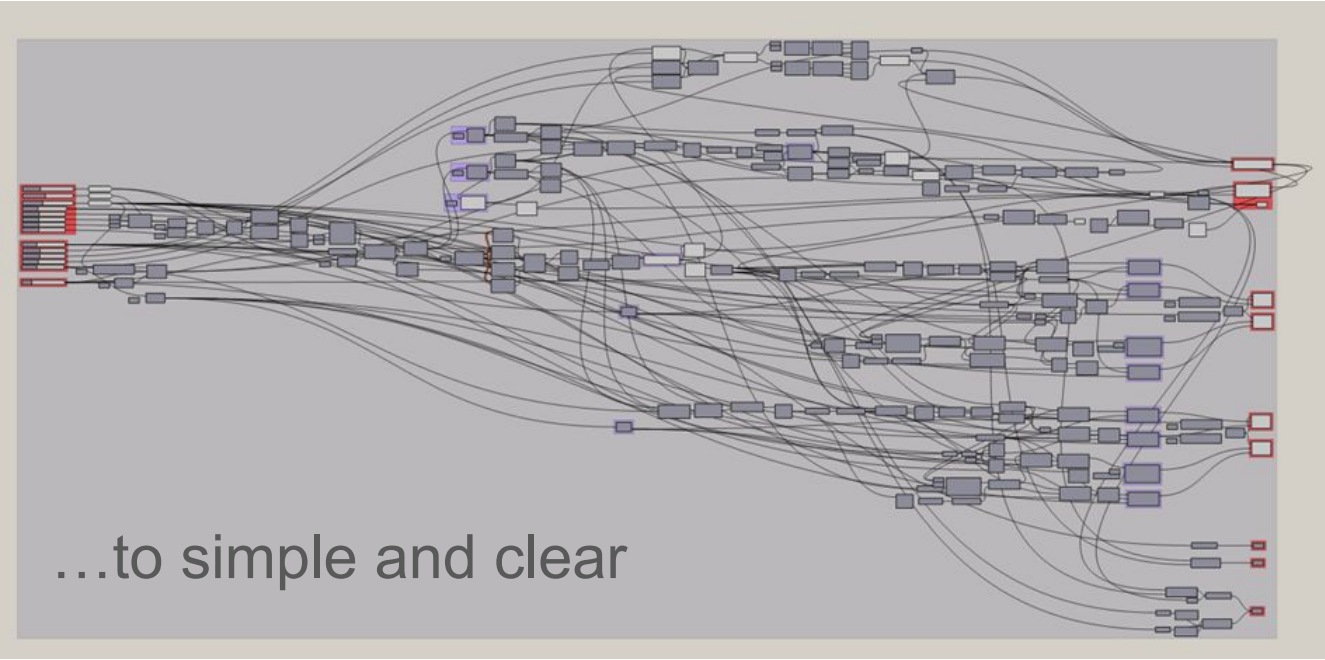
Current results: Parametric thread model



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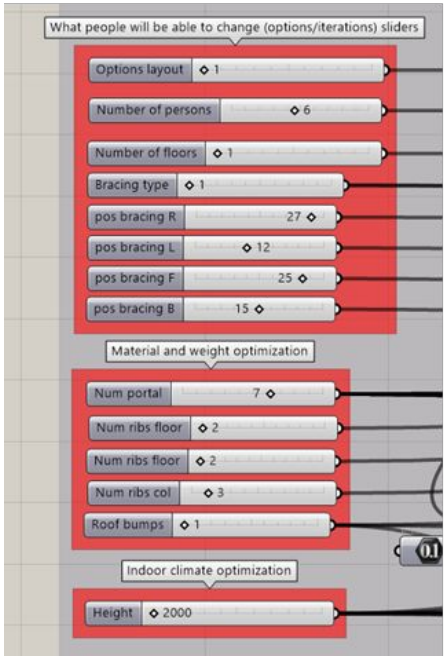
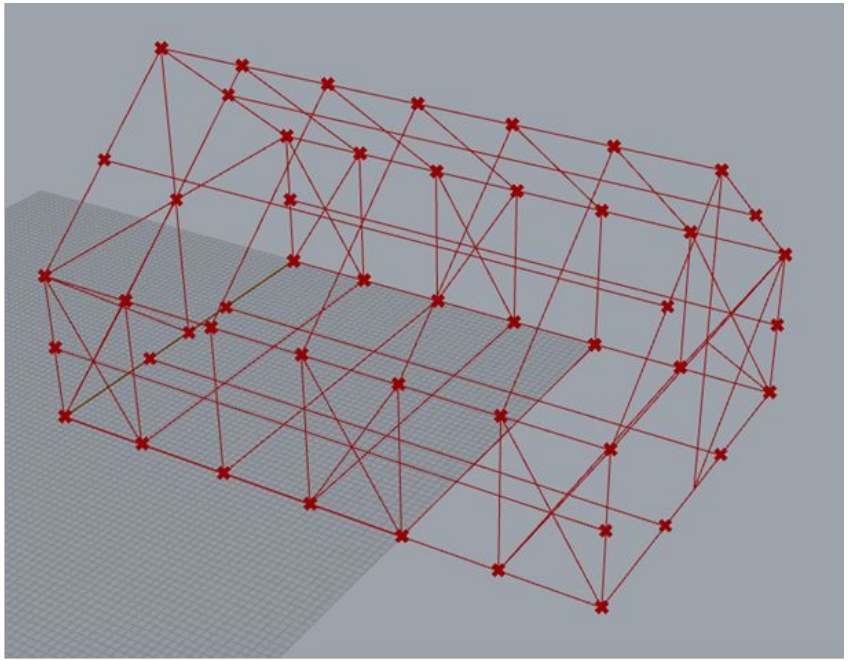
Current results: Parametric thread model





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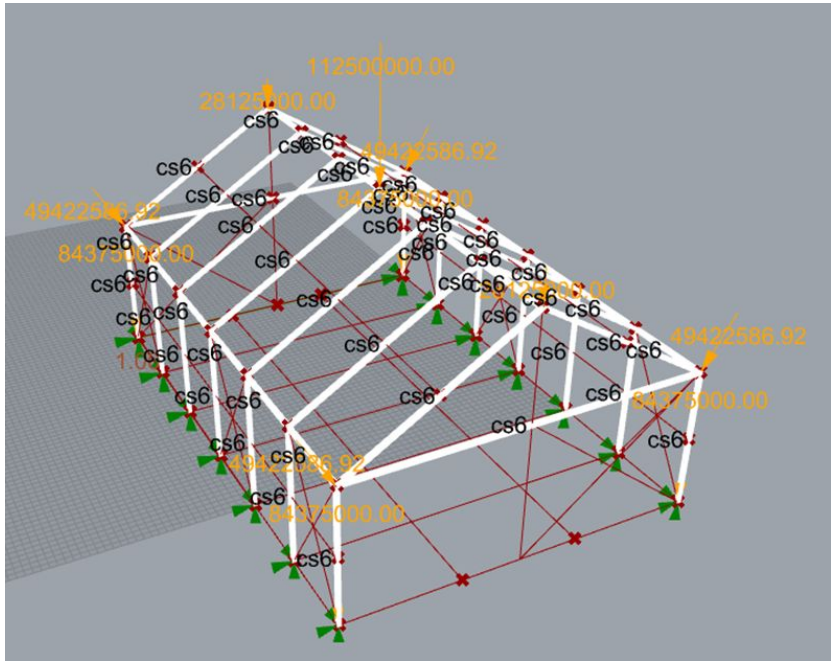
\Karamba loads change of method

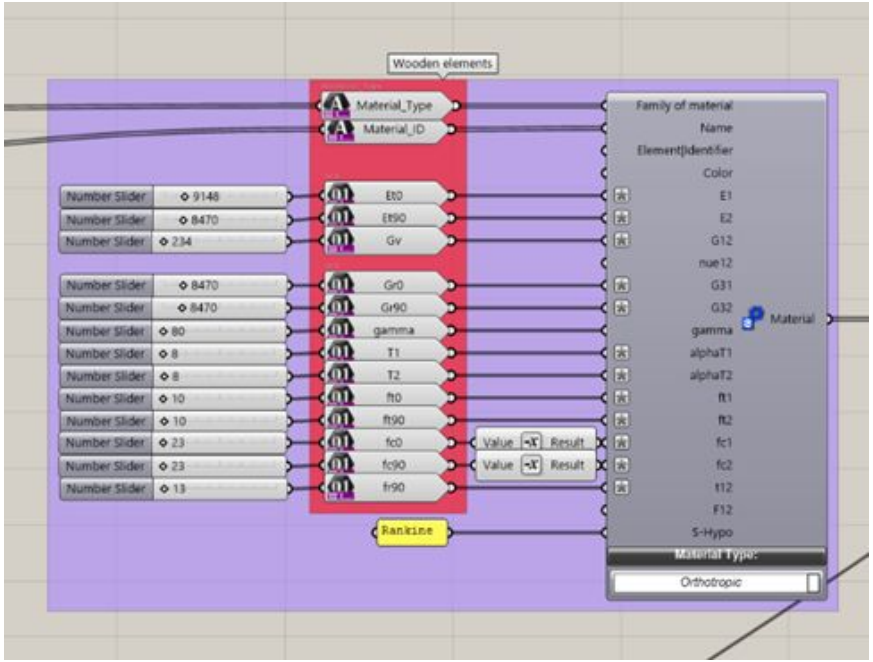


Snow centric			
Snow excentric			
Wind load left side			
Wind load front side			
Wind underpressure			
Wind overpressure			
Floor load distributed			
Floor load concentrated			
Seizmic load/ movements			
Thermoplastic load			
Permanent load	Value		
Roof	#N/A	kN/m^2	
Floors	#N/A	kN/m^2	
Outside walls	#N/A	kN/m^2	
Inside walls	#N/A	kN/m^2	
Total	#N/A	kN/m^2	

:

Karamba loads change of method

```
# Step 3: Construct input parameters
input_parameters = {
    "Et0": Et0,
    "Et90": Et90,
    "Gv": Gv,
    "Gr0": Gr0,
    "Gr90": Gr90,
    "gamma": gamma,
    "T1": T1,
    "T2": T2,
    "ft0": ft0,
    "ft90": ft90,
    "fc0": fc0,
    "fc90": fc90,
    "fr90": fr90,
    "Longitude": longitude,
    "Latitude": latitude,
    "Material_ID": Material_id_param,
    "Material_Type": material_type,
    "Thickness_wood": Thickness_wood,
}
```



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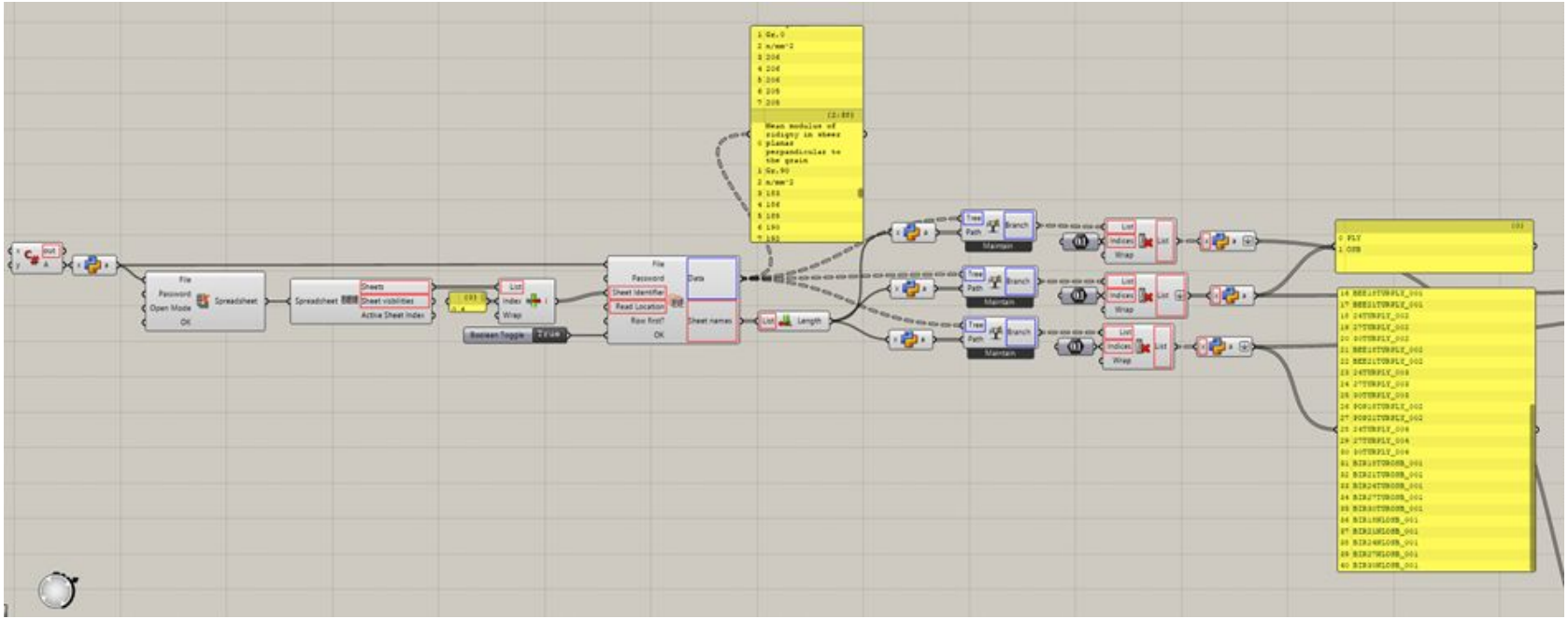
Karamba loads change of method



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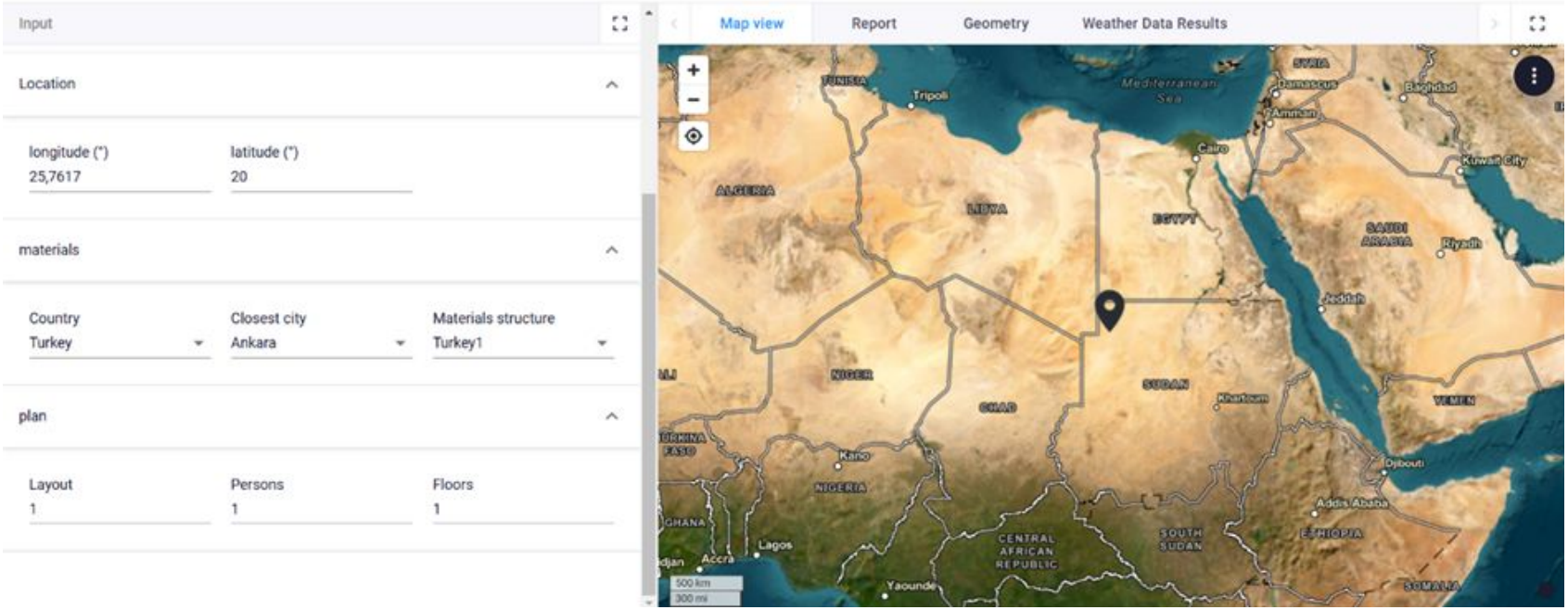
Current results: User interface



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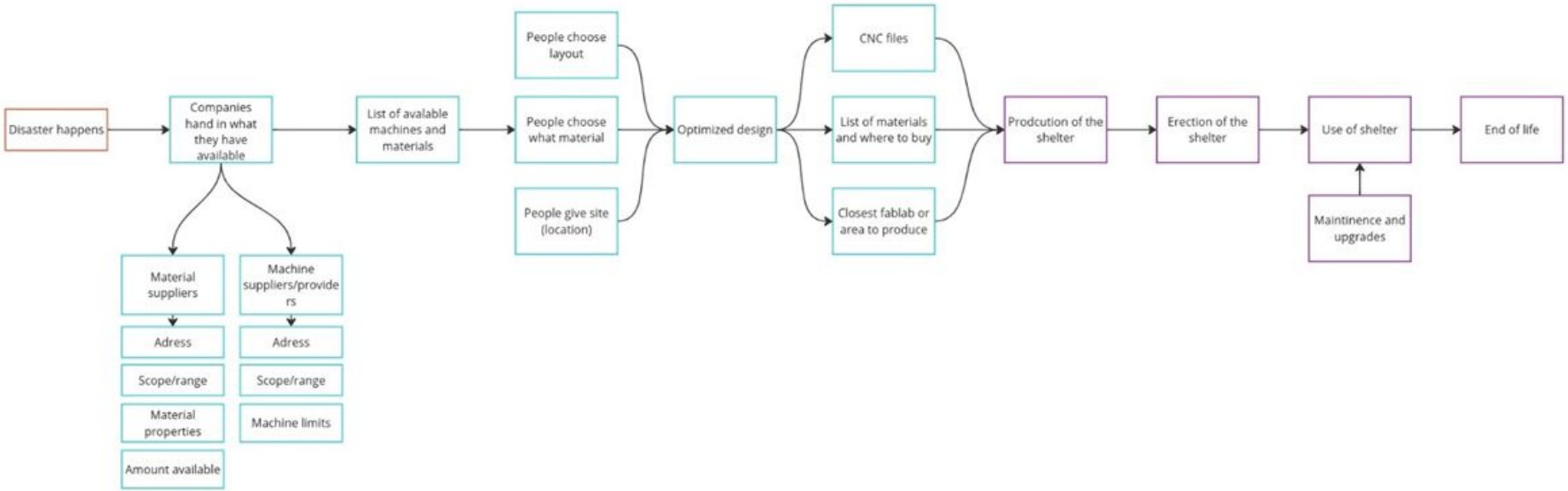
Broader context

Response	Recovery	Mitigation	Preparedness
Move the perpaired shelter pieces to site and erect it in it's simplest form.	Upgrade the shelter along the way until a permanent solution is met	Let them take the time to 'build back better', meaning to make sure the permanent solution is better resistant against next disaster	Produce custom structural items before disaster in Makerspaces, let the people design their shelter, produce them and store them in a safe place to be prepaired for coming disaster

:

Broader context



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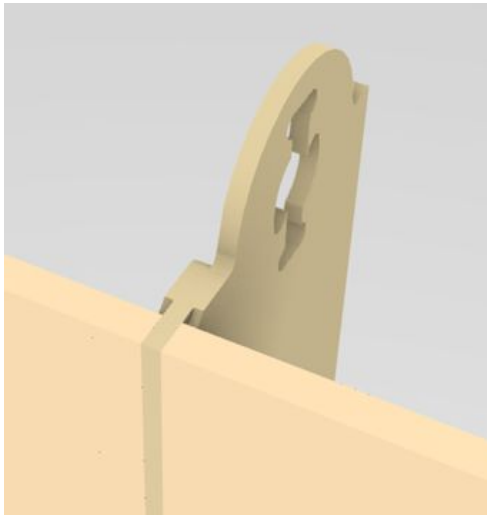
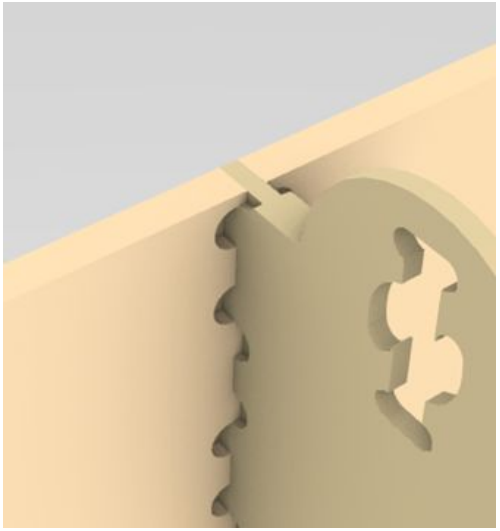
Limitations

- Flat roofs
- Ease of production
- Digital vs reality
- Expert involvement
- Availability of resources





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Conclusions

How can CNC-routing and computational tools facilitate the design and local production of customizable wood-based shelters by non-experts in post-disaster contexts?

Pieter Stoutjesdijk: A digital revolution

“What’s coming now is the revolution in digital fabrication.”

“Factories in the cloud’ make even the highest-end tools available for everyone with an internet connection and a credit card”

:

Future research

- Work out all load cases
- Developing the application more
- Joinery
- User feedback

Thank you all so much for listening!