Design for disassembly and reuse of timber structures

Dr Liam Ottenhaus, The University of Queensland



Image Adobe Stock Educational License

Acknowledgment of **Country**

The University of Queensland (UQ) acknowledges the Traditional Owners and their custodianship of the lands on which we meet.

We pay our respects to their Ancestors and their descendants, who continue cultural and spiritual connections to Country.

We recognise their valuable contributions to Australian and global society.





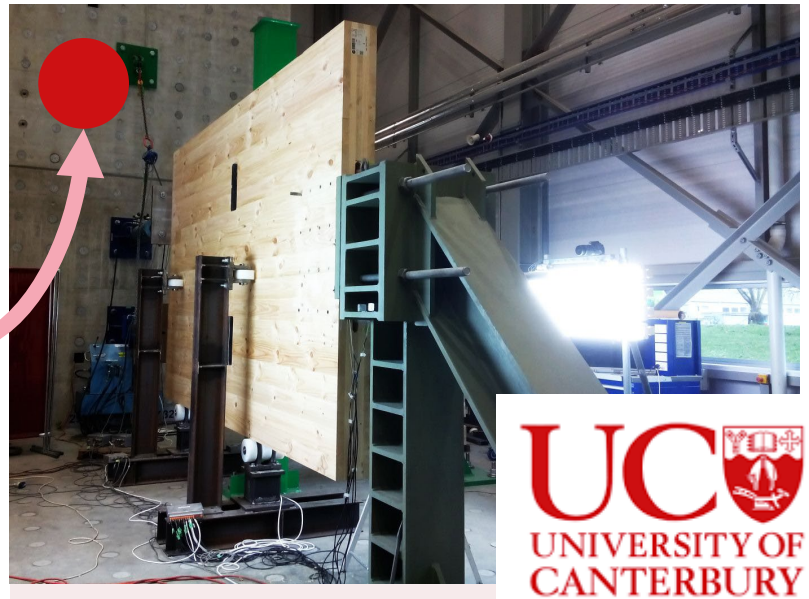
Karlsruher Institut für Technologie

2009-2012 Bachelors



2012-2015 Masters

TU Delft Delft University of Technology



2015-2019 PhD

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND



THE UNIVERSITY OF QUEENSLAND AUSTRALIA



ADVANCE TIMBERHUB

2019-today: Senior lecturer structural timber engineering



The Problem

Average **building age** at time of demolition

Australia 40-60 years

Europe 30-60 years

National Heritage Resources Act

South Africa > 60 years

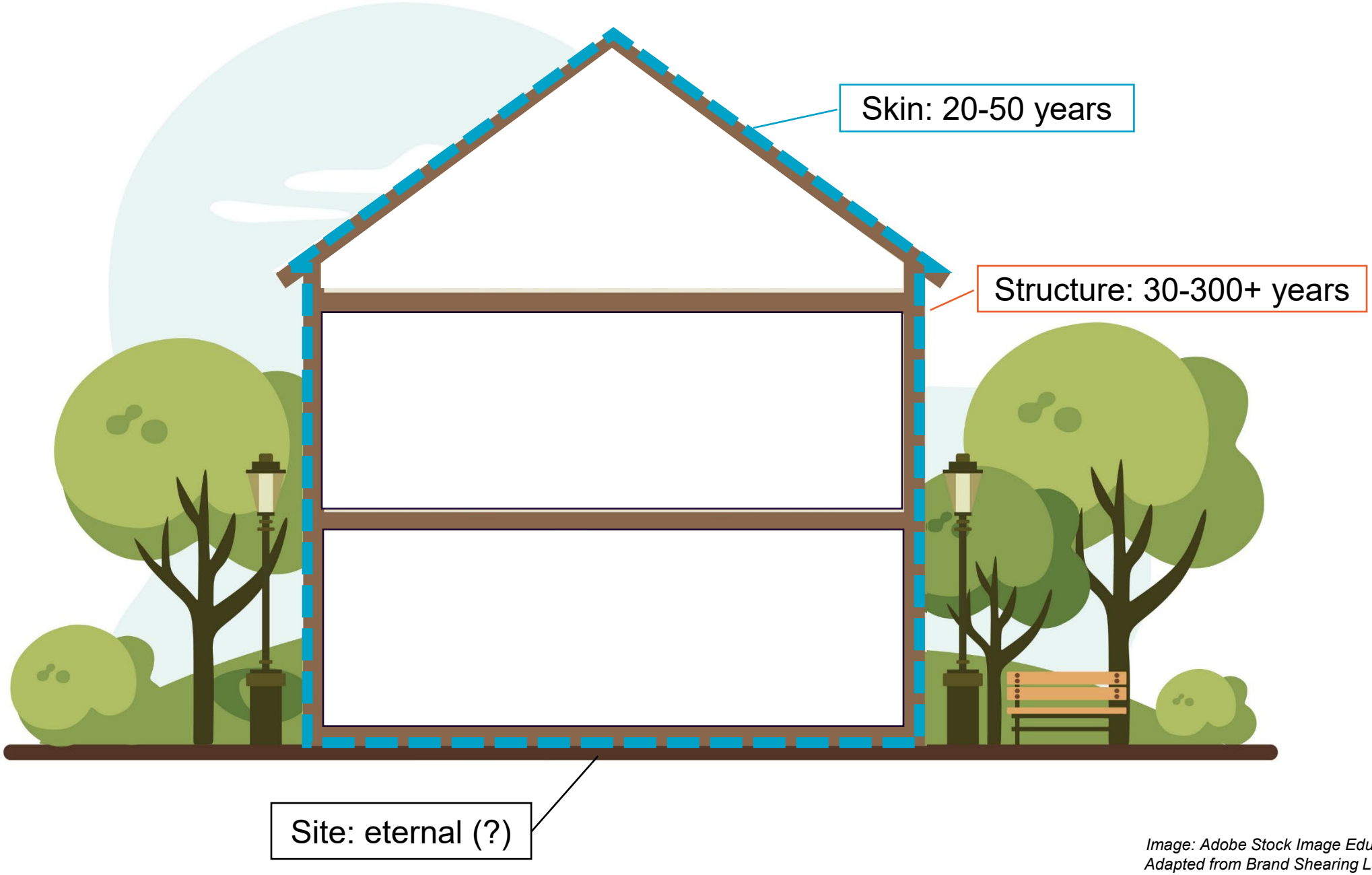


Image: Adobe Stock Image Educational License
Adapted from Brand Shearing Layers of Change
Source: Huuhka, S., & Lahdensivu, J. (2014) Statistical and geographical study on demolished buildings. Building Research and Information 44(1)

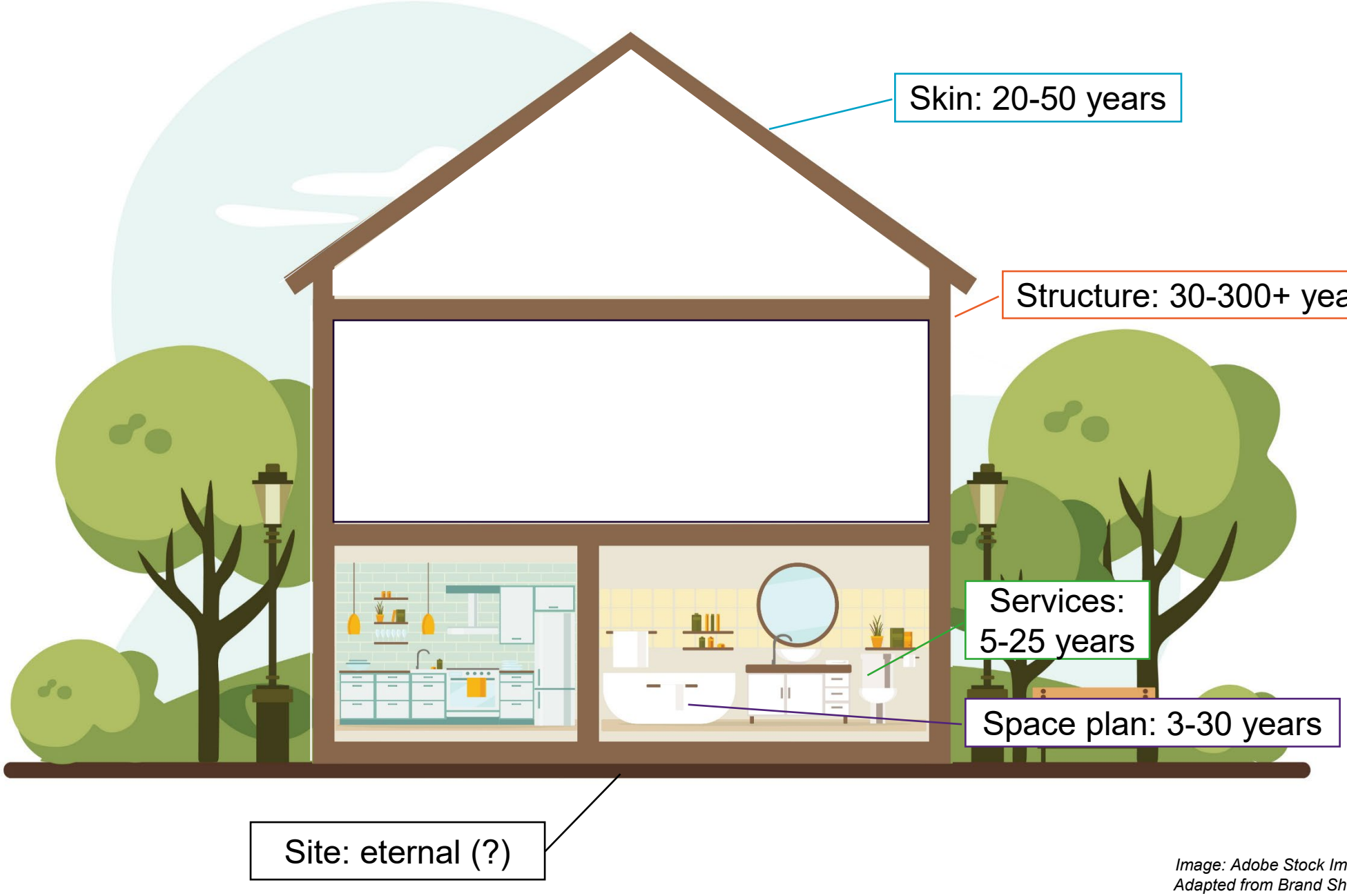


Image: Adobe Stock Image Educational License
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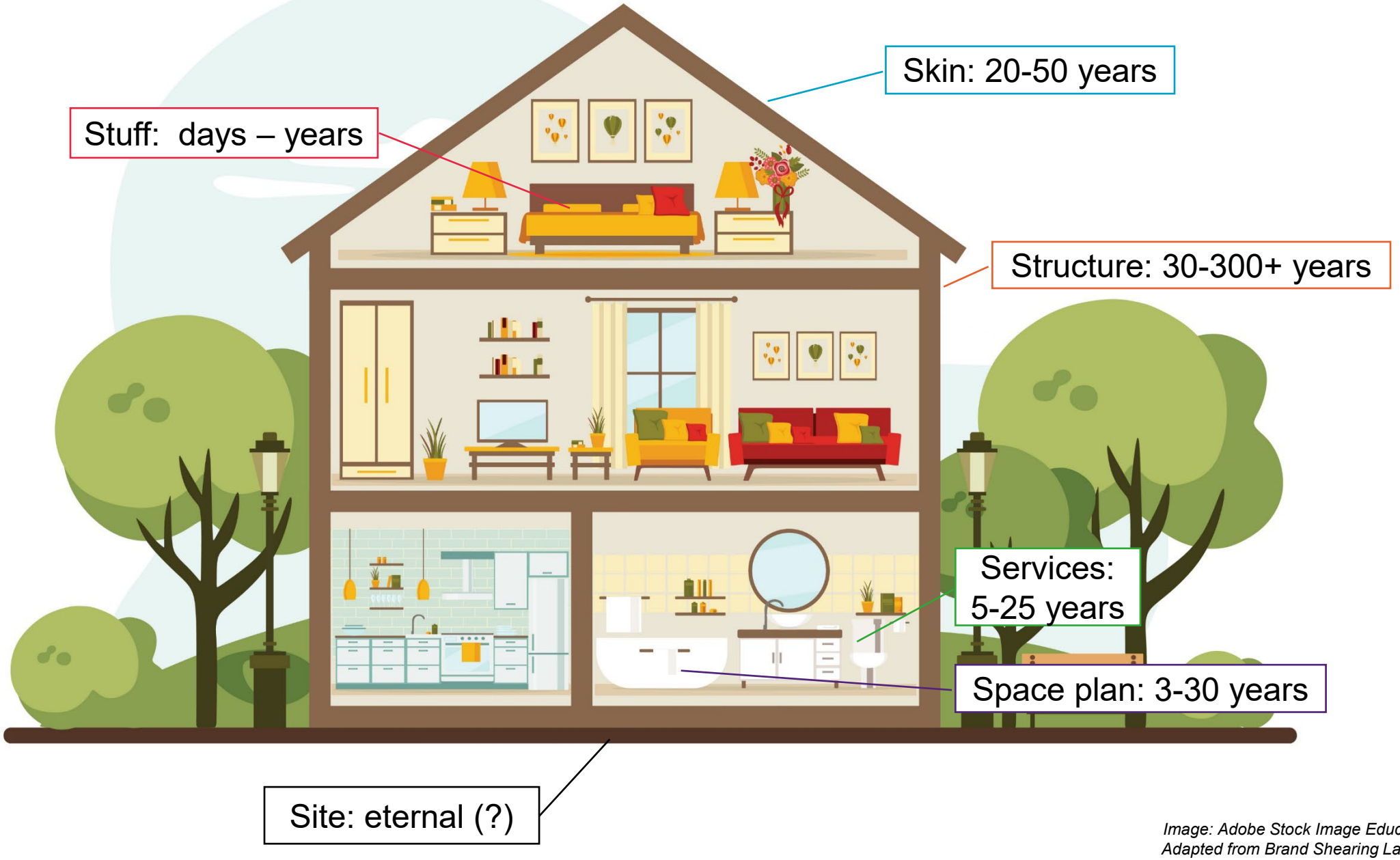


Image: Adobe Stock Image Educational License
Adapted from Brand Shearing Layers of Change
Source: Huuhka, S., & Lahdensivu, J. (2014) Statistical and geographical study on demolished buildings. Building Research and Information 44(1)

Construction and Demolition Waste (CDW)

CDW is **33%** of all waste in the EU, **17%** of Australia's total annual waste.

South Africa generates 5-8 million tonnes of CDW per year (concrete, bricks, soil, metals, plastics, etc.)

In EU countries, **50%** of CDW is recycled, in Australia **76%** of CDW is recycled

In South Africa, **illegal dumping** of CDW is common due to landfill scarcity, 48% of CDW is landfilled.



Less than **47%** of timber waste is recycled in Australia

In Queensland, only **8%** of CDW timber is recycled

In South Africa, CDW is reused and recycled informally.

We have a massive resource, but we are lacking efficient official pathways for reuse & recycling.

Image Adobe Stock Educational License

Maqsood et al. (2019). SBEnrc P1.65 "A National Economic Approach to Improved Management of Construction and Demolition Waste." Research Report 5 Timber Department of Environment & Science (2019) Queensland Waste & Resource Recovery Infrastructure Report European Commission (2018). EU Construction and Demolition Waste Protocol and Guidelines. https://www.timberbiz.com.au/25-million-tonnes-of-waste-wood-in-europe-every-year/

Ichebadu G. Amadi, Jeffrey Mahachi, State-of-the-art review on construction and demolition waste: The South African context, Cleaner Waste Systems, Volume 11, 2025, 100251, https://doi.org/10.1016/j.clwas.2025.100251

S. Berge, H. von Blottnitz (2022). An estimate of construction and demolition waste quantities and composition expected in South Africa, South Afr. J. Sci. (2022), 10.17159/sajs.2022/12485

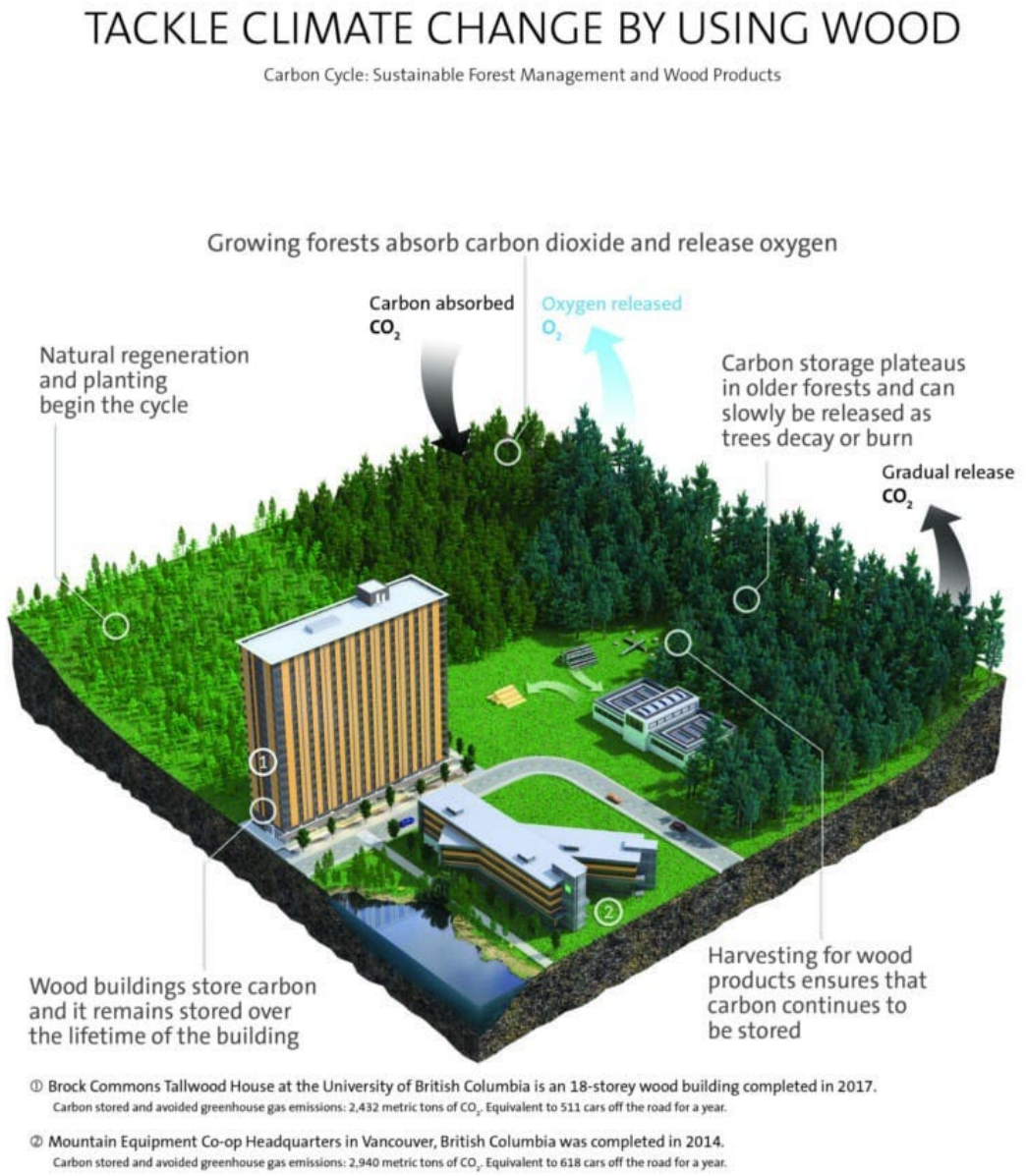
Carbon cycle

Timber is a renewable sustainable material.

Durable wood products store carbon while in use.

The longer you can keep timber buildings and components in use, the longer the carbon storage.

In conventional construction most timber waste is recycled / chipped / burned, but little of it is reused.



Source: https://www-cycle.nies.go.jp/eng/column/page/202303_01.html **naturallywood.com**

Why do this?



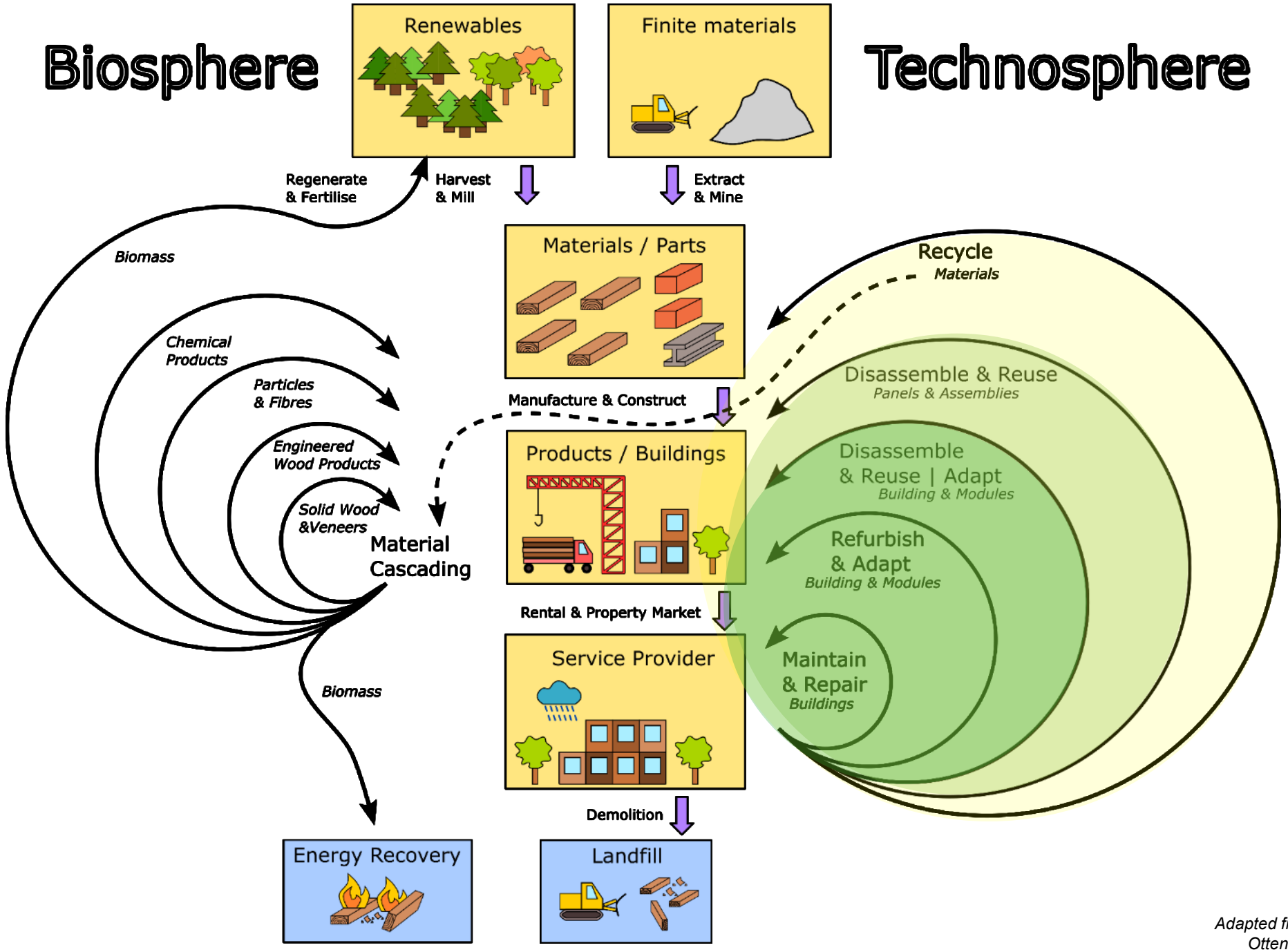


Sources: Department of Environment & Science (2019) Queensland Waste & Resource Recovery Infrastructure Report
Image Adobe Stock Educational License

When we could be doing this?

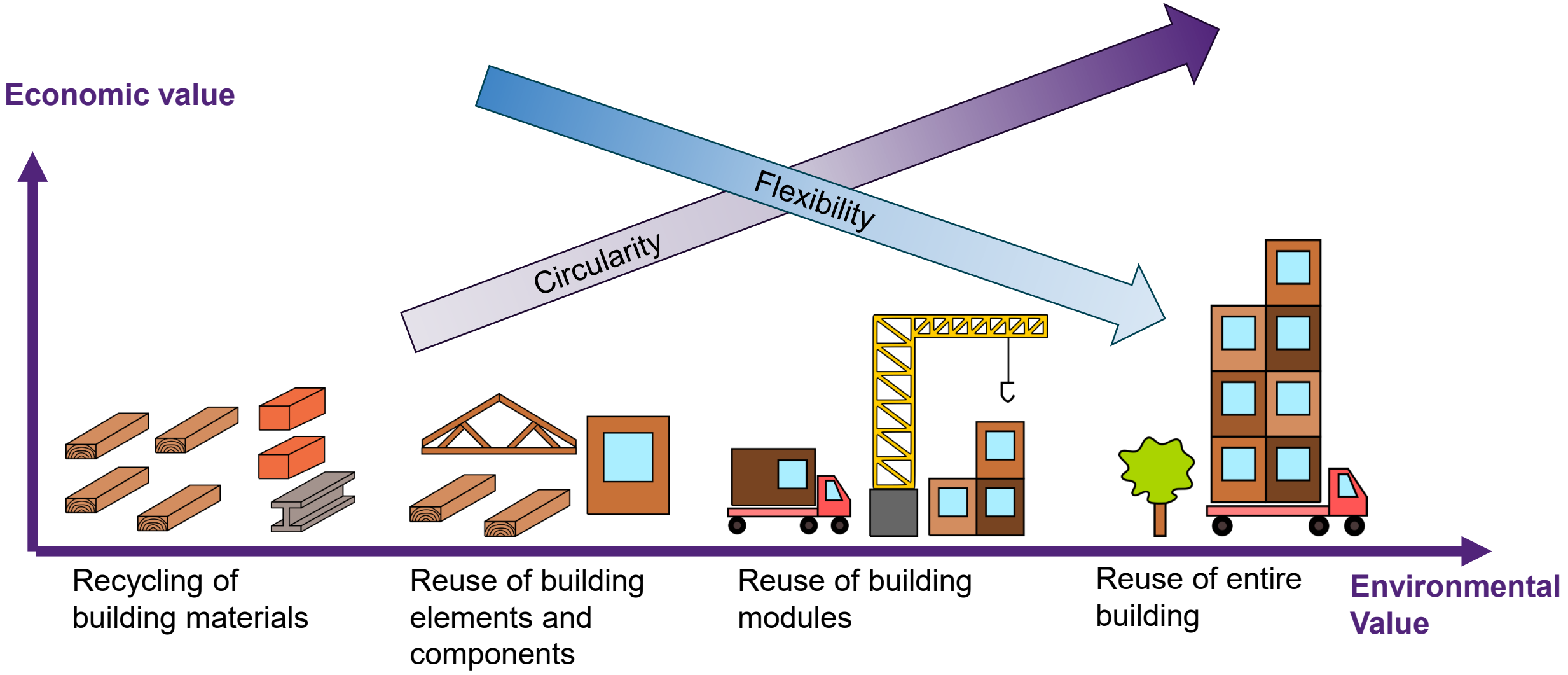


Photo taken at Ironwood Australia



Adapted from Ellen MacArthur Foundation's Butterfly Diagram
Ottenhaus (2022) "Butterfly Diagram of Circular Building."
https://doi.org/10.6084/m9.figshare.21249573.v1.

Reuse of buildings & materials



Based on Eberhardt, Leonora & Birgisdottir, Harpa & Birkved, Morten. (2019). Potential of Circular Economy in Sustainable Buildings. IOP Conference Series: Materials Science and Engineering. 471. 092051.

History



Image A Victorian home being moved on Steiner Street, 1908, San Francisco
https://www.sfgate.com/local/article/San-Francisco-bizarre-history-of-moving-houses-15803776.php



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AUSTRALIA

Native American Tipi

Image Library of Congress http://hdl.loc.gov/loc.pnp/ppmsc.02515



https://www.messynessychic.com/2018/09/28/the-towns-that-were-moved-by-horses/



https://www.messynessychic.com/2018/09/28/the-towns-that-were-moved-by-horses/

Singapore Cottages, Melbourne, Australia





*"In 1853, […] **15,960 wooden houses** were delivered to Melbourne "*

*"Houses, school buildings, theatres and churches were **ordered from catalogues** and came in a wide variety of materials."*

*"Wooden houses came from **Singapore, India, New Zealand and Europe**."*

*"The portable buildings were brought from places including **Germany, Scotland, England, Singapore** and **Hong Kong**."*



Left: https://www.rbaarchitects.com.au/projects/singapore-cottage/
Right: Jean Edwards, ABC, https://www.abc.net.au/news/2021-04-17/victorian-heritage-building-push/100073818
https://builtoffsite.com.au/emag/issue-01/historic-perspective-everything-old-new/

PORTABLE COLONIAL COTTAGES.

H MANNING, 251 HIGH HOLBORN, respectfully solicits the attention of intending settlers to the high character his COTTAGES have obtained. Their usefulness and superiority of construction, either as stationary or moveable residences, as regards durability, comfort, and the facility with which they may be taken down, removed, and refixed by the most inexperienced, is now fully ascertained and acknowledged. In evidence of which H. M. refers to the private and published letters of T. B. Hack, Esq., the Rev. C. B. Howard (Colonial Chaplain), Robert Gouger, Esq. (Colonial Secretary), T. B. Strangways, Esq. (Colonial Secretary, *pro tem.*), G. Kingston, Esq. (Colonial Surveyor)—[the three latter gentlemen have each ordered a second Cottage *since their experience in the Colony* of the first which they took]—to Capt. Hindmarsh (late Governor of South Australia), Capt. Chesser, and numerous other gentlemen in and from the Colony. Also to Capt. J. G. Hall, Worgrave, near Henley-on-Thames, who has there resided, in one of these Cottages, for several years.

See Gouger's 'South Australia,' page 71; and Loudon's 'Encyclopædia of Cottage Architecture,' pages 251 to 257.

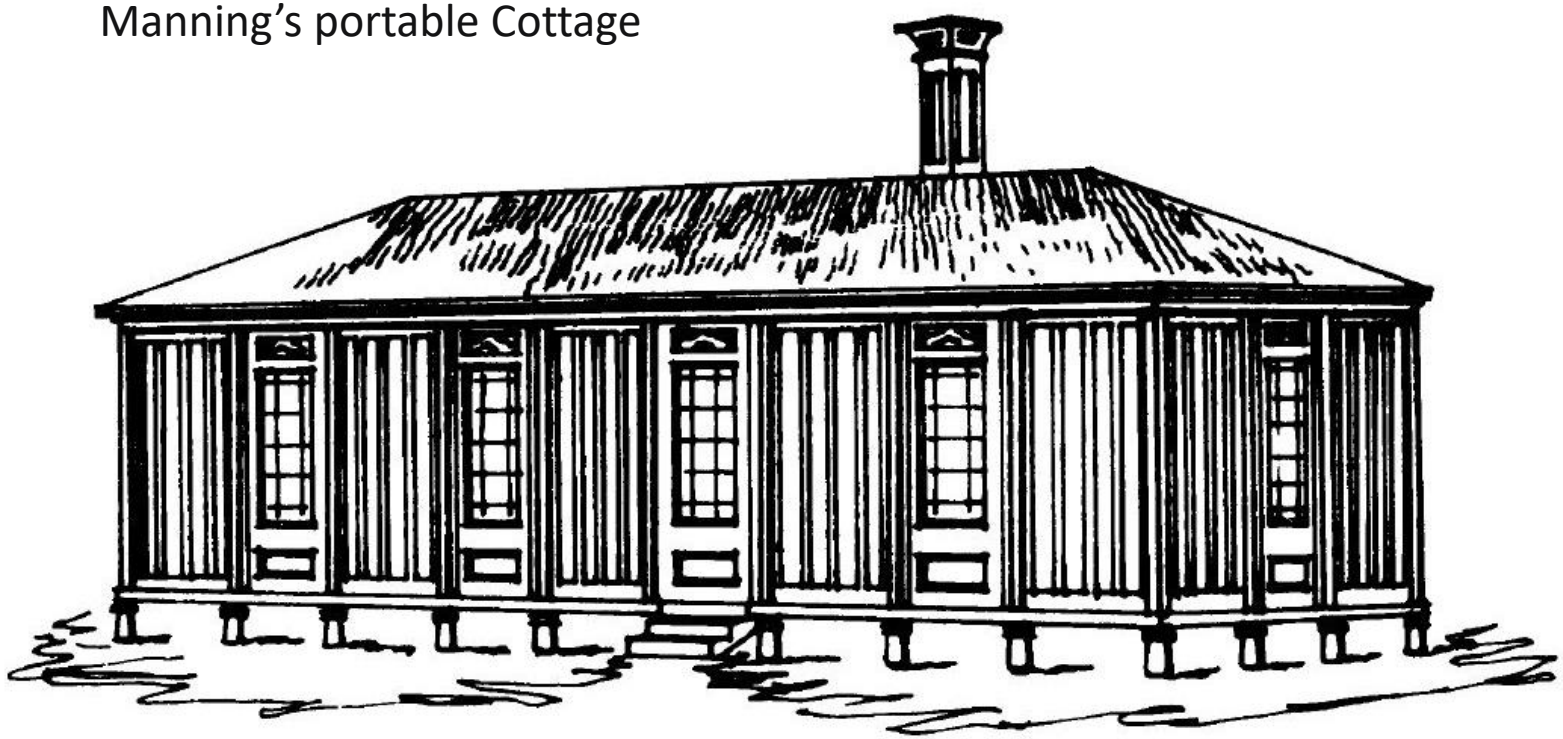
H. M. has lately had the satisfaction to make and ship a Cottage, on a large scale, to South Australia, for the Chief Justice Cooper.

From the well-known superiority of these Cottages over any others hitherto introduced into South Australia, H. M. considers it unnecessary to add more than to state that they pack in a small compass, and may be completely erected in a few hours, with joists, floors, doors, and locks; windows glazed and painted, inside and outside. Price 15*l.* and upwards.

Dressers, Safes, Tables, and every description of economical Colonial Furniture made to pack in each other to save freight.

Letters (of inquiry only) must be post paid.

Manning's portable Cottage

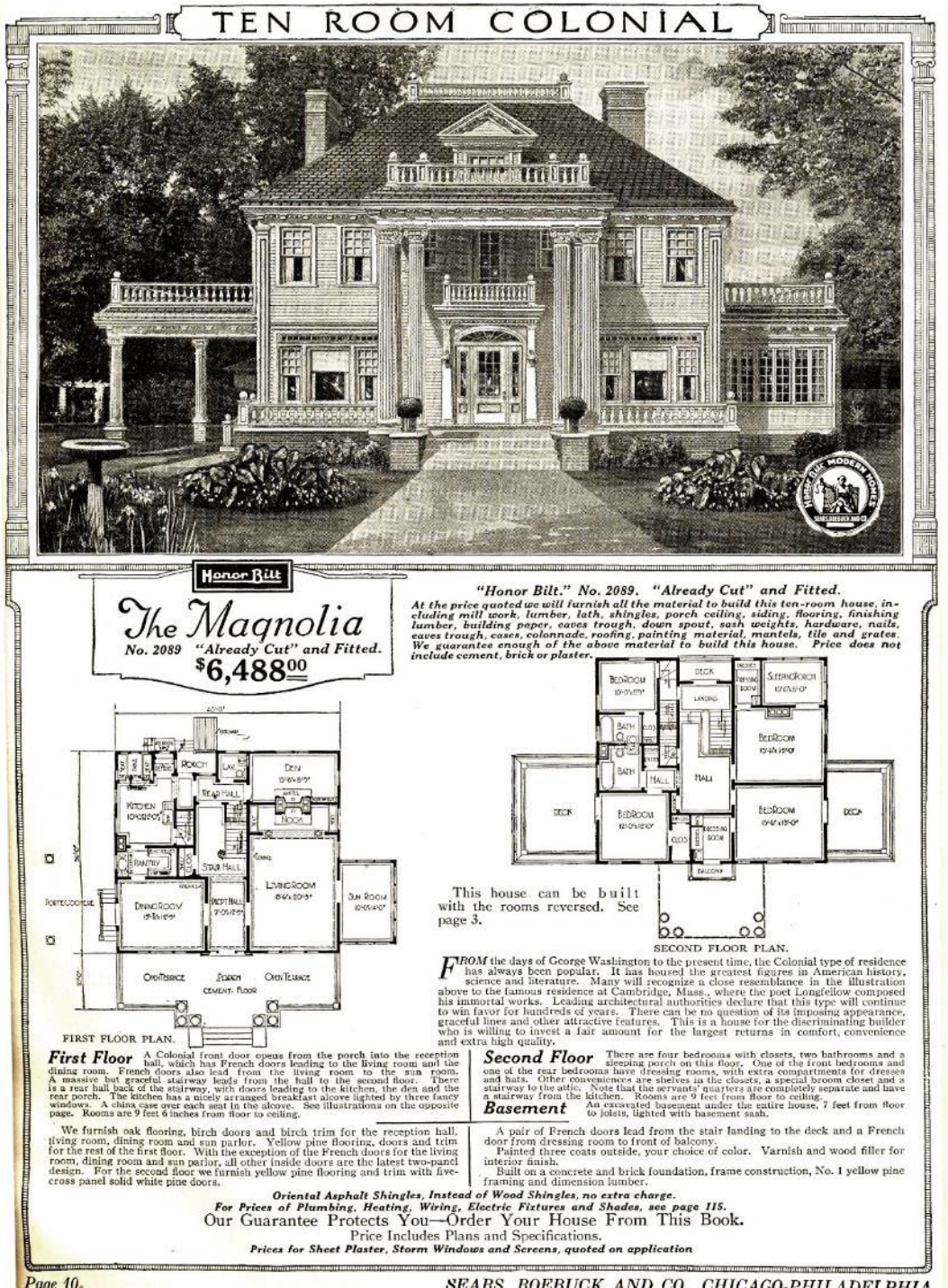


*"… moveable residences […] the facility with which they may be **taken down**, **removed**, and **refixed** by the most inexperienced …*
*… **erected in a few hours**, with joists, floors, doors, and locks;"*

Image Manning's portable cottage
http://quonset-hut.blogspot.com/2012/12/the-manning-portable-colonial-cottage.html

Herbert, G. (1972). The Portable Colonial Cottage. Journal of the Society of Architectural Historians, 31(4), 261–275.
Crowther, P. (1999). Historic Trends in Building Assembly. ACSA/CIB International Science and Technology Conference - Technology in Transition: Mastering the Impacts.

Sears Modern Homes, USA


TEN ROOM COLONIAL

Honor Bilt

The Magnolia

No. 2089 "Already Cut" and Fitted.

$6,488.00

"Honor Bilt." No. 2089. "Already Cut" and Fitted.

At the price quoted we will furnish all the material to build this ten-room house, including mill work, lumber, lath, shingles, porch ceiling, siding, flooring, finishing lumber, building paper, eaves trough, down spout, sash weights, hardware, nails, eaves trough, cases, colonnade, roofing, painting material, mantels, tile and grates. We guarantee enough of the above material to build this house. Price does not include cement, brick or plaster.

FIRST FLOOR PLAN.

SECOND FLOOR PLAN.

This house can be built with the rooms reversed. See page 3.

FROM the days of George Washington to the present time, the Colonial type of residence has always been popular. It has housed the greatest figures in American history, science and literature. Many will recognize a close resemblance in the illustration above to the famous residence at Cambridge, Mass., where the poet Longfellow composed his immortal works. Leading architectural authorities declare that this type will continue to win favor for hundreds of years. There can be no question of its imposing appearance, graceful lines and other attractive features. This is a house for the discriminating builder who is willing to invest a fair amount for the largest returns in comfort, convenience and extra high quality.

First Floor A Colonial front door opens from the porch into the reception hall, which has French doors leading to the living room and the dining room. French doors also lead from the living room to the sun room. A massive but graceful stairway leads from the hall to the second floor. There is a rear hall back of the stairway, with doors leading to the kitchen, the den and the rear porch. The kitchen has a nicely arranged breakfast alcove lighted by three fancy windows. A china case over each seat in the alcove. See illustrations on the opposite page. Rooms are 9 feet 6 inches from floor to ceiling.

Second Floor There are four bedrooms with closets, two bathrooms and a sleeping porch on this floor. One of the front bedrooms and one of the rear bedrooms have dressing rooms, with extra compartments for dresses and hats. Other conveniences are shelves in the closets, a special broom closet and a stairway to the attic. Note that the servants' quarters are completely separate and have a stairway from the kitchen. Rooms are 9 feet from floor to ceiling.

Basement An excavated basement under the entire house, 7 feet from floor to joists, lighted with basement sash.

We furnish oak flooring, birch doors and birch trim for the reception hall, living room, dining room and sun parlor. Yellow pine flooring, doors and trim for the rest of the first floor. With the exception of the French doors for the living room, dining room and sun parlor, all other inside doors are the latest two-panel design. For the second floor we furnish yellow pine flooring and trim with five-cross panel solid white pine doors.

A pair of French doors lead from the stair landing to the deck and a French door from dressing room to front of balcony.

Painted three coats outside, your choice of color. Varnish and wood filler for interior finish.

Built on a concrete and brick foundation, frame construction, No. 1 yellow pine framing and dimension lumber.

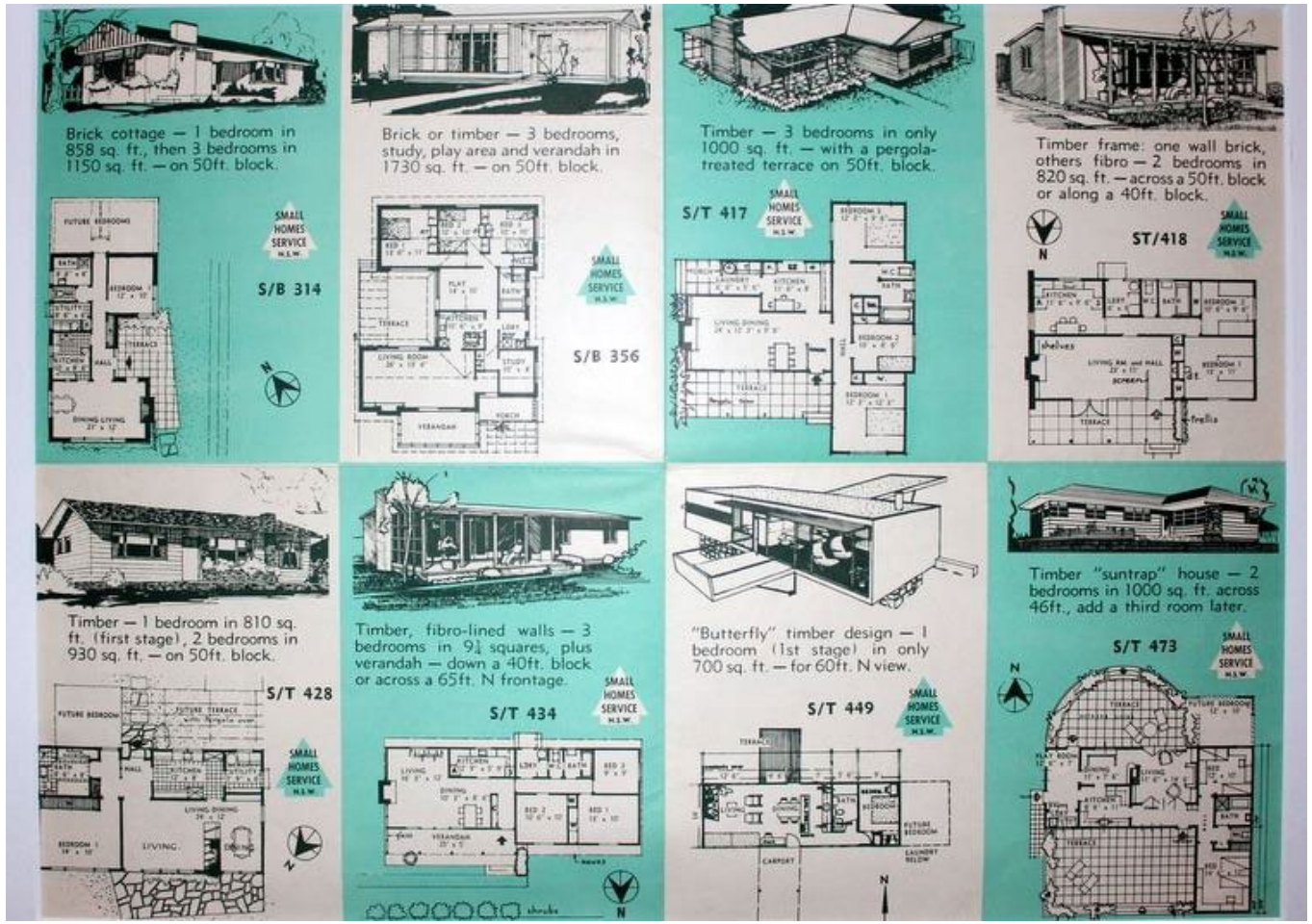
Oriental Asphalt Shingles, Instead of Wood Shingles, no extra charge.

For Prices of Plumbing, Heating, Wiring, Electric Fixtures and Shades, see page 115.

Our Guarantee Protects You—Order Your House From This Book.

Price Includes Plans and Specifications.

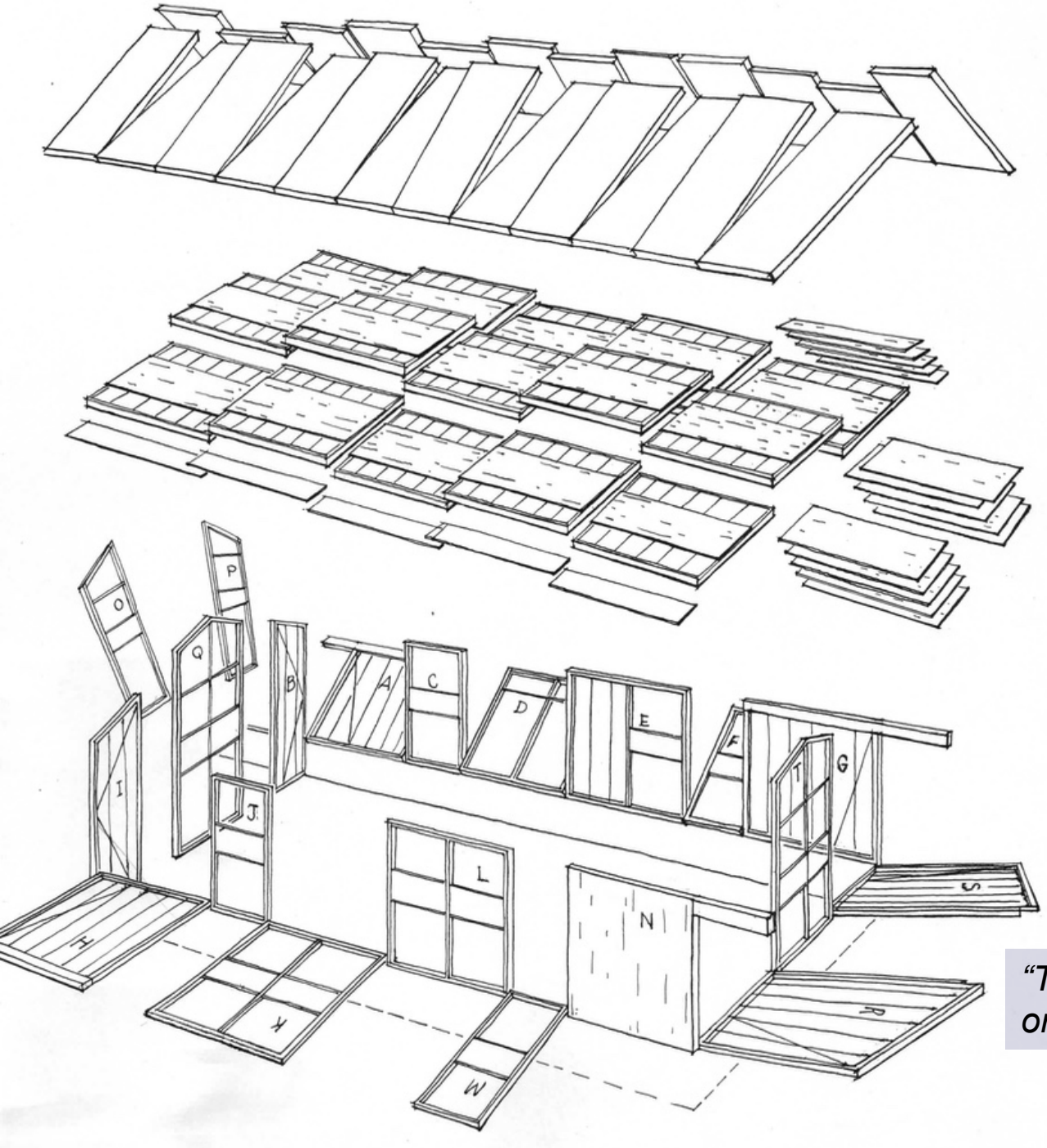
Prices for Sheet Plaster, Storm Windows and Screens, quoted on application



Small Homes Service, Australia

*"Many plans were designed to incorporate **future extensions** as a family's size and income grew."*

Image Left: Sears Modern Homes https://en.wikipedia.org/wiki/Sears_Modern_Homes
Image Right: Small Homes Service, National Library of Australia. https://www.abc.net.au/news/2018-06-14/treasure-trove-small-homes-helped-deliver-great-australian-dream/9861204



TECHBUILT PACKAGE — MARCH 22, 1955

1. Panels. All roof, floor and wall panels necessary to erect the basic shell.
2. Sub-Floor Pieces. To complete the second floor.
3. Milled Peak Section ('24' width houses only).
4. Beveled Beam Fillers.
5. Beveled Plates.
6. Panel Spacers.
7. Fascia Board.
8. Posts. (second floor).
9. Outside Trim.
10. Floor Ties.
11. Panel Joint Cover Pieces.
12. Floor Girders.
13. Roof Beams.
14. Ledgers.
15. Stairs.
16. Exterior Flush Door prehung with hardware.
17. Exterior Frame Door prehung with hardware.
18. Fixed Glass for all openings from Pittsburgh Plate Glass Company.
19. Horizontal Sliding Aluminum Sash.
20. Kitchen Cabinets by Geneva.
21. Formica Counter Tops.
22. Polyethylene Plastic Vapor Barrier.

Optional at Extra Cost

Hot Point built-in Range	
Oven with timer	$130.53
4 Unit Surface Section	$ 85.74
Gaboon Ceilings	
E House	$300.00 additional
F House	$360.00 additional
Glass doored overhead kitchen cabinets opening on two sides for Excursion kitchen	$150.00 additional

The adaptable Techbuilt House

*"In the Techbuilt house there is room for up to five bedrooms, two baths, […] built around a **core** containing the utilities and immovable fixtures: **stairs, chimney**, fireplace and **bathroom**."*

*"The system specifically allowed for **dismantling** and **reassembly** on a different site." - "This house grows with your pocketbook."*

https://thetechbuilthouse.com/

Cristescu, C., Honfi, D., Sandberg, K., Sandin, Y., Shotton, E., Walsh, S., …Krofl, Z. (2020). InFutURe Wood Report 1: Design for deconstruction and reuse of timber structures – state of the art review. ForestValue

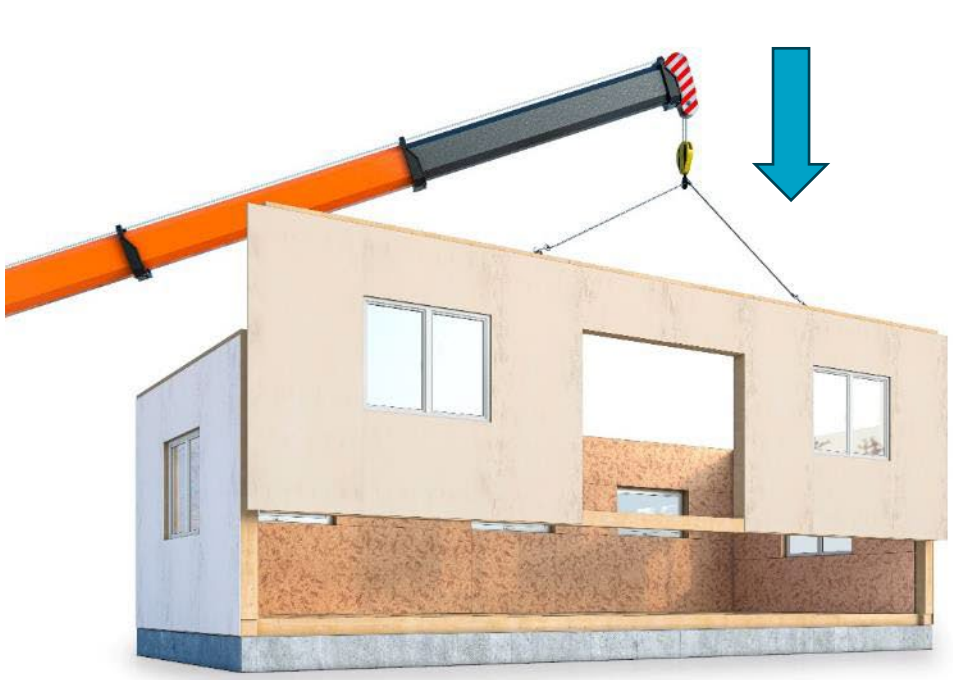


Image: A horse team moving a house from Creswick through Allendale, about 1905.
Museums Victoria
https://collections.museumsvictoria.com.au/items/773702



https://www.tjkinghouserelocators.com/

Structural Design Principles



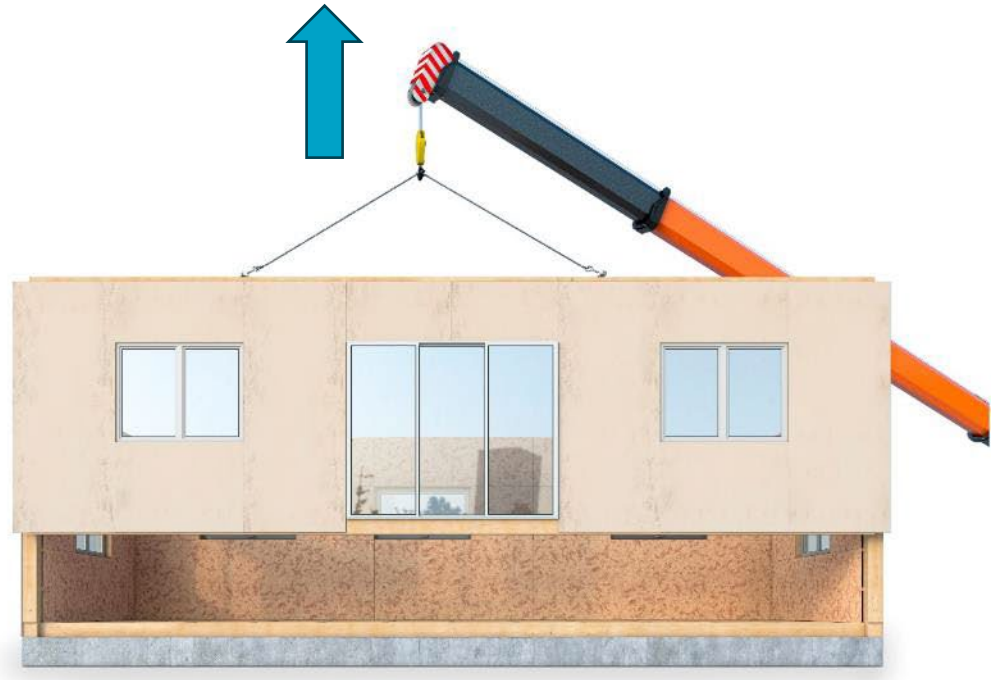
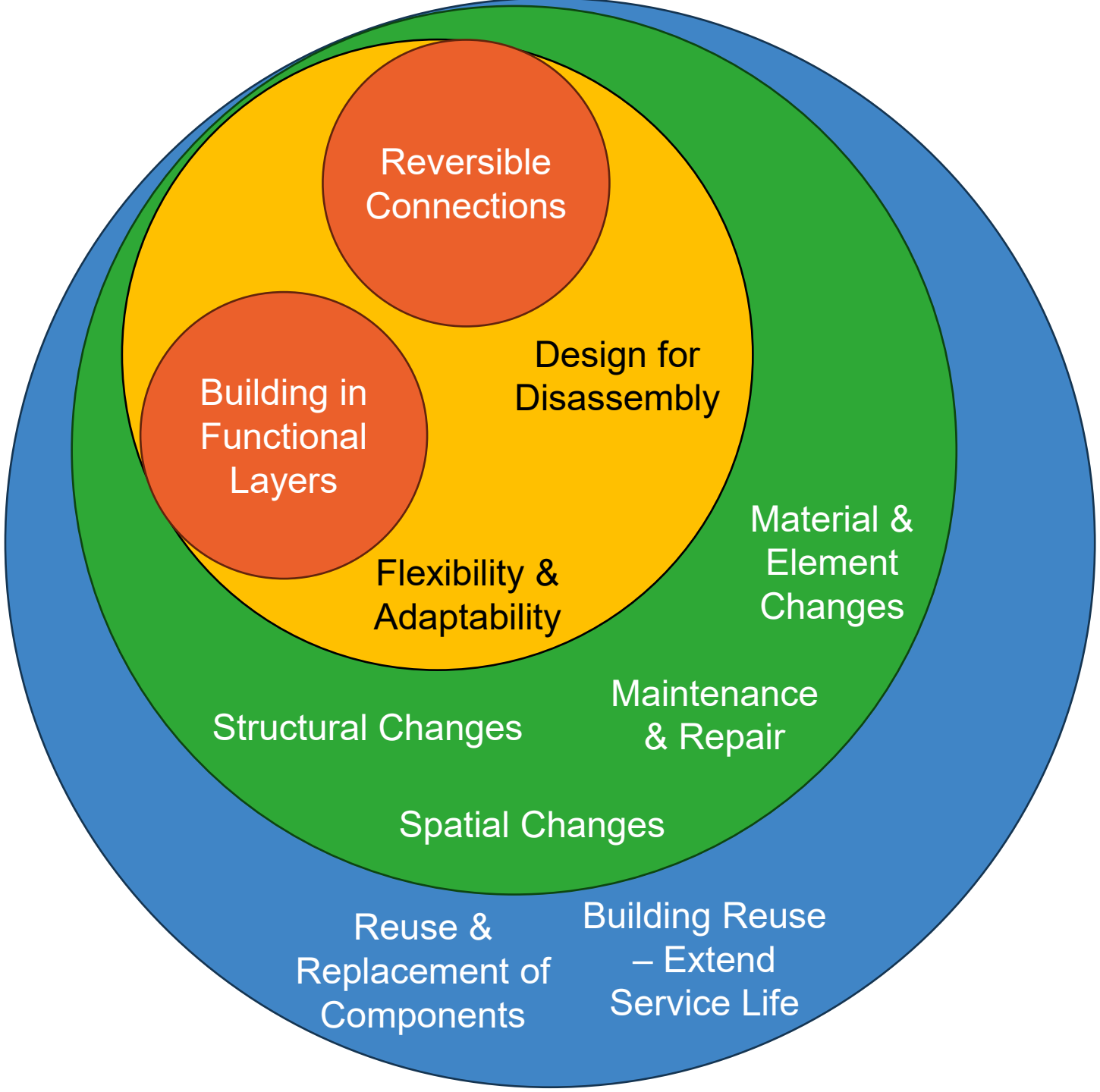


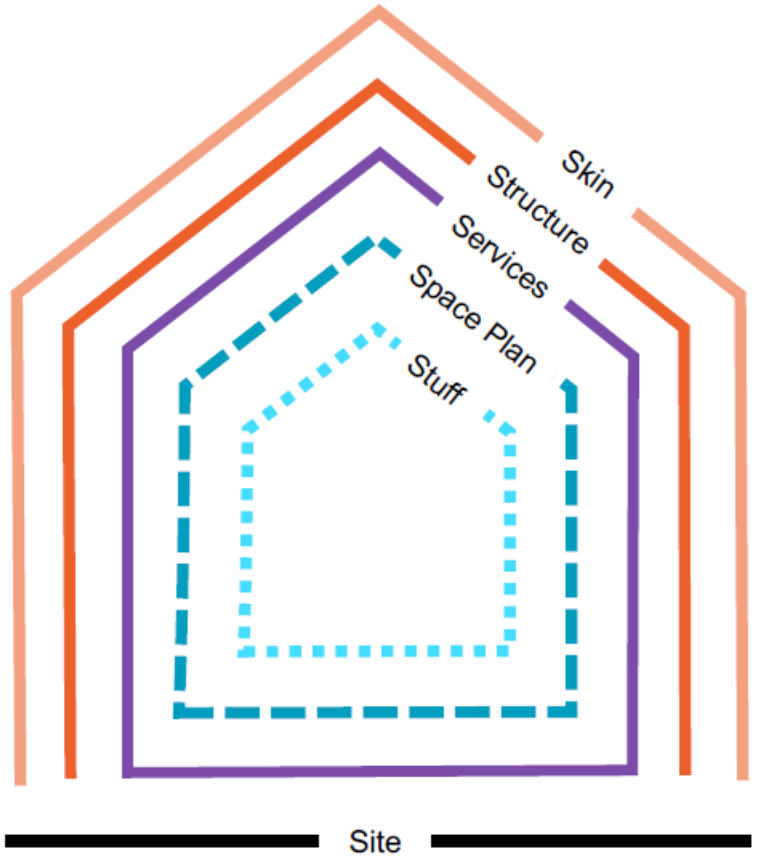
Image Adobe Stock Educational License


Standardisation
Prefabrication
Kit of Parts
Buildings in Shearing Layers
Material Passports
DfMA + D
Durability
Reuse: Assess Remaining Service Life
Monitoring
Reversible connections
Buildings as Material Banks



Adapted from Durmisevic, E. (2019). Design Strategies for Reversible Buildings (Issue 642384).

Functional layers

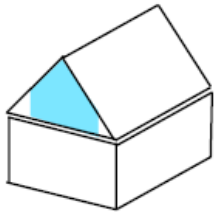


Adaptable buildings allow changes of use to the envelope regarded as 'hard' strategies. However, the building needs to be designed for future change.
(Schneider & Till 2007; Friedman1997; Kronenberg 2007; Schmidt & Austin 2016)

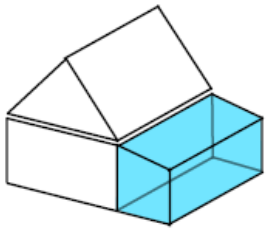
Flexible buildings allow changes of use to occur within the envelope by 'soft strategies' such as indeterminate space, slack space, unfinished space, joining/dividing units, movable partitions.
(Schneider & Till 2007)

Figure c/o Lisa Kuiri based on Brand (1995)

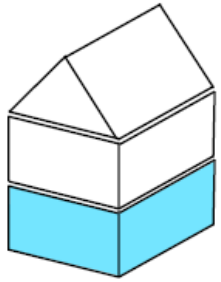
Add-in extensions occur within interior of house with little change to structure



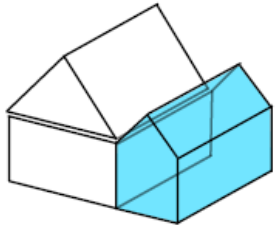
Finishing attic



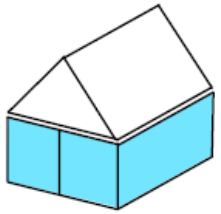
Converting veranda into room



Finishing basement or undercroft

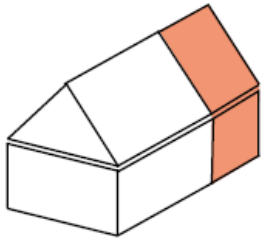


Converting garage into room

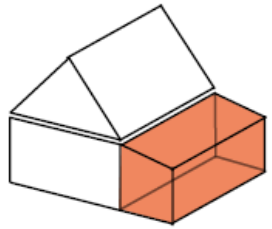


Dividing existing house into two dwellings

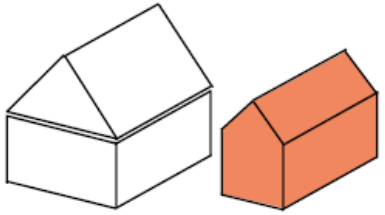
Add-on extensions occur to exterior of house requiring change to structure



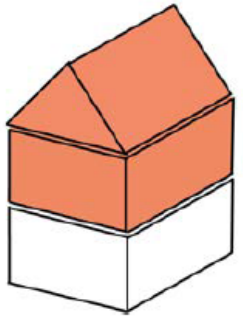
Extending back of house



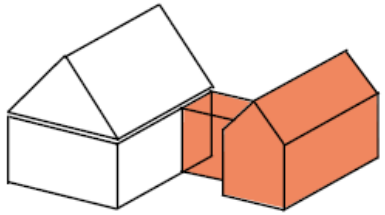
Extending side of house



Building ancillary unit

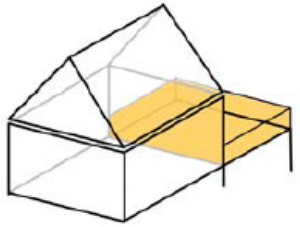


Adding floor to house

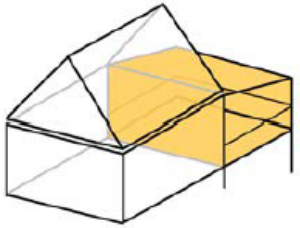


Connecting ancillary unit to main house

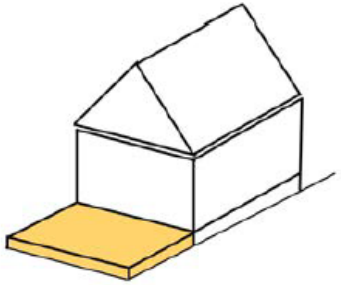
Add-on extensions for outdoor areas



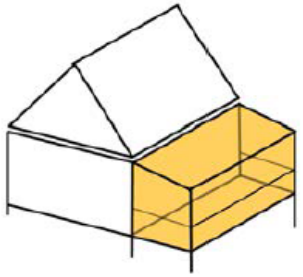
Add back deck



Add back veranda



Add front terrace



Add side veranda

Figure c/o Lisa Kuiri based on Friedman (2002)

Design for Disassembly - Principles

Functionally **independent layers** or modules (e.g. bathroom pods) in hierarchical order

Standardisation, modular prefab construction, regular grid

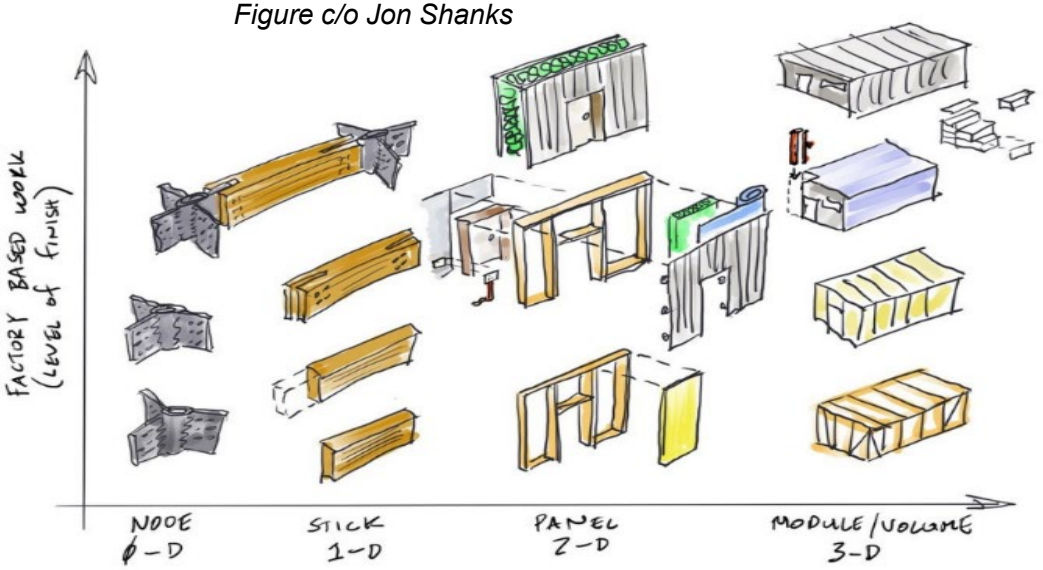
Durability of structural layer – environmentally justifiable lifetime

Capacity of core elements to support different spatial uses

Accessible **information** and permanent identification, retention of information (MP, BIM, Digital Twin, etc.)

Spare parts and onsite storage if possible

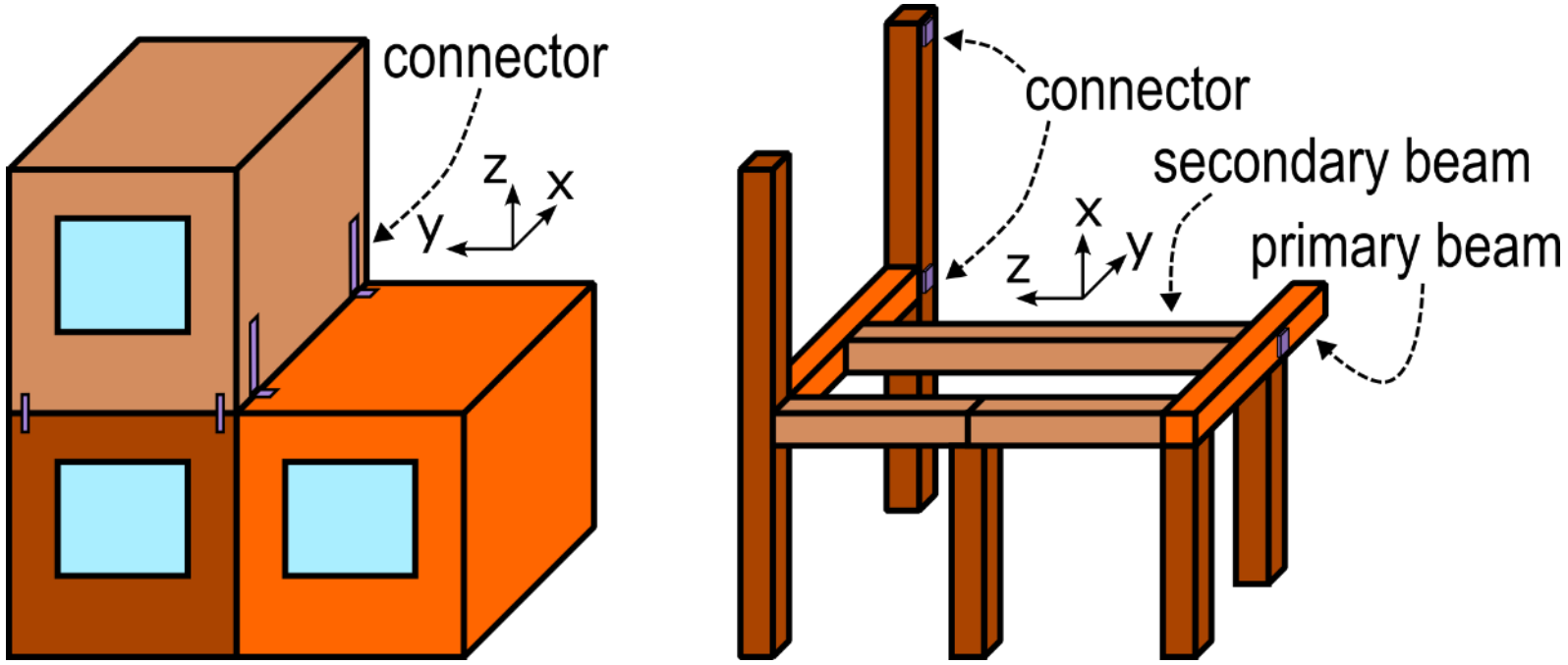
Figure c/o Jon Shanks





Crowther, P. (2009). Designing for disassembly. Technology, Design and Process Innovation in the Built Environment, 12(November), 25–27.
Nordby, A. S. (2009). Salvageability of building materials: Reasons, criteria and consequences regarding architectural design that facilitate reuse and recycling.
Durmisevic, E. (2019). Design Strategies for Reversible Buildings (Issue 642384).
Smith, S., Smith, G., & Chen, W. (2012). Disassembly sequence structure graphs: An optimal approach for multiple-target selective disassembly sequence planning. Advanced Engineering Informatics, 26(2), 306–316.

Reversible connections



Ottenhaus, L.M., Yan, Z., Brandner, R., Leardini, P., Fink, G., Jockwer, R. (2023) "Design for Adaptability, Disassembly and Reuse – A Review of Reversible Timber Connection Systems." Construction and Building Materials

Carpentry joints



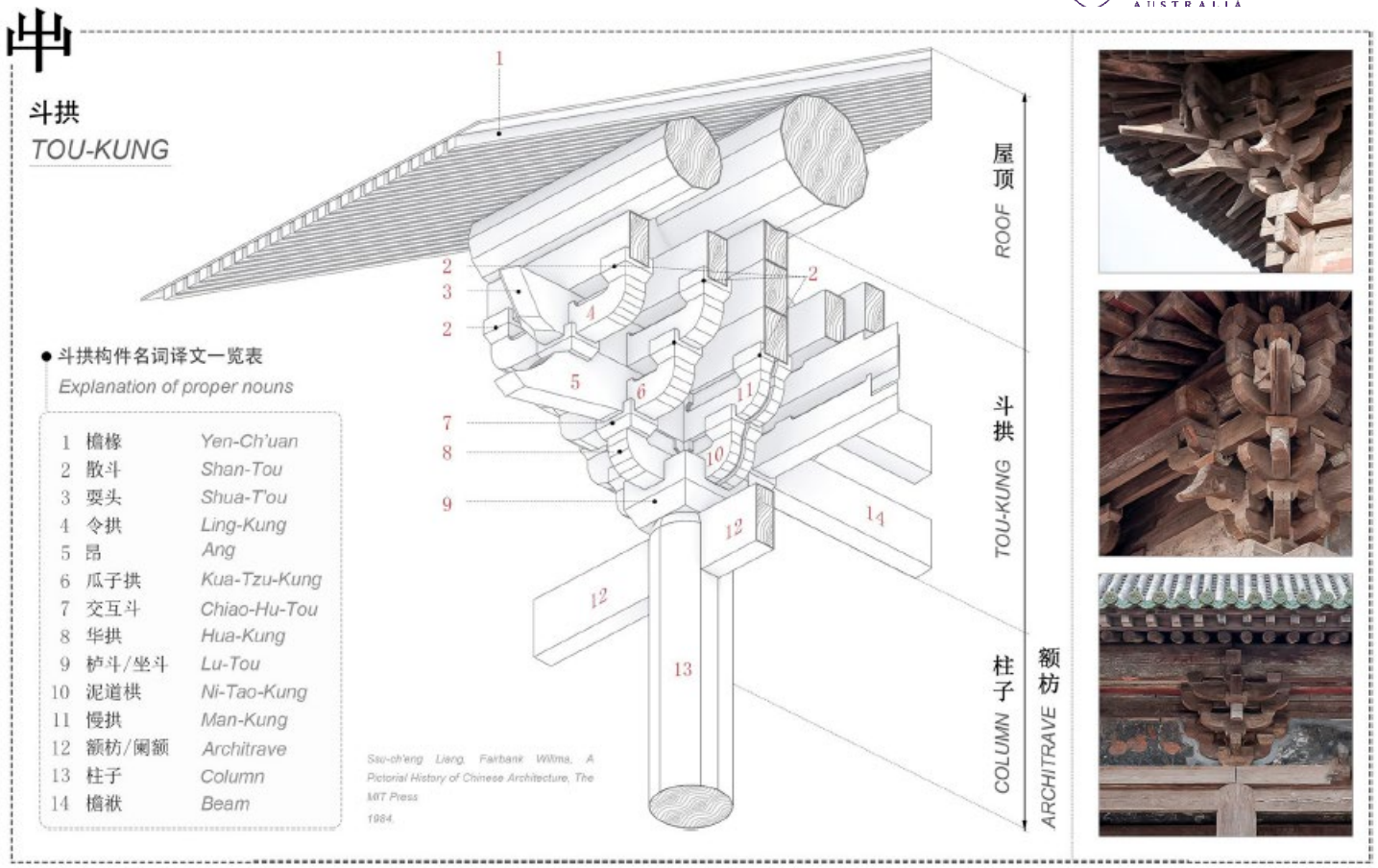


Fig. 1 Principal parts of a Chinese timber-frame building

Duan, Cheng & Shen, Su & Bao, Ding Wen & Yan, Xin. (2023). Innovative design solutions for contemporary Tou-Kung based on topological optimisation. 2. 1-16.

Carpentry joints

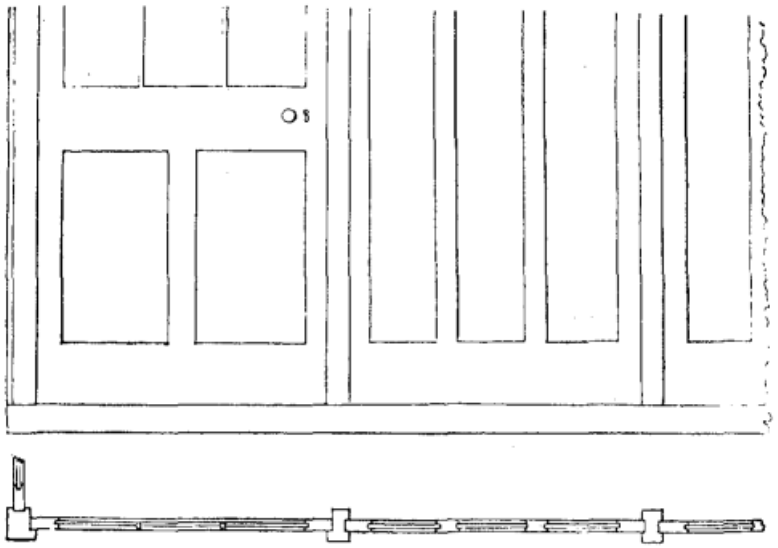


Fig. 5: Manning's system, showing the form of the panels in part-elevation and plan. Loudon 1846: 255.

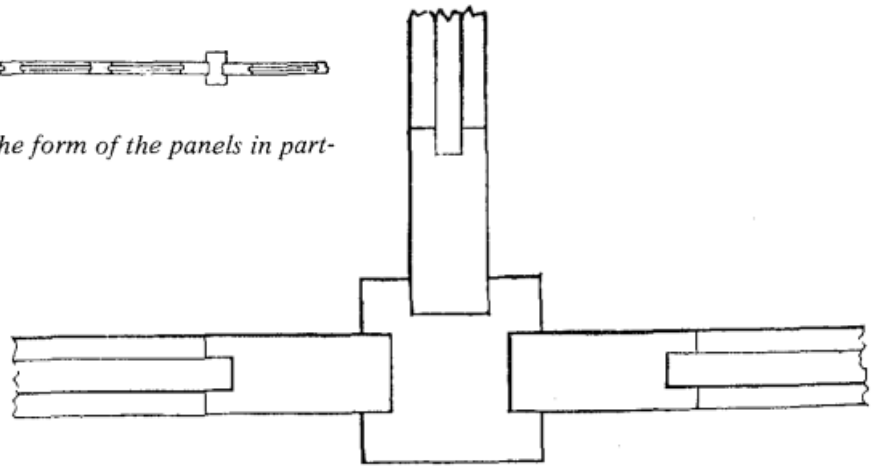
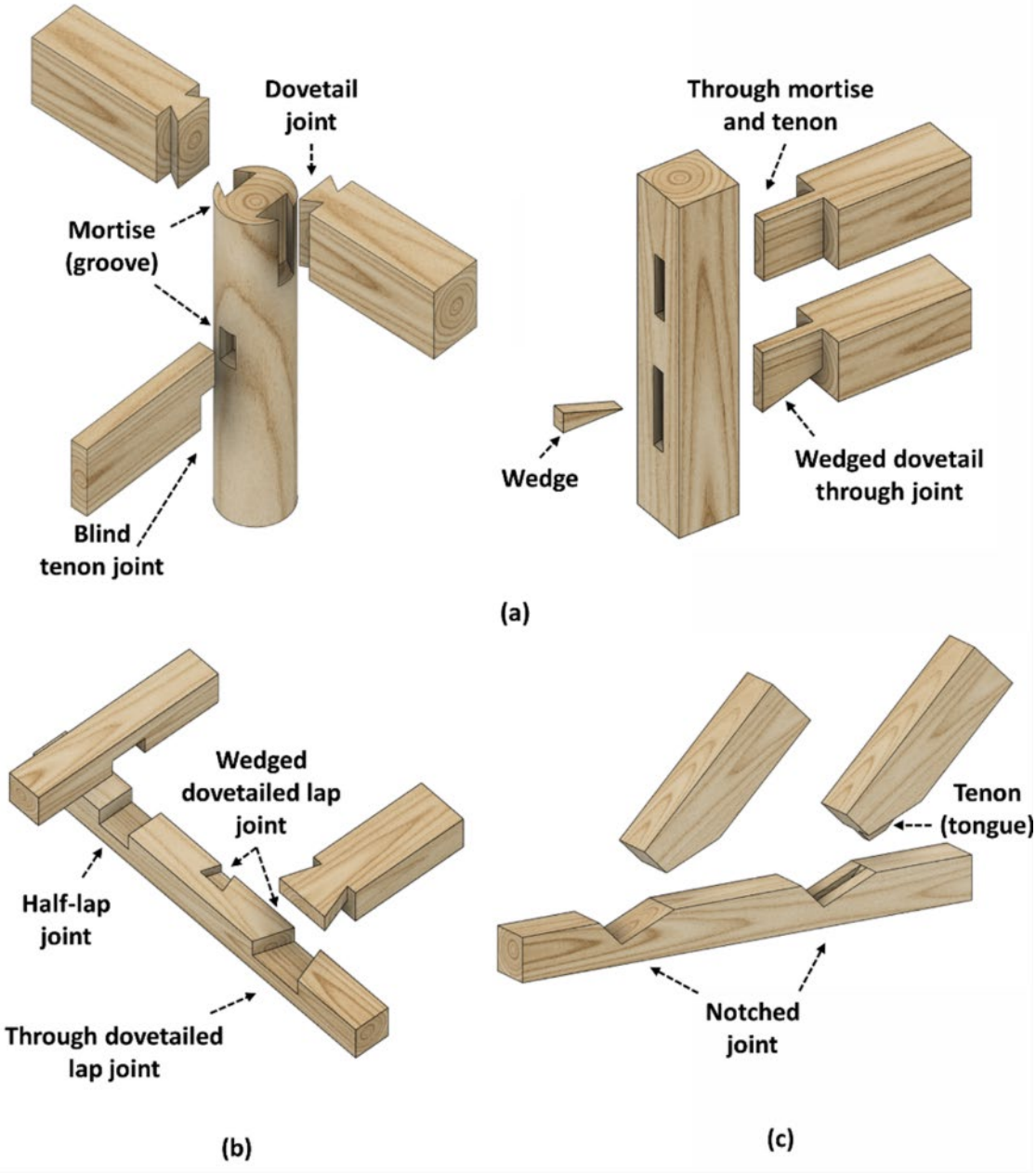


Fig. 4: Plan of a junction of post and panels on Manning's system. Loudon 1846: 255.



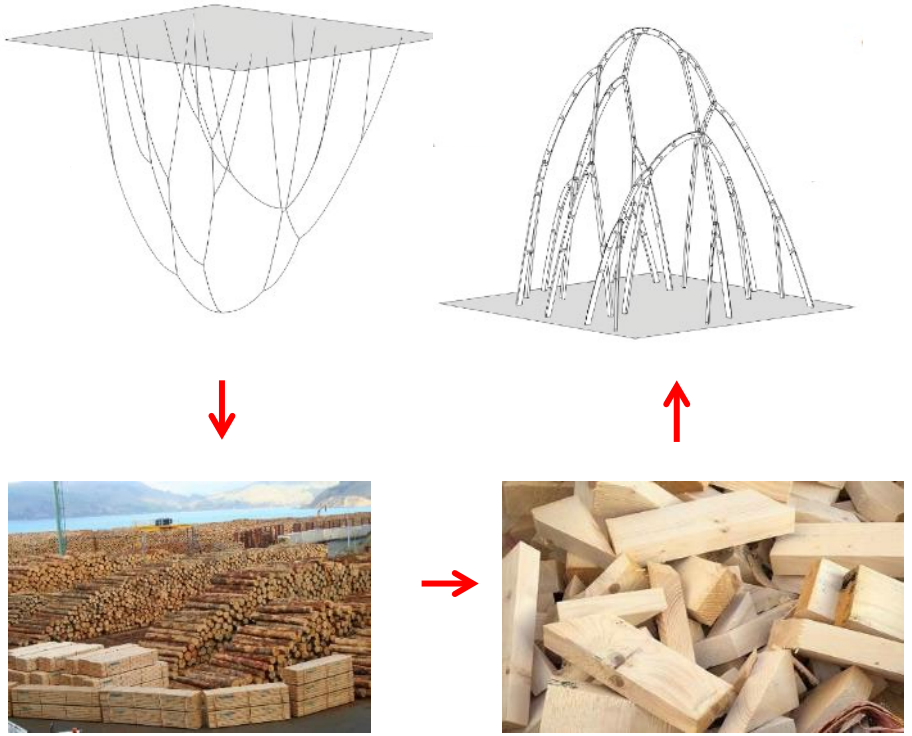
Left: Lewis, Miles (1985) The Diagnosis of Prefabricated Buildings. Australian Historical Archaeology, 3, 1985
Rights: Ottenhaus, Yan, Brander, Leardini, Fink, Jockwer (2023) "Design for Adaptability, Disassembly and Reuse – A Review of Reversible Timber Connection Systems." Con Build Mat

Case Study: Suspended Remnants

Baber, Burry, Chen, Gattas, Bukauskas

Inventory Constrained Design

- ✓ Form finding model
- ✓ Resource with defects
- ✓ Optimal assignment of inventory
- ✓ Designed for disassembly









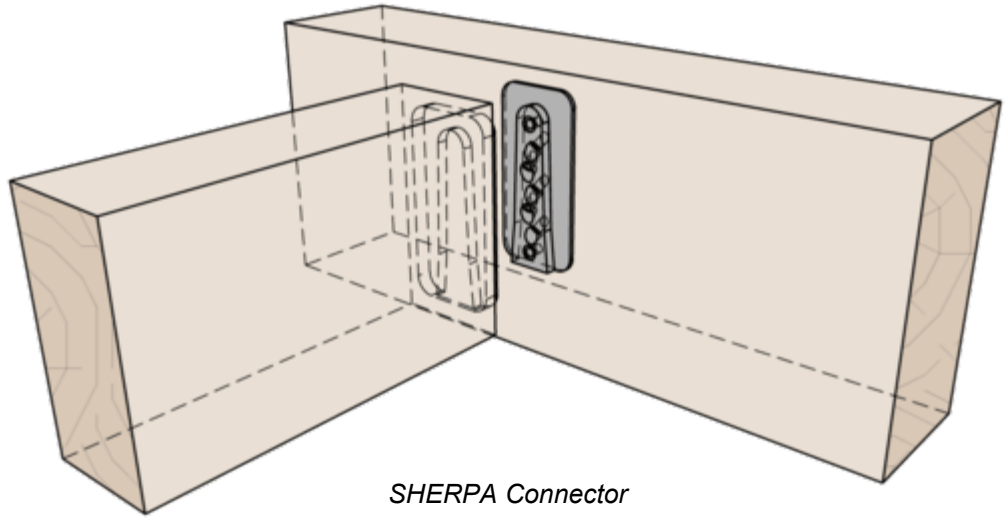


Suspended Remnants _Kim Baber+Jane Burry + Canhui Chen + Joe Gattas+Aurimas Bukauskas

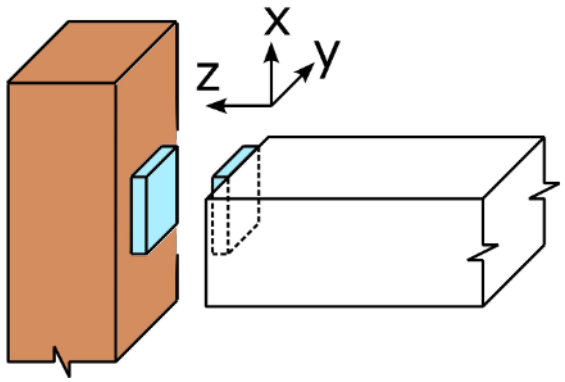
Post and beam systems

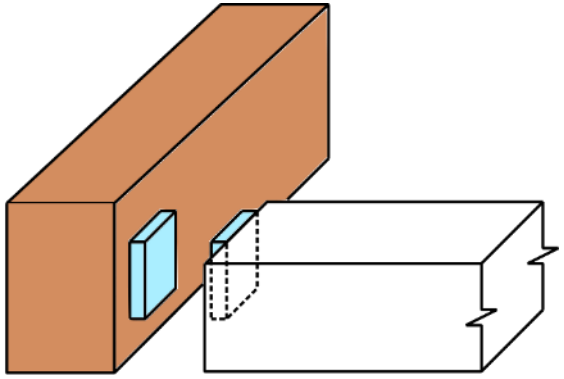


KNAPP RICON



SHERPA Connector





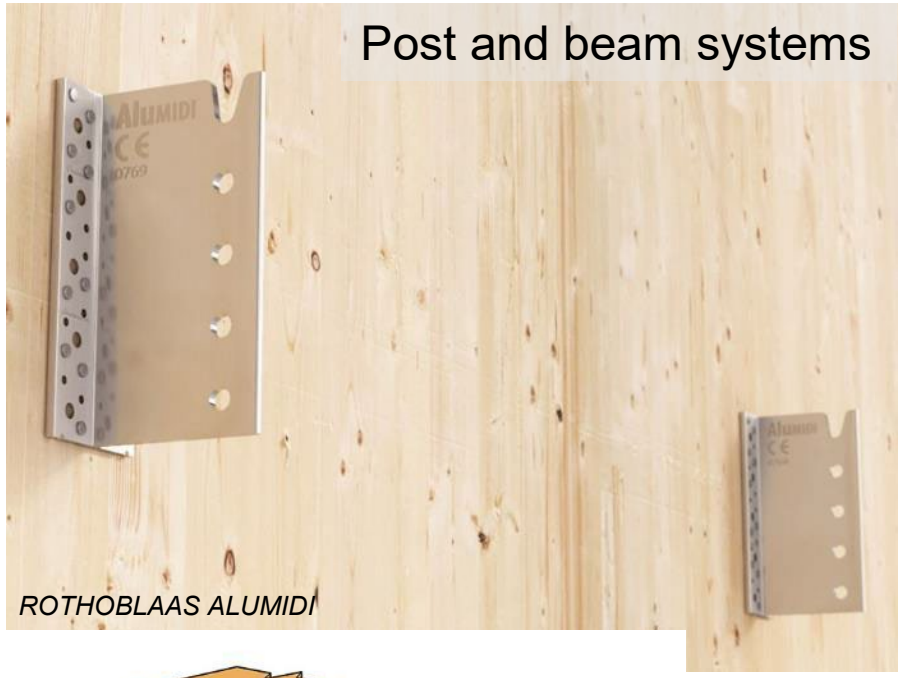


EUROTEC Magnus



SIHGA HobaFix

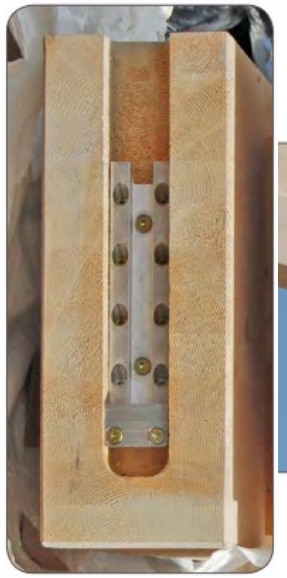
Post and beam systems

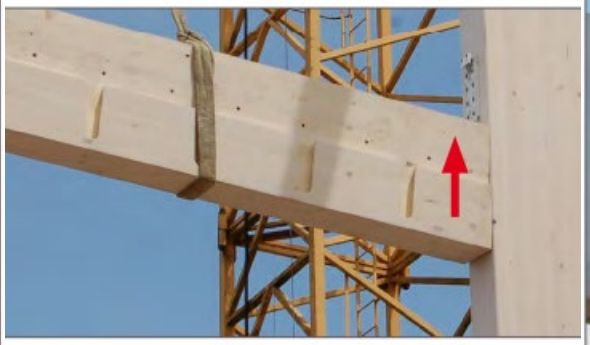


ROTHOBLAAS ALUMIDI



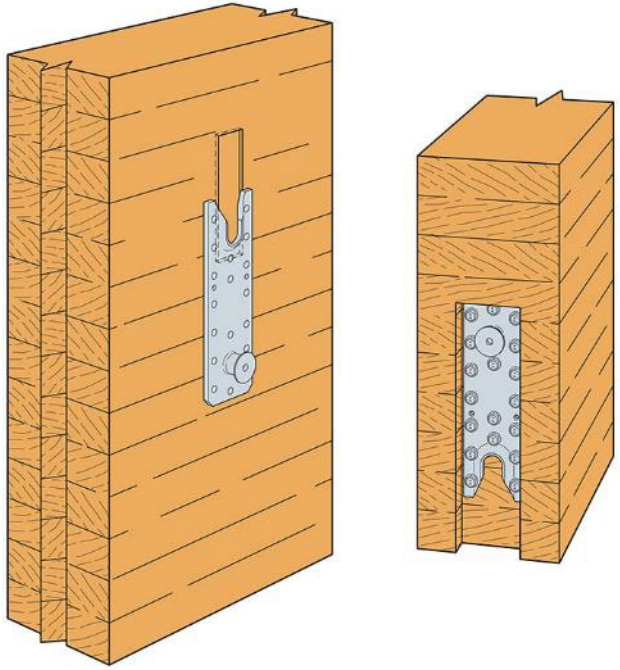
GH Connectors TOP UV





KNAPP MEGANT





SIMPSON STRONGTIE Concealed Beam Hanger





PITZL HVP



ROTHOBLAAS LOCK-T

Mass timber panels





SHERPA CLT Connector

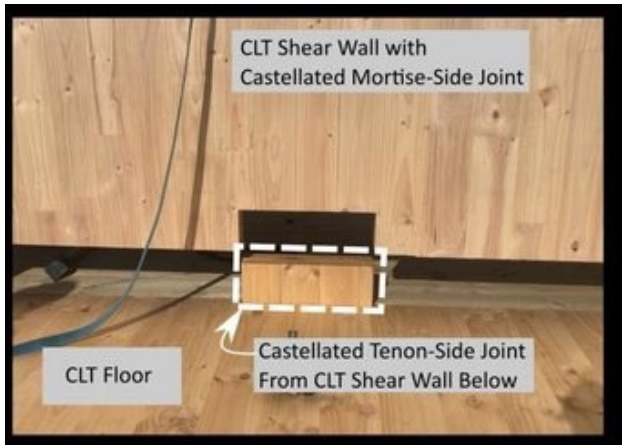
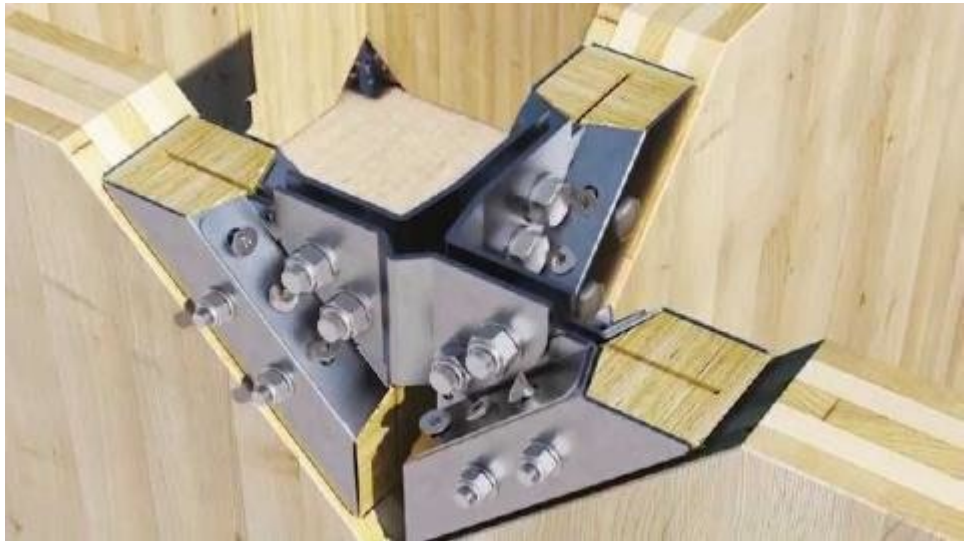


Image Justin Brown

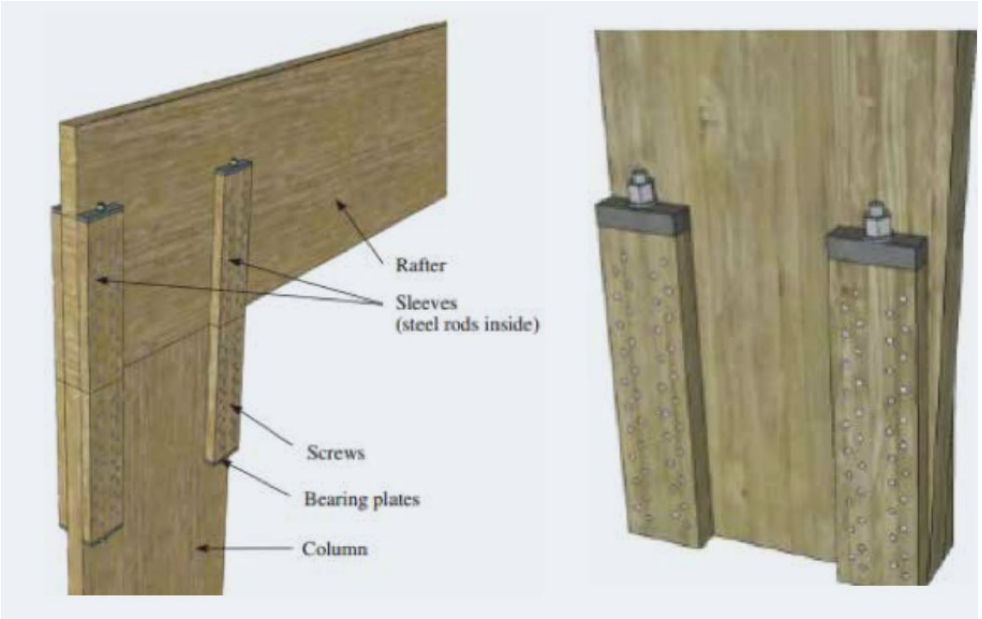


ROTHOBLAAS X-RAD

ROTHOBLAAS LOCK T



Rods



Quick Connect Moment Connection. *Wood Solutions TDG 33*.



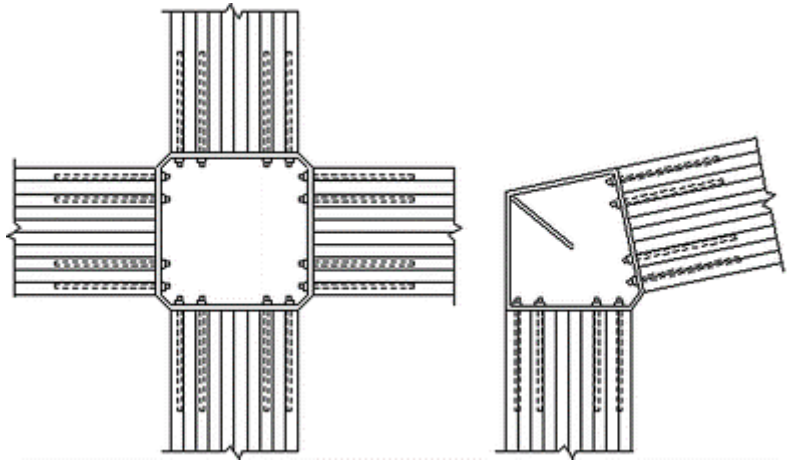
Trimble Navigations Christchurch, Aotearoa New Zealand



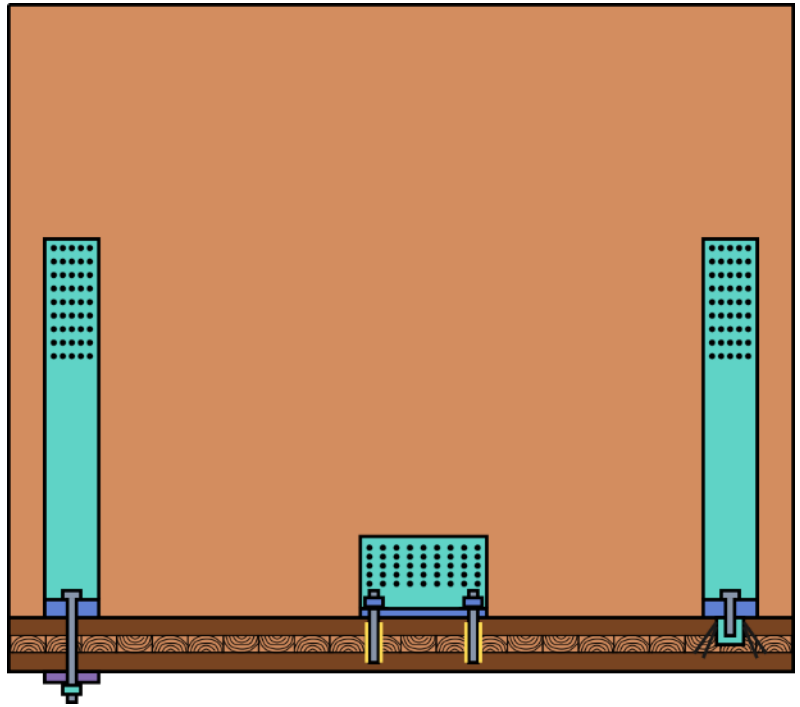
SIHGA IdeFix



ROTHOBLAAS DISC FLAT



*Tlustochowicz, G., Serrano, E. & Steiger, R. State-of-the-art review on timber connections with glued-in steel rods. Mater Struct **44**, 997–1020 (2011).*



Reversible Connections - Principles

Parallel and **partial disassembly** &

reassembly NOT sequential

No specialised tools

Adequate **tolerances** for repeated disassembly & reassembly (limit damage and deformations)

Accessible **single-translation** motions

Easy removal of boundary components in **same direction** as target

Minimise number and types of connectors and fasteners

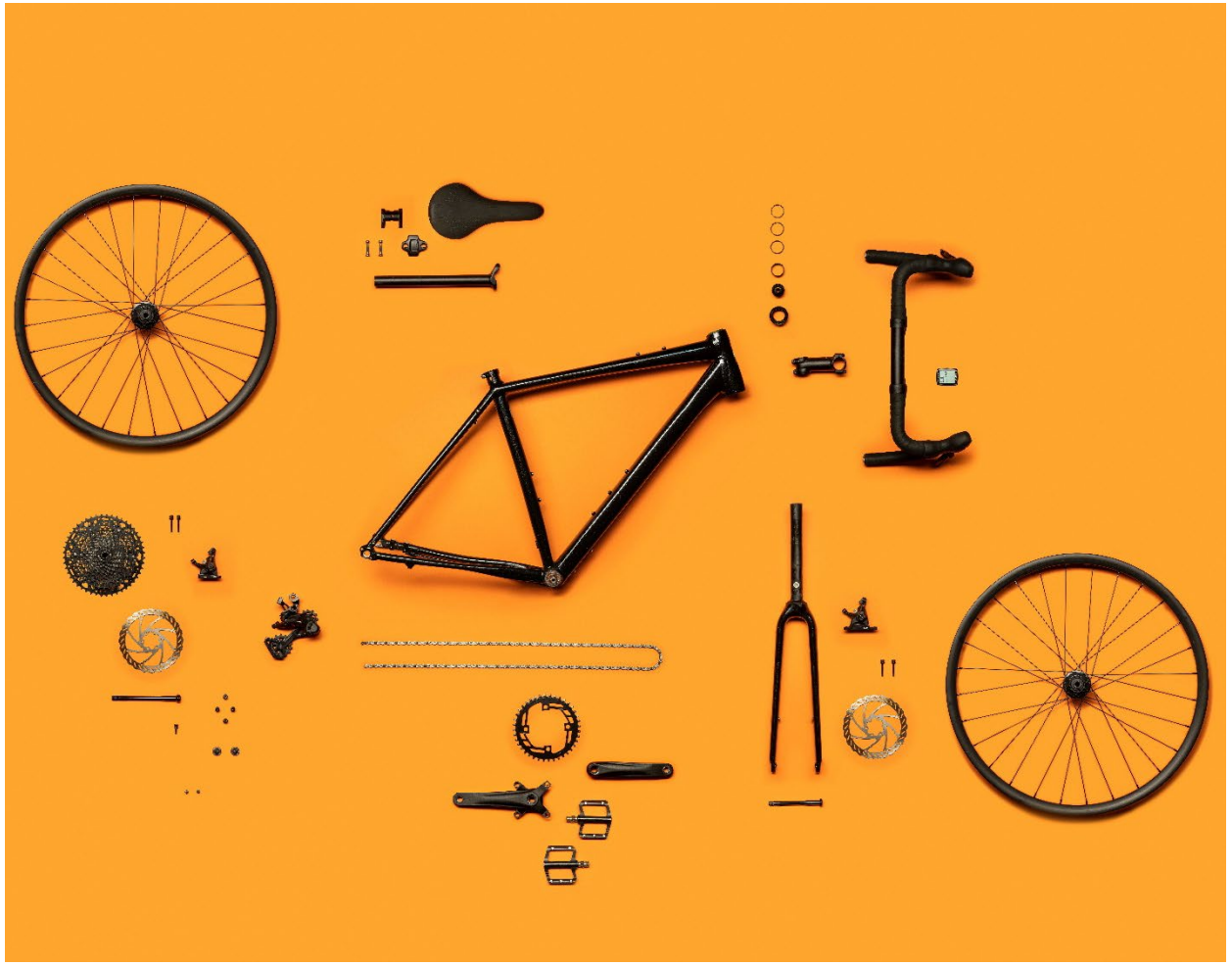


Image Adobe Stock Educational License

Crowther, P. (2009). Designing for disassembly. Technology, Design and Process Innovation in the Built Environment, 12(November), 25–27.

Nordby, A. S. (2009). Salvageability of building materials: Reasons, criteria and consequences regarding architectural design that facilitate reuse and recycling.

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Smith, S., Smith, G., & Chen, W. (2012). Advanced Engineering Informatics Disassembly sequence structure graphs: An optimal approach for multiple-target selective disassembly sequence planning. Advanced Engineering Informatics, 26(2), 306–316.



Research at the University of Queensland

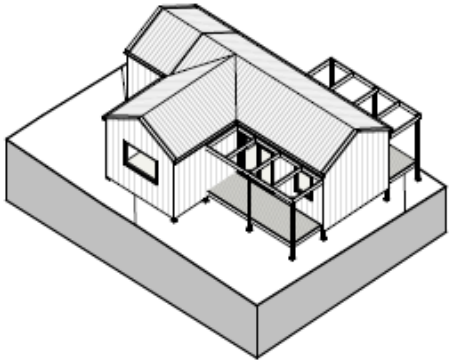


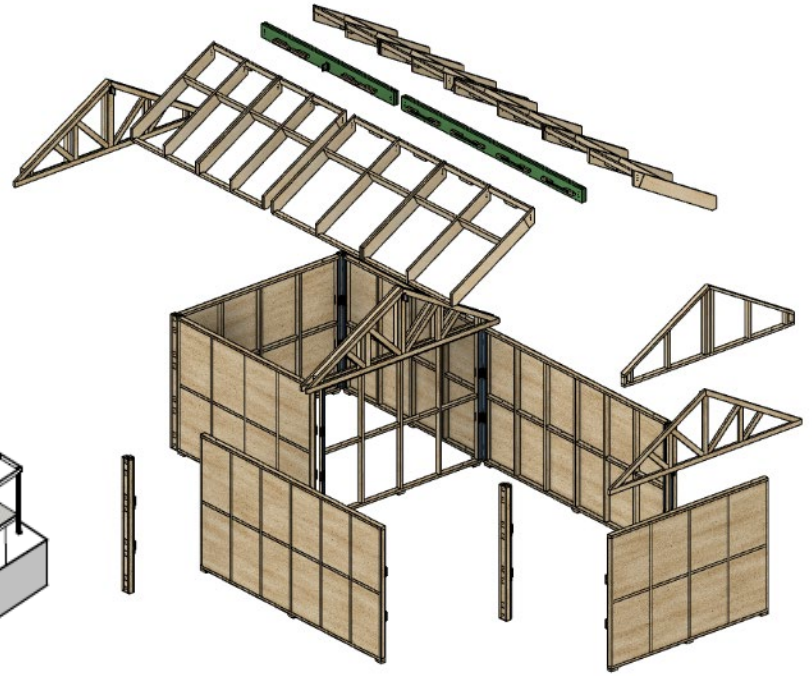
Adaptable, Reversible, Deconstructable

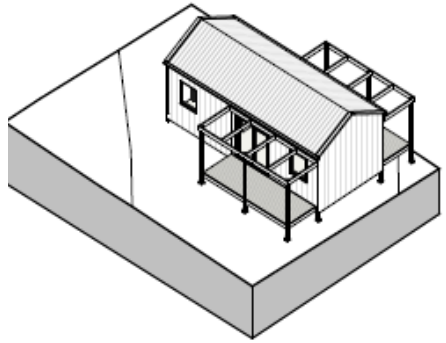
ARC Linkage Project (2022-2027): OFFSITE MANUFACTURE REIMAGINED FOR HIGH-PERFORMANCE ADAPTABLE HOUSING

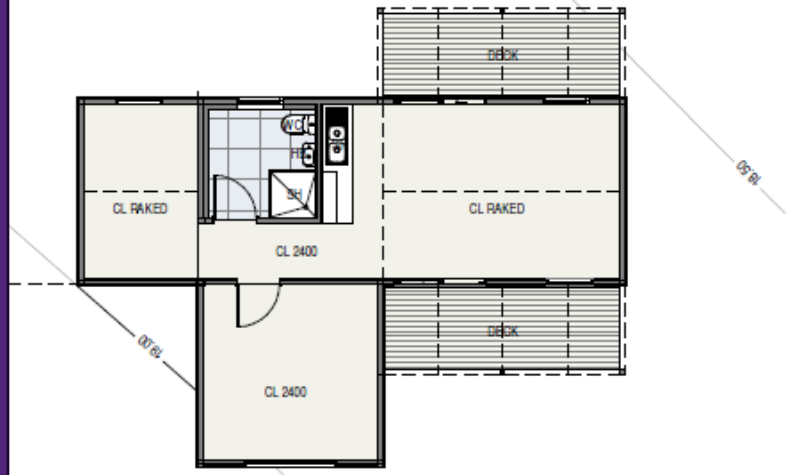
Leardini, Ottenhaus, Yan, Strang, Crews & Fairweather Homes

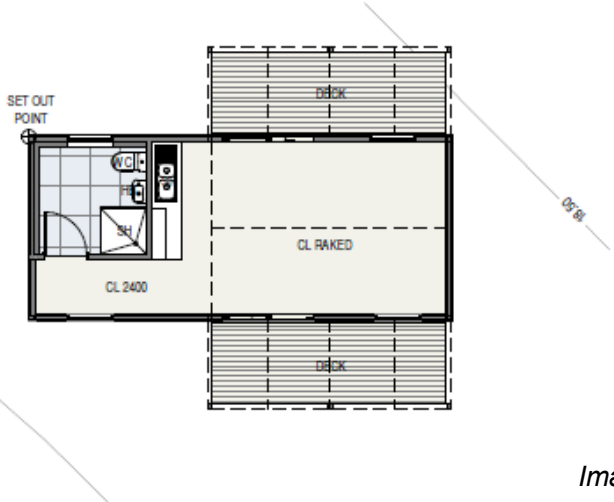






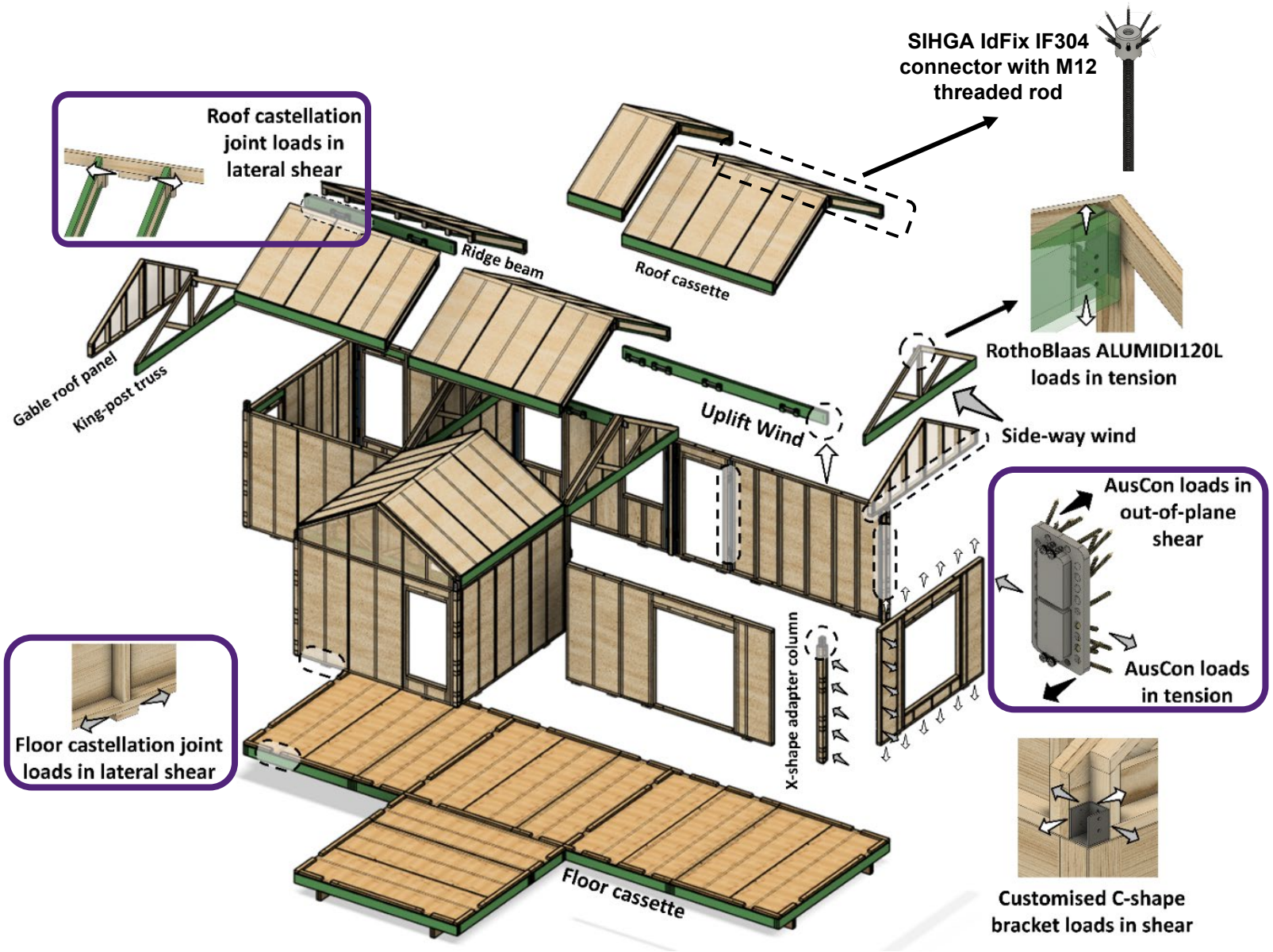


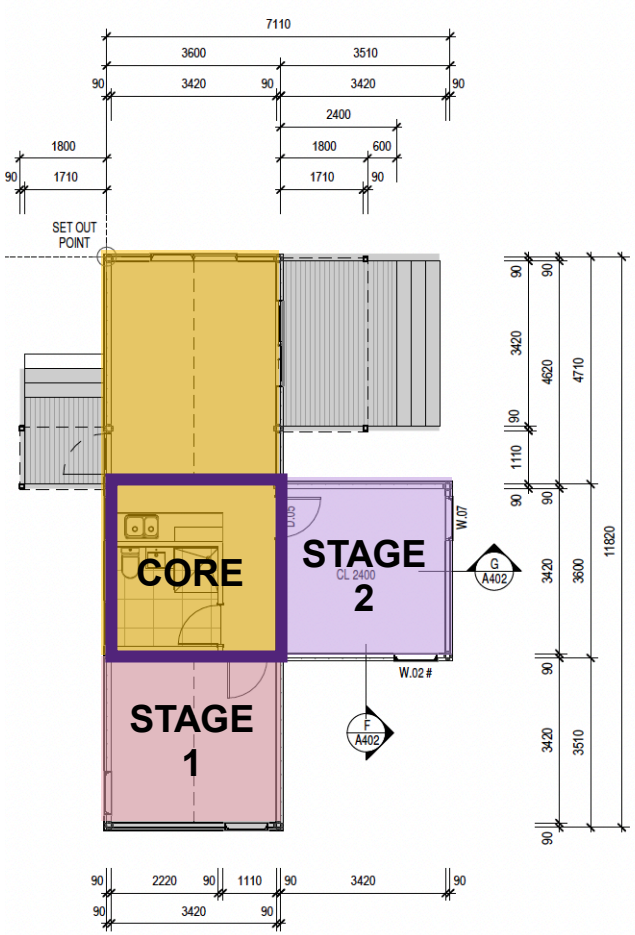




Images c/o Zidi Yan and Fairweather Homes

Structural Design



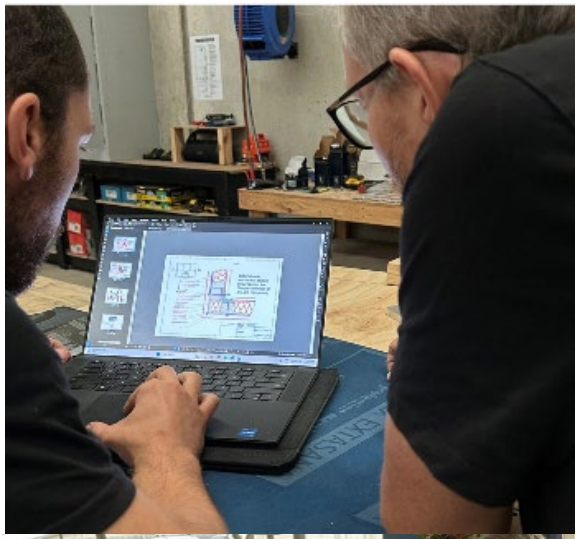


FLOOR PLAN (STAGE 2)

SCALE: 1 : 100

Research collaboration









- Prototyping & testing
- 3D modelling & in-person hands-on workshops
- Construction sequencing, standardised components & sub-assemblies
- Iterative process, listen & learn from each other

Supply chain & local context

- Working with local supply chain
- Understand material availability
- Minimise working from heights
- Standardised & fewer connections
- Reversible connections









Building for the future



What can we do?

On a community level:

Understand **local context,** material availability, and supply chain.

Listen and learn from each other; don't reinvent the wheel. Understand your stakeholders' needs and perspective.

On a government level:

Encourage and allow for reuse of building components with **policy** and **legislation**.

Encourage deconstruction and reuse with **financial incentives** and **subsidies**.

Support researchers, communities, and businesses to **innovate together**.



We can do better!

Thank you

Dr Liam Ottenhaus

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Further reading

Ottenhaus, L., Hernández-Aldaz, M., Davies, A., and Cabrero, J. M. (2025). Evaluating the disassembly potential of timber buildings: development of calculation tool and proof of concept. Wood Material Science and Engineering 20 (4) 881-909. https://doi.org/10.1080/17480272.2025.2510562

Novais Passarelli, R., Chiletto, T., Brandner, R., and Ottenhaus, L. (2025). Circulation of structural timber for structural purposes: a review of opportunities and challenges. Wood Material Science and Engineering 20 (4) 778-799. https://doi.org/10.1080/17480272.2025.2493711

Yan, Z., Strang, M., Ottenhaus, L., Leardini, P., Adams, P., and Crews, K. (2025). Implementation of adaptable design principles for high-performance light timber framed panelised buildings: an Australian case study. 14th World Conference on Timber Engineering 2025 (WCTE 2025), Brisbane, QLD, Australia, https://doi.org/10.52202/080513-0156

Ottenhaus, L., Yan, Z., Brandner, R., Leardini, P., Fink, G., and Jockwer, R. (2023). Design for adaptability, disassembly and reuse – a review of reversible timber connection systems. Construction and Building Materials 400 132823 1-16. https://doi.org/10.1016/j.conbuildmat.2023.132823

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The views expressed herein are those of the authors and are not necessarily those of the Australian Government or Australian Research Council.