MASTER IN MASS TIMBER DESIGN

MMTD

2020/21

Prefabricated Mass Timber Modular ADU Protoype Adaptable to the Steep Hillsides of Southern California

BARCELONA

Institute for advanced architecture of Catalonia

MASTER IN MASS TIMBER DESIGN

Project Title: Prefabricated Mass Timber modular ADU Prototype Adaptable to the Steep Hillsides of Southern California

Research Studio:
Master in Mass Timber Design

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ABSTRACT

The state of California is currently going through a housing crisis, experiencing both a lack of homes as well as high prices in the market, making the housing crisis a recurring topic discussed by community leaders and politicians. At the same time, California residents have witnessed a dramatic increase in the homeless population in recent years. California keeps growing, due both to natural reasons, such as birth rates exceeding death rates, as well as the natural influx of people migrating for several reasons. The state has not been able to keep up with the housing demand. Solutions must be found, and one of the ways to alleviate this crisis is with Accessory Dwelling Units (ADUs), which are additional dwellings on single-family lots that are separate from the main dwelling unit. Most of these ADUs are built from cost-effective lightweight wood frames that, thanks to their size, are relatively quick to build. This thesis aims to investigate a prefabricated Mass Timber modular ADU prototype adaptable to the steep hillsides of Southern California. The carbon storage in contrast to an ADU built from a light-frame wood structure, as well as the health benefits of living in a space built from solid wood, air quality, and acoustics, are all good reasons to migrate from light-frame wood structures to prefabricated Mass Timber structures. A prefabricated Mass Timber ADU can take advantage of the wood sourced from sustainably managed forests in the country, alleviating the housing crisis as well as playing a part in fighting climate change through carbon storage.

Keywords: California, ADU, mass timber, housing crisis, prefabrication

CLT Image, Stora Enso. https://lamellammc.com/ (accessed August 2022)

01 INTRODUCTION

California’s Housing Crisis

CALIFORNIA'S HOUSING CRISIS

The current median home price in LA is $920,000, while in San Francisco the median price is 1.5 million[1]. Today 160,000 (Fig. 1) people in California will sleep on the streets, in cars, or in shelters. It is contradictory how, in a state that is classified as equitable and sustainable, there are people who cannot afford a home. Due to its size, California has more homeless and unemployed people than smaller states. The current situation in relation to housing is so critical that in recent years the state legislature has been working on a solution. UCLA professors have studied the rising cost of rent, the effect of the pandemic-related moratorium on evictions, suggestions to legalize so-called granny flats (ADUs), and the impact of unequal housing policy. In the particular case of Los Angeles, the city was built around the suburbs. In both popular media and in real life, one-story houses with large lots with swimming pools were the emblem of the mid-century America. But that model has been put to the test as the prices of these homes are out of reach for the working class. Confronted with exorbitant prices and accelerated growth, as well as the increases traffic and pollution brought on with this model, developers are now betting on density. Since land is at a premium, more houses are needed on a parcel thus reducing the cost per unit. In the sprawling suburbs of the Los Angeles area this opportunity is attractive.

Today many houses include separate structures that are used as offices or guest houses. In most cases, these structures are not allowed to be occupied full-time. Taking this situation into account, a policy has been worked out to allow these structures to become ADUs. This policy also encourages the construction of these structures for houses that do not have them.[2]

1 California Real State Market, https://www.realtor.com/realestateandhomes-search/California/overview
2 California's Housing Crisis - UCLA Newsroom, accessed April 2022, https://newsroom.ucla.edu/magazine/california-housing-crisis-solutions

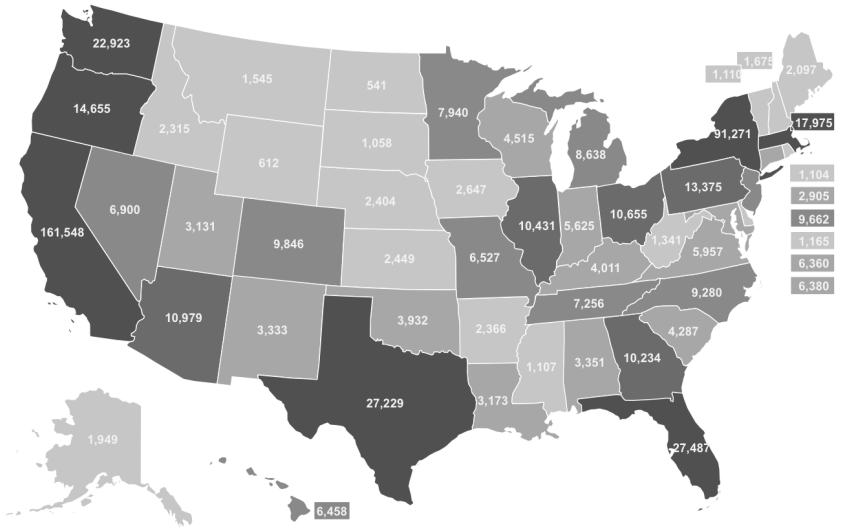


FIG. 1. Total People Experiencing Homelessness in 2020, U.S. Interagency Council on Homelessness. https://www.usich.gov/homelessness-statistics/ca/ (accessed April 2022).

02 BACKGROUND

Accesory Dwelling Units

ACCESORY DWELLING UNITS

ADU'S

An Accessory Dwelling Unit (ADU) is a residential unit that can be attached to la lot with an existing home (Fig. 2). They are also known as granny flats, in-law units, backyard cottages, or secondary units.[3] The ADUs can be a detached structure, attached or part the primary residence, or they could be a converted garage. ADUs are self-contained units that have their own kitchen, bathrooms, living areas, and entrances. For the subject of this essay we will concentrate on the ADUs as a detached units. These kinds of units can be a maximum 1200 sq. ft, they need to be built 5 ft minimum from the side and rear property lines, 10 ft minimum between main house and ADU, and there has to be a parking space unless the ADU is located within half of a mile of public transit.

3 California Department of Housing and Community Development - ADUs. https://www.hcd.ca.gov/policy-research/accessorydwellingunits.shtml (accessed April 2022).

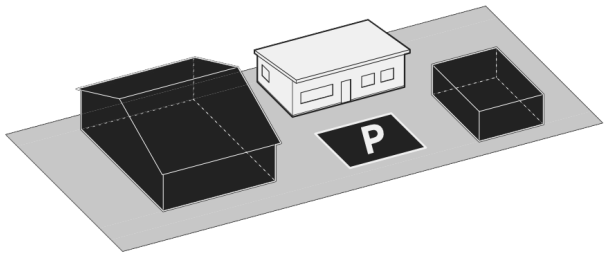


FIG. 2. Detached ADU, Building an ADU. Citylab, UCLA. https://citylab.ucla.edu/adu-guidebook (accessed April 2022).

PRE-APPROVED ADU'S

ADU pre-approved plans are ADU designs that have been vetted by city building and/or planning departments for fast-track approval. They can be selected for use by homeowners for their own ADU projects.[4] Under the Standard Plan Program in Los Angeles County, plans are designed by licensed architects and engineers to accommodate various site conditions (Fig. 3). These pre-approved Standard Plans are designed and owned by the listed design firms and may be purchased directly from the plan owner.[5]

Cities with Pre-Approved ADU Programs:

- San Jose
- Los Angeles
- Fremont
- Cupertino
- Napa-Sonoma

4 Cottage https://www.cotta.ge/resources/2021-07-15-adu-pre-approval-plans-is-it-right-for-you (accessed July 2022)
5 LA County Pre-Approved ADU's. https://ladbs.org/adu/standard-plan-program/approved-standard-plans/ (accessed July 2022).

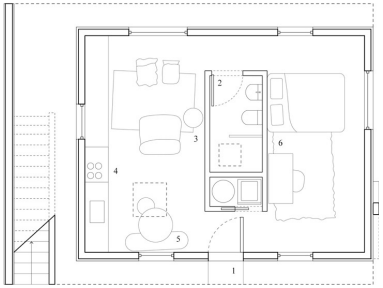


FIG. 3. Jennifer Bonner, MALL Pre-approved 60m² ADU, LA County Pre-Approved ADU's. https://ladbs.org/adu/standard-plan-program/approved-standard-plans/ (accesed July 2022).

03 METHODOLOGY

Design Research Methodoly

METHODOLOGY

The research method used in this report is based on the Design Research Methodology[6] (DRM) as a framework for the development of a prefabricated Mass Timber modular ADU prototype adaptable to the steep hillsides of Southern California. The DRM Framework is formed by four stages: Research Clarification, Descriptive Study, Prescriptive Study, and Descriptive Study II. The first stage helps to understand the current and the overall research aim, develop a research plan, and provide a focus for the subsequent stages. Based on the above stages, we will analyze two 50m2 ADUs (Fig. 4) constructed with different building methods: light frame construction and mass timber. The second stage aims at increasing the understanding of both designs and the factors that influence their success. This stage is based on observation and analysis of the differences between the two timber structural systems. The third stage aims at proposing a prototype ADU taking into account the results of the second stage. A site with a steep slope and with the climatic conditions of the region will be proposed. The last stage focuses on evaluating the usability and applicability of the prototype.

6 Blessing L., Chakrabarti A., DRM, a Design Research Methodology, 2009 (Springer-Verlag London Limited)

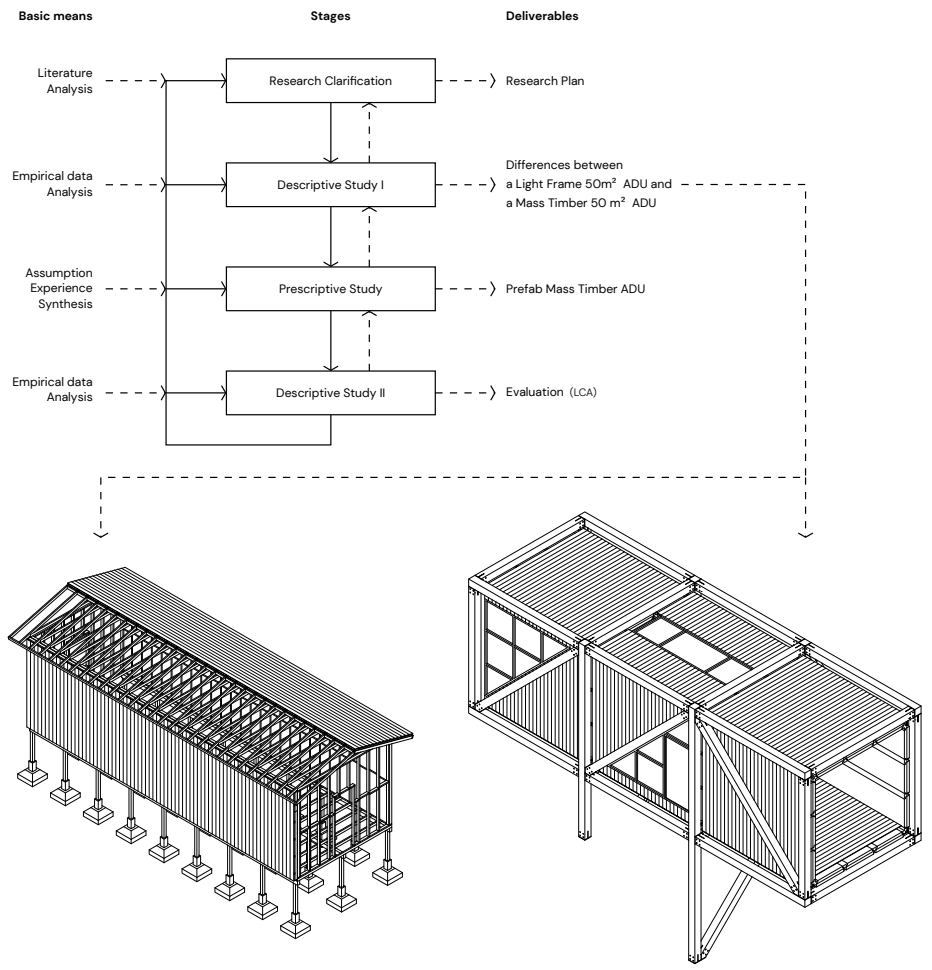


FIG. 4. DRM Methodology Diagram. Light Frame ADU (Left), Mass Timber ADU (Right) by the Author.

04 LITERATURE REVIEW

Structural Wood Building Systems

STRUCTURAL WOOD BUILDING SYSTEMS

DEMAND DRIVERS FOR TIMBER STRUCTURE ADUs

Selecting the right material for a sustainable and safe home is one of the demands of homeowners who plan to build an ADU on their properties. Choosing wood as a construction system, whether it is a light structure or mass timber, has benefits for building such as: versatility of the material, a sustainable supply chain; as well as benefits for the occupant, such as thermal, acoustic, seismic and fire resistance. Lumber can also help maximize value through gains in square footage and building height. Light-framed wood construction has long been the preferred choice for residential building construction. Cost effectiveness, material efficiency, ease of assembly, minimal environmental impact, and ready availability of labor and materials make light-frame construction the most common type of wood construction in North America. While mass timber structures are often built as off-site components and assembled at the project site, light frame construction is usually done entirely on site.[7]

LIGHT FRAME ADU

According to the California Department of Housing and Community Development, ADUs are built with cost-effective timber light frame construction[8], which is a system of construction using many small and closely spaced timber studs that can be assembled with nails (Fig. 5). This is the standard for U.S. suburban housing. The balloon-frame house with wood cladding, invented in Chicago in the 1840s, aided the rapid settlement of the western U.S. The framed building enjoyed an extensive revival after World War II in the form of platform frames. In platform framing, each floor is framed separately, as contrasted with balloon framing, in which the studs (vertical members) extend the full height of the building. Freed from the heavy timbers of the post-and-beam system, platform framing offers ease of construction. Due to the aforementioned reasons, the majority of ADUs are built with this system, although it has evolved to pre-assembled wood light frame panels.

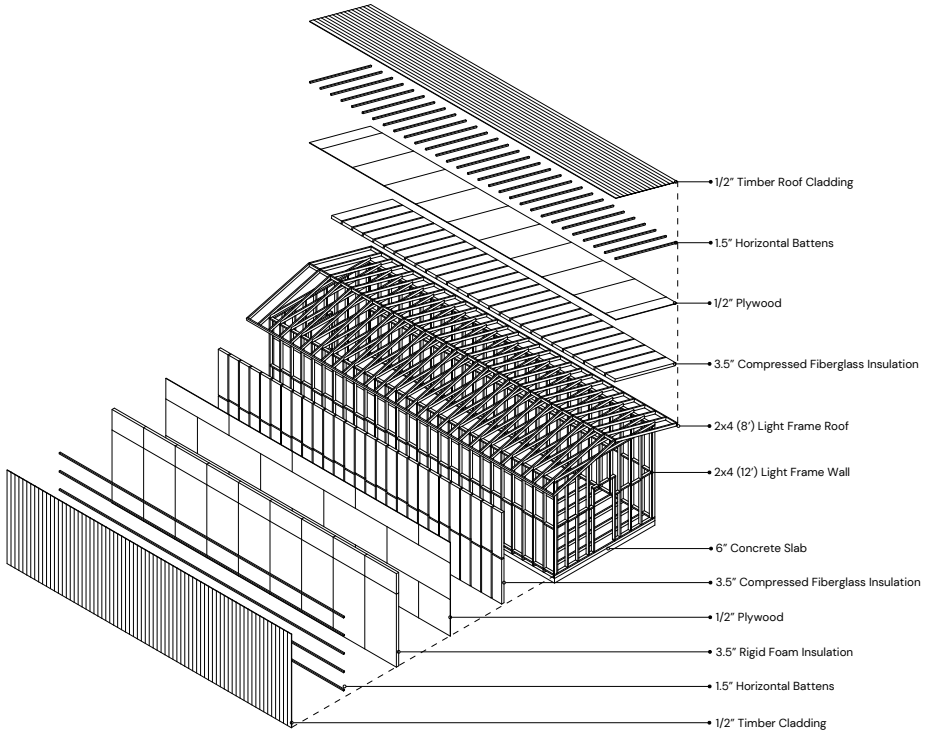


FIG. 5. Structure of a Light Frame 50m2 ADU by the Author.

7 Structural Wood Building Systems, Thin Wood. https://www.thinkwood.com/continuing-education/structural-wood-building-systems-choosing-right-material (accessed July 2022)

8 Accesory Dwelling Units, California Department of Housing and Community Development. https://www.hcd.ca.gov/accessory-dwelling-units (accessed April 2022)

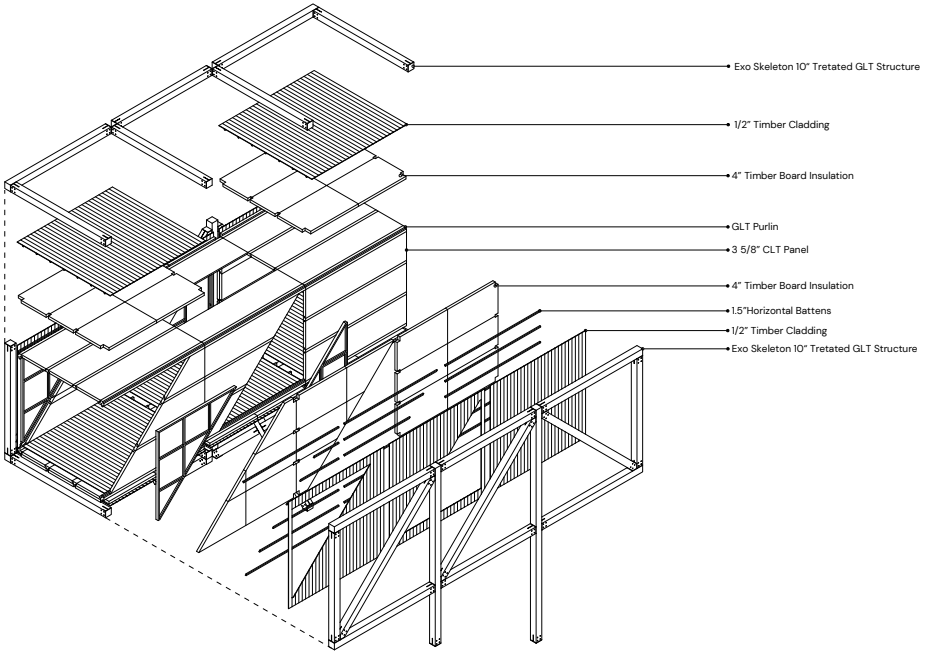


FIG. 6. Structure of a Mass Timber 50m2 ADU by the Author.

MASS TIMBER ADU

Mass timber is a category of framing styles typically characterized by the use of large solid-wood panels for wall, floor, and roof construction (Fig. 6). Building with mass timber offers a reduced carbon footprint, construction efficiency, fire and life safety, and occupant well-being.[9] Currently, the mass timber movement on the west coast is only exploiting its full potential in the state of Oregon.[10] There is a producer of ADUs based on CLT panels near the city of Portland that is betting on the advantages of building with mass timber.[11] The unit is made of thick, solid wood panels and paired with a continuous rigid insulation. The CLT panels are prefabricated and custom assembled off-site, which allows quick assembly on site and reduced construction time. This process also lessens the noise, debris, and traffic impacts of construction activity in the neighborhoods in which it takes place. There is no framing around doors and windows. The structure is highly efficient because there are no thermal breaks. This design has the potential to reduce stress levels and improve the health of the occupants, since it has been shown that exposure to some natural element, in this case wood, reduces sympathetic nervous system activation. Another advantage of a home with exposed cross-laminated timber interiors is that the quality of the air is improved: wood absorbs excess moisture from indoor air, and when the air becomes too dry, it returns the moisture. Likewise, wood has good acoustic performance, dampens sound naturally, and offers excellent noise control. It absorbs sounds and creates a calm and relaxing atmosphere.

9 Structural Wood Building Systems, Thin Wood. https://www.thinkwood.com/continuing-education/structural-wood-building-systems-choosing-right-material
10 Sturdy, strong and sustainable: Mass timber's popularity grows in Pacific Northwest, https://www.registerguard.com/story/news/environment/2021/12/15/mass-timber-popularity-growing-oregon-pacific-northwest-cross-laminated-timber/8910241002/ (accessed April 2022)
11 Watershed Structures, https://www.watershedstructures.com/ (accessed April 2022)

PREFABRICATED ADU

Prefabricated wood components used in both light wood frame and mass timber construction can help to solve many design and engineering challenges such as material and process efficiency, environmental performance and life safety. Wood prefabrication has a multitude of benefits: process efficiency, controlled environment, greater return on investment, material efficiency, reduced waste both on and off-site and sustainability.[12] Due to its size, a prefabricated ADU is a good candidate for prefabrication. In the flourishing ADU market, there is a sector that is betting on the prefabrication of these units. These companies can complete a project in as little as 4 to 12 weeks from permit to delivery. They build the ADUs through a process where they take care of the entire structure offsite, deliver it to the home on the back of a truck, and handle all on-site work needed to prep the foundation for the unit to be placed in the ground.[13] Another form of prefabrication that occurs in the ADU market is the delivery of kits that are assembled on site with pre-assembled wood light frame panels such as the walls and roofs.[14] In either case, a concrete slab foundation is required on site prior to the kit or module delivery. After the foundation is in place, some companies deliver a complete panel plan and installation manual to aid a contractor with installation. When the kit arrives a truck full of panels turns into a home with two or three helpers and the ADU could be ready within a day for a smaller unit or two days for a large one.

12 Designing Sustainable Prefabricated Wood Buildings. Think Wood CEU (2008)
13 Abodu. https://abodu.com (accessed April 2022)
14 PrefabADU. https://www.prefabadu.com (accessed April 2022)

MODULAR ADU

Modular refers to something built or organized from independent units. As noted in McKinsey and Company's Modular Construction: From Projects to Products report[15], construction has lagged when compared to other sectors in productivity performance for decades. Today a paradigm shift is taking place, and many aspects of construction are transitioting from traditional on-site projects to off-site fabrication-style production. Modular construction is not a new concept, but it is attracting a new wave of interest and investment thanks to changes in the technological and economic environment. This way of building is part of a subset of the ADU industry where on-site installation time is the differentiating factor from other prefabricated ADUs that are not necessarily based on a modular system. Most of the companies that offer this system use pre-sized modules that can be connected to each other, generating different configurations. For the purposes of this thesis we will be treating the individual components of this construction such as the panels, the beams, the purlins as the modular elements from which we will desing the prototype.

15 Construction from Projects to Products, McKinsey_Modular (2019)

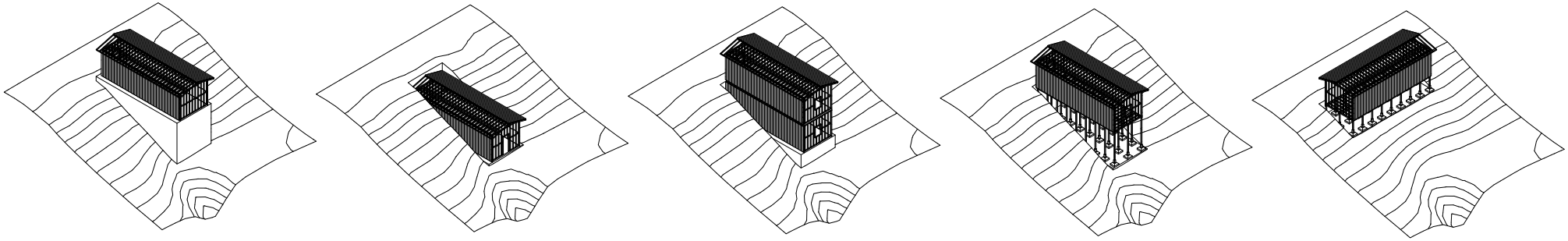


FIG. 7. Adaptabilty of a light frame ADU on a hillside (left to right). 1) Concrete retaining walls over the slope. 2) Concrete retaining walls in the hillside. 3) Concrete platform and retaining walls with a second level. 4) Concrete retaining walls and base and post foundation system. 5) Concrete retaining walls and base and post foundation system rotating the ADU by the Author.

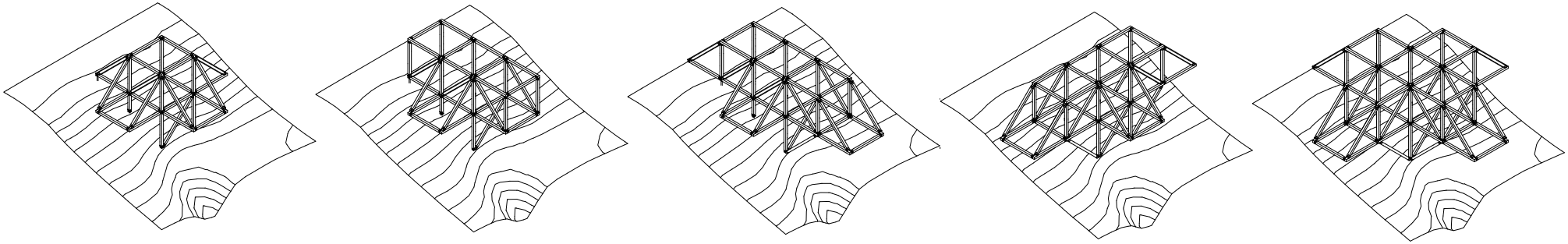


FIG. 8. Adaptabilty of a Mass Timber ADU with a exo skeleton GLT structure (left to right). 1) the module 14'x 14' over the hillside. 2)The module increases in one direction. 3) The module takes advantage of diagonal beams to have more support over the hillside. 4) The module increases in the oposite direction. 5) The module increases in both directions, by the Author.

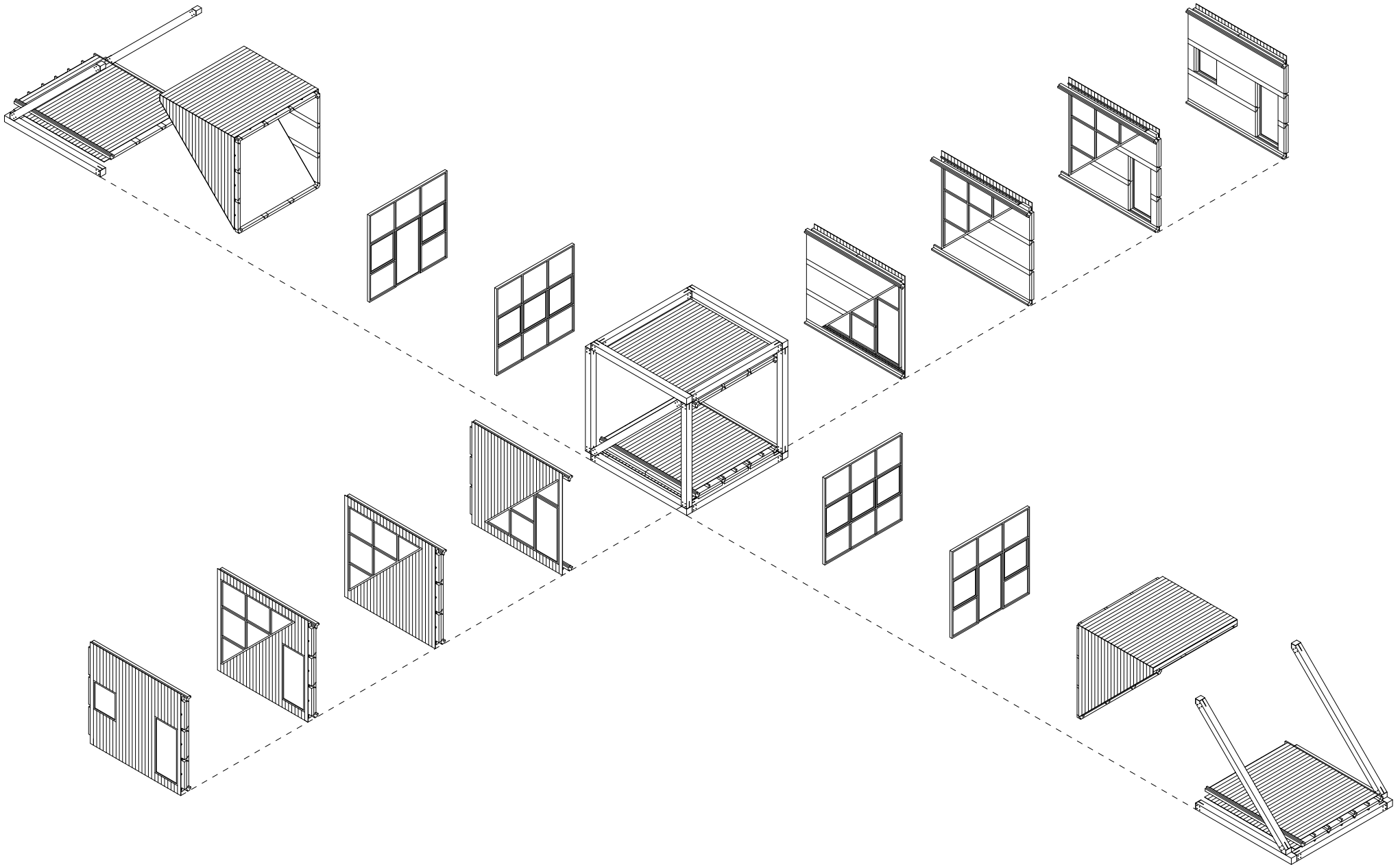


FIG. 9. Prefab panels variations. The panels could be assembled on site or previously in a warehouse. The diagonal beams allow to create diferent openings in relation with the main structure, by the Author.

05 CASE STUDY

Prefab Mass Timber Modular ADU
Prototype Adaptable to the Steep
Hillsides of Southern California

SITE

The proposed site (Fig. 10) is part of Climate Zone 7 that is the southernmost coastal region of California (see Appendix A). The warm ocean water and latitude make this climate very mild. The temperature of the ocean water affects the air temperature over it, and this in turn moderates temperatures over the coastal strip.

The ocean influences the weather most of the time, however the wind changes sometimes, bringing in the hot and extremely drying Santa Ana winds. The weather in the summer is warm and comfortable, but hot enough that cooling is necessary on some days.

However, daily high fogs naturally cool the area at night. The winters are cool and heating is necessary sometimes. The weather and comfort standards in this region are in concurrence as shown by the low consumption of energy use[16].

The life cycle of a Mass Timber ADU (Fig. 19)

16 The Pacific Energy Center's Guide to: California Climate Zones. https://www.pge.com (Accessed July 2022)

FIG. 10. Conceptual Map of Southern California, GIS Geography.

PROTOTYPE

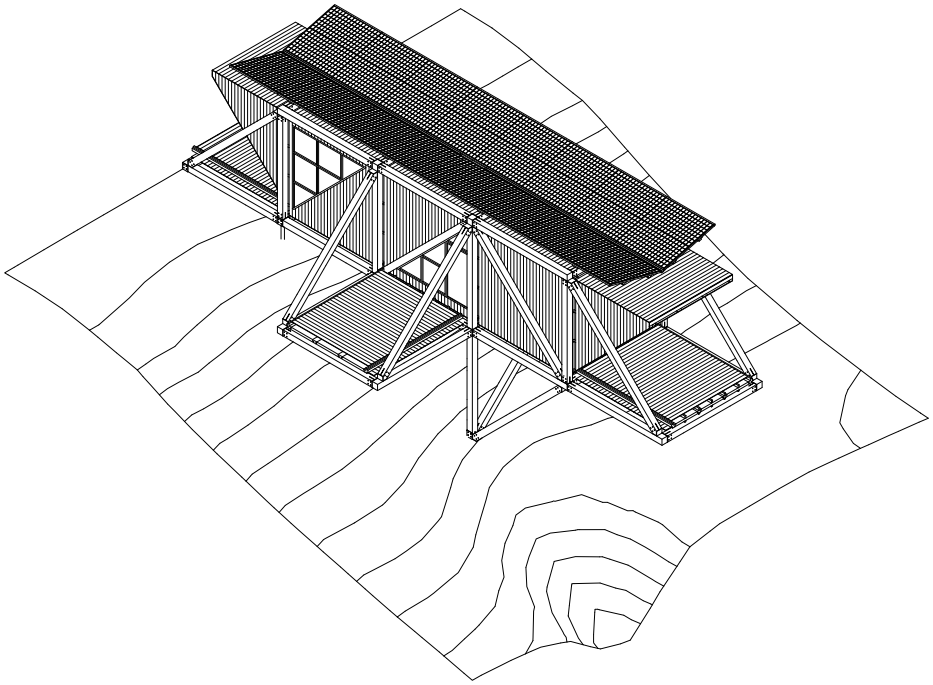


FIG 11. Prrefab Mass Timber Isometric View, by the Author.

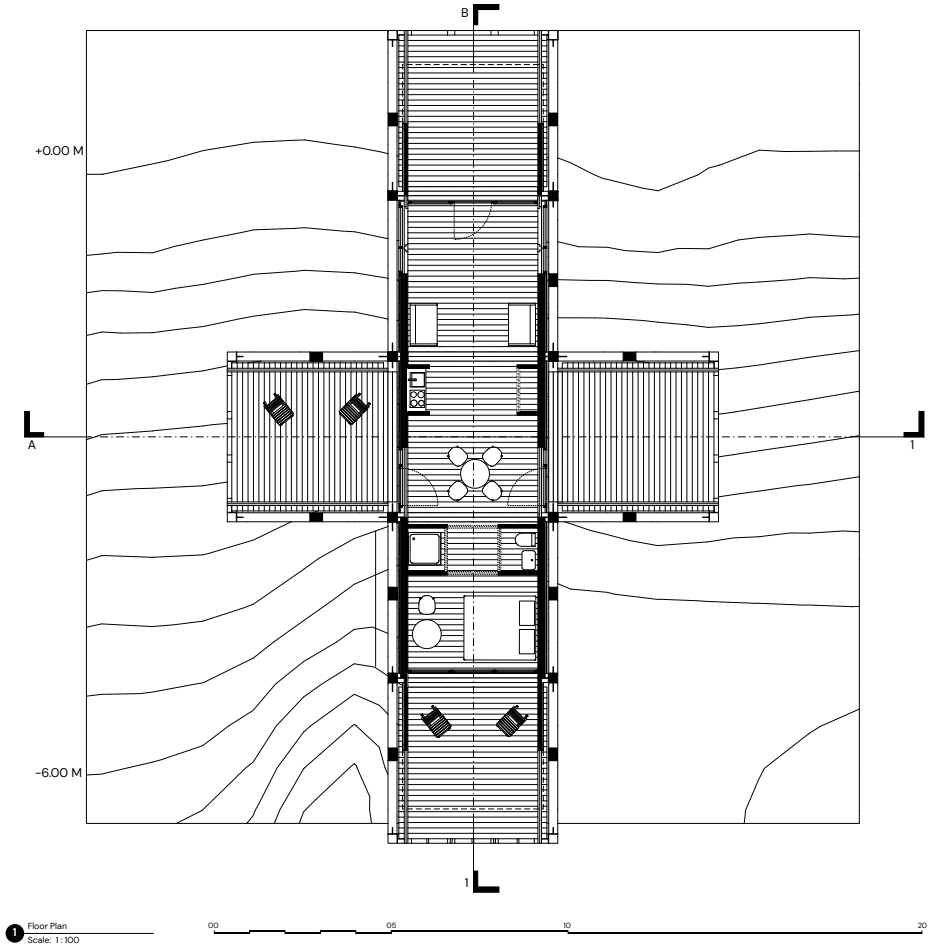
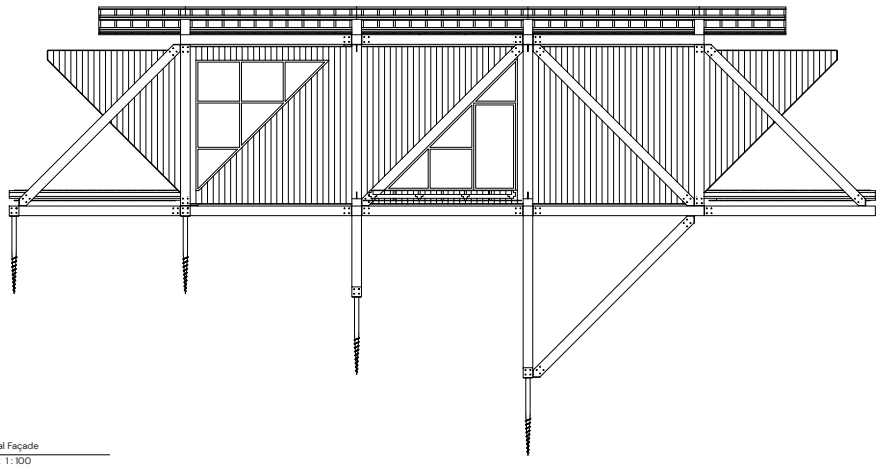
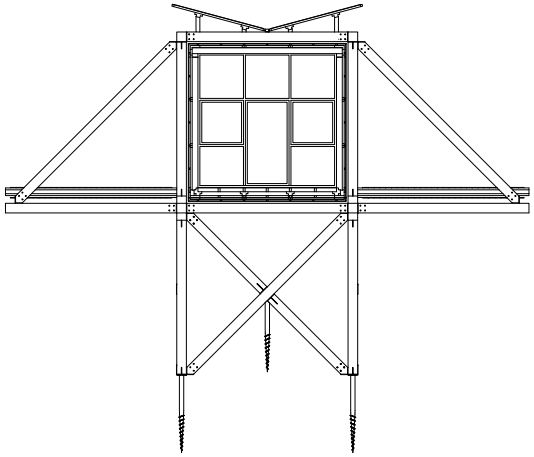


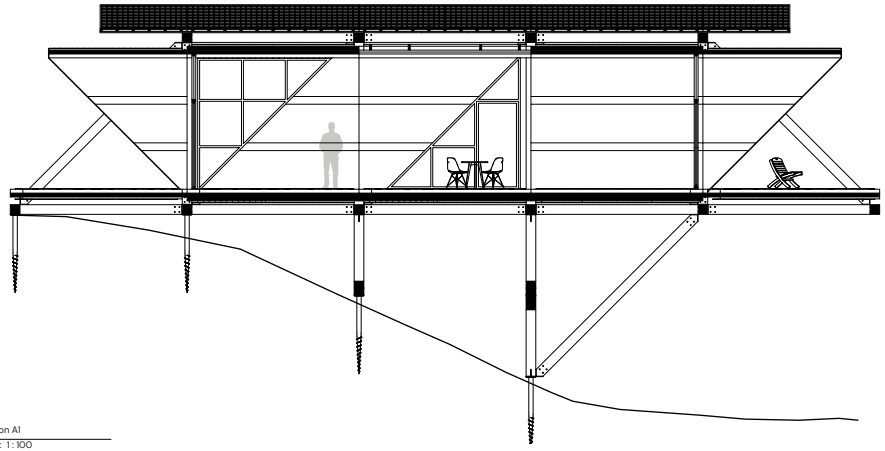
FIG. 12. Prefab Mass Timber ADU Plans, by the Author.



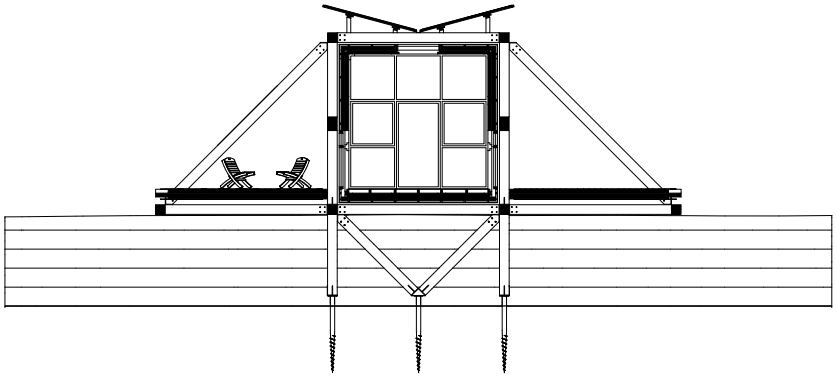
2 Lateral Façade
Scale: 1 : 100



3 Front Façade
Scale: 1 : 100



4 Section A1
Scale: 1 : 100



5 Section B1
Scale: 1 : 100

FIG. 13. Prefab Mass Timber ADU Plans, by the Author.

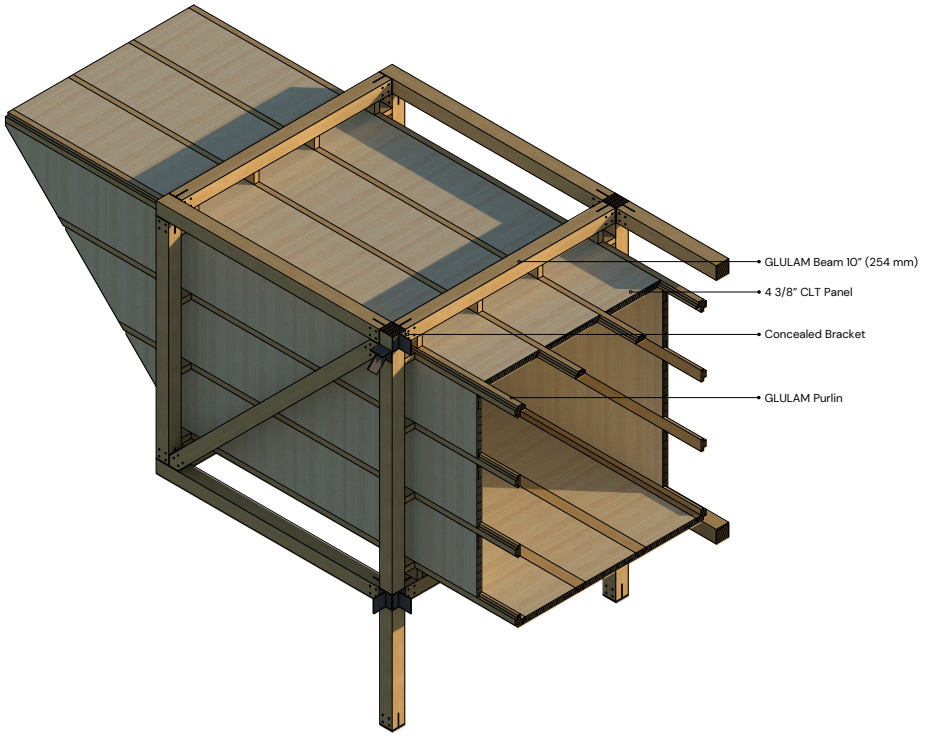


FIG. 14. Constructive Detail, by the Author.

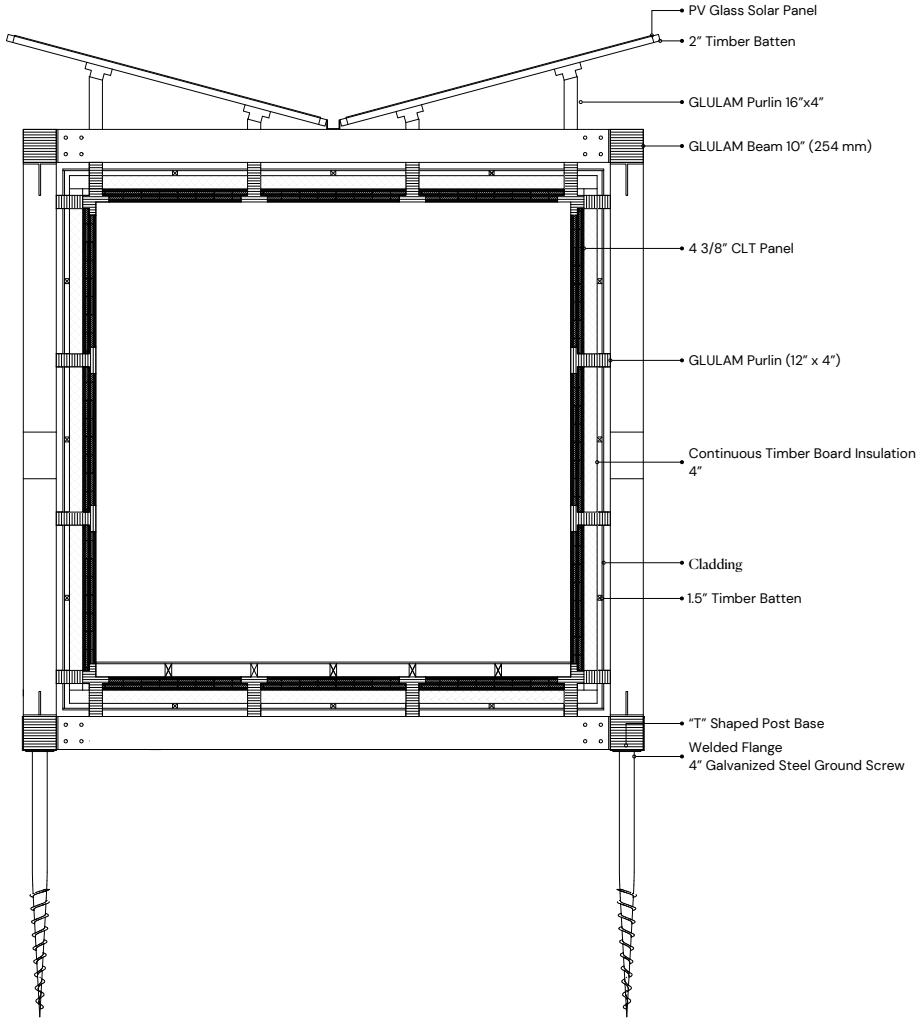


FIG. 15. Detail 1:20, by the Author.

1:50 BASS WOOD SCALE MODEL

FIG. 16. Conceptual Model to demonstrate the adaptability of the Prototype to be built in different terrain conditions.

1:50 BASS WOOD SCALE MODEL

FIG. 17. The model was built following a similar proccess to the proposed real life methodology. The exo skeleton structure was built first, and then the purlins were attached to the structure. Finally the panels were glued together with two layers to generate the section that fits in the proposed notch.

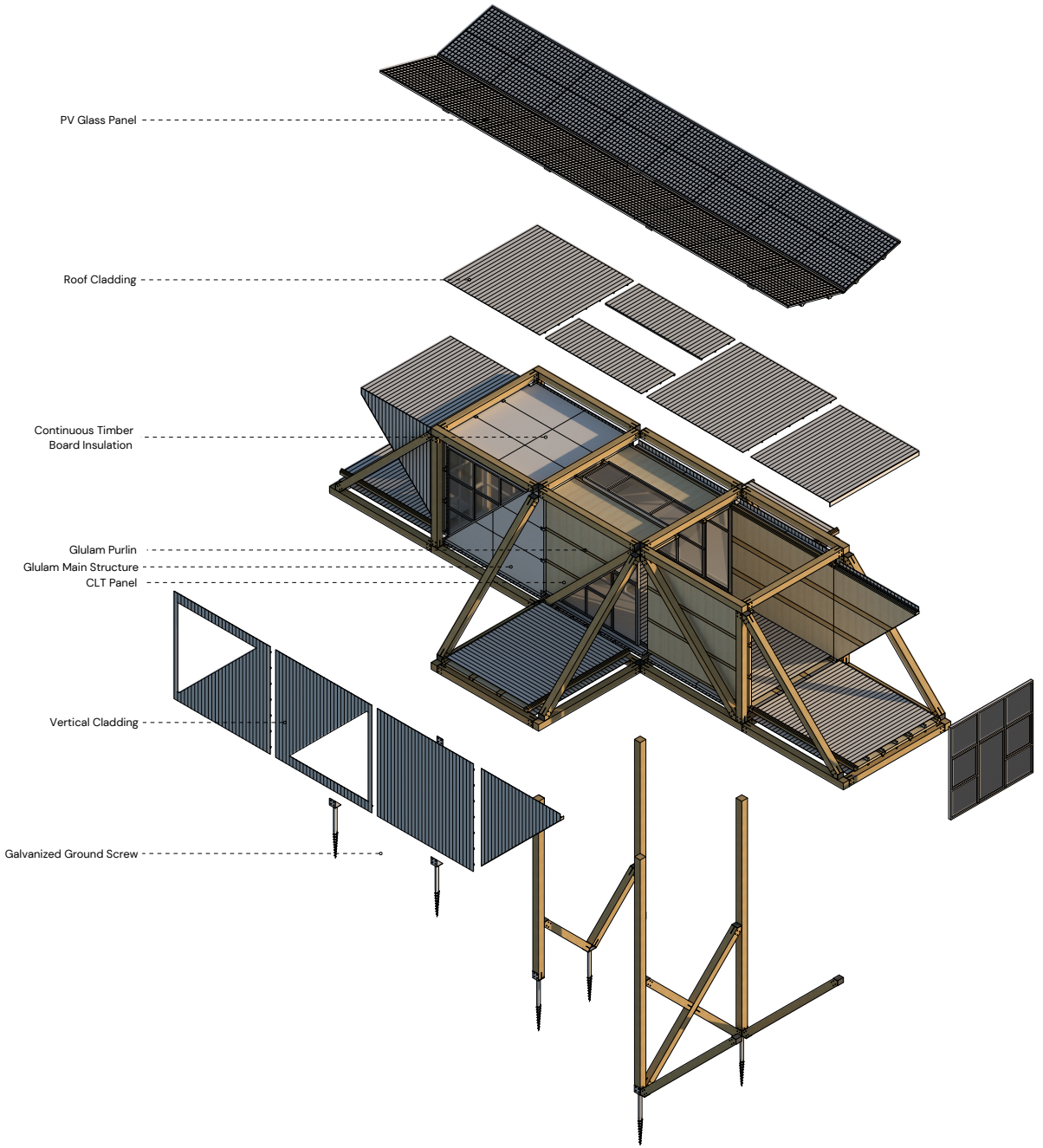


FIG. 18. Prefab Mass Timber ADU Structure, by the Author.

06 LIFE CYCLE ASSESMENT

LIFE CYCLE ASSESMENT OF A MASS TIMBER ADU

starts in the Certified Forests[17] which, acting as a biobase resource, capture and store carbon. These have to be managed sustainably for the people and the planet. The raw material is processed into Mass Timber, which will be incorporated as a material in the architectural design elements and in the construction design system. In the first design phase, the architect, the owner, the structural designer, and the different engineering specialties work together. The first ADU built is the first use of timber in the proposed cycle, which throughout its life will generate emissions and at the same time store carbon in its structure. At the end of its life cycle it will be dismantled, and the timber can be disposed of as Cross Laminated Secondary Timber (CLST)[18]. Later this CLST will be collected as waste, and can be recycled as secondary raw material. After that, it will be processed as biomass energy and the emissions will be captured by the forests, closing the cycle, while the waste could be treated as compost for the forests.

17 "Business contribution to the Circular Bioeconomy Forests and the circular economy session". UNECE. WBSCD, 2019.
18 Rose, Colin. Systems for Reuse, Repurposing and Upcycling of Existing Building components. University College London, 2019, p. 150.

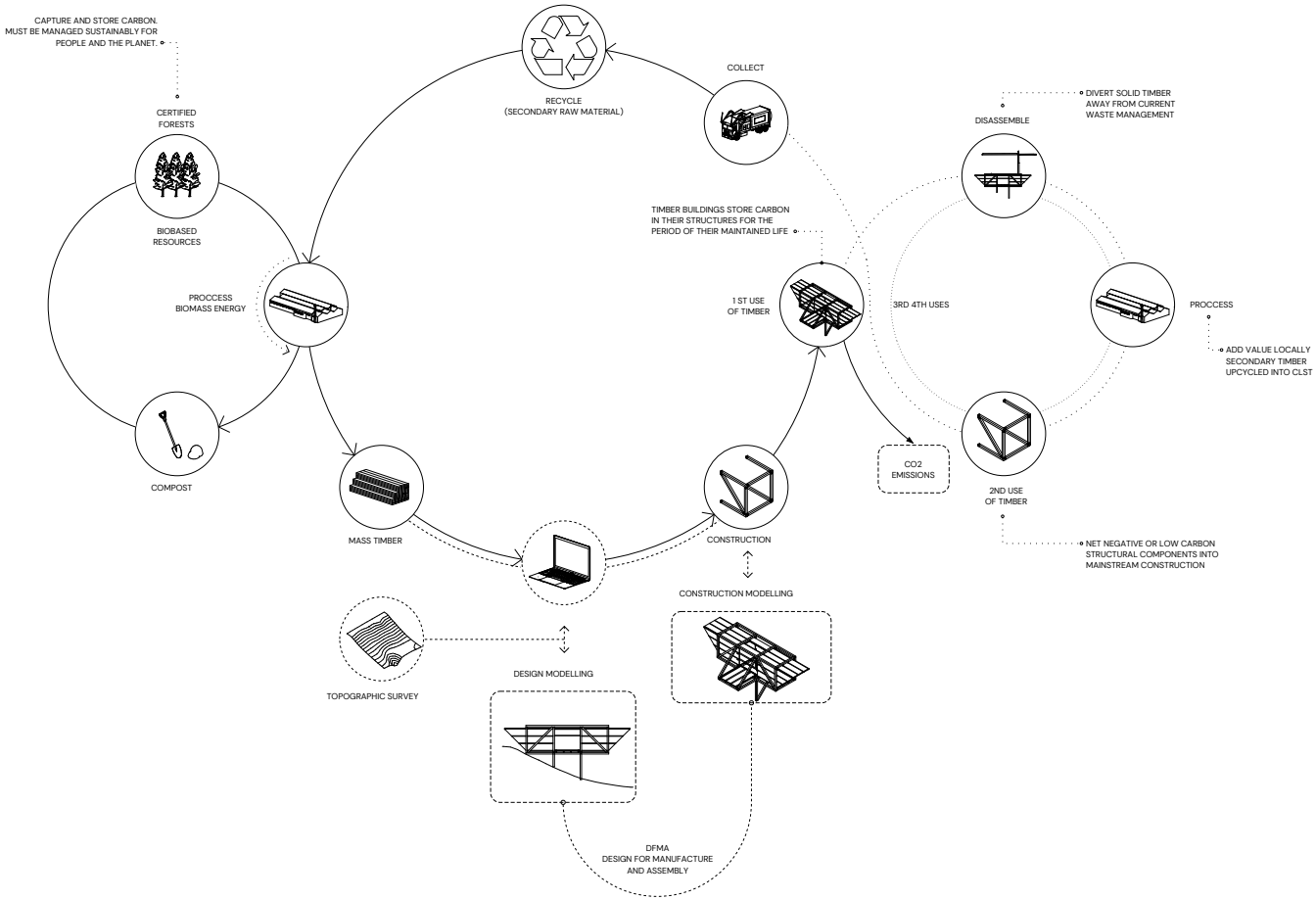


FIG. 19. Life Cycle Assessment of a Mass Timber ADU, by the Author.

QUANTITATIVE ANALYSIS

The Prefab Mass Timber ADU protoype was analyzed to quantify the amount of CO2 stored in it (see Appendix B), and compared with the light frame ADU. The analyzed components are the structure, the foundation, and the insulation (Fig. 20). The R value was taken into account (see Appendix C) to evaluate the performance of both ADUs as well as the variation of CO2 emissions depending on the insulation of each case.

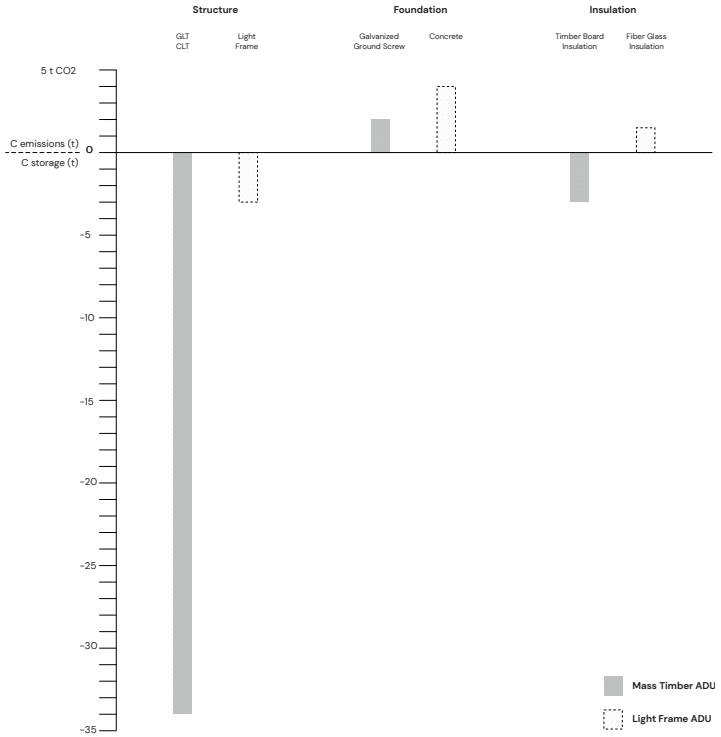


FIG. 20. Comparission of CO2 emissions and CO2 storage of a light frame ADU and a Mass Timber ADU, by the Author

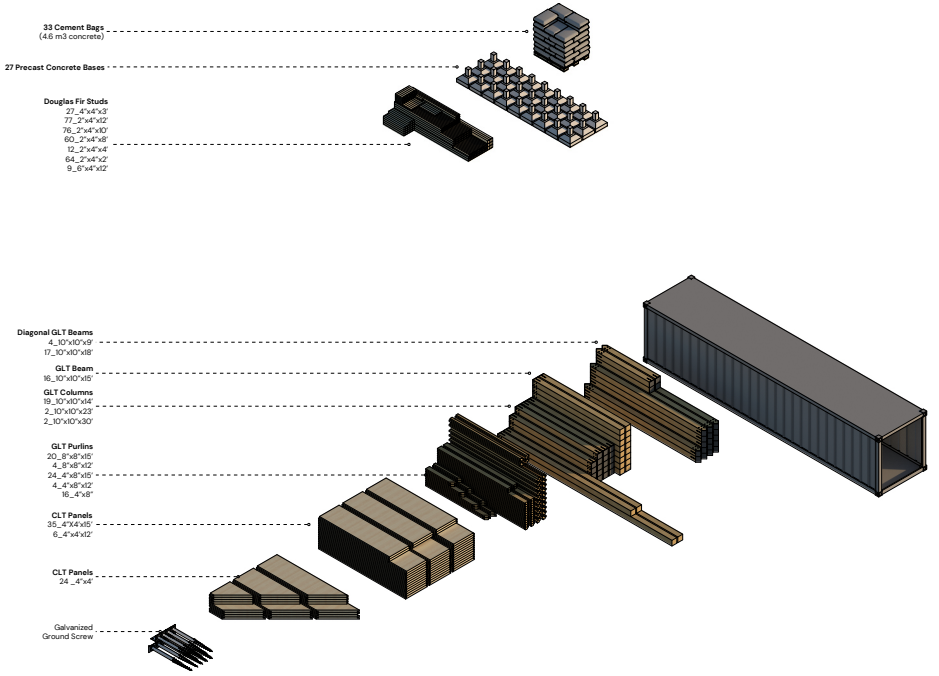


FIG. 21. Quantitative Analysis of a light frame ADU and a Mass Timber ADU, by the Author.

07 CONCLUSIONS

CONCLUSION

In a state with an alarming housing crisis, the solution does not lie in generating more developments further away from the city centers, which in turn require more cars and more access freeways. Investing in density in existing cities is now an option with recently passed laws that allow ADUs to be built on land with existing houses that meet a certain minimum requirement.

Building ADUs with light timber frame system is a viable option, but all the advantages that a Mass Timber ADU can offer is a much better solution. The carbon storage is greater, while also providing the benefits of a natural wood interior for the occupant. Greater speed and cleanliness at the time of assembly as well as less construction noise compared to the traditional timber frame system are additional advantages.

The varied topography of Southern California requires practical and fast solutions to build ADUs. The system proposed in this thesis tests the construction of an ADU that can be easily installed on any terrain, and allows it to be expanded according to the needs of the occupant. At a time when carbon absorption is so important due to the global warming crisis, building with Mass Timber ensures carbon is stored for a long time.

The first Master in Mass Timber Design cohort is part of a generation of architects that faces serious challenges, and that must find solutions to existing problems before it is too late. Paraphrasing R. Buckminster Fuller, “You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.” The difference is that this time the new model already existed, and its development was stopped suddenly last century. It is time to look back and make use of the solutions we already have at our dispossal to meet the demands of tomorrow.

FIG. 22. Perspective view of the proposed Mass Timber ADU by the Author.

FIG. 23. Interior viewof the Mass Timber ADU by the Author.

08 Methods

METHODS

1. OPAQUE 3 | Society of Building Science Educators
2. The Construction Material Pyramid |CINARK – Centre for Industrialised Architecture
3. SKETCHUP | Trimble Version 22.0.353
4. LAYOUT | Trimble Version 22.0.353
5. Pre Design | Trimble Version 22.0.353
6. Numbers | Apple Inc. version 12.1
7. Lumion Student Version 12.5 Pro
8. Calculator - Fast + Epp

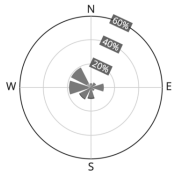
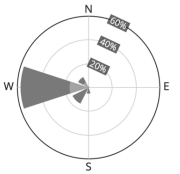
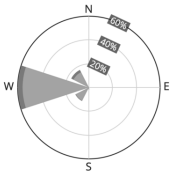
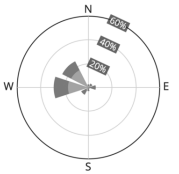
09 References

REFERENCES

1. California Real State Market, https://www.realtor.com/realestateandhomes-search/California/overview (accessed April 2022)
2. California's Housing Crisis - UCLA Newsroom, accessed April 2022, https://newsroom.ucla.edu/magazine/california-housing-crisis-solutions (accessed April 2022)
3. California Department of Housing and Community Development - ADUs. https://www.hcd.ca.gov/policy-research/accessorydwellingunits.shtml (accessed April 2022).
4. Cottage https://www.cotta.ge/resources/2021-07-15-adu-pre-approval-plans-is-it-right-for-you (accessed July 2022)
5. LA County Pre-Approved ADU's. https://ladbs.org/adu/standard-plan-program/approved-standard-plans/ (accessed July 2022).
6. Blessing L., Chakrabarti A., DRM, a Design Research Methodology, 2009 (Springer-Verlag London Limited)
7. Structural Wood Building Systems, Thin Wood. https://www.thinkwood.com/continuing-education/structural-wood-building-systems-choosing-right-material (accessed July 2022)
8. Accesory Dwelling Units, California Department of Housing and Community Development. https://www.hcd.ca.gov/accessory-dwelling-units (accessed April 2022)
9. Structural Wood Building Systems, Thin Wood. https://www.thinkwood.com/continuing-education/structural-wood-building-systems-choosing-right-material (accessed July 2022)
10. Sturdy, strong and sustainable: Mass timber's popularity grows in Pacific Northwest, https://www.registerguard.com/story/news/environment/2021/12/15/mass-timber-popularity-growing-oregon-pacific-northwest-cross-laminated-timber/8910241002/ (accessed April 2022)
11. Watershed Structures, https://www.watershedstructures.com/ (accessed April 2022)
12. Designing Sustainable Prefabricated Wood Buildings. Think Wood CEU (2008)
13. Abodu. https://abodu.com (accessed April 2022)
14. PrefabADU. https://www.prefabadu.com (accessed April 2022)
15. Construction from Projects to Products, McKinsey_Modular (2019)
16. The Pacific Energy Center's Guide to: California Climate Zones. https://www.pge.com (Accessed July 2022)
17. "Business contribution to the Circular Bioeconomy Forests and the circular economy session". UNECE. WBSCD, 2019
18. Rose, Colin. Systems for Reuse, Repurposing and Upcycling of Existing Building components. University College London, 2019, p. 150.

10 Appendices

APPENDIX A

	Dec 21 to Mar 20 Winter – cool, dry Typically fine	Mar 21 to Jun 20 Spring – pleasant, dry Fine to dull and dreary	Jun 21 to Sep 20 Summer – warm, dry Frequently glorious	Sep 21 to Dec 20 Fall – pleasant, dry Glorious to fine
Weather	Avg min 10°C Avg max 18°C Usually breezy Occasionally calm, rarely strong winds Meaningful precipitation (184 mm over 19 days) No snow	Avg min 14°C Avg max 20°C Mainly breezy Occasionally calm, rarely strong winds Very low precipitation (27 mm over 5 days) No snow	Avg min 18°C Avg max 25°C Overwhelmingly breezy Rarely calm or strong winds Negligible precipitation No snow	Avg min 13°C Avg max 22°C Usually breezy Sometimes calm, rarely strong winds Negligible precipitation (4 mm over 2 days) No snow
Impact of Wind	 Calm 19% hrs	 Calm 10% hrs	 Calm 9% hrs	 Calm 23% hrs

APPENDIX B

THE CONSTRUCTION MATERIAL PYRAMID

THE DETAIL IS CRUCIAL

Build Better! – Make your own pyramid

choose materials in the pyramid (click) to include them in the calculation.
See the data used for the materials by double-clicking on the material in the pyramid.

show result in pyramid ↑	reset calculation	type project name		m^2		

	material	group	impact / m3	volume [m3]	area [m2]	thickness [mm]	result
1	Glulam	trae	-610.0 kg CO2eq/m3	25.95 m3	m2	mm	-15,829.5 kg $CO_{2\ eq}$
2	Cross-laminated-timber CLT	trae	-644.0 kg CO2eq/m3	27.97 m3	m2	mm	-18,572.1 kg $CO_{2\ eq}$
3	Wood fibre insulation	biobaseret	-173.1 kg CO2eq/m3	18.48 m3	m2	mm	-3,198.9 kg $CO_{2\ eq}$
4	Galvanised steel	metal	22923.1 kg CO2eq/m3	.09 m3	m2	mm	2,063.1 kg $CO_{2\ eq}$

-35,537.4 kg $CO_{2\ eq}$

Build Better! – Make your own pyramid

choose materials in the pyramid (click) to include them in the calculation.
See the data used for the materials by double-clicking on the material in the pyramid.

show result in pyramid ↑	reset calculation	type project name		m^2		

	material	group	impact / m3	volume [m3]	area [m2]	thickness [mm]	result
1	Construction timber	trae	-680.0 kg CO2eq/m3	4.01 m3	m2	mm	-2,726.8 kg $CO_{2\ eq}$
2	Concrete C30/37	mineralsk	288.0 kg CO2eq/m3	9.3 m3	m2	mm	2,678.4 kg $CO_{2\ eq}$
3	XPS insulation	kunststof	96.3 kg CO2eq/m3	9.72 m3	m2	mm	936.0 kg $CO_{2\ eq}$
4	Structural steel	metal	8831.2 kg CO2eq/m3	.1395 m3	m2	mm	1,232.0 kg $CO_{2\ eq}$

2,119.6 kg $CO_{2\ eq}$

Det Kongelige Akademi
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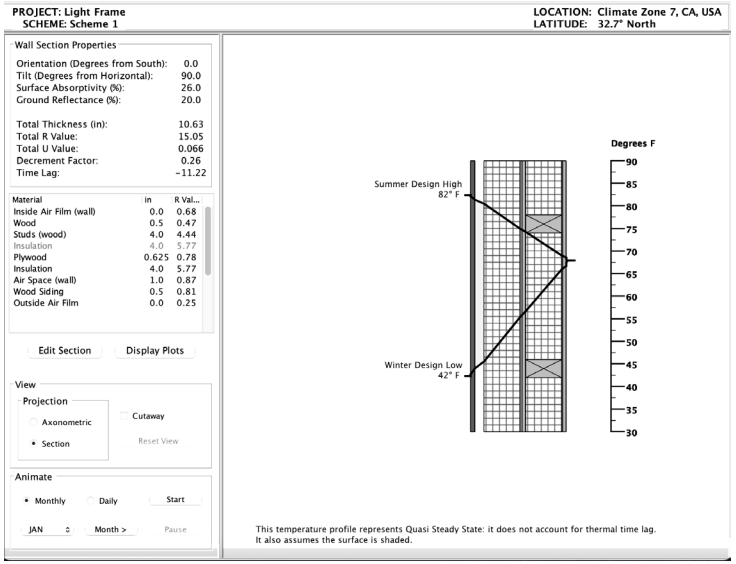
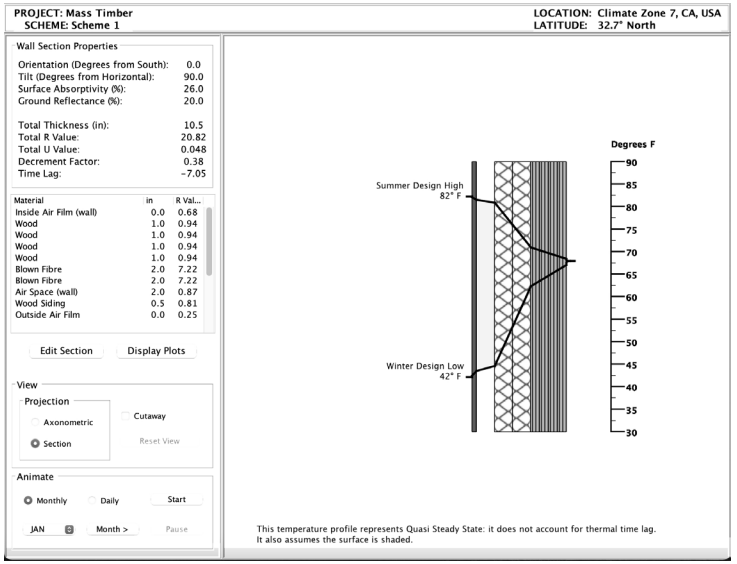
The Construction Material Pyramid

Project group:
CINARK by Anne Beim, Ulrik Stylsvig Madsen, Line Kjær Frederiksen, Julie Zepernick Jensen, Tone Ida Vecht
Contact person: Pelle Munch-Petersen
Vandkunsten Architects by Jan Schipull Kauschen, Amal El-Khatib, Michael Granby-Larsen, Nanna Larsson
Professional sparring:
Kristoffer Tejlgaard, Atelier Kristoffer Tejlgaard
Lisa Ellehrim and Jan Bostrom, Sundahus (health risks)
Supported by: Boligfonden Kuben

APPENDIX C


PROJECT: Light Frame
SCHEME: Scheme 1
LOCATION: Climate Zone 7, CA, USA
LATITUDE: 32.7° North
Wall Section Properties
Orientation (Degrees from South): 0.0
Tilt (Degrees from Horizontal): 90.0
Surface Absorptivity (%): 26.0
Ground Reflectance (%): 20.0
Total Thickness (in): 10.63
Total R Value: 15.05
Total U Value: 0.066
Decrement Factor: 0.26
Time Lag: -11.22
Material in R Val...
Inside Air Film (wall) 0.0 0.68
Wood 0.5 0.47
Studs (wood) 4.0 4.44
Insulation 4.0 5.77
Plywood 0.625 0.78
Insulation 4.0 5.77
Air Space (wall) 1.0 0.87
Wood Siding 0.5 0.81
Outside Air Film 0.0 0.25
Edit Section
Display Plots
View
Projection
Axonometric
Section
Cutaway
Reset View
Animate
Monthly
Daily
Start
JAN
Month >
Pause
Degrees F
90
85
80
75
70
65
60
55
50
45
40
35
30
Summer Design High 82° F
Winter Design Low 42° F
This temperature profile represents Quasi Steady State: it does not account for thermal time lag.
It also assumes the surface is shaded.


PROJECT: Mass Timber
SCHEME: Scheme 1
LOCATION: Climate Zone 7, CA, USA
LATITUDE: 32.7° North
Wall Section Properties
Orientation (Degrees from South): 0.0
Tilt (Degrees from Horizontal): 90.0
Surface Absorptivity (%): 26.0
Ground Reflectance (%): 20.0
Total Thickness (in): 10.5
Total R Value: 20.82
Total U Value: 0.048
Decrement Factor: 0.38
Time Lag: -7.05
Material in R Val...
Inside Air Film (wall) 0.0 0.68
Wood 1.0 0.94
Wood 1.0 0.94
Wood 1.0 0.94
Wood 1.0 0.94
Blown Fibre 2.0 7.22
Blown Fibre 2.0 7.22
Air Space (wall) 2.0 0.87
Wood Siding 0.5 0.81
Outside Air Film 0.0 0.25
Edit Section
Display Plots
View
Projection
Axonometric
Section
Cutaway
Reset View
Animate
Monthly
Daily
Start
JAN
Month >
Pause
Degrees F
90
85
80
75
70
65
60
55
50
45
40
35
30
Summer Design High 82° F
Winter Design Low 42° F
This temperature profile represents Quasi Steady State: it does not account for thermal time lag.
It also assumes the surface is shaded.