Columbia | CBIPS
Center for Buildings, Infrastructure and Public Space

Construction Technology

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OVERVIEW

CASE STUDY

- Carmel Place (nArchitect)

NEW CONCEPT & TECHNOLOGY

- Design and Construction
- 3D Printing
- Shipping Containers

APPLICATION & FUTURE TREND

- Affordable Housing
- Emergency Architecture (as response to Pandemic or Disasters)
- Infrastructure Renovation
- Sustainability

CONCLUSION

Summary, Challenges & Recommendation

Case Study

CARMEL PLACE

- Client: Monadnock Development / NYC Department of Housing Preservation and Development
- Location: 335 E 27th Street, Kips Bay, Manhattan, NY
- Status: Completed
- Dates: 2013-2016
- Sq Footage: 35,000sf
- Program: Manhattan's first micro unit apartment building, with 55 micro-unit apartments, shared amenities, and retail.
- Environmental: LEED Silver target
- Design Team: Eric Bunge, Mimi Hoang | Ammr Vandal | Tony-Saba Shiber, Daniel-Katebini Stengel, Albert Figueras, Zach Cohen, Amanda Morgan, Cheryl Baxter, Gabrielle Marcoux
- Collaborators: Structure: Denardis Engineers | MEP: Abraham Joselow | Sustainability: Liro Engineers, Philip Habib & Associates | Developer and General Contractor: Monadnock | Modular Fabrication: Capsys

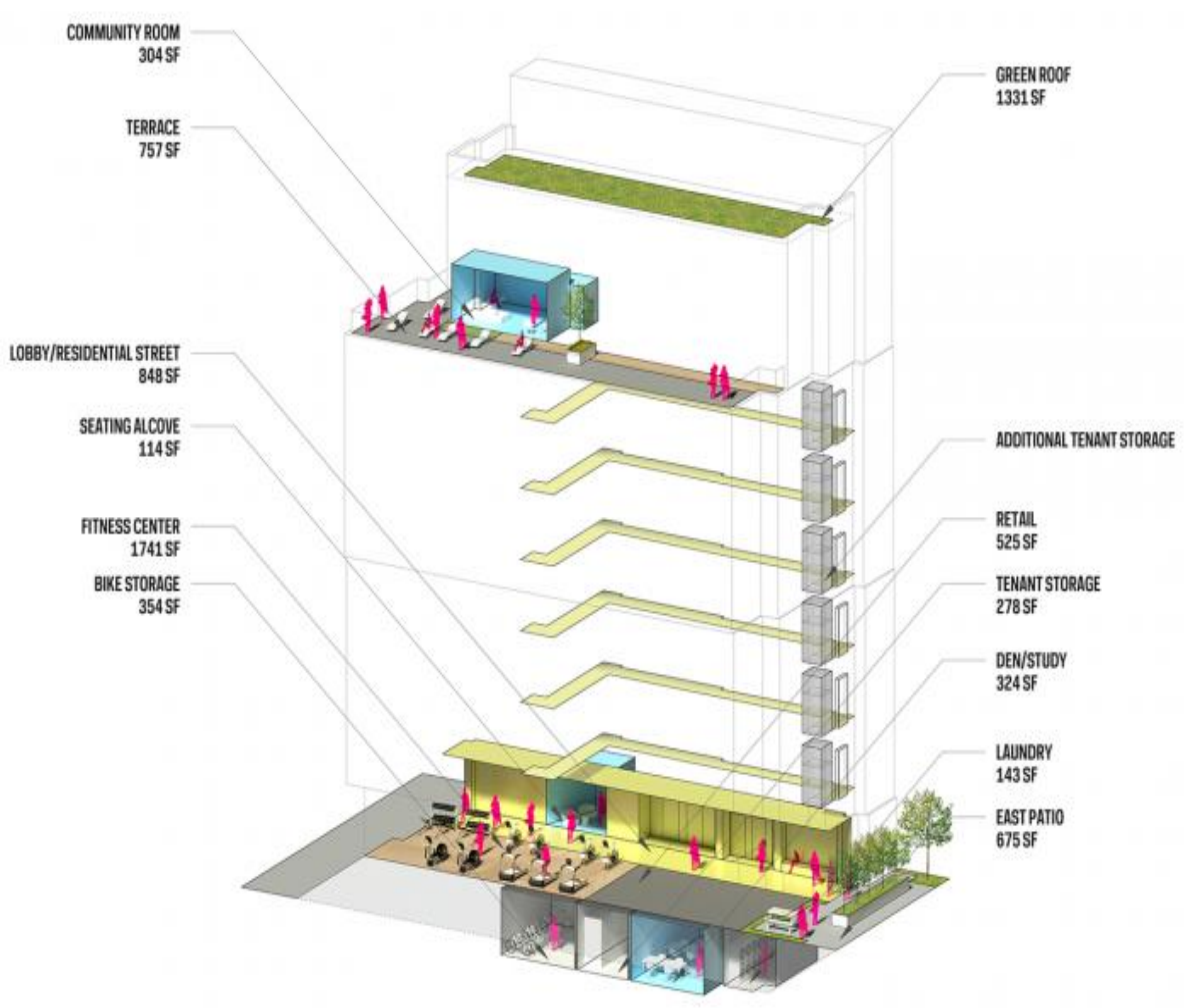
https://narchitects.com/work/carmel-place/

CARMEL PLACE

Carmel Place was created in response to New York's current housing problem. It was chosen for building as part of the City's New Housing Marketplace Plan through the adAPT NYC competition to address shifting demographics, particularly the tendency toward small households.

The project examines the feasibility of reducing the minimum apartment size (from 400 to 300 square feet) while maintaining the need for more social space. The building's 55 rental apartments, which range in size from 260 to 360 square feet net, are complemented with ample common amenities located throughout the building, fostering social contact amongst residents. The apartment interiors provide ample light, fresh air, high ceilings, and ample storage space, showcasing new possibilities for micro-living without sacrificing quality of life through smart design.

Carmel Place has received international fame as a new home model and for its pioneering use of modular construction, which cut construction time and noise while allowing for a 1/8" construction tolerance. Following Carmel Place, the city altered its zoning code to encourage modular development and expand housing alternatives through micro-units.



Case Study

CARMEL PLACE

Interview with Eric Bunge from nArchitects

- The most challenging part of Carmel Place project was renting the manufacturing site and on site area available for assembling.
- There was no problem when it comes to transportation. In fact, they had police escorts helping them transport the pre-fabricated materials.
- They definitely saved money and time compared to traditional method of construction. However, there were several cost over runs and ultimately the cost of per sq foot was $400 (expected $350).
- The key to success in this project was the experience with working on modular construction. The time saved during the on site work and assembling.
- You always have to design from scratch and nothing is readily available.
- The little problems that arises with assembling the modules needs to be done effectively and sometimes have a different approach in tackling it. Traditional methods are pretty straight forward in what has to be done.
- The most important person is the structural engineer. The other new competencies needed could be providing modular and prefab construction courses on campus.
- Safety has been a great improvement when it comes to modular construction compared to traditional. All modules parts are pre fabricated in factories and the workers come into picture only for assembly works on site which is low risk.
- For success, It's necessary to make some adjustments to complete the project for some legal or compatible reasons.
- The supply chain plays a huge role as well.

https://www.world-architects.com/en/architecture-news/reviews/carmel-place-1

Design and Construction for Modular

- Introduction
- Pre-Design
- Design
- Post-Design

INTRODUCTION

The commercial modular building industry is comprised of two distinct divisions: *Relocatable Buildings* (*RB*) and *Permanent Modular Construction* (*PMC*).

Modular Building Type:

1. Permanent Modular Construction (PMC):

- PMC buildings are subject to the same building codes and requirements.
- As site-built structures, depreciate in much the same manner, and are classified as real property.
- Utilizing lean manufacturing techniques to Prefabricate single or multi-story in deliverable volumetric module sections.
- Are manufactured in a safe, controlled setting
- Can be constructed of wood, steel, or concrete.
- Can be integrated into site-built projects or stand alone as a turnkey solution

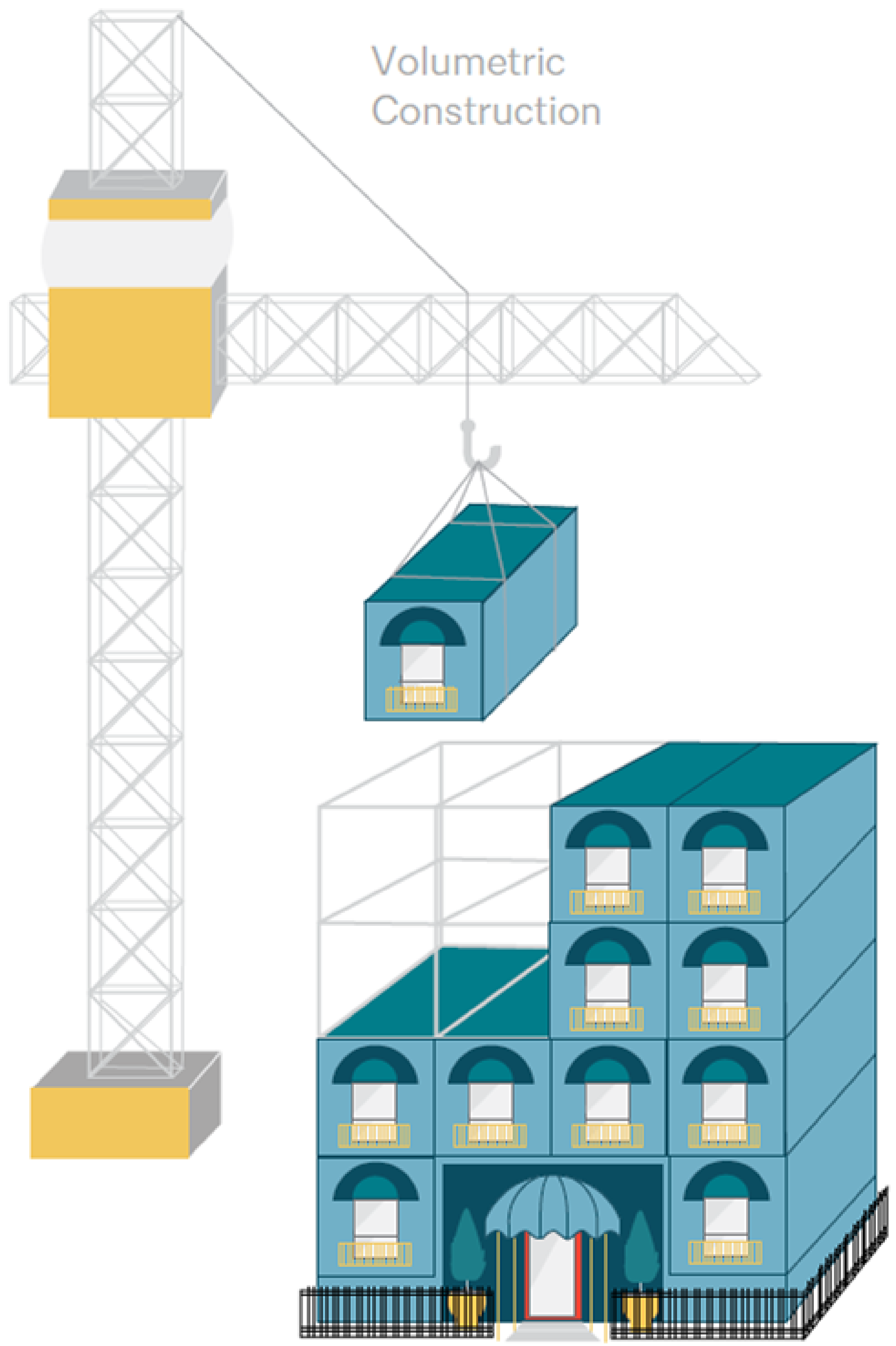
Modular Building Type:

2. Relocatable Buildings (RB) :

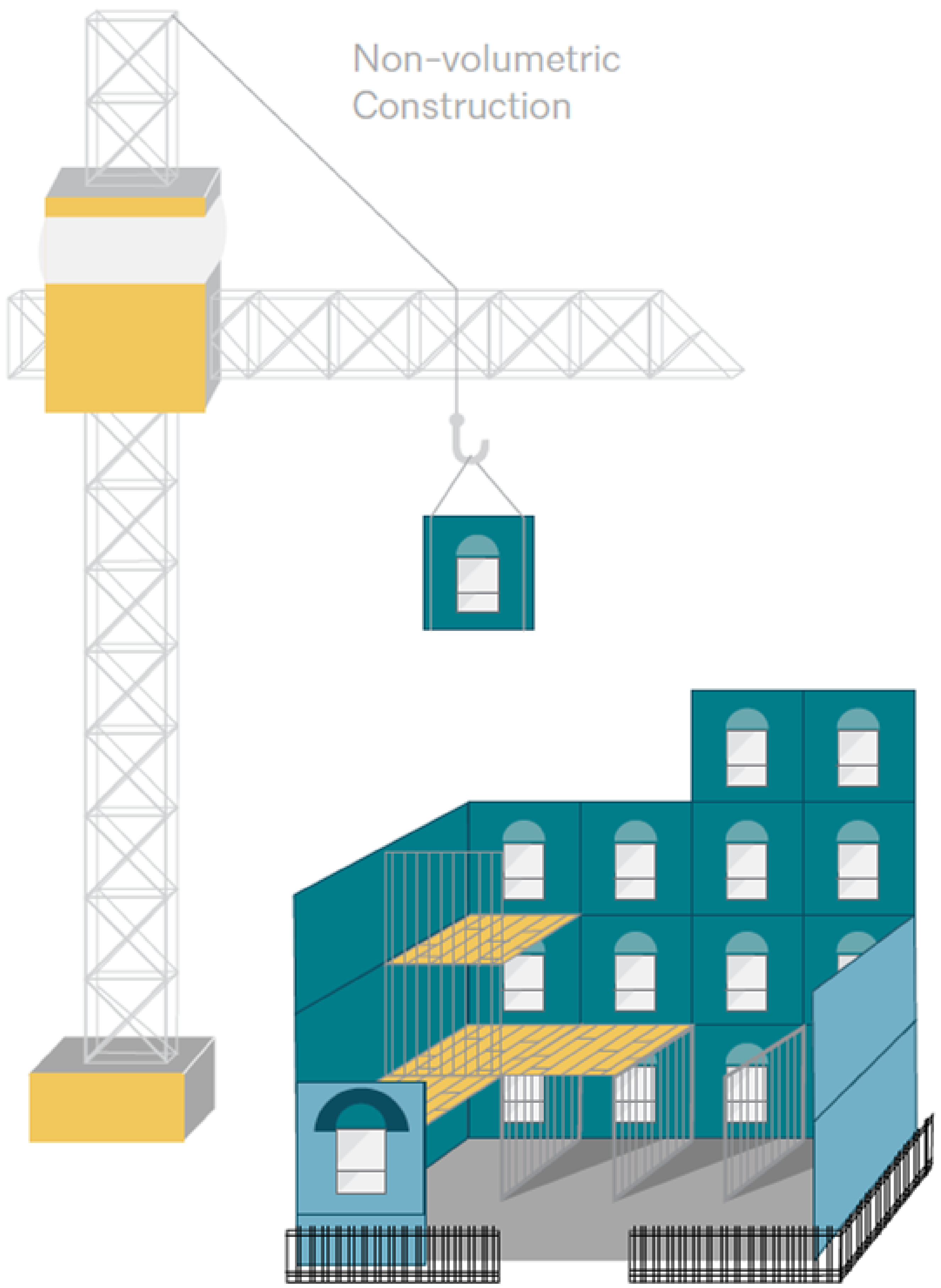
- Partially or completely assembled buildings constructed and designed to be reused multiple times and transported to different building sites.
- Complies with applicable codes or state regulations
- Constructed in a building manufacturing facility using a modular construction process.
- Offer fast delivery, ease of relocation, low-cost reconfiguration, accelerated depreciation schedules and enormous flexibility.
- Not permanently affixed to real estate.
- Essential in cases where speed, temporary space, and the ability to relocate are necessary.

- <u>Modular Building Elements:</u>

1. Volumetric Units



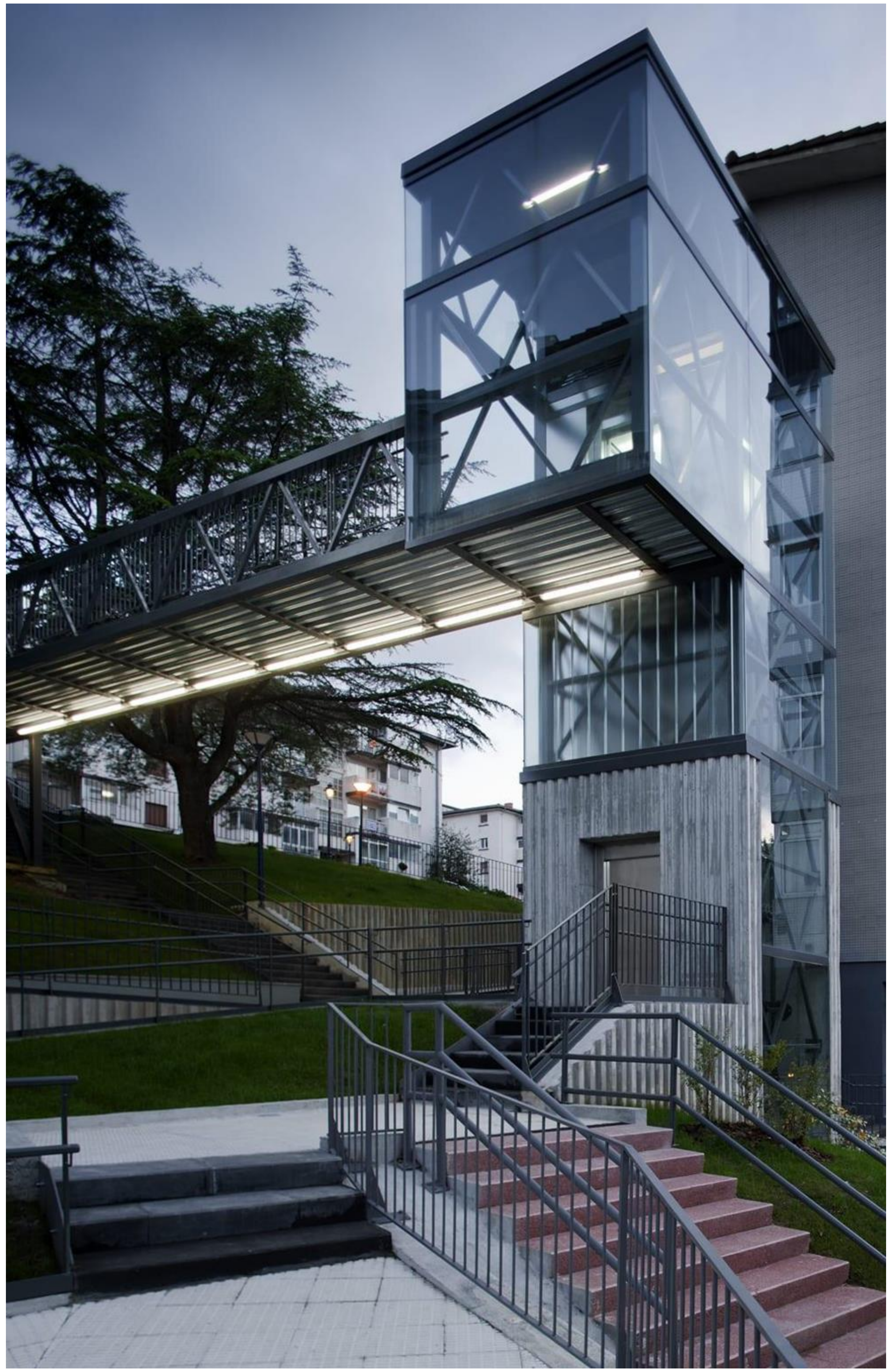
2. Non-volumetric Components



3. Combination of volumetric and non-volumetric components

Modular Building Elements:

- <u>Volumetric modular construction:</u>
- Individual three-dimensional units of enclosed space that are then connected on-site to form a single building.
- Example: multiunit residential projects like hotels, dormitories, and apartment buildings. Each unit, depending on its size, may be made up of one or more modules.
- Other examples of volumetric elements include patient rooms, bathroom pods, and sections of elevator or stair cores.



Modular Building Elements:

- <u>Non-volumetric Components:</u>
- The off-site prefabrication of building elements (commonly referred to as sub-assemblies) that are then connected once on-site.
- Examples: Structural elements such as frames, beams and columns, Sections of building façade and cladding, Wall panels and interior partitions, Floor cassettes and planks, Roof trusses.
- Require additional assembly and sealing work on-site.

Modular Building Approach:

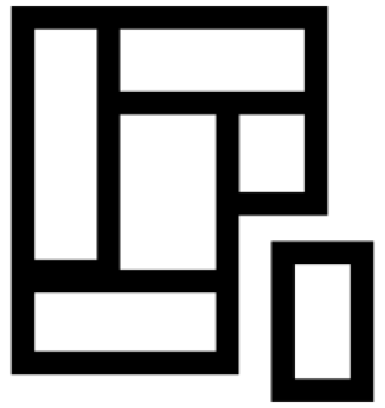
- Modular construction can be used to build structures up to any height, unless otherwise restricted by the local code.
- Volumetric modular components may be manufactured as structural or non-structural components.
- In most cases, the modular manufacturer will take on structural engineering responsibilities
- Manufactured from a range of different materials—including steel, concrete, and wood—and can meet the requirements for Type-I, -II, -III, and -V construction,
- Most readily applied in Type-II (Non-combustible) and Type-V construction (Combustible/Wood).

Modular Building Approach:

- Up to 95 percent of the building will be fabricated off-site (National Institute of Building Sciences).
- The level of finish that is applied off-site generally ranges from 50–90 % percent and will depend on a number of factors.
- The more work that can be completed off-site, the greater the efficiency gained.
- Modular off-site construction involves significant integration of the design, fabrication, and construction.
- Key approach is Design for Manufacture and Assembly (DfMA)

WHEN TO SELECT MODULAR:

Schedule reduction or time to market is a primary motivator for the owner



Repetitive elements such as identical classroom units, dormitory units, office spaces, or labs

Relatively dense framing and no excessive spans

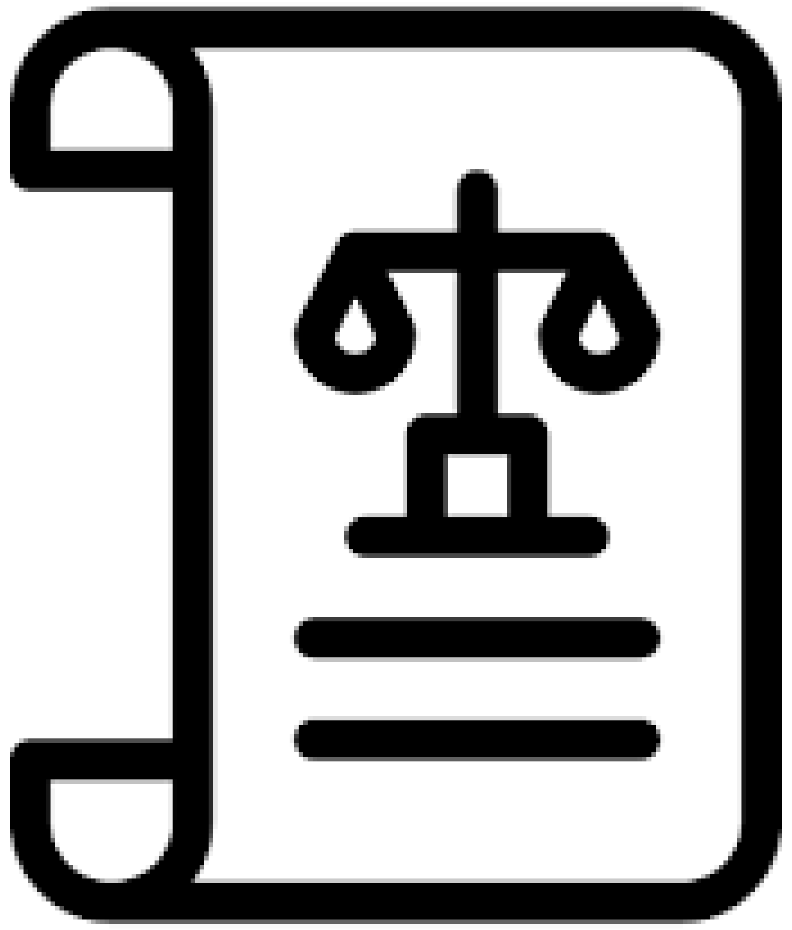
Located in areas where labor is not readily available

Located on remote or less accessible sites , constricted build seasons, materials, labor, and/or land is expensive

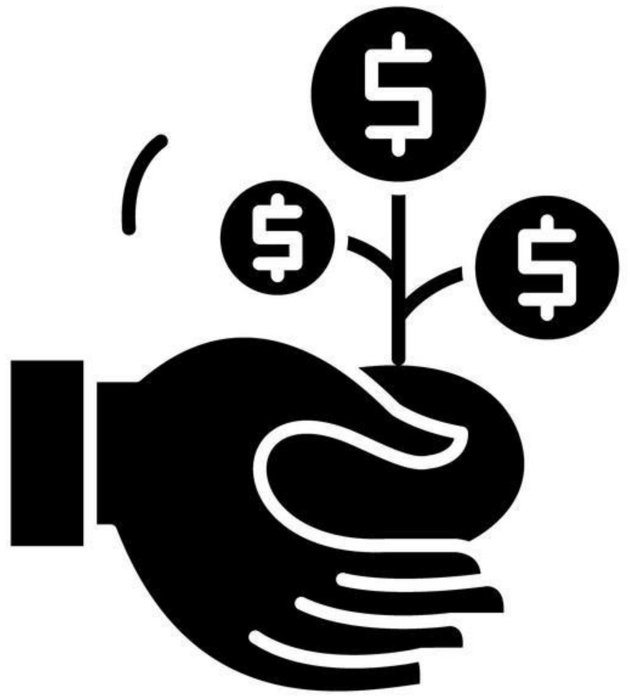
PRE-DESIGN

Does off-site aid in meeting the cost, time, labor, site and programmatic goals for the project?

Legality



Financing



Insurance

Delivery

PRE-DESIGN

Legality › Financing › Insurance › Delivery

- Most states use the International Building Code (IBC) as their base model code. Some states have building codes amended with modular construction considerations.
- Some states have such an agency responsible for the approval of the modular manufacturer, QA/QC, and plan approvals. Local Authority Having Jurisdiction (AHJ) in other states. The state agencies will determine whether inspections will be on-site or at the factory (if required).
- Construction needs to meet all applicable codes and requirements where the building is located, not fabricated. Make sure modular manufacturer is approved in your state.
- Make clear module manufacturer is building to specification (and not designing a product).
- Depending on the jurisdiction, modular fabricator may need to hold license as a GC, Plumber or Electrician.

PRE-DESIGN

Legality | Financing | Insurance | Delivery

Modular projects can require higher upfront costs for technical approval compared to traditional construction projects.

Modular construction may also involve a different cash conversion cycle because construction time can be substantially reduced.

Modular projects do not easily fit into traditional lender calculations because modules delivered to the site ready to be installed are categorized as materials.

Creates a challenge regarding payment certifications that some publicly funded projects may not permit.

PRE-DESIGN

Legality > Financing > **Insurance** > Delivery

There is risk related to the transportation of modules and the increased use of cranes for assembly on-site.

Manufacturer's responsibility to coordinate with the carrier to confirm that the carrier's insurance will adequately cover transportation risks.

The labor that's usually performed on-site occurs off-site. This will influence the specific insurance policies that need to be put in place.

If completed modules will have to be stored at a location off-site due to schedule delays, the project will need to obtain a provision amending the coverage of builder's risk insurance.

PRE-DESIGN

Legality > Financing > Insurance > **Delivery**

- Design/build and Integrated Project Delivery (IPD) models are more ideal for modular construction.
- The early involvement of all necessary stakeholders and enable the level of information flow required to successively implement modular construction

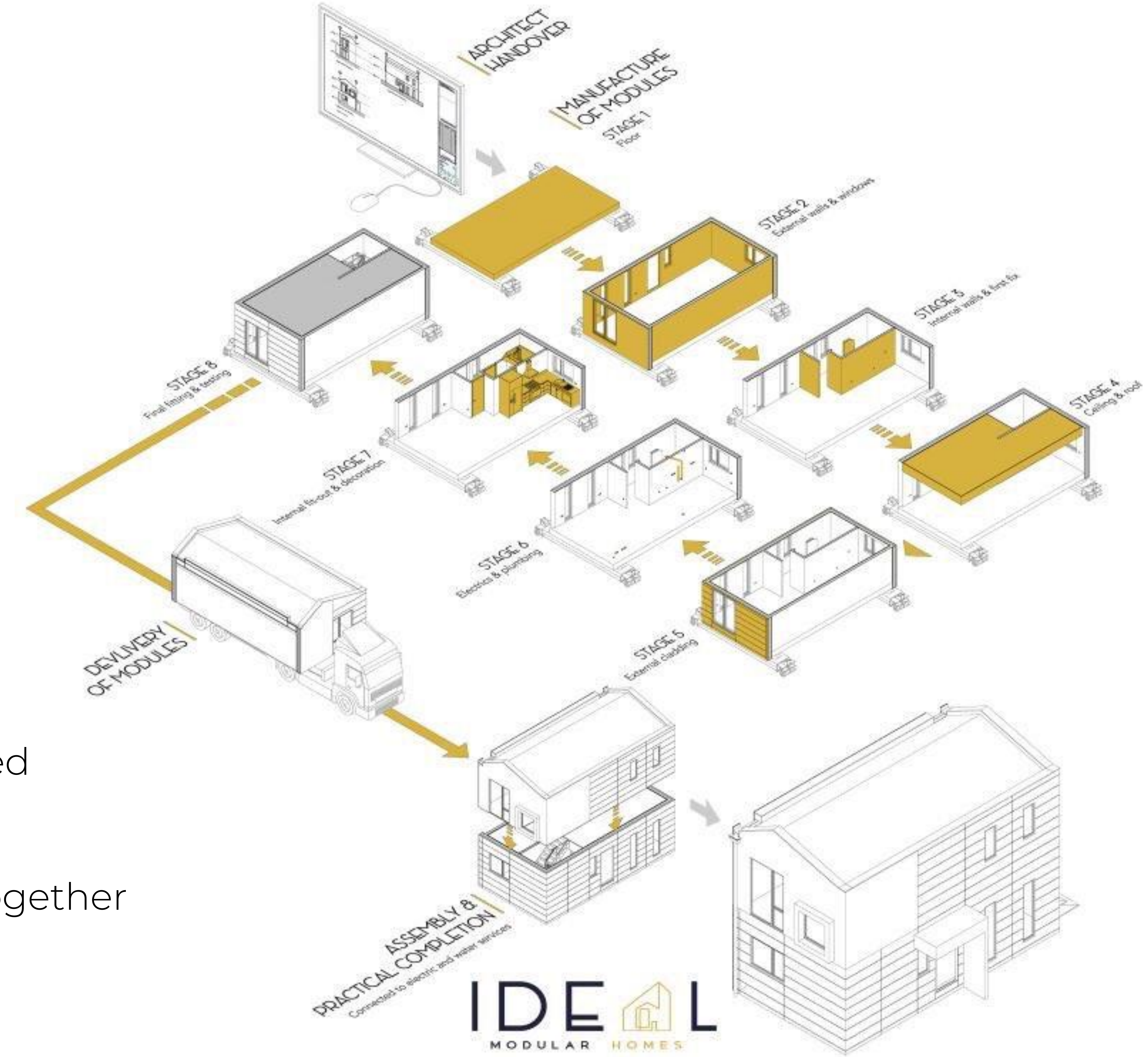
Manufacturer's Scope		
The modular manufacturer acts as a subcontractor and hands off the completed modules to the GC	The modular manufacturer acts as a subcontractor that also performs the installation	The modular manufacturer acts as the general contractor, responsible for all aspects

PRE=DESIGN:
Commit and Communicate Early

Incorporating design changes to modules once fabrication has begun can be very expensive

Integration are all typically completed earlier on modular projects

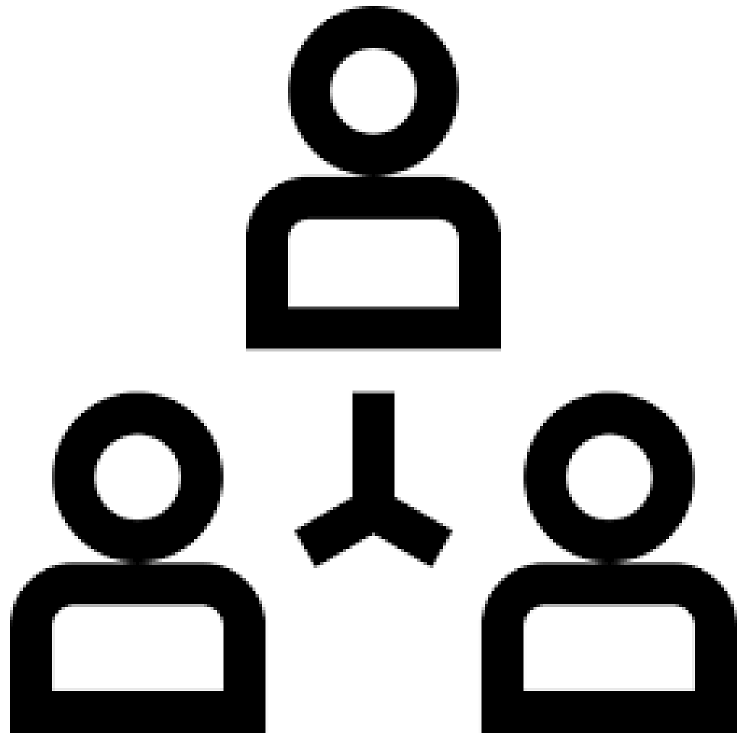
Training composite crews to work together



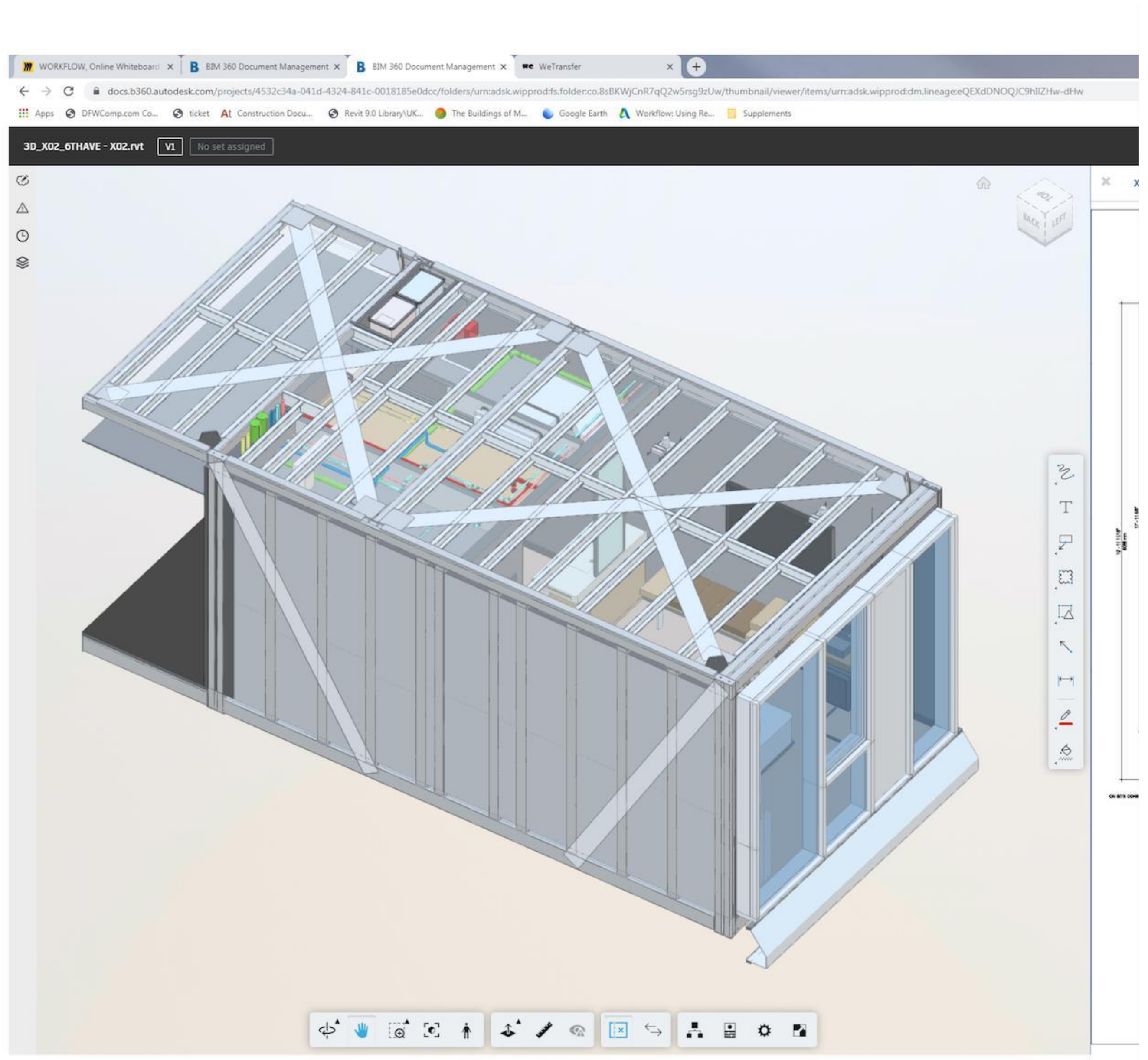
DESIGN

Manufacturer

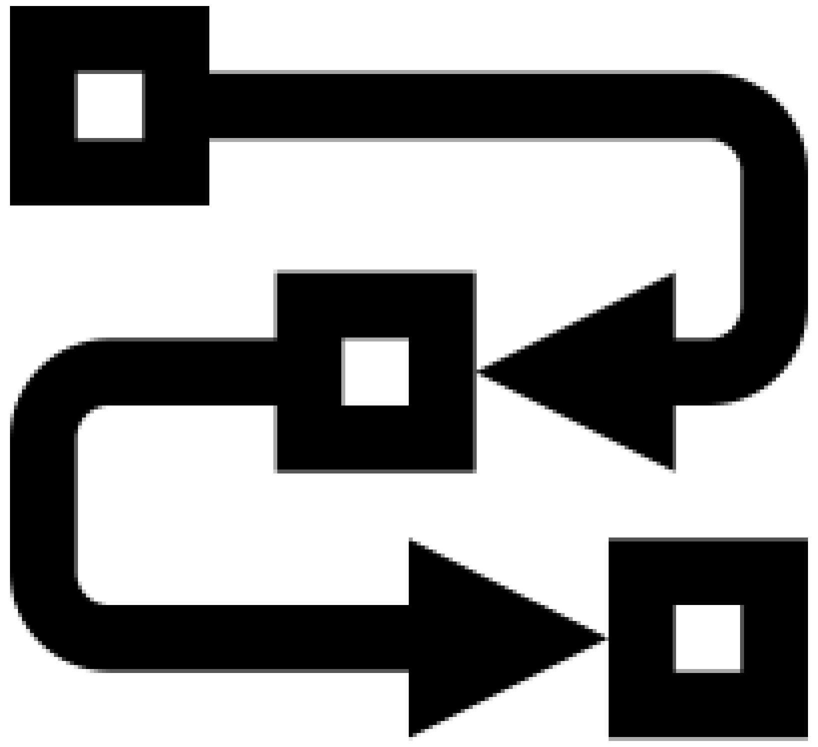
Coordination



BIM



Process



Engage a modular manufacturer early; Allows the project team to benefit from the manufacturer's expertise and knowledge of available products and techniquesa

The architect should be careful to clearly establish the specific scope of the modular manufacturer's responsibility.

The project team should research the industry by requesting referrals and reviewing case studies of similar projects and issue pre-qualification.

Criteria for Manufacturer:

Level of experience with specific project type and level of design complexity	Production capacity relative to project scale and schedule	Extent of established network of resources	Proximity of plant location(s) to project site (locations within about a 350- to 500-mile radius.)

DESIGN | Manufacturer | Coordination | Integrated Process

"Clearly define the responsibilities and scope of work of each project team member"

DESCRIPTION	DESIGNER	OWNER	NRB	G C	OTHERS (SPECIFY)	COMMENTS
X = responsible N/A = applicable NOTE: COMMENTS COLUMN MUST BE USED TO EXPAND ON OR PROVIDE ADDITIONAL DETAILS						
X may appear in more than one column. Use the comments column to explain.						
Division 0 – General Summary of Modular						
Building (see also all other Divisions for details)						
Modular building manufacturing						
Modular Building Transportation						
Transportation to the site						
Inspect building modules on arrival						
Modular Building Installation						
Modular offload to staging area						
Provide clear access to building location						
Remove temp weather protection/bracing						
Set modular units on foundation						
Connect modular units to foundation						
Structurally connect modular units						
Roof seams – modular splits/penetrations						
Finish exterior mate line seams						
Finish interior mate line seams						
Site install roof top equipment						
Verify, inspect, ship loose items						

SCOPE OF WORK CHECK LIST (Responsibility matrix)

The American Institute of Architects

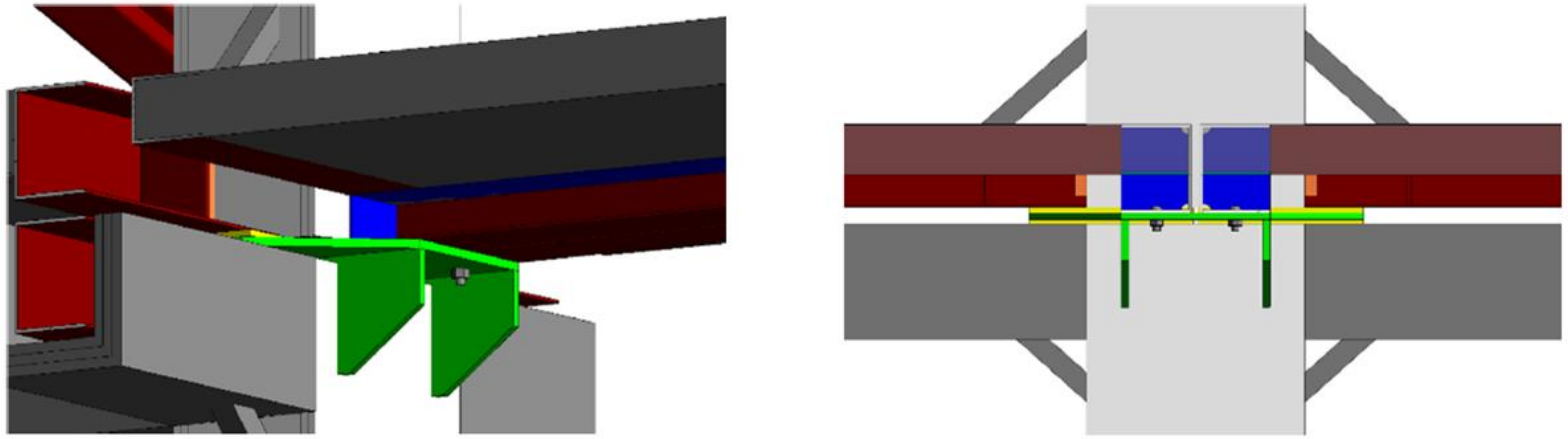
https://content.aia.org/sites/default/files/2019-03/Scope_of_Work_Matrix.pdf

Building information modeling (BIM) tasks for modular construction project

Which BIM task should be applied to which activity?

Code	BIM Task
T1	Detailed 3D modeling for critical joints
T2	3D shop drawings
T3	Creation of a 3D model for site layout and conditions
T4	Creation of a 4D simulation model
T5	Creation of a 4D sequence model for critical joints
T6	Creation of a 4D model for the lifting plan
T7	Integration of a 4D model with quantity take-off

Myungdo Lee, Dongmin Lee , Taehoon Kim and Ung-Kyun Lee , Practical Analysis of BIM Tasks for Modular Construction Projects in South Korea, 2020.



(a) (b)

Figure 3. Example of detailed three-dimensional (3D) modeling for critical joints (T1): (**a**) 3D view of

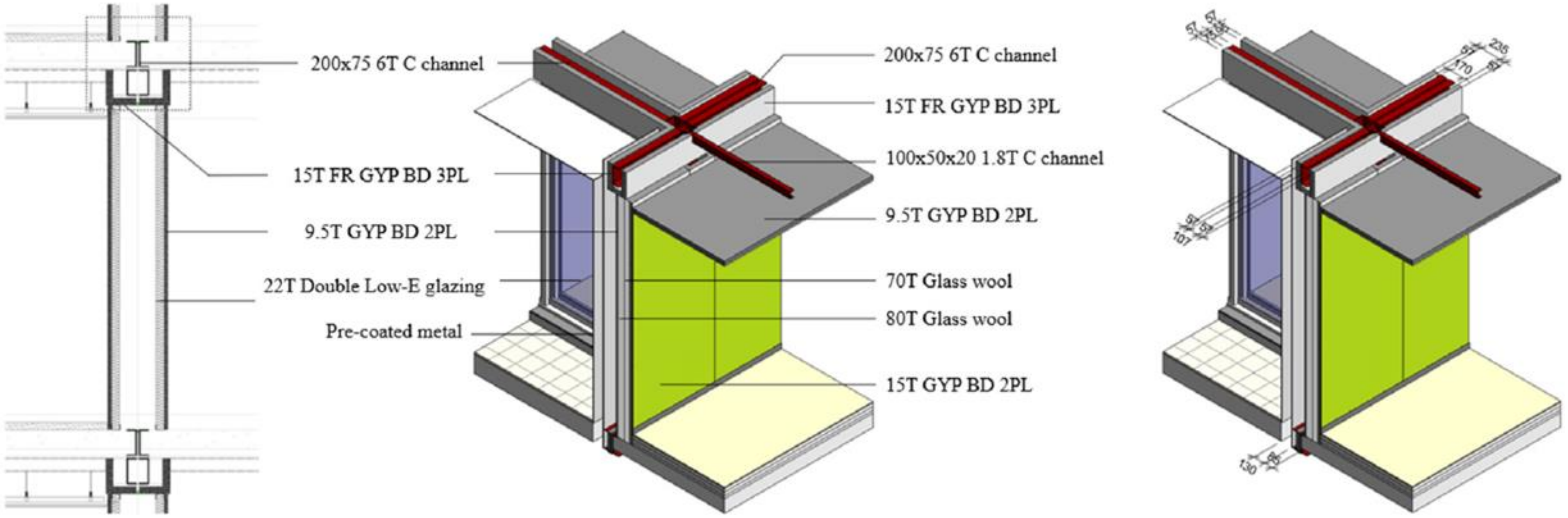
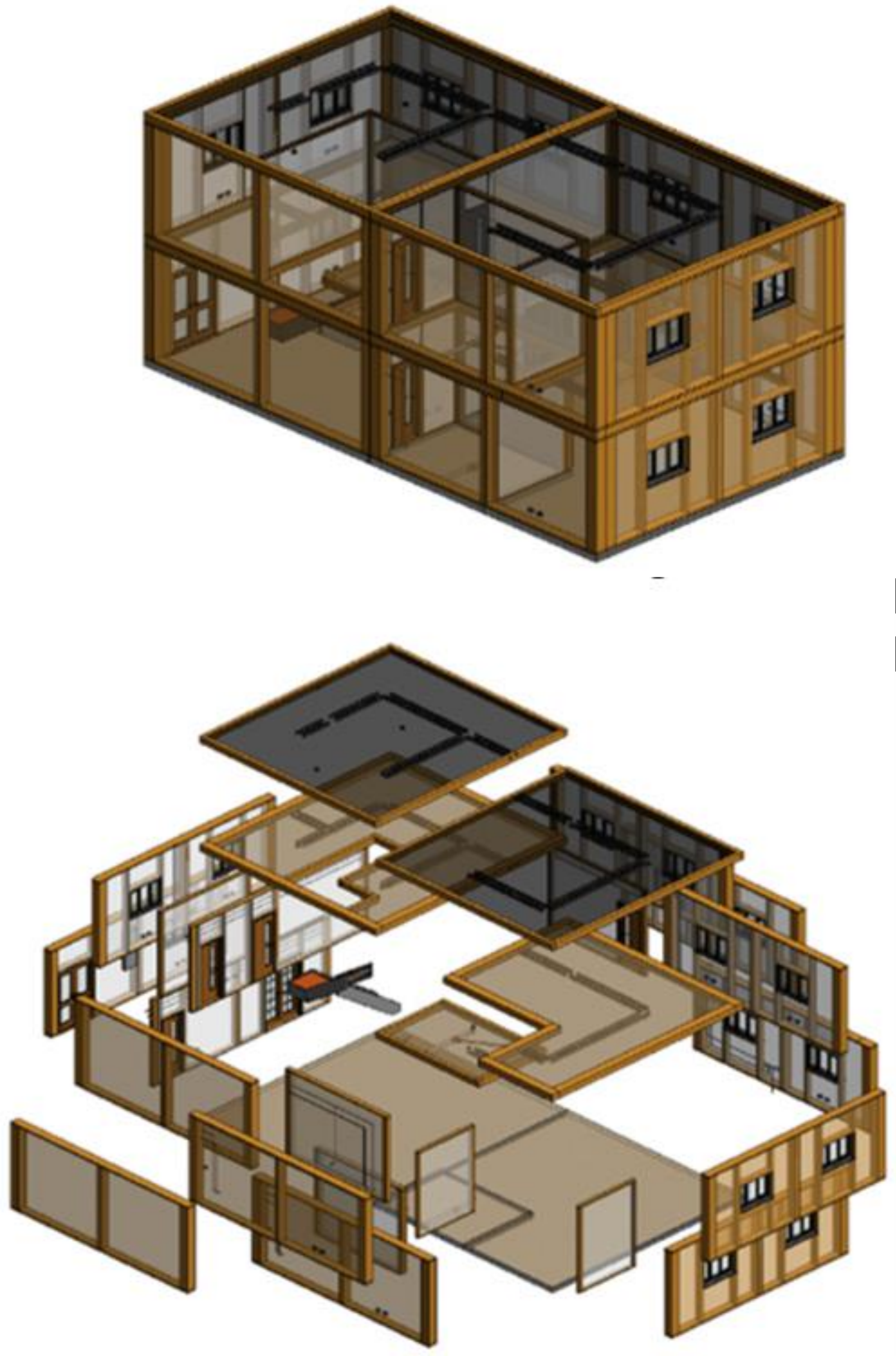


Figure 4. Example of T2 (part of the 3D shop BIM model).

Design for Manufacturing and Assembly (DFMA)

- Standardisation, with repeatable processes and designs
- Based on optimization where designers maximise the delivery process for clients. This naturally includes all activities, from concept through to automation and logistics.

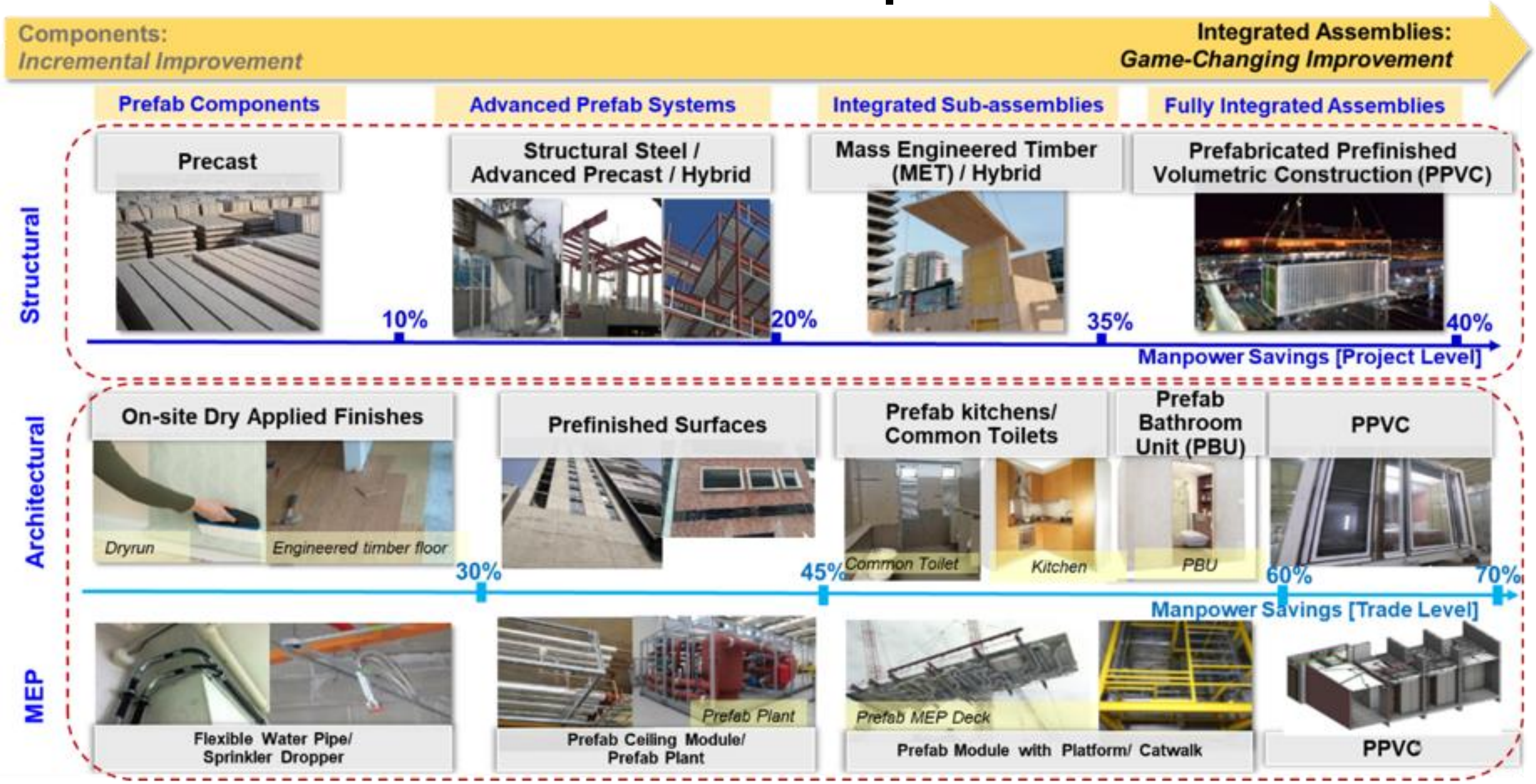
3D Model



Identification DFMA Element

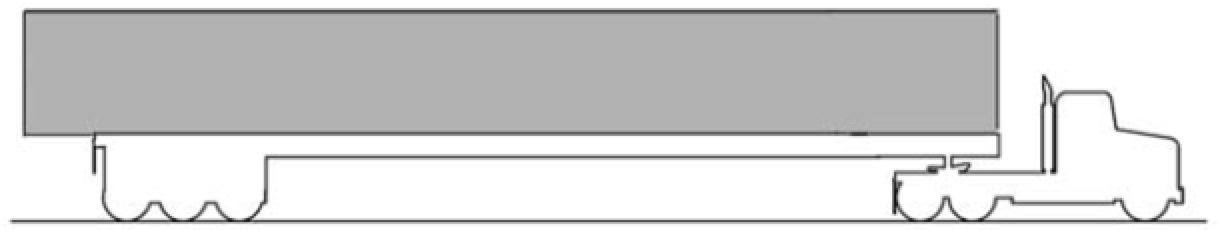
BIM data exchange standards (e.g., industry foundation classes (IFC)

DFMA Component



Transportation Considerations

- The geometric design of the constituent modular components will also be affected by transportation-related constraints on the size and shape of modules.
- Modules typically measure between **12- to 14-feet wide**, **50- to 60-feet long**, and **11.5- to 13-feet** high.



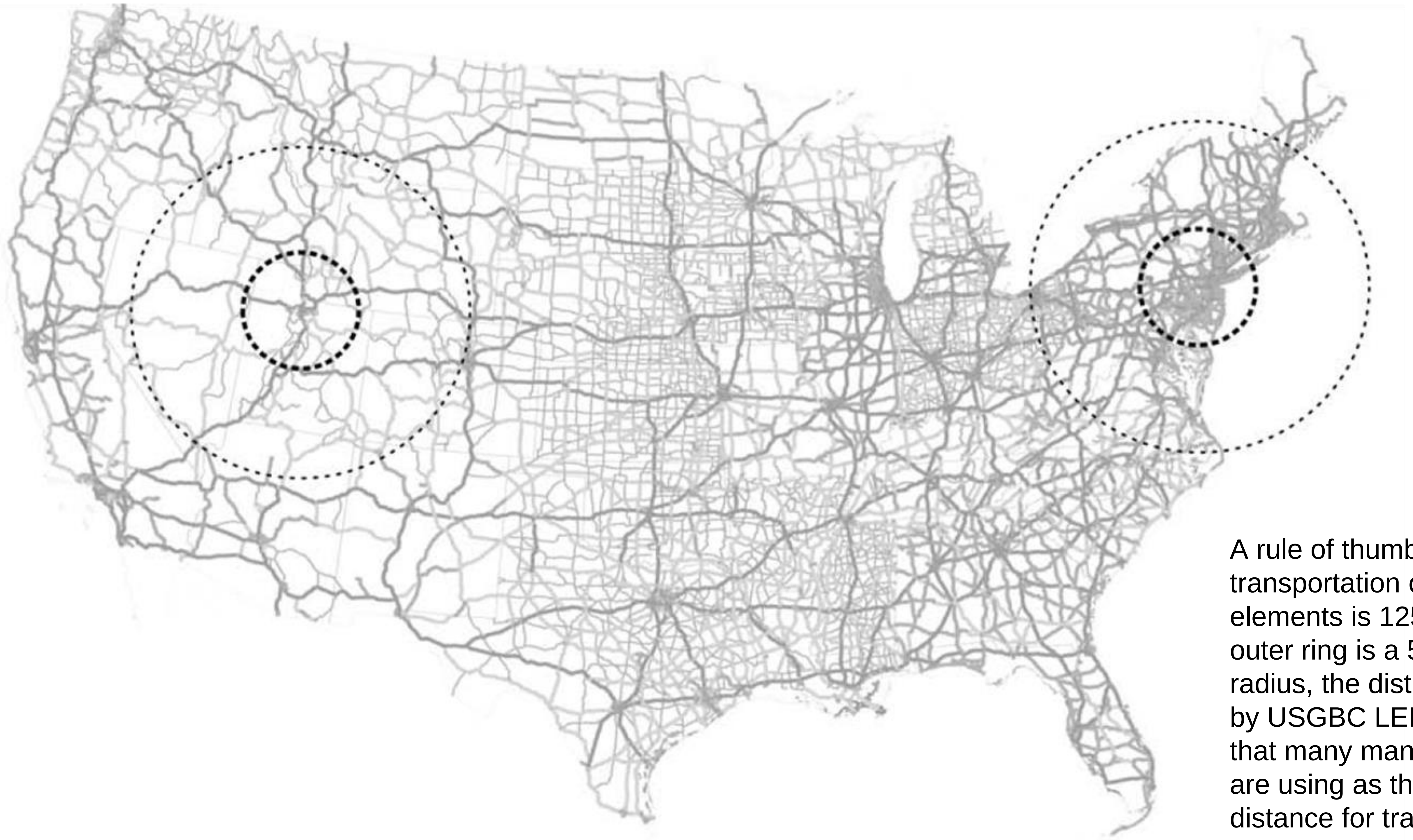
Flatbed trailer for longer elements

Single-drop deck

Double-drop deck for tall elements.

State	Width	Height	Length
Alabama	12' (16')	* (16')	76' (150')
Alaska	10' (22')	*	100' (*)
Arizona	11' (14')	* (16')	* (120')
Arkansas	12' (20')	15' (17')	90' (*)
Califonia	12' (16')	* (17')	85' (135')
Colorado	11' (17')	13' (16')	85' (130')
Connecticut	12' (16')	14' (*)	80' (120')
Delaware	12' (15')	15' (17'-6")	85' (120')
District of Columbia	12' (*)	13'-6" (*)	80' (*)
Flordia	12' (18')	14'-6" (18')	95' (*)
Georgia	12' (16')	15'-6" (*)	75' (*)
Idaho	12' (16')	14'-6" (16')	100' (120')
Illinois	* (18')	* (18')	* (175')
Indiana	12'-4" (16')	14'-6" (17')	90' (180')
Iowa	8' (16'-6")	14'-4" (20')	85' (120')
Kansas	* (16'-6")	* (17')	* (126')
Kentucky	10'-6" (16')	14' (*)	75' (125')
Louisana	10' (18')	* (16'-5")	75' (125')
Maine	8'-6" (18')	8'-6" (*)	80' (125')
Maryland	13' (16')	14'-6" (16')	85' (120')
Massachuetts	12' (14')	13'-9" (15')	80' (130')
Michigan	12' (16')	14'-6" (15')	90' (150')
Minnesota	12'-6" (16')	*	95' (*)
Mississippi	12' (16'-6")	* (17')	53' (*)
Missouri	12'-4" (16')	15'-6" (17'-6")	90' (150')

State	Width	Height	Length
Montana	12'-6" (18')	* (17')	* (120')
Nebraska	12' (*)	14'-6" (*)	85' (*)
Nevada	8'-6" (17')	* (16')	105' (*)
New Hampshire	12' (16')	13'-6" (16')	80' (100')
New Jersey	14' (18')	14' (16')	100' (120')
New Mexico	* (20')	* (18')	* (190')
New York	12' (14')	14' (*)	80' (*)
North Carolina	12' (15')	14'-5" (*)	100' (*)
North Dakota	14'-6" (18')	* (18')	75' (120')
Ohio	14' (*)	14'-10" (*)	90' (*)
Oklahoma	12' (16')	* (17')	80' (*)
Oregon	9' (16')	*	95' (*)
Pennsylvania	13' (16')	14'-6" (*)	90' (160')
Rhode Island	12' (*)	14' (*)	80' (*)
South Carolina	12' (*)	13'-6" (16')	(125')
South Dakota	10' (*)	14'-6" (*)	*
Tennessee	10' (16')	15' (*)	75' (120')
Texas	14' (20')	17' (18'-11")	110' (125')
Utah	10' (17')	16' (17'-6")	105' (120')
Vermont	15' (*)	14' (*)	100' (*)
Virginia	10' (*)	15' (*)	75' (150')
Washington	12' (16')	14' (16')	*
West Virgina	10'-6" (16')	15' (*)	75' (*)
Wisconsin	14' (16')	*	80' (110')
Wyoming	* (18')	* (17')	* (110')

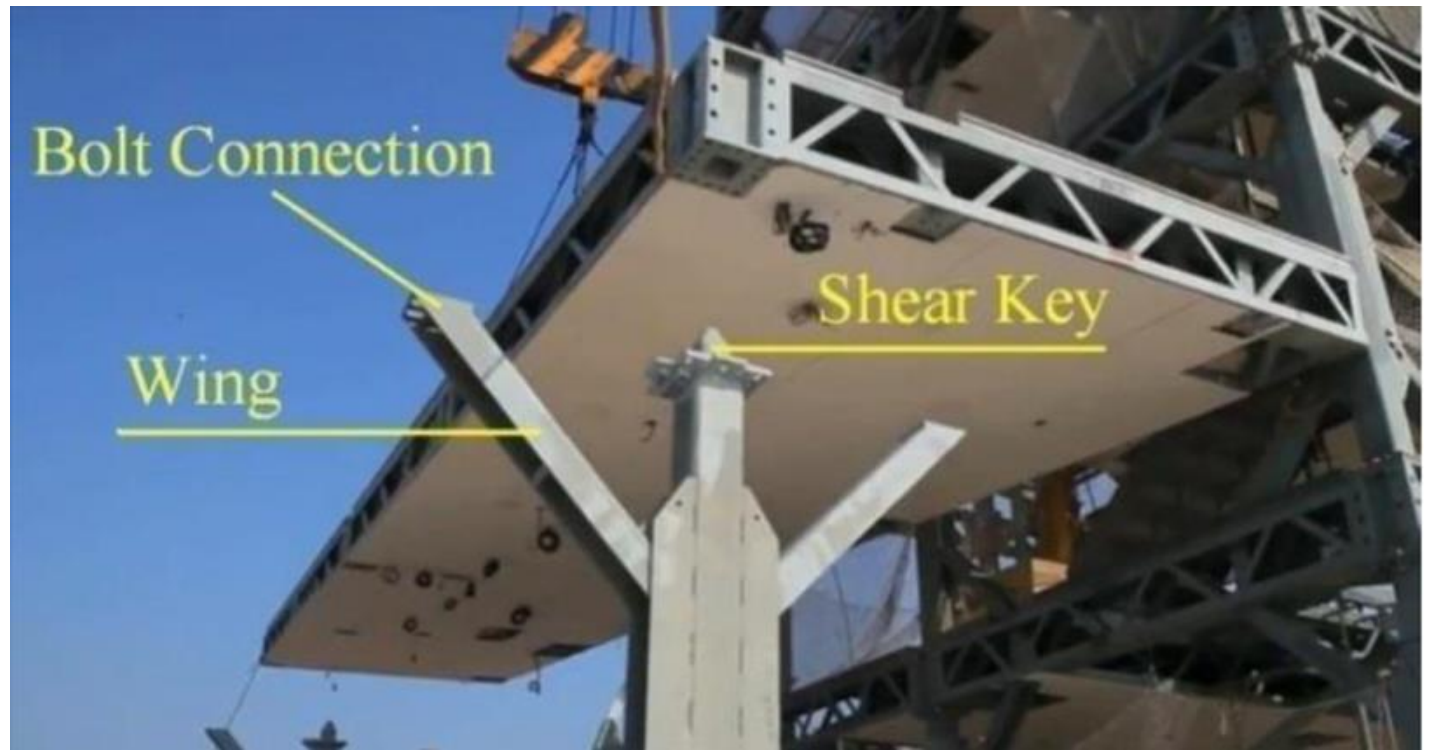


A rule of thumb for transportation of prefab elements is 125 miles. The outer ring is a 500-mile radius, the distance directed by USGBC LEED program that many manufacturers are using as their maximum distance for travel.

STRUCTURAL TYPE OF MULTI-STORY MODULAR BUILDING

1. 2D Systems

The structure has two main components, which are roof/floor cassettes and columns.



2. 3D Systems

The structure consists of many 3D modules, which are stacked vertically and attached horizontally to create the 3D building. Each module can be part of a unit, one complete unit, or even more than one unit.

Wall-Load Bearing systems

In wall-load bearing systems, gravity loads (live and dead) are transferred to the walls, which will then transfer loads to the foundation. Lateral loads within the module are resisted by bracing elements and/or sheathing.

Figure 2. Wall-Load Bearing module with steel C-section profiles (Lawson et al., 2005b)

Corner-Supported systems

The corners of the modules support the gravity loads, which are transferred by edge beams of the modules. The columns and edge beams (normally deeper than those in wall-bearing modules) carry gravity loads, while some bracing elements or sheathings resist the lateral loads.

Figure 6. Corner-Supported module (Lawson et al., 2005b)

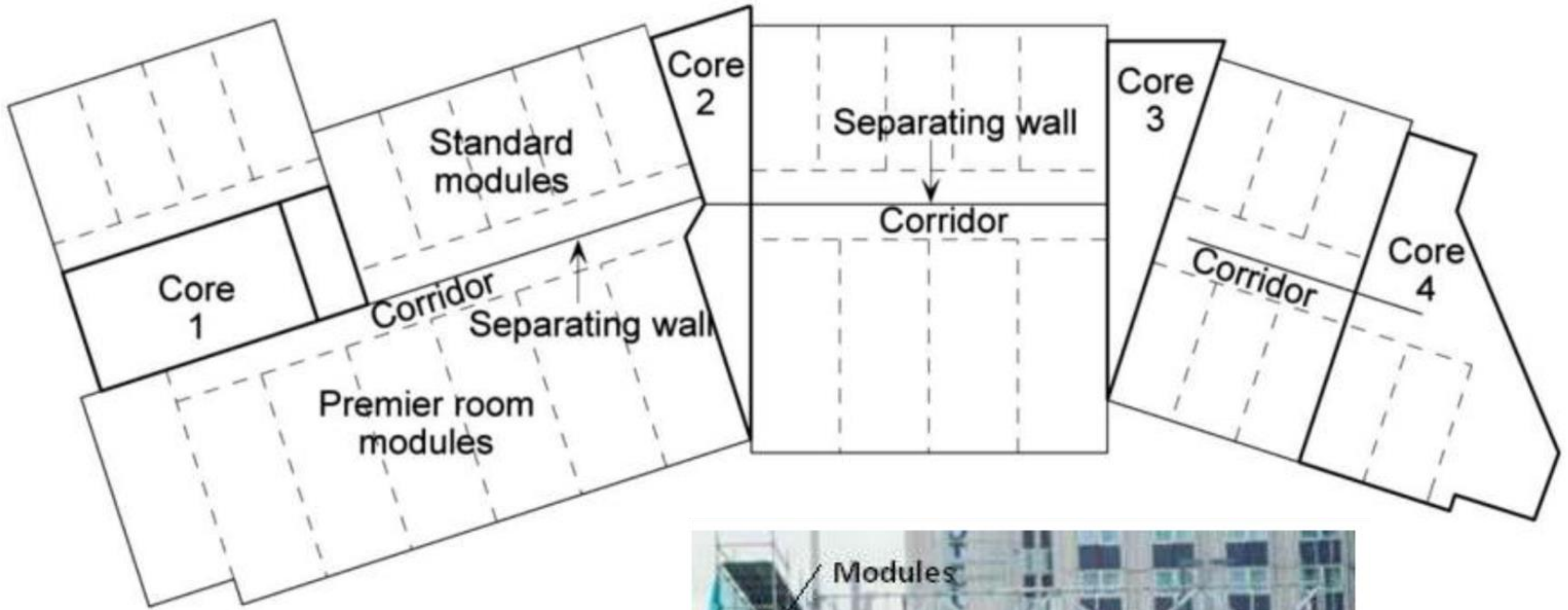
Structural Type Of Multi-story Modular Building

3. The Open Building System

Two integrated framing systems transfer both gravity and lateral loads to the foundation. The interior structure of the module is one of these frames. The second frame is the exterior frame, which consist of columns on exterior edge of the structure (or some in the middle rows) at a constant spacing.

4. Hybrid Cored-Modular Systems (Cluster)

As the height of a structure increases, the magnitude of the total lateral and gravity loads increase and therefore, the size of load-bearing elements in lower modules will have to be larger beyond what is needed just for gravity loads. In cluster systems the size of these elements are limited by considering a core for the structure.



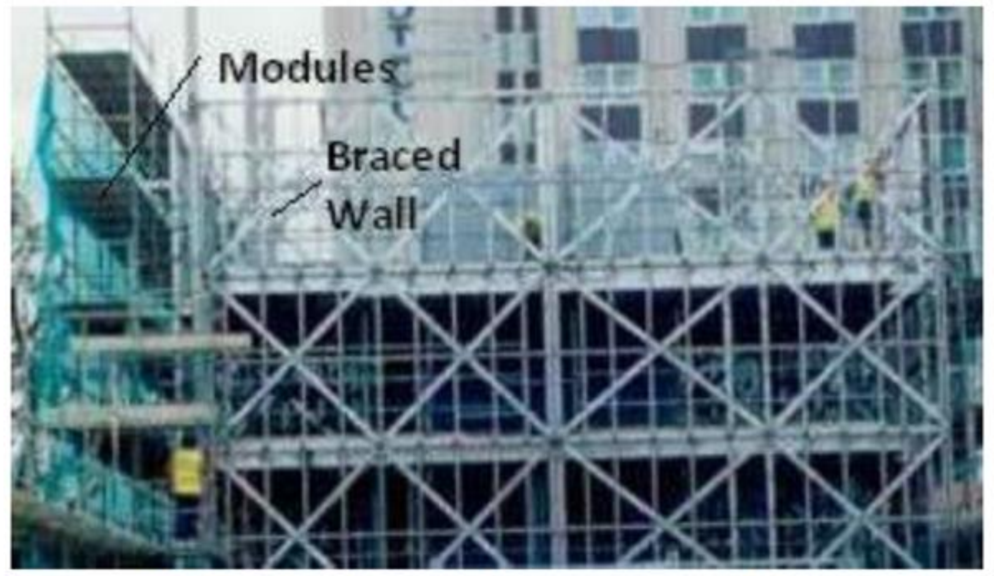


Figure 10.Stacked modules, supported by steel frame (Lawson et al., 2005)

Structural Type Of Multi-story Modular Building

5. Hybrid Podium

Used in structures that need longer bay spans in lower stories. In podium-modular systems, some of the bottom stories (usually two stories) are built using conventional structural steel or concrete frames with long spans. Then, the modular part of the building would be installed on top of the podium.

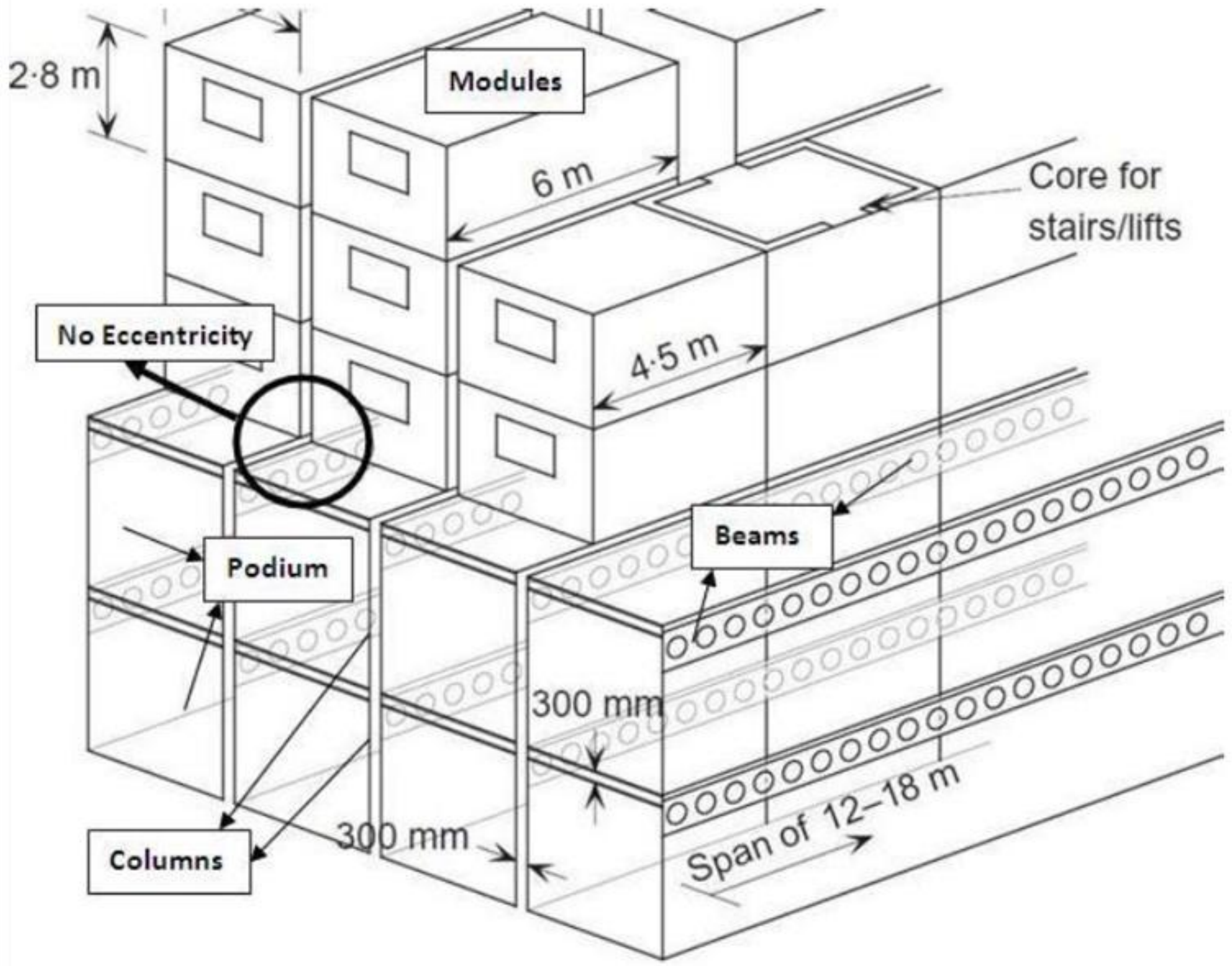
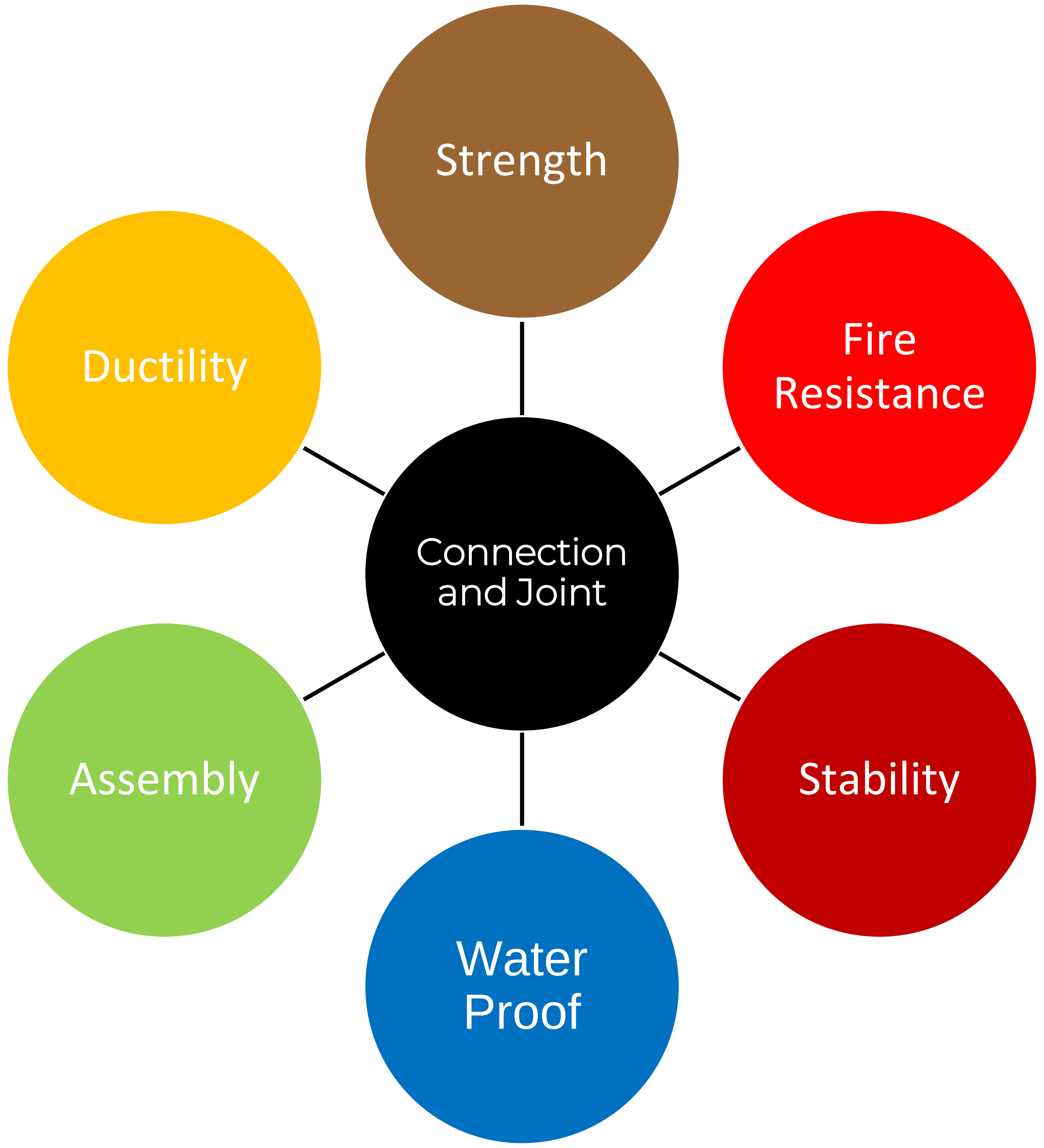


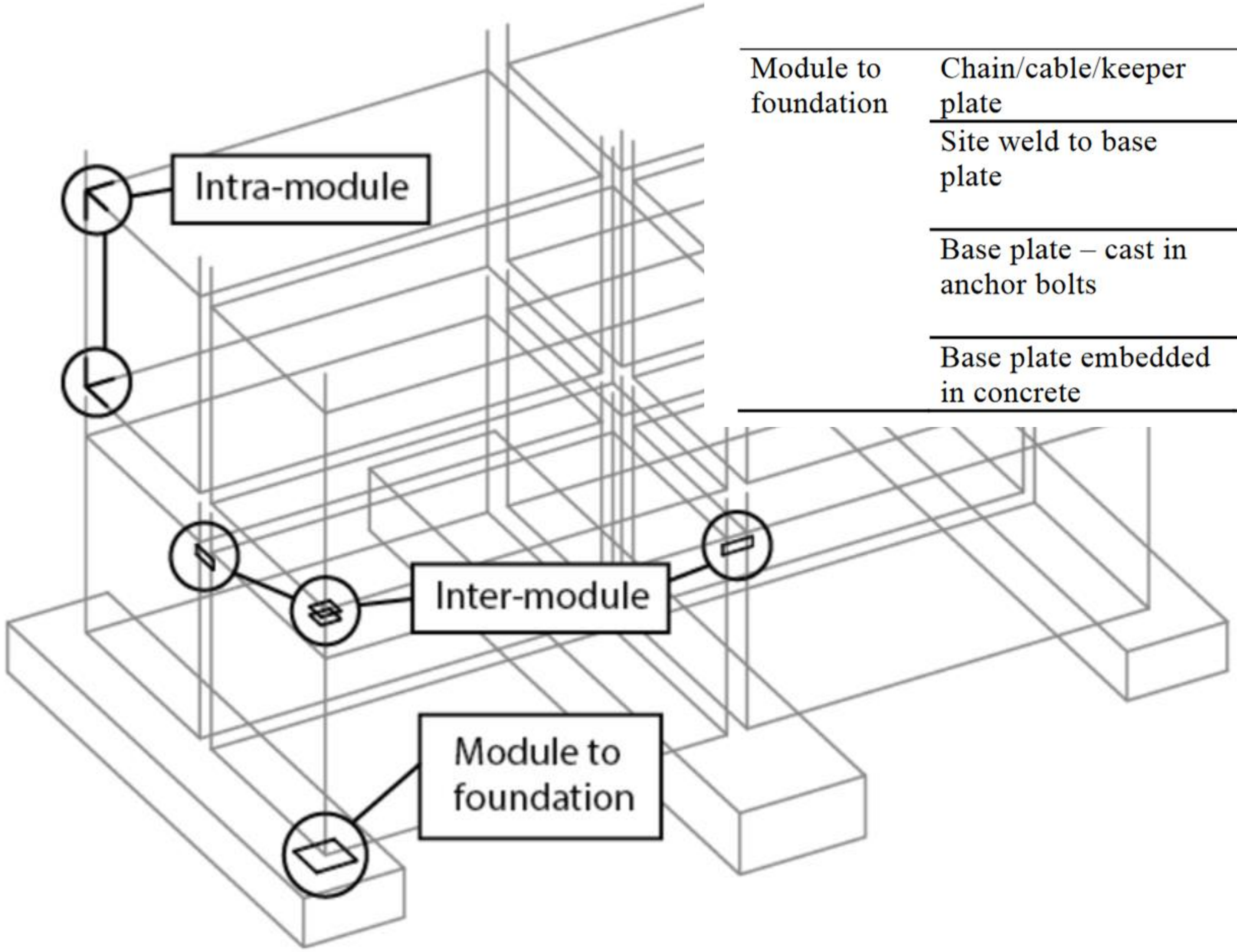
Figure 12.A 2-Story podium beneath a multi-story modular building (Lawson et al., 2010)

6. Framed Unit systems

In this system, the main structure of the building is not constructed as modular. The main structure of this type of construction is a conventional structural frame. After erection of the main structural frame, prefabricated units will be placed and fitted between beams and columns of the structural frame.

Figure 14.Contemporary Resort Hotel in Disney land (1971)





Type	Sub-Type	Advantage	Disadvantage
Inter-module	Bolted	Reduced site work; demountable	Access, slotted holes, slip, bolt tensioning
	Welded	No slip, compact, accommodate misalignment	Site work, corrosion, not demountable
	Composite (concrete-steel)	Strength, no slip, compact	Site work, not demountable
Intra-module	Bolted	Tolerance for shop assembly, deconstructable	Relatively low moment capacity, ductility and rotation capacity
	Welded	Suited to factory based construction using jig to ensure module uniformity	Does not permit rotation, steel members should be designed for hogging moments and axial forces
Module to foundation	Chain/cable/keeper plate	Low cost	Limited to low rise construction; tensioning requirements
	Site weld to base plate	Rigid connection	Additional trade on site, hot work, damage to steel corrosion protection system
	Base plate – cast in anchor bolts	Ductility	Positioning of cast in anchor bolts, tolerance in steel base plate, corrosion
	Base plate embedded in concrete	Full column strength and good ductility	Positioning of column during concrete curing, site welding

Prototyping

- Build prototypes or mockups of components or entire modules, as a way to evaluate the constructability and performance of different design options.

1. Rapid Prototypes

Rapid prototypes are a scale model (which may be smaller or in some cases larger than the final element) of a physical part or assembly which are developed using a 3D CAD model, with parts created using 3D printing technology

2. Mock Ups

Mock ups comprise fabrication of a scale model of an assembly or element, but not necessarily in the final materials that will be used. For example, a mock up in timber and cardboard is relatively quick and easy to amend and adjust, while the final product may be proposed in steel or concrete.

3. Full Scale Prototypes

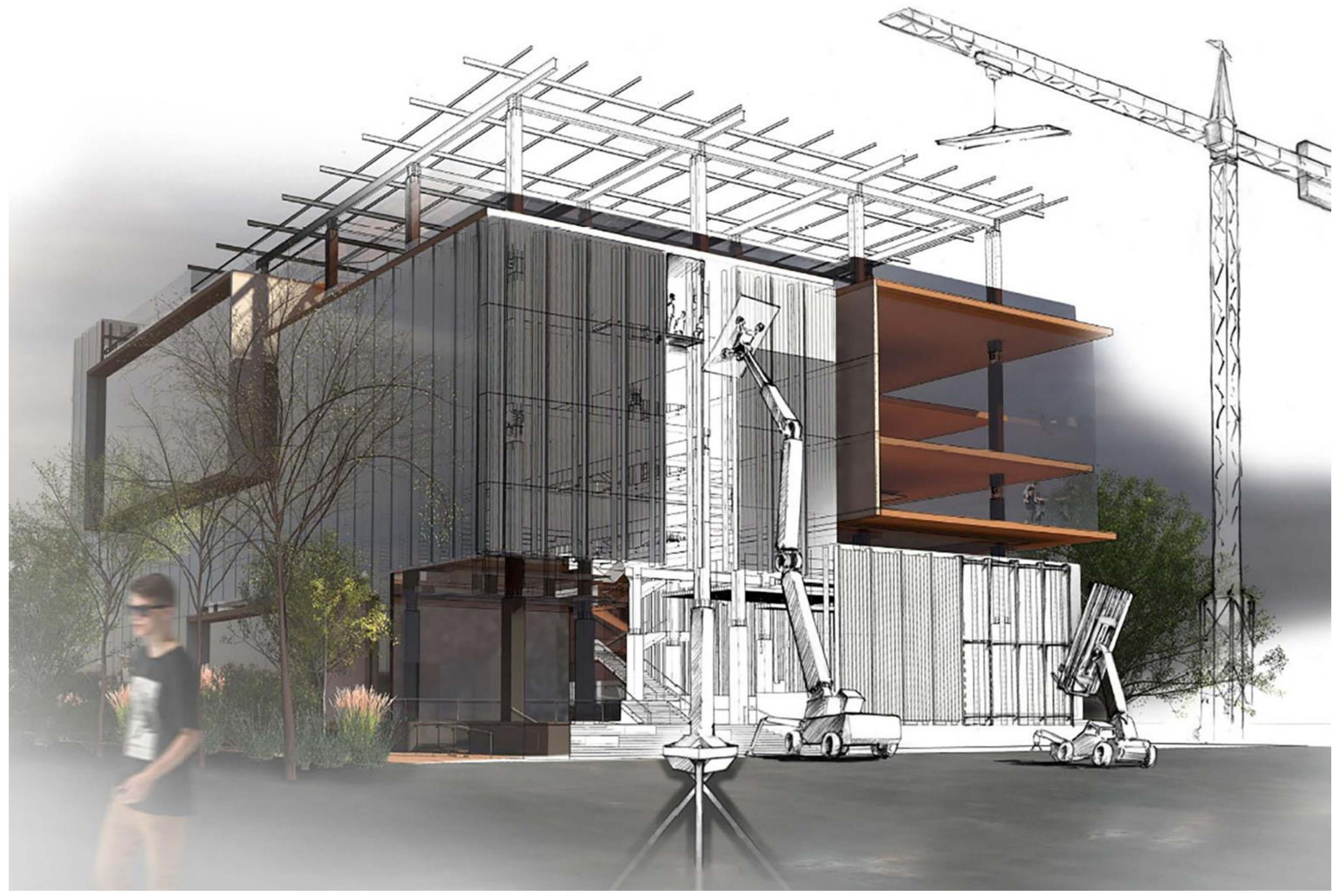
Full Scale Protoype can be used to test the physical characteristics of an element or system as well as installation methods. Prototypes are typically created for learning purposes only, not for deploying in a 'live' environment.

4. First Run Studies

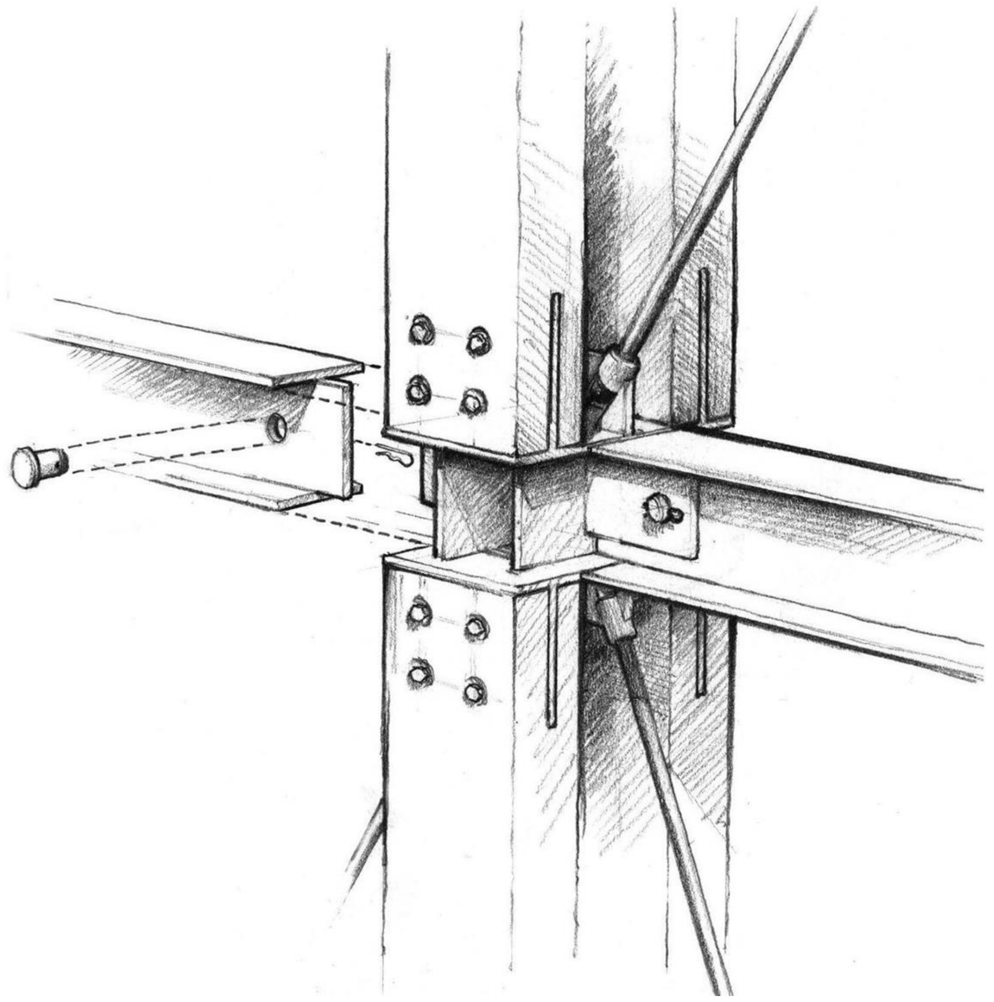
It is anticipated that the 'first run' will, with minor modifications, be used in the final 'live' environment for which the element is proposed.

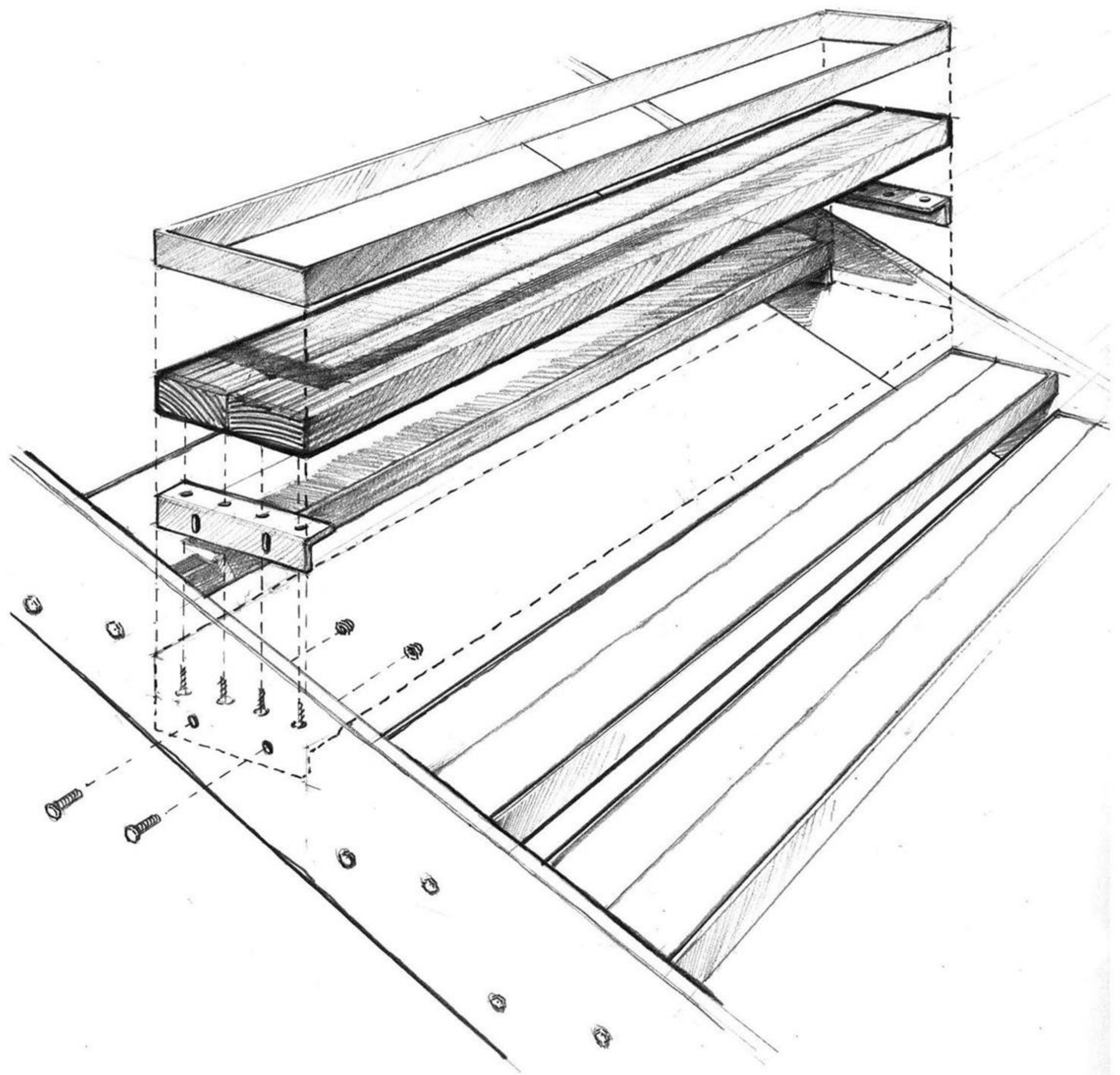
Design for disassembly

Design of buildings to facilitate future changes and dismantlement (in part or whole) for recovery of systems, components and materials, thus ensuring the building can be recycled as efficiently as possible at the end of its lifespan. (Andreea Cutieru, 2020)



To maximize sustainability or to meet a project requirement for future relocatability or repurposing





POST-DESIGN

Manufacturing

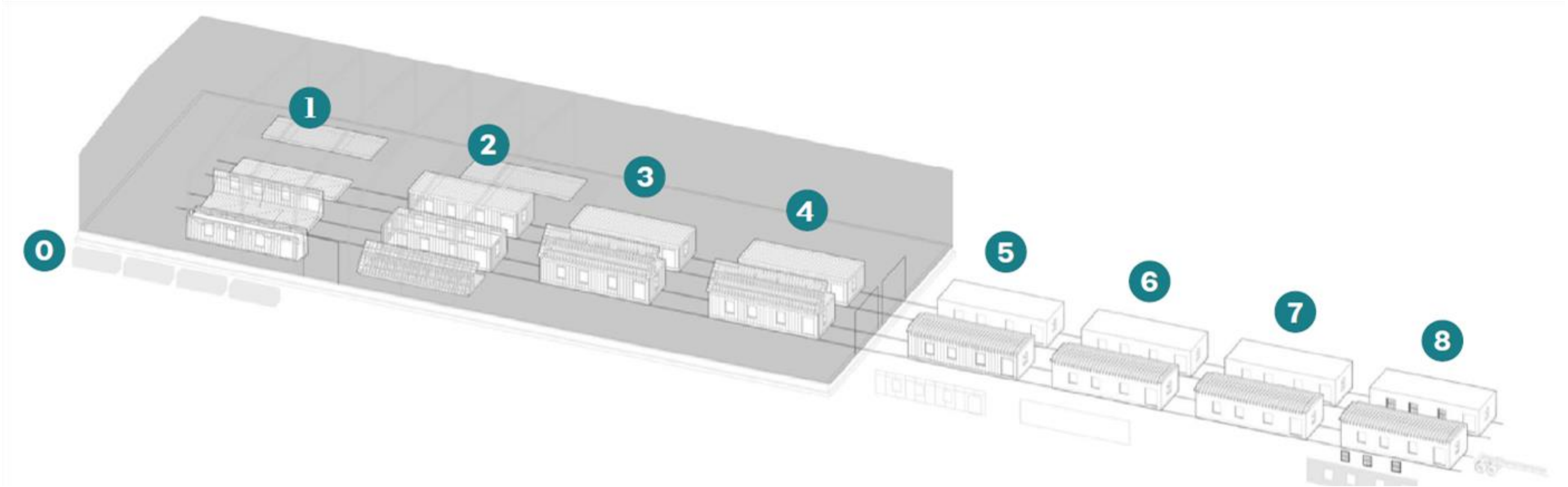
Transport

Site Preparation

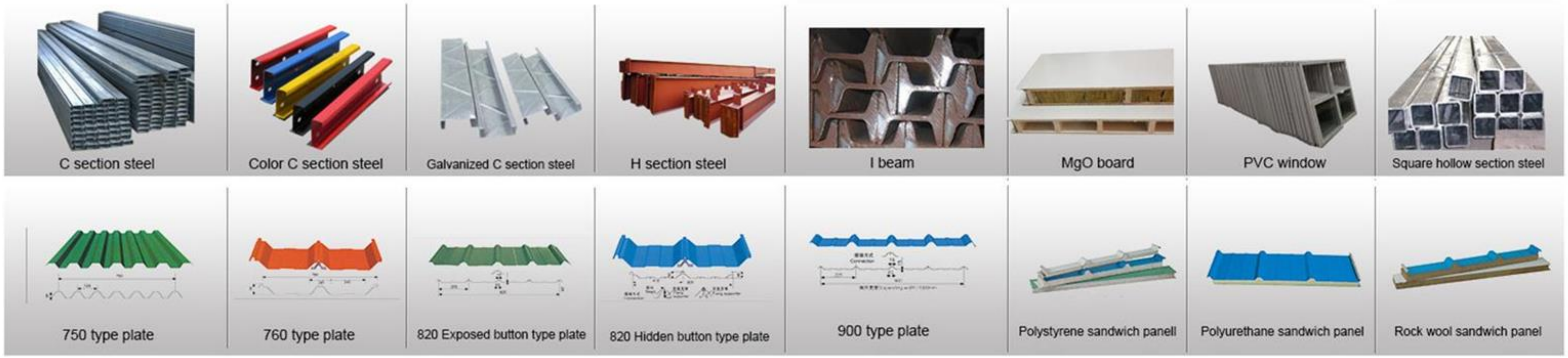
Assembly

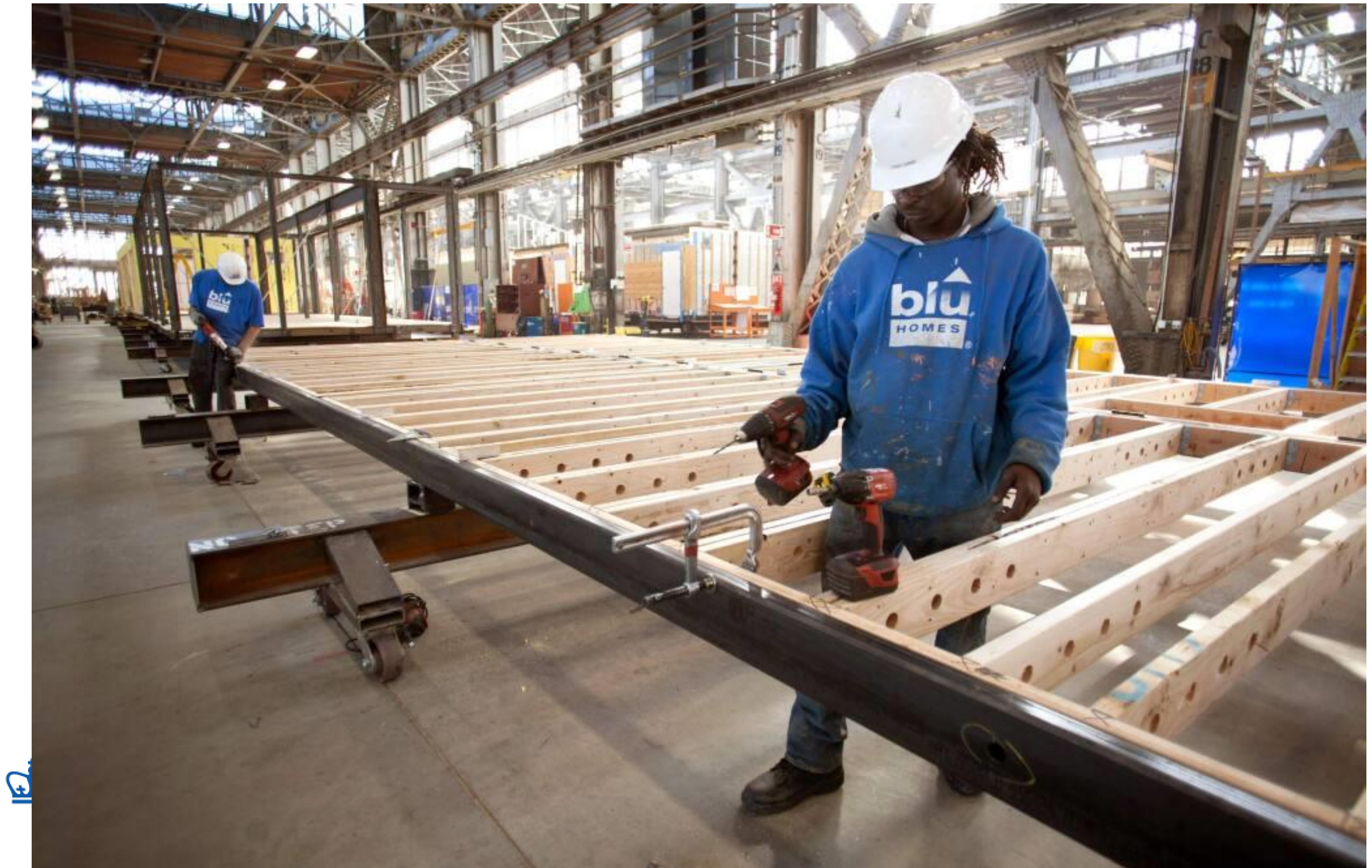
Modular Building Manufacturing Processes:

- Fabrication of modules should be considered as part of the design of modular projects.
- Designers should understand the central role of digital technologies in the fabrication of modular components (BIM, CAD, CAM, and CNC).
- Prefabricated volumetric building modules are typically constructed from the inside out.
- Different manufacturers may have different processes.

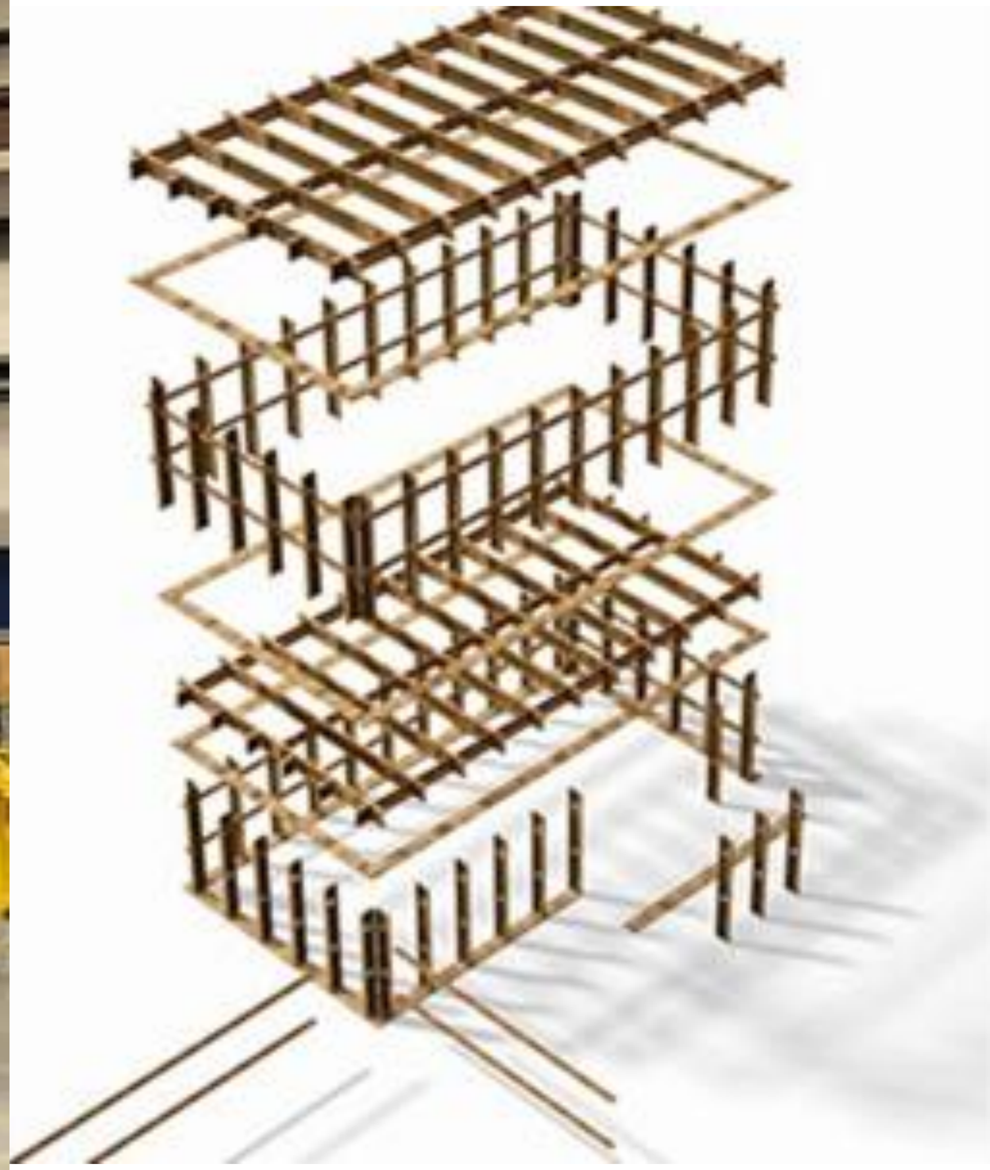


Phase 0: Material assembly

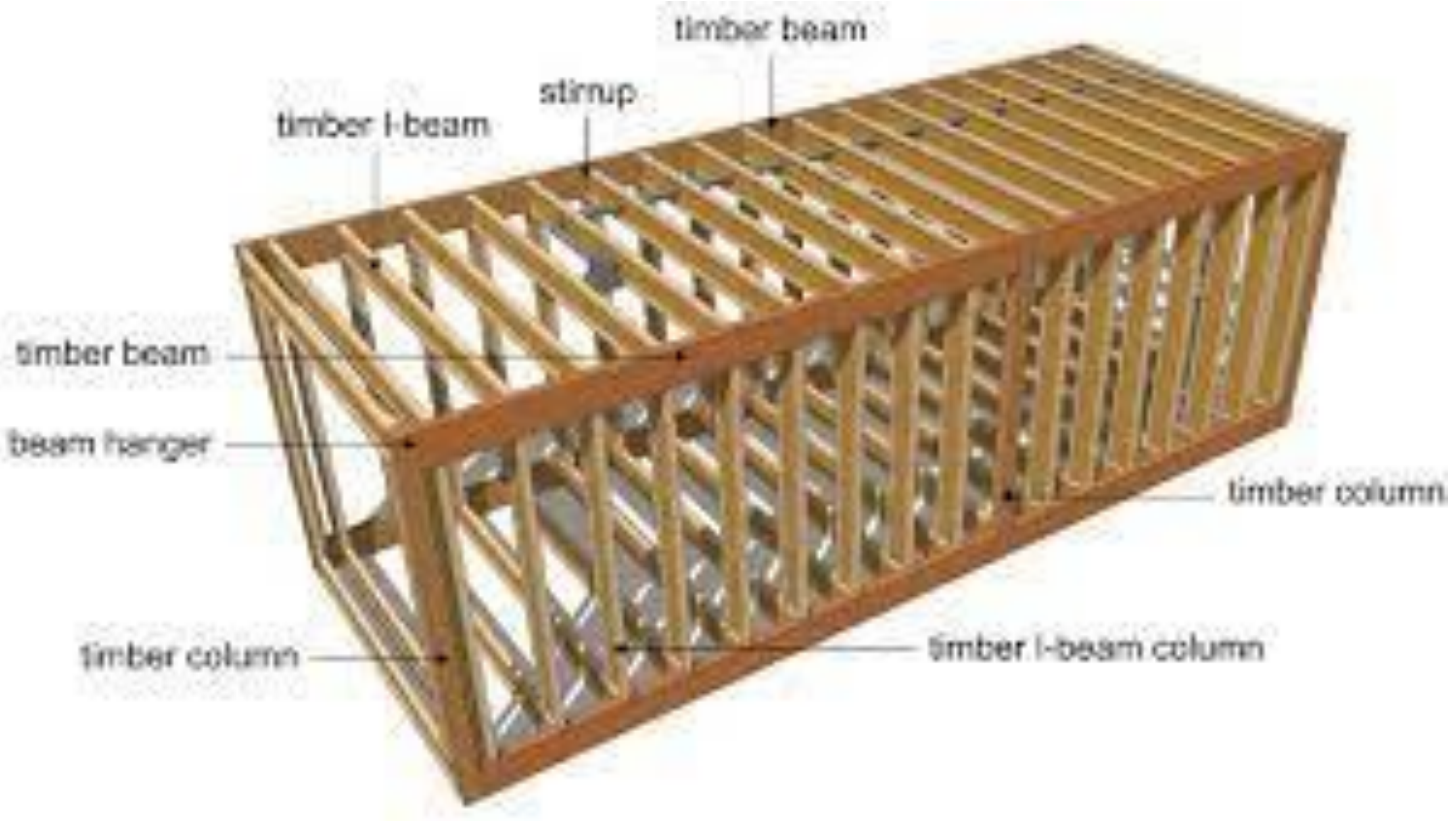


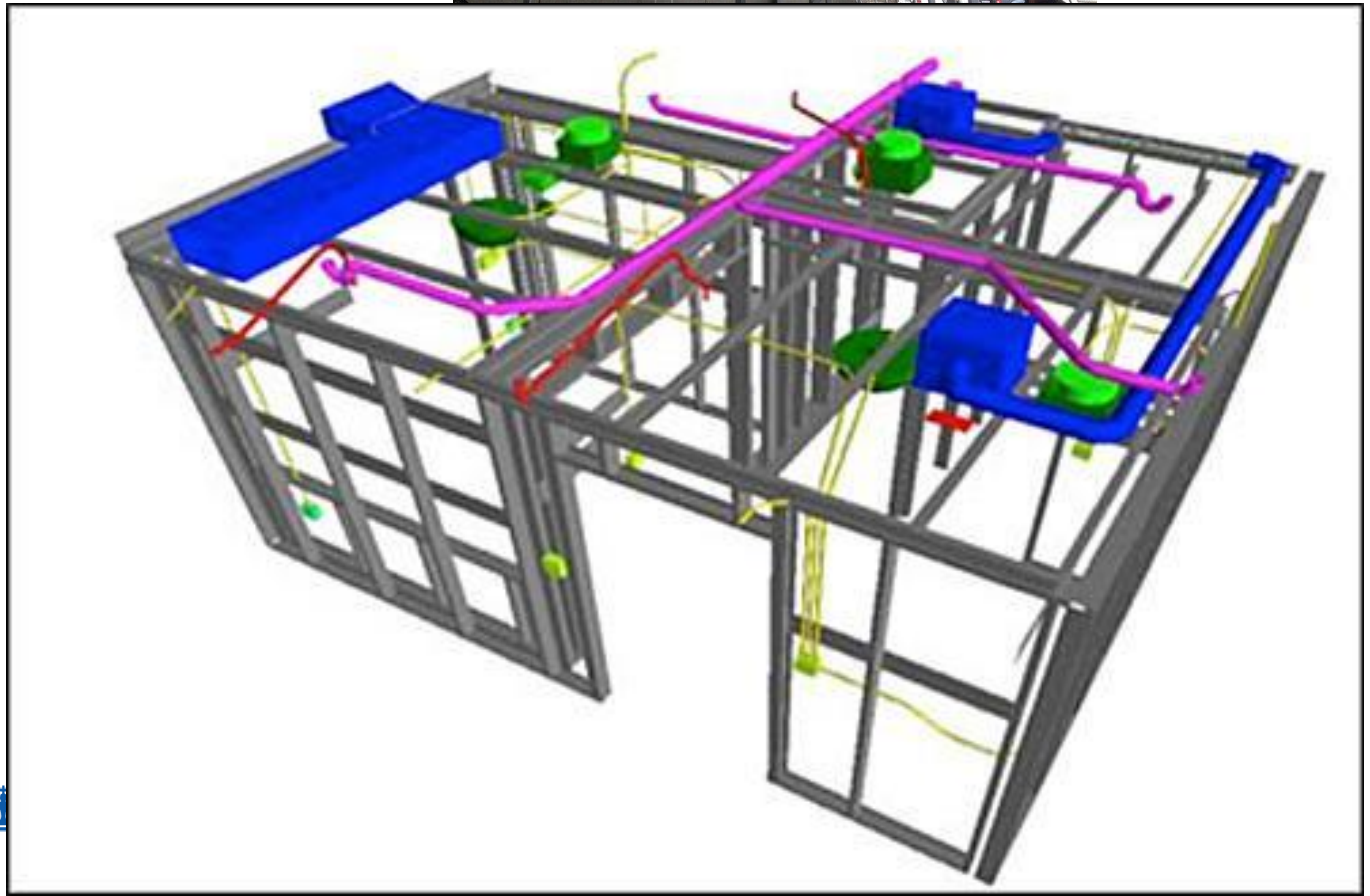


Phase 1: Floor framing & decking int./ext. wall framing 'box' mounted to chassis

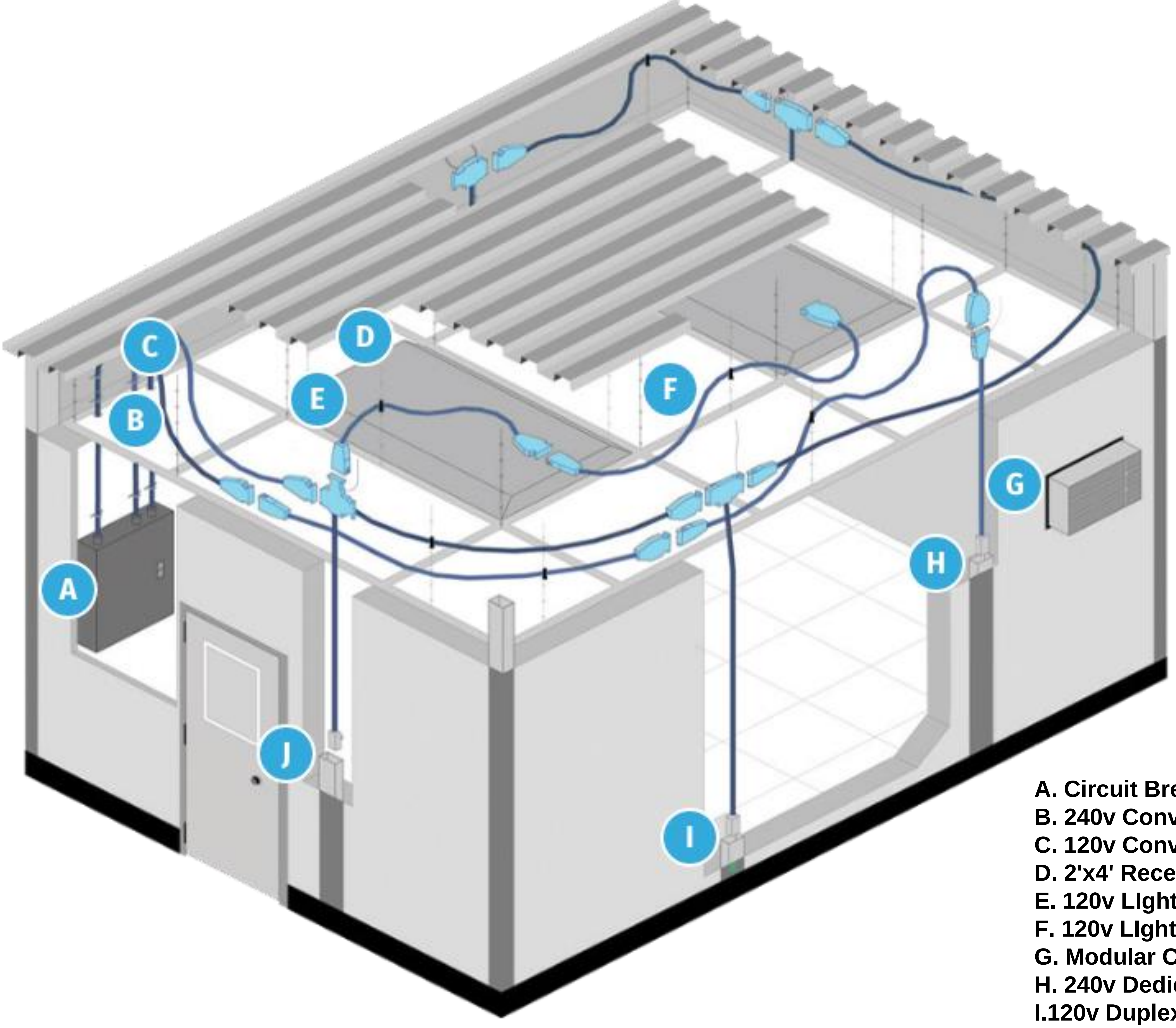


Phase 2: roof framing/mounting ceiling attached to 'box' interior partition installation rough plumbing





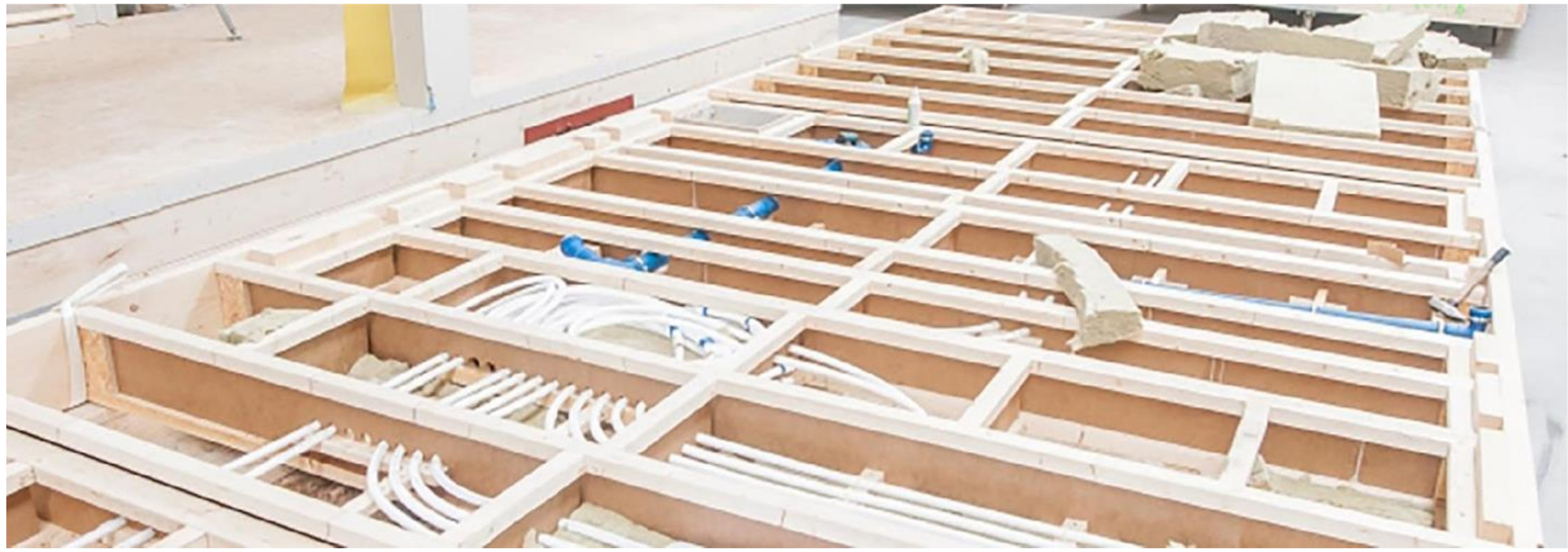
Phase 3: sheetrock (walls) rough electrical (walls)
Phase 4: sheetrock (ceiling), batt/spray foam insulation, rough electrical



A. Circuit Breaker Box
B. 240v Converter Cable
C. 120v Converter Cable
D. 2'x4' Recessed Light Fixture
E. 120v LIghting Fixture Cable
F. 120v LIghting Extender Cable
G. Modular Climate Control
H. 240v Dedicated Receptacle Drop
I.120v Duplex Receptacle Drop
J. 120v Extender Cable
K. 120v Switch Drop

Phase 5: Exterior plywood sheathing, rough opening cleanup, general interior cleanup
Phase 6: Exterior plastic sheathing interior finish work (paint, trim)

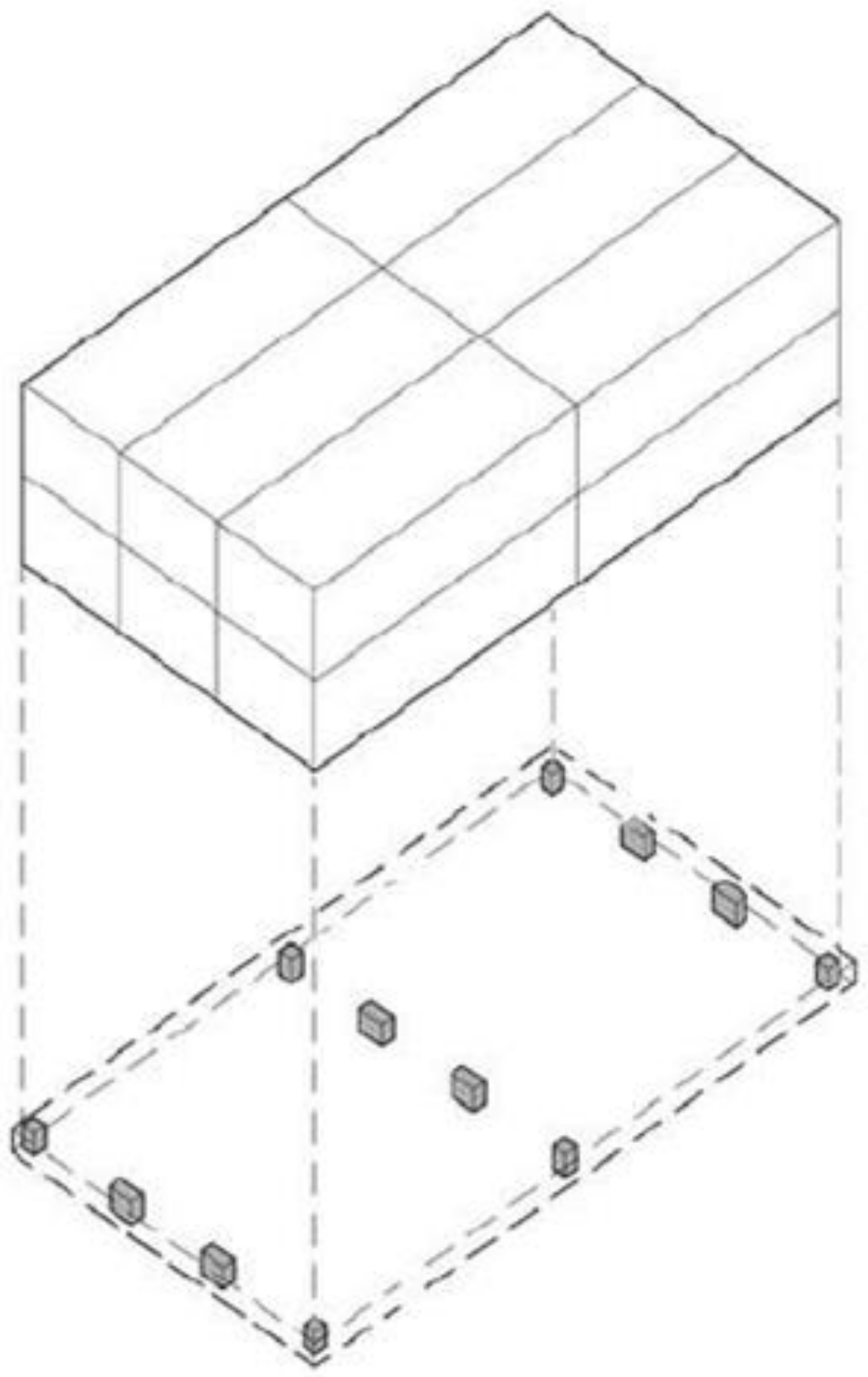
Phase 7: finish plumbing, finish electrical, install flooring



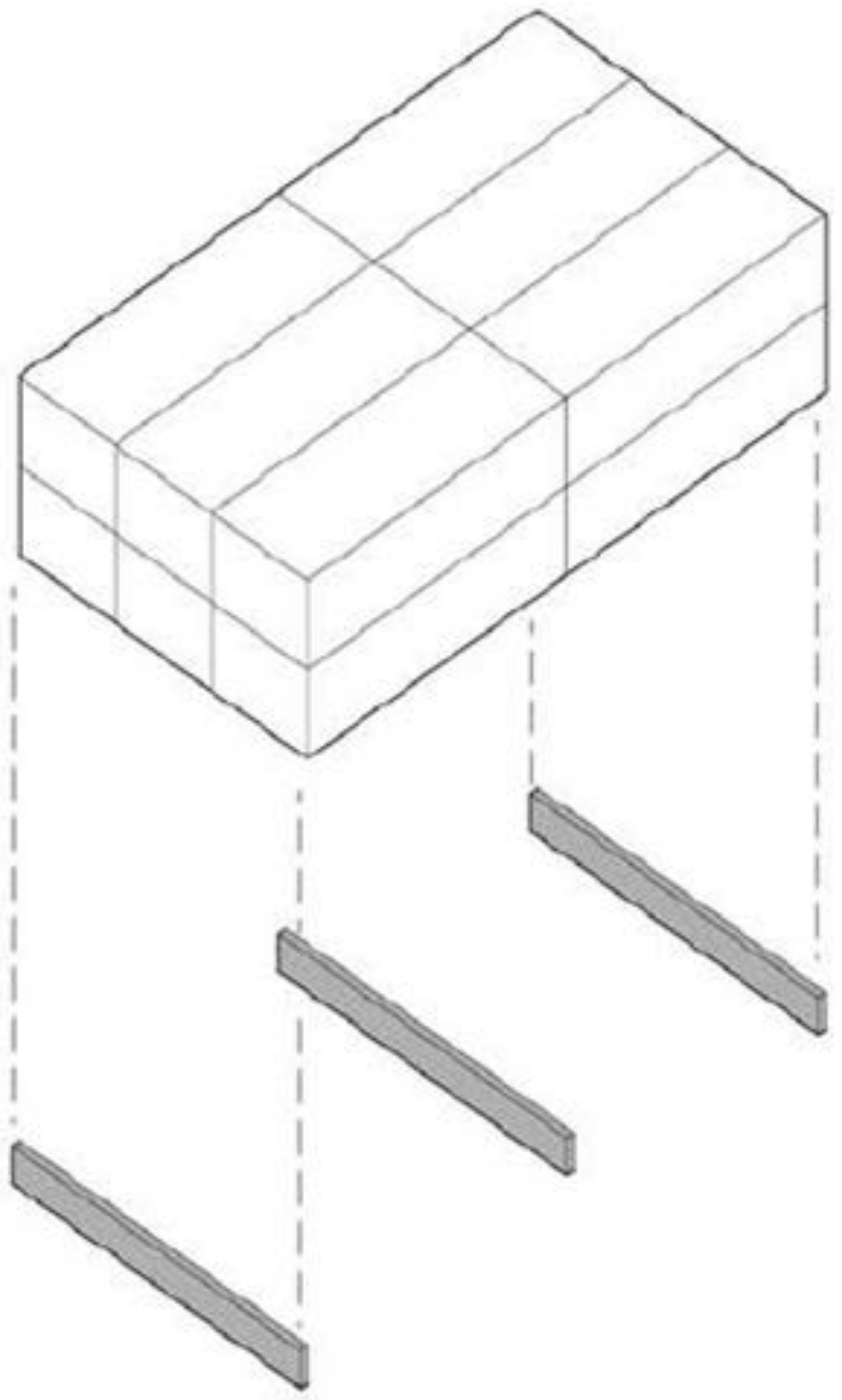
Phase 8: install windows, install siding weatherproof

Site Preparation

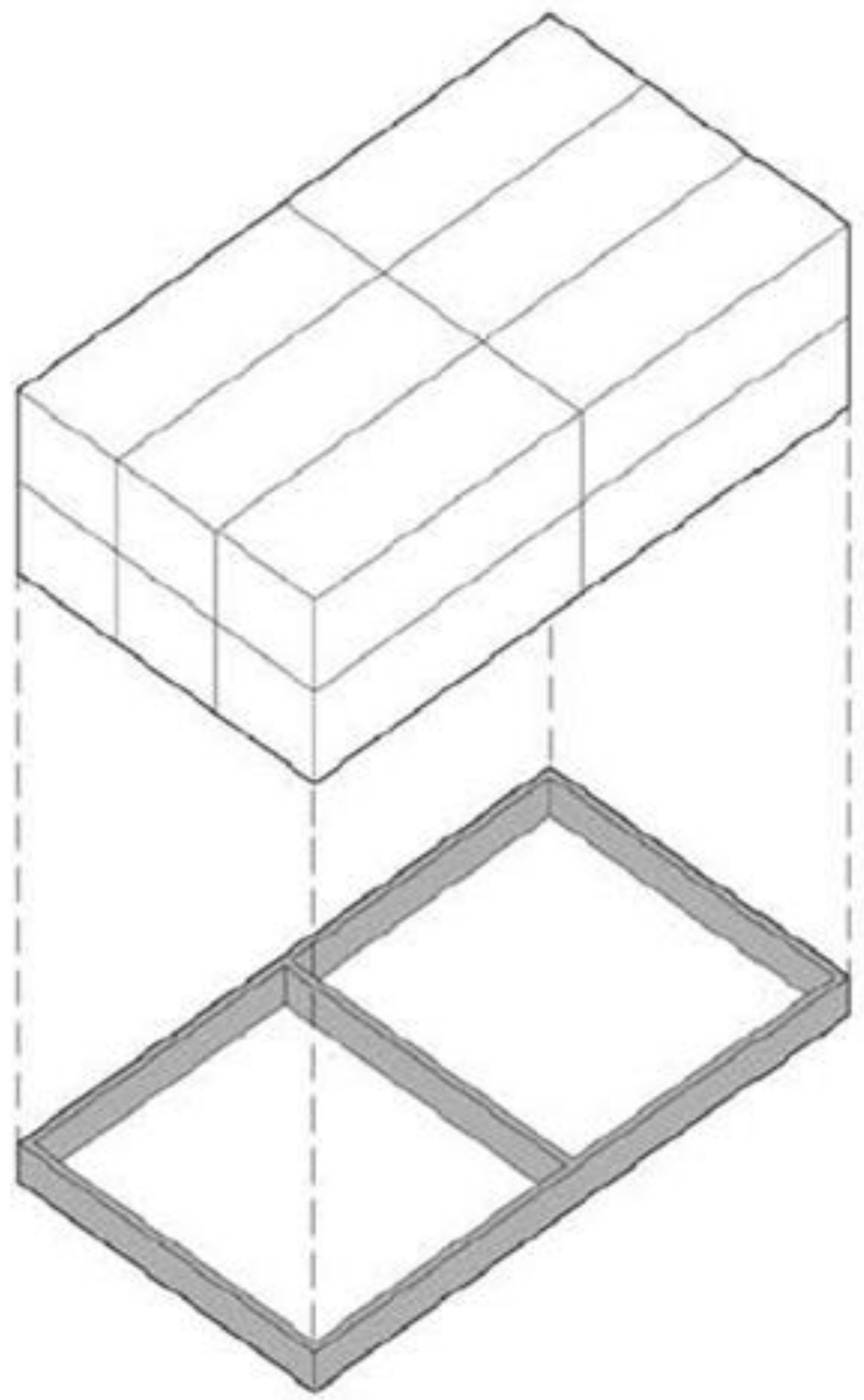
- Permits
- Surveying
- Demolition
- Excavation
- Grading
- Site drainage
- Foundation construction
- Utility installation



Piers



Linear Footings

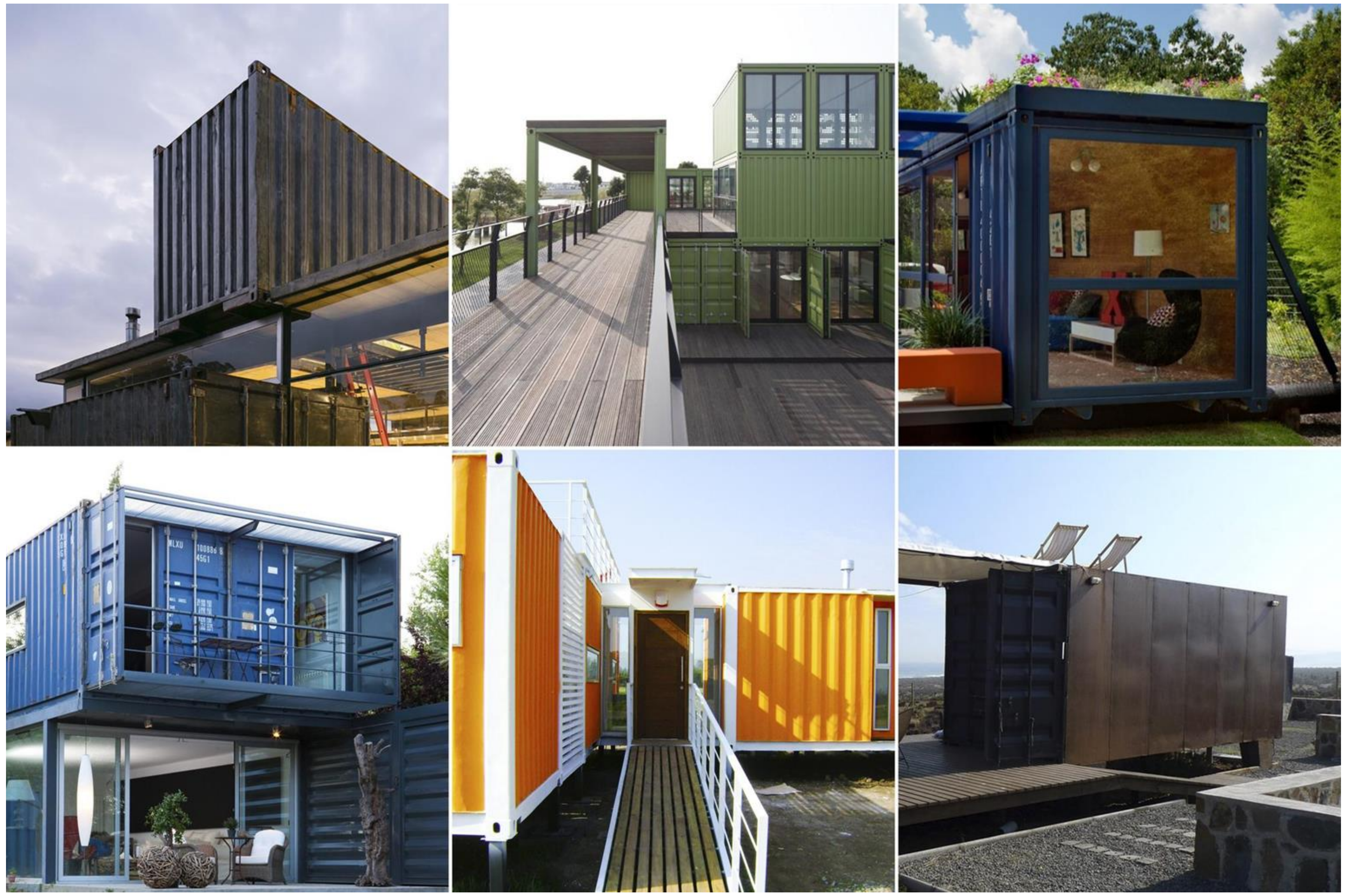


Continuous Footings

Transport

1. Route to site
2. Access to site
3. Permits and clearances
4. Details for transport securing
5. Road closure
6. Delivery times

Container Shipping



Containers are standardized in size, pick points (method of lifting and locating), attachment between adjacent units and shipping chassis and decks by the International Standards of Organization (ISO)

Dimensional or Cargo Shipping

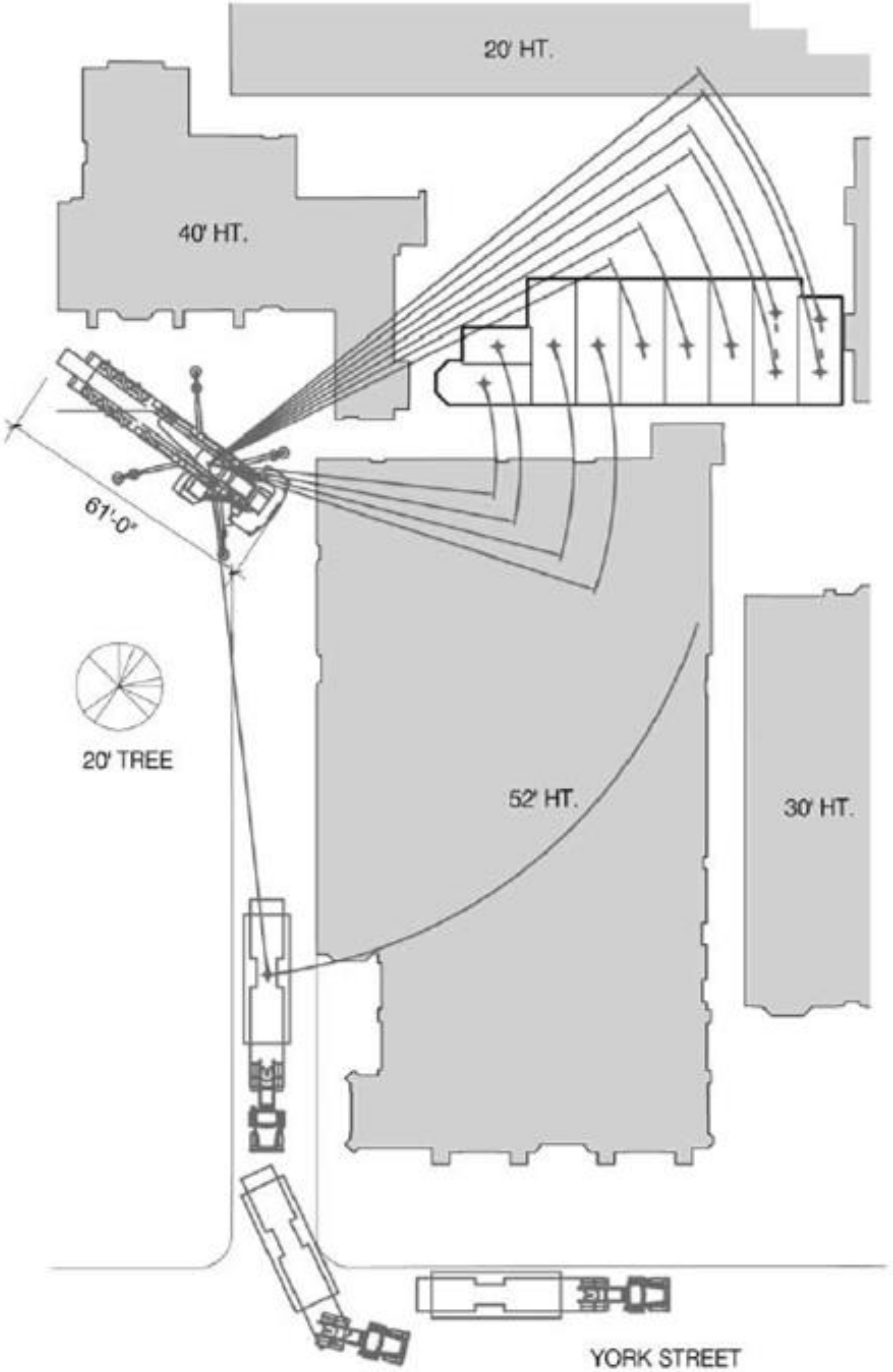
Abnormal shipping sizes or unique custom dimensions outside of the ISO unit standards. These terms apply to all methods of shipment including rail, truck, ship, air, and on rare occasion, helicopter.

Assembly

- Access onsite
- Crane location
- Crane selection
- Crane reach and loads
- Permits and clearances
- Road closures for crane

Assembly requires that architects and engineering and construction professionals rehearse sequences before construction.

The critical path is the engagement of labor. Inefficiencies in schedule as a result of too many trades can slow a project down.



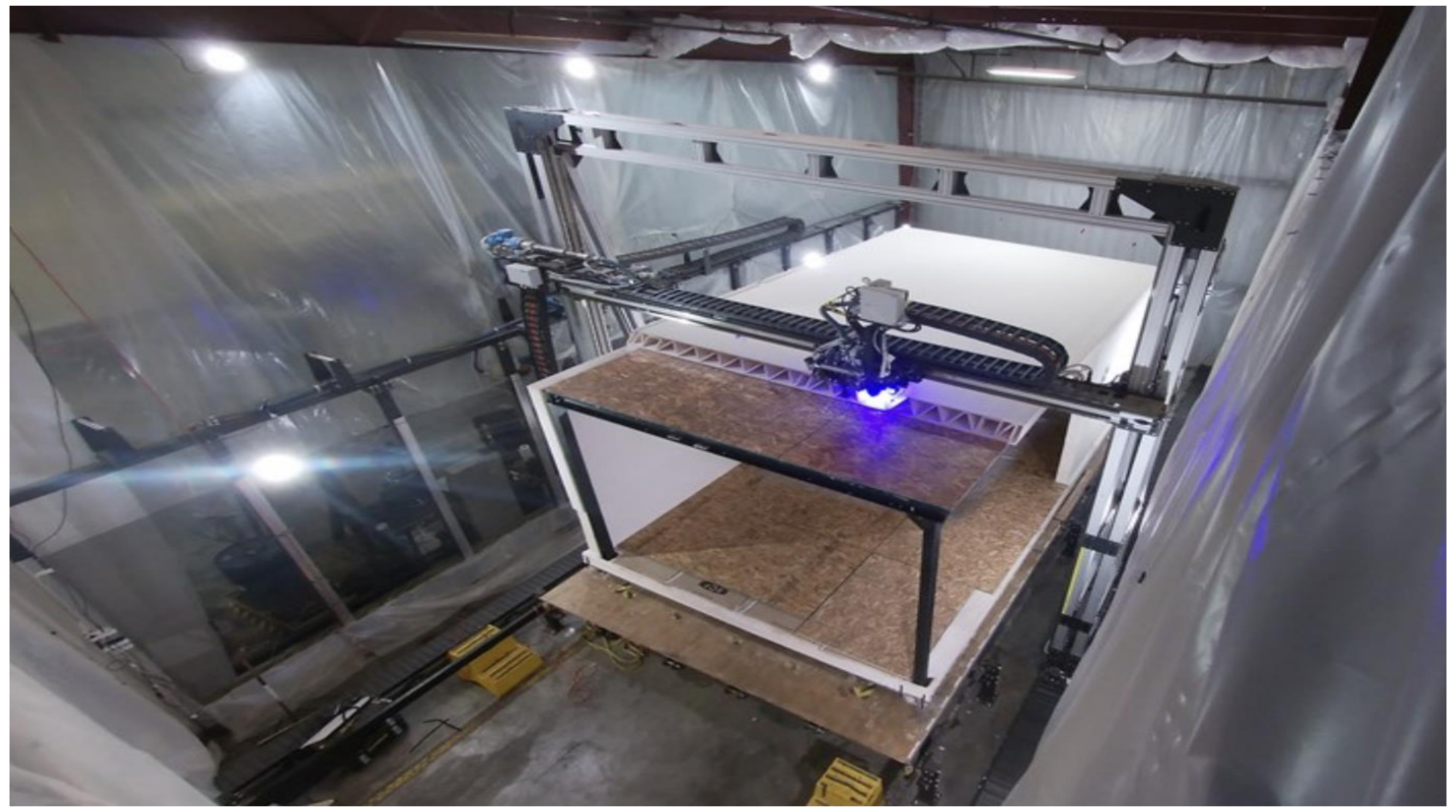
Crane Path Rehearsed in Detail Before Execution

3D Printing & Modular Construction

- 3D printing refers to a variety of techniques that are used to print a physical structure. The technology is developing rapidly, and materials as diverse as concrete, metal, and resin are currently used to build entire structures like bridges and houses, as well as individual building components.

- The use of 3D printing technologies in construction, also known as a Autonomous Robotic Construction System, involves the transportation of a 3D printer (industrial robots) to the site and automatically constructing the building with 3D printed concrete or mechanically cut bricks.

- It also substantially reduces the energy consumption, noise pollution and greenhouse gas emissions when compared to a traditional construction phase.



"Heat Recovery Ventilation." *Wikipedia*, Wikimedia Foundation, 31 Oct. 2021, en.wikipedia.org/wiki/Heat_recovery_ventilation.

Ibrahim, Naser Nader. "Striatus - a First of Its Kind 3D Concrete Printed Arched Bridge - Now Open." *AmazingArchitecture*, Amazing Architecture, 19 July 2021, amazingarchitecture.com/bridge/striatus-a-first-of-its-kind-3d-concrete-printed-arched-bridge-now-open.

"How Will Prefabricated Construction & 3D Printing Build Construction's Future?" *How Prefabricated Construction & 3D Printing Shape Construction's Future*, www.unearthlabs.com/blogs/prefabricated-construction-and-3d-printing.

Striatus Bridge, Venezia, Italy

- Striatus Bridge: An arched 3D-concrete-printed masonry bridge, is a project by the Block Research Group (BRG) and Zaha Hadid Architects Computation and Design Group.

- Unlike typical extrusion 3D printing in simple horizontal layers, Striatus uses a two-component (2K) concrete ink with corresponding printing head and pumping arrangement to precisely print non-uniform and non-parallel layers. This new generation of 3D concrete printing in combination with the arched masonry design allows the resulting components to be used structurally without any reinforcement or post-tensioning.

- The angular differences between start and end planes of all 53 printed blocks have been simultaneously adjusted to meet multiple criteria such as an appropriate structural contact and angle between adjacent blocks, and maximum print inclination.

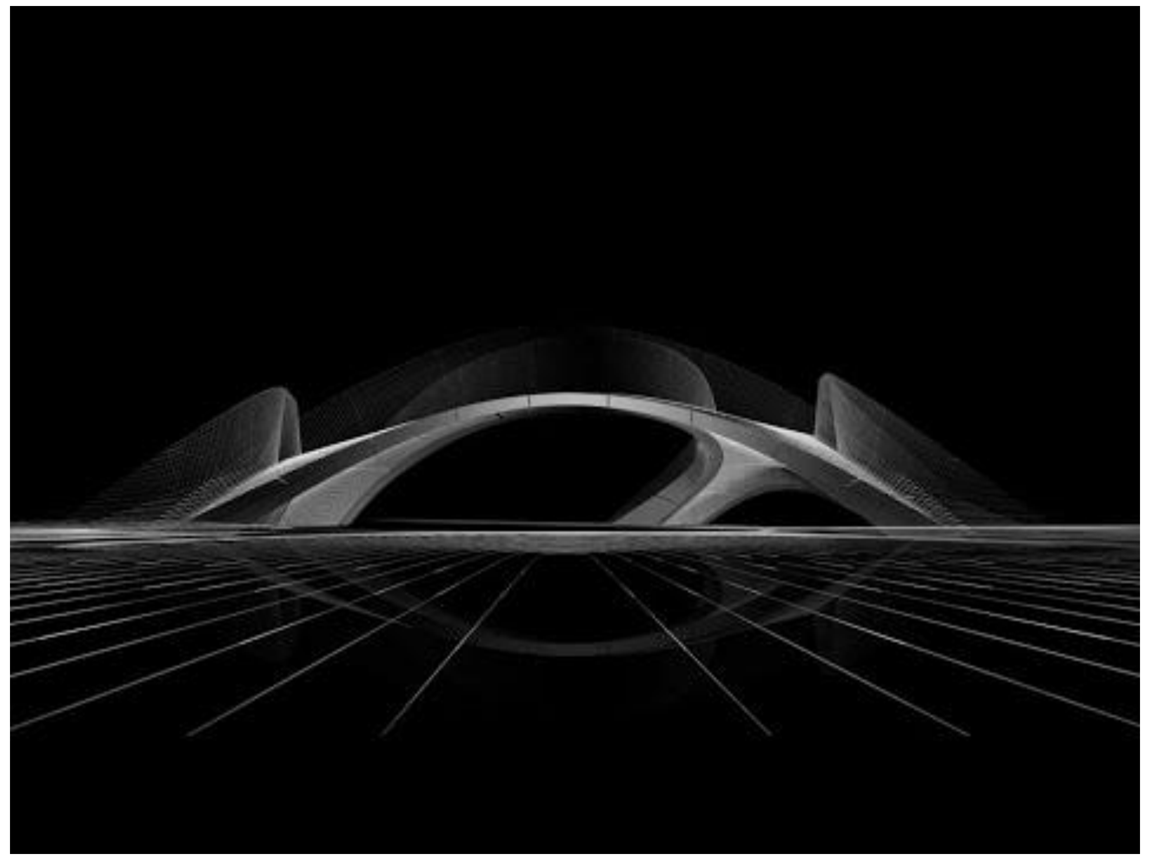
Ibrahim, Naser Nader. "Striatus - a First of Its Kind 3D Concrete Printed Arched Bridge - Now Open." *AmazingArchitecture*, Amazing Architecture, 19 July 2021, amazingarchitecture.com/bridge/striatus-a-first-of-its-kind-3d-concrete-printed-arched-bridge-now-open.

Striatus Bridge, Venezia, Italy

- The careful design and iterative refinement of the hollow cross-sections and infill triangulation have ensured that material is placed corresponding to the precisely analysed, local structural performance of each block. This design and optimisation have been applied to each individual layer of every block (with 500 print layers on average per block), ensuring that all blocks are as hollow and light as possible, and consequently use the least amount of material possible while maintaining structural integrity under all loading conditions.

- The resulting intricate cross-sectional design has been processed into a single, continuous print path meeting various criteria that include appropriate print speed and turning radius, structurally required material width and thickness, and controlled expression of naturally occurring printing artefacts.

- All of Striatus' components are designed to be infinitely disassembled and reused. The concrete blocks can be easily recycled, with limited energy and cost. The recycling process is simple and cost-efficient as no materials sorting is needed, due to the absence of reinforcements, glue or binders.



"Striatus: The First-of-Its-Kind 3D Concrete Printed Bridge." Holcim.com, 12 Aug. 2021, www.holcim.com/striatus-bridge.

Ibrahim, Naser Nader. "Striatus - a First of Its Kind 3D Concrete Printed Arched Bridge - Now Open." *AmazingArchitecture*, Amazing Architecture, 19 July 2021, amazingarchitecture.com/bridge/striatus-a-first-of-its-kind-3d-concrete-printed-arched-bridge-now-open.

Riverhead Home, Riverhead, NY

- Riverhead Home: A 3D Printing house in Riverhead, New York, is a project by SQ4D company. It is 1,500 square feet, with three bedrooms, two bathrooms and a garage. It is listed at just under $300,000. That's about half the price of a comparable newly built home in the area.

- The company can set up its Autonomous Robotic Construction System at a build site in six to eight hours. It then lays concrete layer by layer, creating footing, the foundation of a house and the interior and exterior walls of the structure.

- The cost of construction is 50% cheaper than the cost of comparable newly-constructed homes in Riverhead, New York, and 10 times faster.

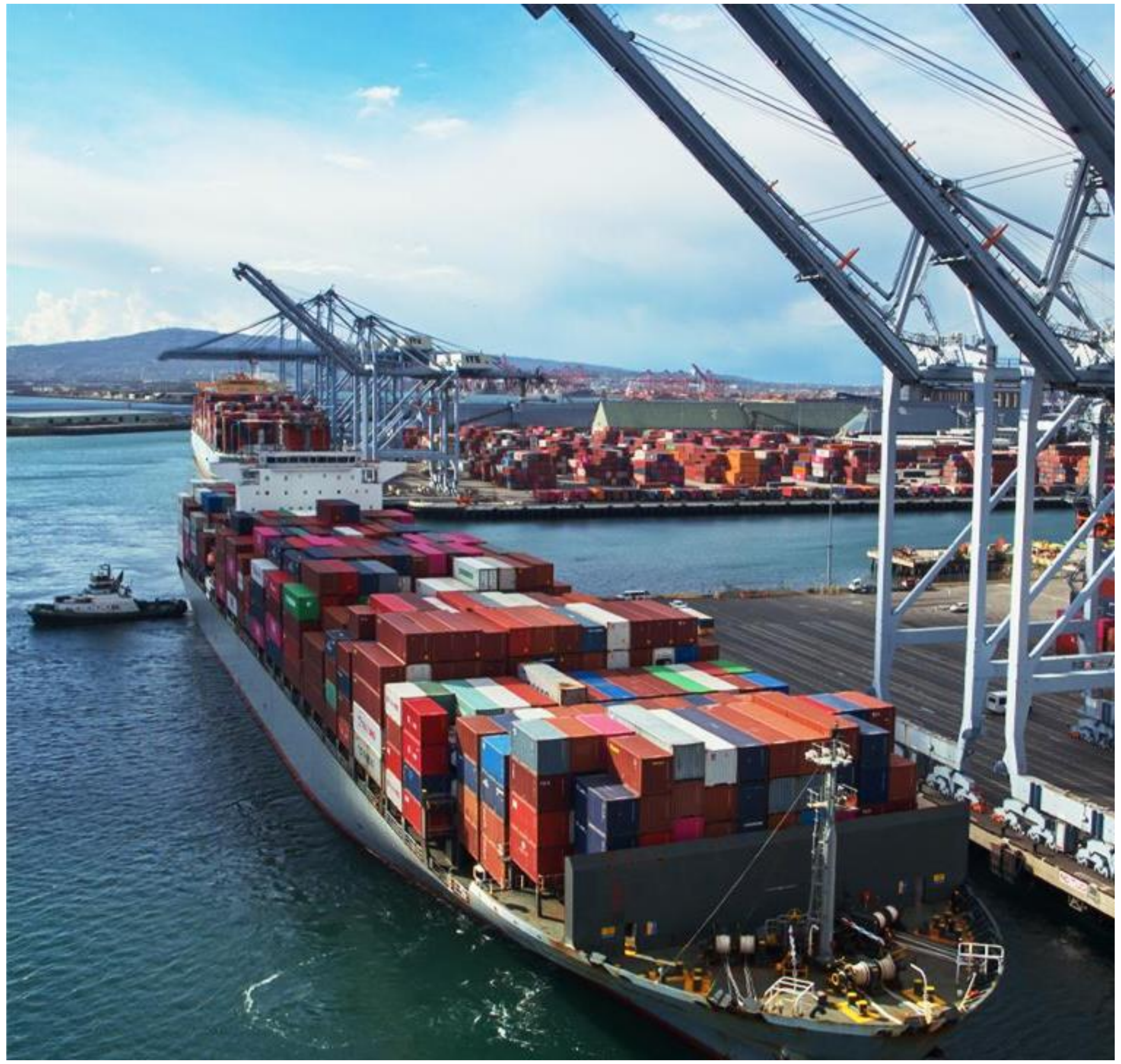
Higgins, Cole. "A 3D Printed House Is for Sale in New York. Builders Say It Will Cut Housing Construction Costs." *CNN*, Cable News Network, 7 Feb. 2021, www.cnn.com/2021/02/07/us/3d-printed-house-united-states-for-sale-trnd/index.html.

"You Can Buy a 3D Printed House in NY. Is This the Future of Home Building?" *Brick Underground*, 1 Sept. 2021, www.brickunderground.com/buy/3D-printed-house-for-sale-sq4d-new-york-long-island-affordable-housing-customizable.

"How Will Prefabricated Construction & 3D Printing Build Construction's Future?" *How Prefabricated Construction & 3D Printing Shape Construction's Future*, www.unearthlabs.com/blogs/prefabricated-construction-and-3d-printing.


Demand & Challenges
• Transportation
• Design
Contents
• Shipping Container
• For Buildings
• Organization
• Case study
• Future Utilization
New Concept & Technology
Modular Construction and Shipping Containers

Modular Construction and Shipping Containers



Shipping Container (Intermodal Container)

Standard

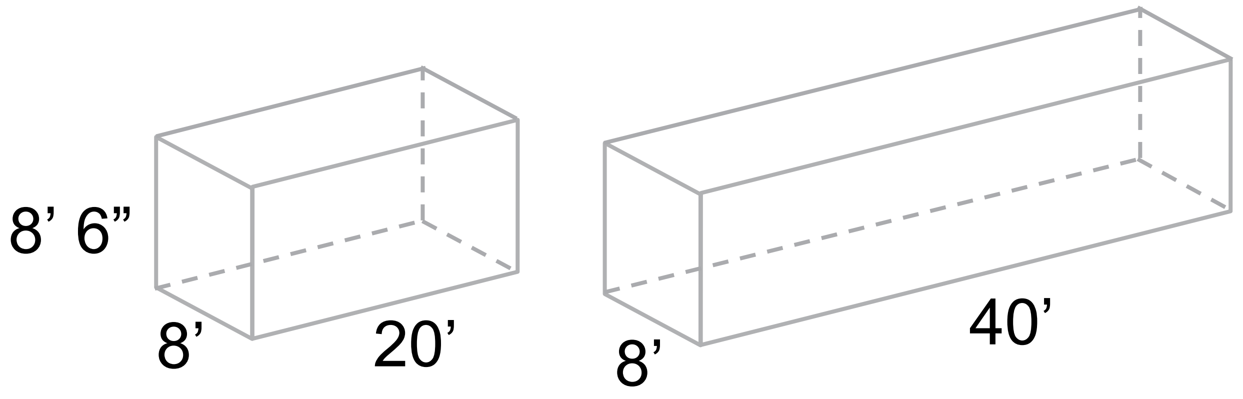
Standardized by
- International Standard Organization
- International Maritime Organization

International Organization for Standardization ISO

IMO INTERNATIONAL MARITIME ORGANIZATION

Size

11 types, but the most common are
- 20 feet (20' long x 8' wide x 8' 6” high)
- 40 feet (40' long x 8' wide x 8' 6” high)

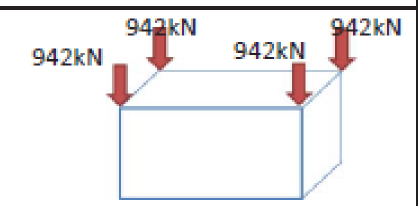
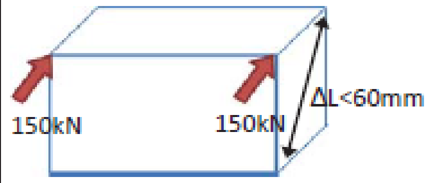
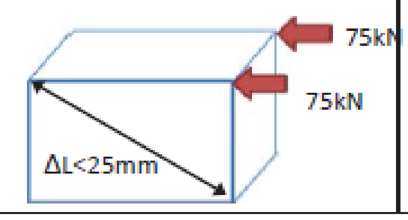


Material

Used specific steel, a type of steel with chemical composition that enabled it to develop rust protective layer against atmospheric corrosion.

Brand	Thickness (mm)	Mechanical Properties			Chemical Composition (%)					
		F_y (N/mm^2)	F_u (N/mm^2)	Elongation (%)	C	Si	Mn	P	S	Cu
ASTM A242 CORTEN A	≤ 20	343	480	22	≤0.15	N.A.	≤1.00	≤0.15	≤0.05	≤0.20
EN S235	≤ 16.0	235	360-510	19	0.16	0.45	0.70	0.04	0.04	0.20
EN S355	≤ 16.0	355	470-630	16	0.19	0.55	1.60	0.04	0.04	0.20

Structural Test

Testing	Loading	Permissible Criteria	
		Deflection under load	Residual Deformation
Staking		Corner Post: 4mm Bottom Side Rail: 4mm Cross Member: 6mm	Corner Post: 2mm Cross Member: 3mm
Rigidity (Transverse)		End Frame: 60mm	End Frame: 10mm
Rigidity (Longitudinal)		Side Frame: 25mm	Side Frame: 7mm

Reference: : P C H Ling et al (2020). Technical Information on ISO Shipping Container. IOP Conf. Ser.: Mater. Sci. Eng. 884 012042.
URL: https://iopscience.iop.org/article/10.1088/1757-899X/884/1/012042/pdf

Modular Construction and Shipping Containers

Dave Southwood courtesy LOT-EK, Johannesburg, South Africa

For Buildings

Strength

Shipping containers are designed for purpose: they are structurally robust and sufficiently waterproof to prevent water ingress during their passage over the world's oceans.

Durability

Built specifically to carry heavy loads and to protect them from damage while in transit, containers are strong and robust. Built to withstand the forces of pressure when stacked on top of one another.

Ease of Use

Designed for portability, containers can be easily transported from place to place. Once they reach the site, they can be craned into position.

Time

Money

Manpower

Prefabricated, modular containers can be fitted out on controlled environments, minimizing potential delays and maximizing project efficiencies. They can then be transported and maneuvered on to the site, reducing construction times and enhancing productivity on each project.
Containers can be stacked or laid out side by side in endless configurations to create inventive, innovative commercial projects for a fraction of the costs that a traditional building would require.

Hart, Aidan (ed). *Modern Container Architecture*. The images Publishing Group. 2016, Australia.

Modular Construction and Shipping Containers

Organization

Institution, Design Company, Construction Company

Institution

Modular Building Institute

MODULAR BUILDING INSTITUTE

SAFE USE AND COMPLIANCE OF MODIFIED ISO SHIPPING CONTAINERS FOR USE AS BUILDINGS AND BUILDING COMPONENTS

A brief overview of how containers can be applied to architecture

	TEMPORARY	PERMANENT
SINGLE UNIT	I GROUND LEVEL OFFICE, CONSTRUCTION OFFICE, STORAGE UNITS	III INDUSTRIAL WORKSPACE, EQUIPMENT ENCLOSURES, SECURITY ACCESS POINTS
MULTI-UNIT	II POP-UP RETAIL, TRADE SHOW STRUCTURES, SPECIAL EVENTS	IV INDUSTRIAL HOUSING, HOTELS, MULTI-FAMILY

Design Company

8

WHITAKER STUDIO

.NL

ROOM 11

J.C. ARCHI-TECTURE

LOT-EK

ARQTAINER DISEÑO • CONSTRUCCION

MMW ARCHITECTS

2712

Construction Company

IQ CONTAINER HOMES

cargohome Think. Inside The Box.

CW DWELLINGS

CONTAINERS IN MOTION

BACKCOUNTRY CONTAINERS CUSTOM BUILDS

CONTAINER KING

BOB'S CONTAINERS

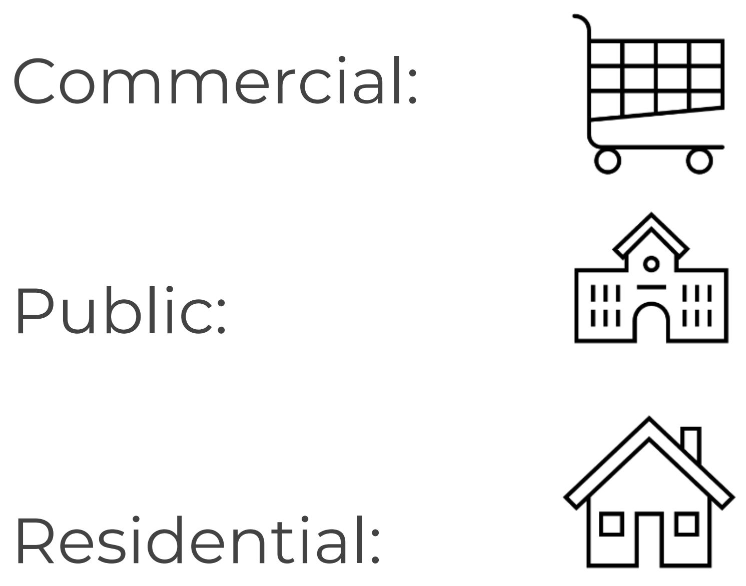
Modular Building Institute. Safe Use and Compliance of Modified ISO Shipping Containers for Use as Buildings and Building Components. URL: https://www.modular.org/Flipbooks/Containers2017/Containers_Flipbook.html

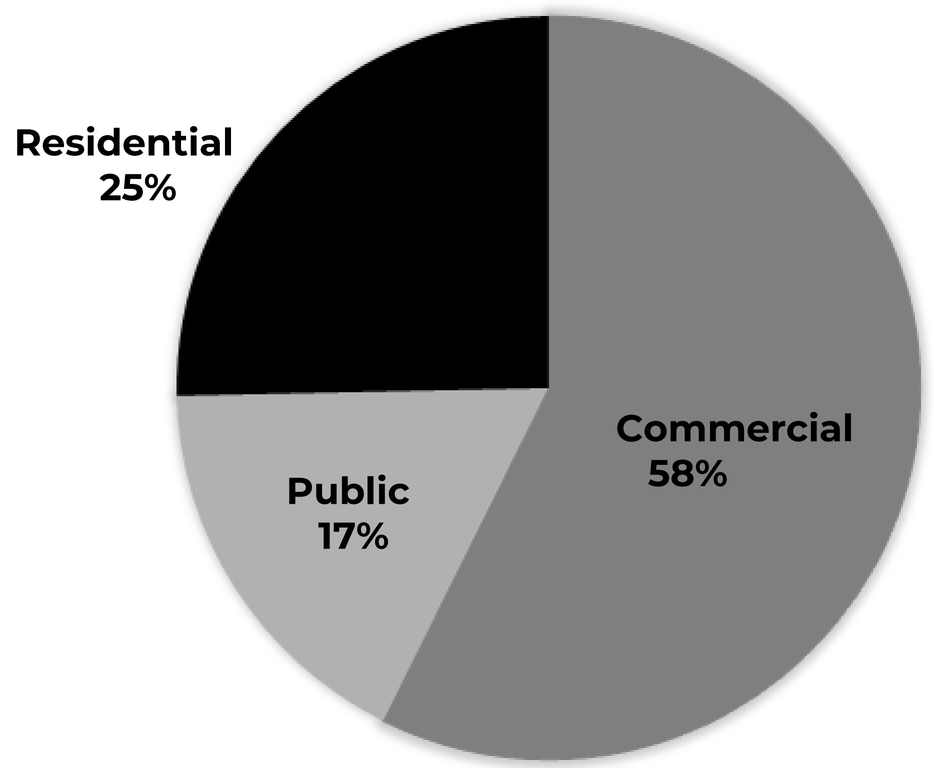
Modular Construction and Shipping Containers

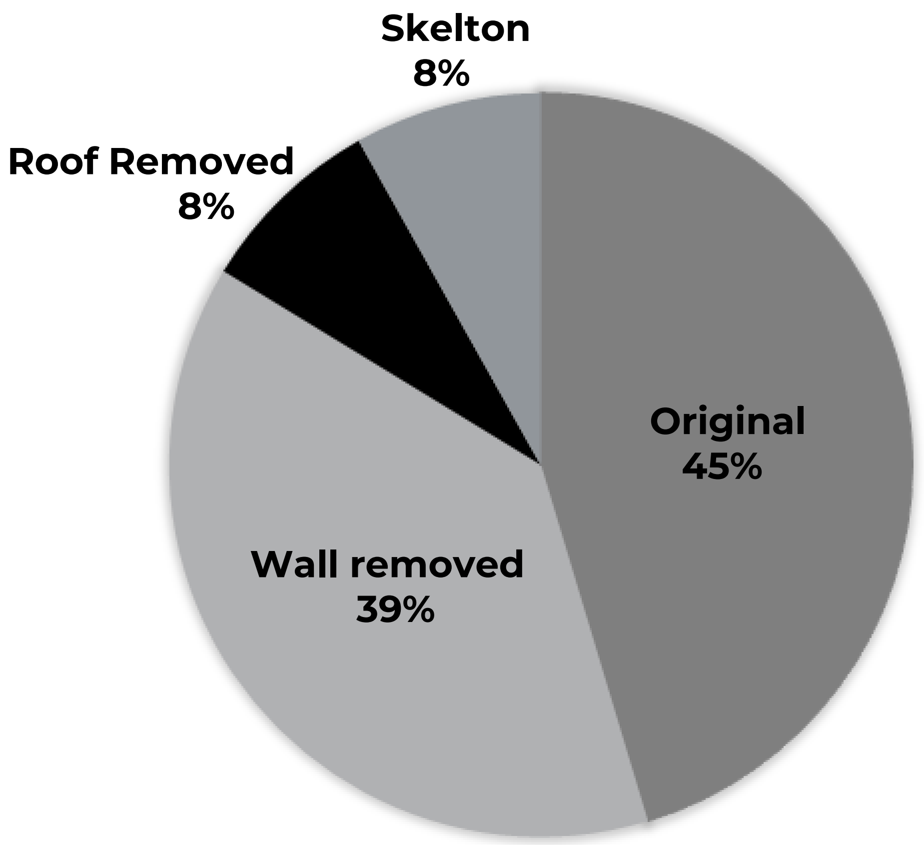
Case Study

75 cases (cumulative total number)

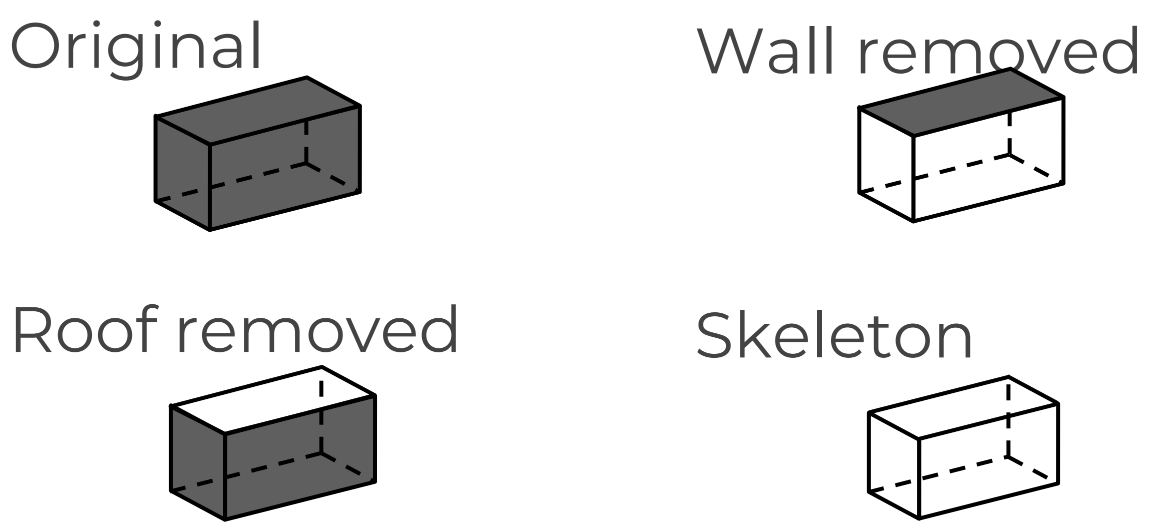
Type of use



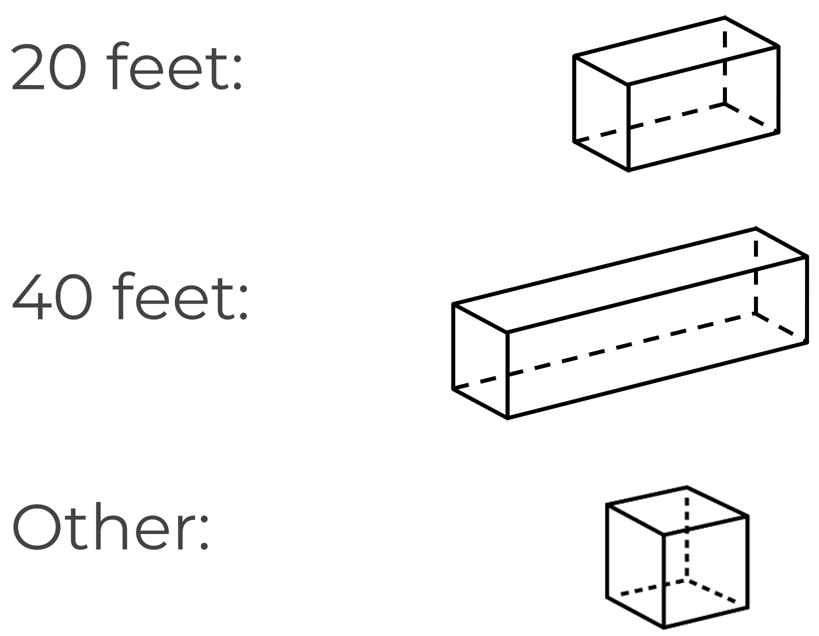


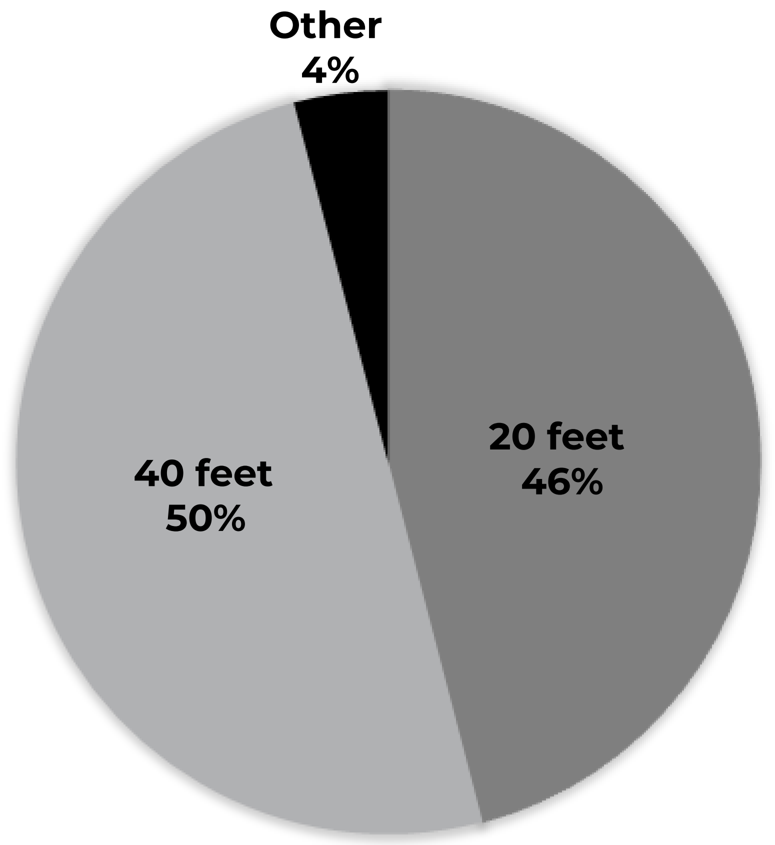


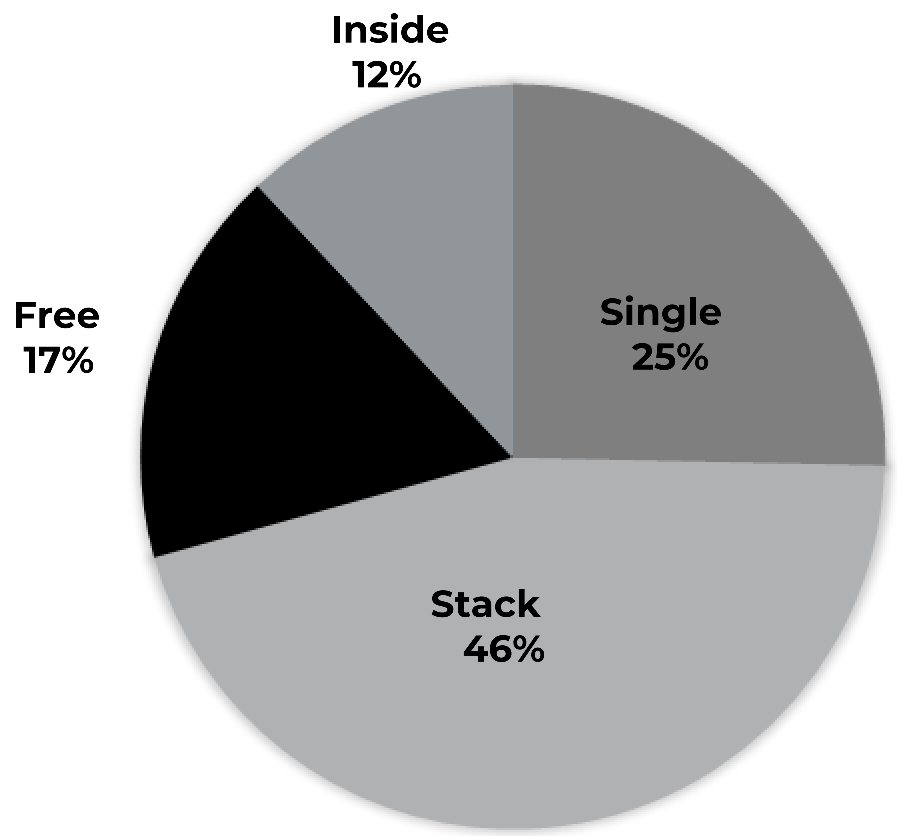
Shape



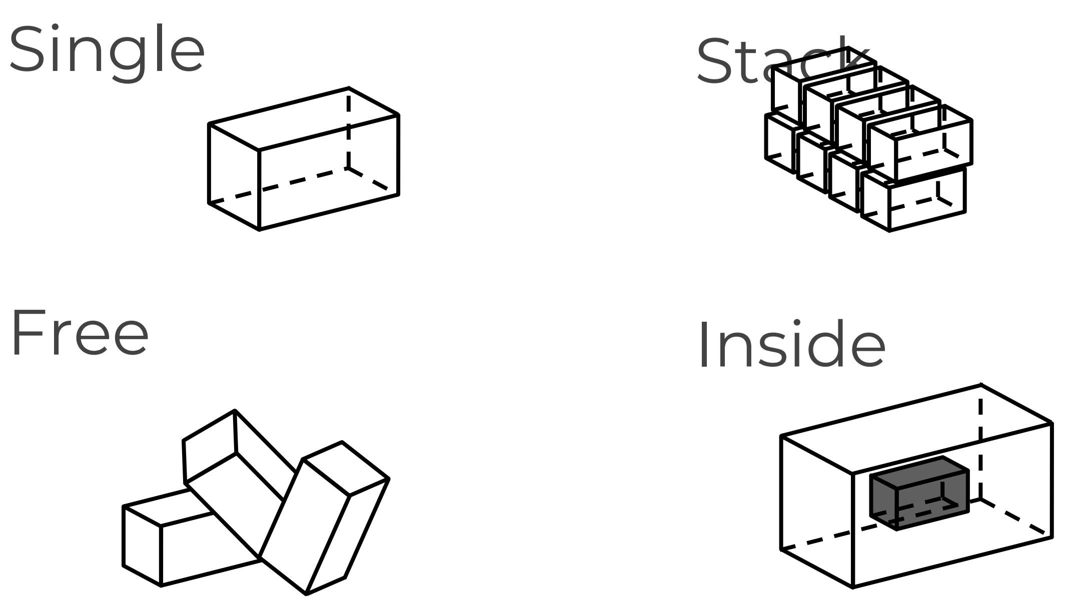
Size







Method



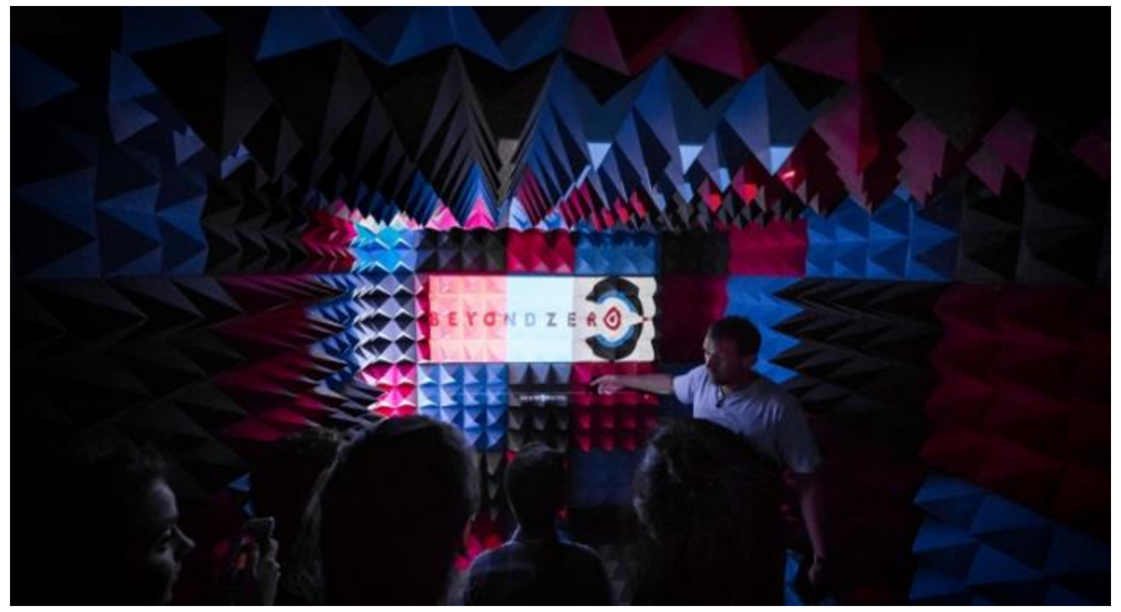
Hart, Aidan (ed). *Modern Container Architecture*. The images Publishing Group. 2016, Australia.
Kramer, Sibylle. *Stack, cut, assemble ISO 668: How to use shipping containers in architecture*. 1st ed,. Braun Publishing AG, 2019.

Modular Construction and Shipping Containers

Case Study

Single


Container Guest House, United States


Caution Cinema, United Kingdom

stack


Cite A'Docks, France


Cruise Ship Terminal, Spain

Free


Joshua Tree Residence, United States


Devil's Corner, Australia

Inside

Cargo, Switzerland


Jenga Play, China

Modular Construction and Shipping Containers

Case Study

Transportation

Project Name: Bayside Marina Hotel

Country: Japan

City: Yokohama

Architects: Yasutaka Yoshimura Architects

Client: Bayside Marina Hotel Yokohama

Completion year: 2009

Container number: 55

Container size: 40

Method: Stuck

Shape: Endwall removed

Architects and construction company decided to import accomplished building, not building material. Bayside Marina Hotel is making use of format of shipping containers in order to transport guest rooms in cottage type. As long as keeping the container forma, transportation cost is getting almost nothing.

Bayside Marina Hotel, Japan

Modular Construction and Shipping Containers

Case Study

Design

Project Name: SEED Library

Country: South Africa

City: Alexandra

Architects: Architects Of Justice

Client: The MAL Foundation

Completion year: 2011

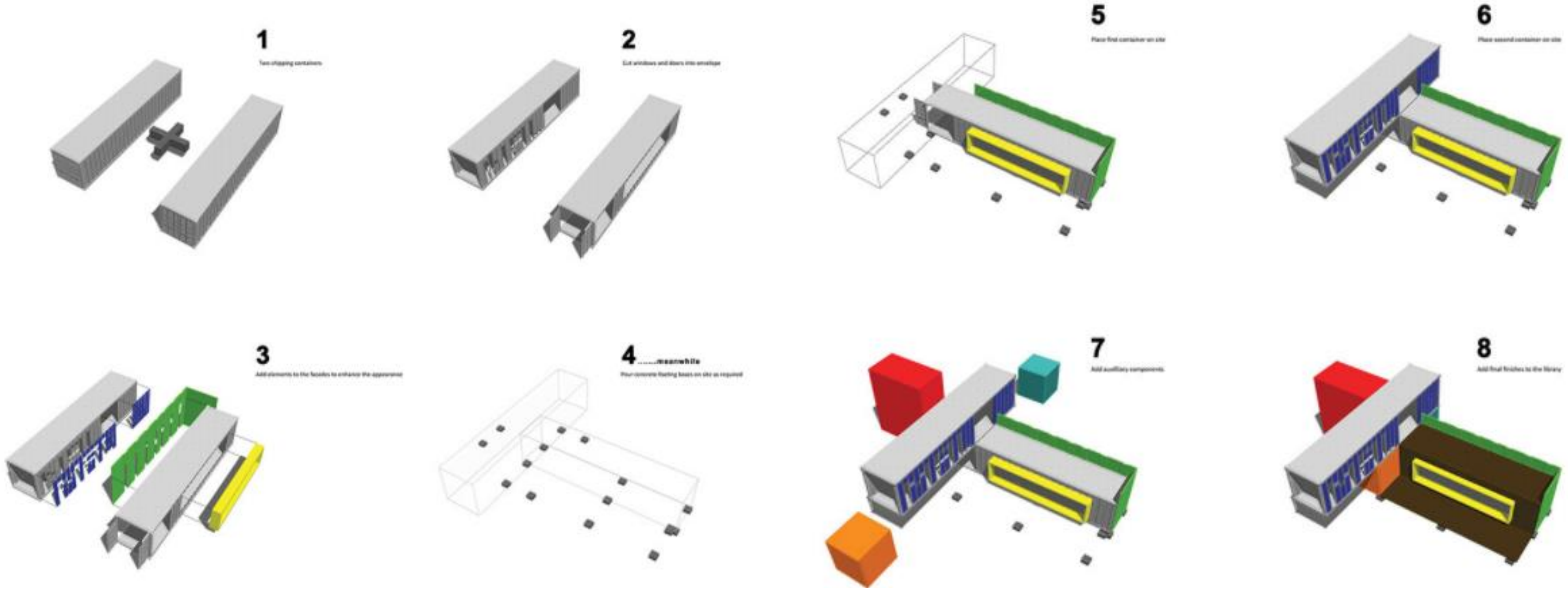
Container number: 2

Container size: 40

Method: Free

Shape: Single. Wall removed, Roof removed

Architects cut and stuck two containers freely. By cutting roof and stacking them, architects can eliminate the height limitation. Other rooms of various shapes and sizes, combined with staircases, create a variety of spaces.

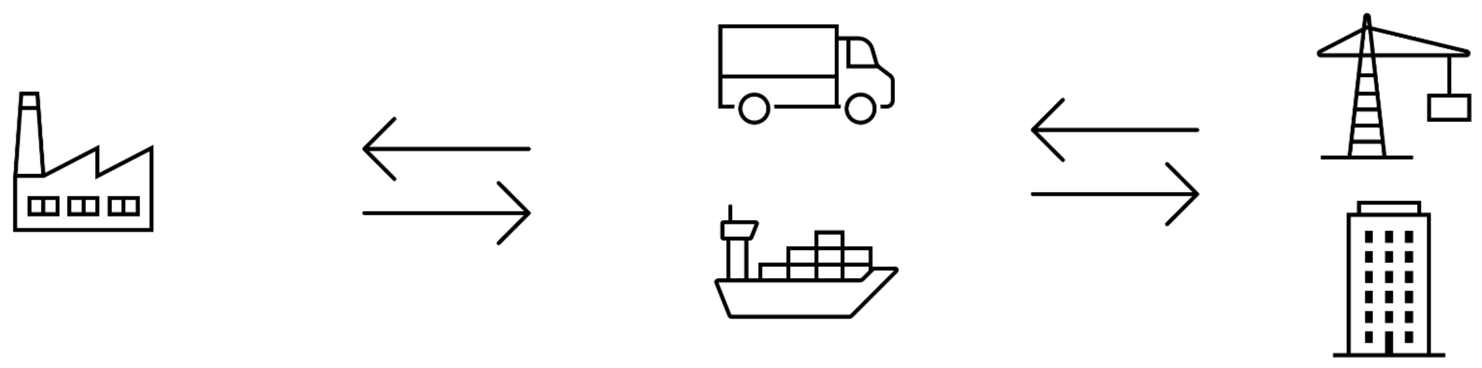


The SEED Library / Architects Of Justice

Modular Construction and Shipping Containers

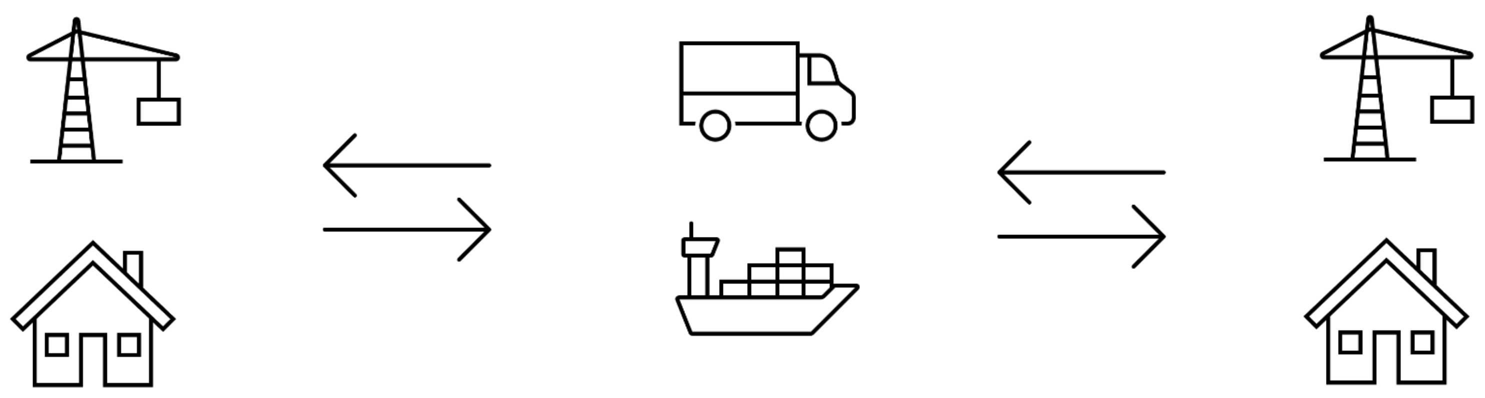
For the Future

Company



Transformation of the construction industry into a manufacturing industry

Individual



People can move around the world with their housing

Modular Construction and Affordable Housing
581 Grant Avenue

- Organization
  - Government: Housing Preservation & Development (HPD)
  - Developer: Thorobird Companies, Bangladeshi American Community Development and Youth Services (BACDYS)
  - Architect: Think! Architecture and Design
  - Manufacturer: FullStack Modular (Brooklyn-based)
- Characteristics
  - Units: 167
  - City awarded the $70 million contract
  - Timeline: announced in 2019

    construction is expected to start in 2021

    planned to be ready for residents by 2022

    expected to be completed 25 to 30 percent faster than a traditional building project
  - This Request for Proposal (RFP) is the first disposition of City-owned land under the City's modular construction initiative announced under Housing New York 2.0.

https://ny.curbed.com/2019/3/5/18251679/new-york-affordable-housing-modular-prefab-construction

https://www.globest.com/2019/03/06/will-nycs-modular-construction-for-affordable-housing-set-a-trend/?slreturn=20211012233907

https://www1.nyc.gov/site/hpd/about/projects-detail.page?project=Grant%20Ave%20Muni%20Lot

Pictures credit: New York Housing Conference https://thenyhc.org/projects/grant-avenue-modular-development/

Application and Future Trend

Modular Construction and Affordable Housing

Housing New York 2.0 - Promoting Innovation in New Construction Methods

Strategies:

Micro-units and Modular Building

- Small apartments can increase housing options for individuals and small households who face a competitive market for small apartments
- The City is currently piloting modular construction through the **Build-It-Back program**, constructing nearly 100 single-family modular homes, and achieving cost savings of roughly 25 percent per home.
- Through this process, City construction managers have gained first-hand experience navigating the logistical, jurisdictional, and permitting issues involved.
- The City will now seek to expand this model, and **release an RFP (Request for Proposal) for multifamily affordable housing developments that use modular construction** to further test whether the benefits of modular construction are achievable at scale in the city's dense urban environment

https://www1.nyc.gov/assets/hpd/downloads/pdfs/about/housing-new-york-2-0.pdf

Modular Construction and Emergency Architecture

- Demands
  - Post-Disaster Relief - The number of disasters has increased by a factor of five over the 50-year period, driven by climate change and more extreme weather. (UNFCCC)
  - Pandemic - 10 states nearing or exceeding hospital capacity during COVID's summer resurgence Many Hospitals With No Beds Left Are Forced To Send COVID Patients To Cities Far Away (the US, Aug 19, 2021)
- Case - Wuhan Huoshenshan Hospital
  - Currently it is closed for backup

https://unfccc.int/news/climate-change-leads-to-more-extreme-weather-but-early-warnings-save-lives

https://www.fiercehealthcare.com/hospitals/10-states-nearing-or-exceeding-hospital-capacity-during-covid-s-summer-resurgence

https://www.npr.org/2021/08/19/1029378744/hospital-beds-shortage-covid-coronavirus-states

http://www.nhc.gov.cn/wjw/jiany/202102/6eae6d5c603a4da3b7ab99e491e73bdd.shtml

Picture Credit: https://news.cgtn.com/news/2020-02-02/Construction-of-Wuhan-Huoshenshan-hospital-completes-NKHEGwUd9u/index.html

Modular Construction and Emergency Architecture

Wuhan Huoshenshsan Hospital

https://www.zhihu.com/question/367930379/answer/985748473

https://www.163.com/dy/article/GKU8KH8V0552IA86.html

https://www.nbcnews.com/news/world/china-s-coronavirus-hospital-built-10-days-opens-its-doors-n1128531

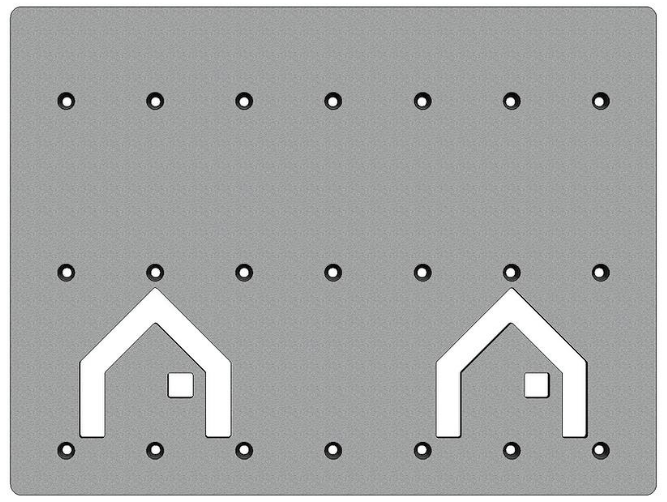
Boxabl - Accessory Dwelling Unit

- Background
    - About Boxabl - Founded in 2017 by Paolo Tiramani
    - Currently only having one product - Casita
    - Fun Fact - Elon Musk
- Casita
    - It's the smallest room module 20 ft x 20 ft
    - It is fitted out as a studio apartment with a Kitchen, Bathroom, living room, and bedroom.
    - The product includes LED lighting, washer, dryer, fridge, stove, electric, HVAC and more. Just need to add your bed and couch.
- Costs of Casita
    - $50,000 includes utility hookups, foundation, landscaping, permits, and more.
    - What is not included in that price is your land and site setup. Depending on your location and the complexity of your site, this cost can range anywhere from $5,000 to $50,000.
    - Shipping fee - A rough budget might be $3-$10/mile from Las Vegas.

https://invest.boxabl.com/invest/regd-offering?investorid=14899&declared_accreditation_status=0
https://purgula.com/construction/boxabl-adu-tiny-home-affordable-housing/
https://www.boxabl.com/

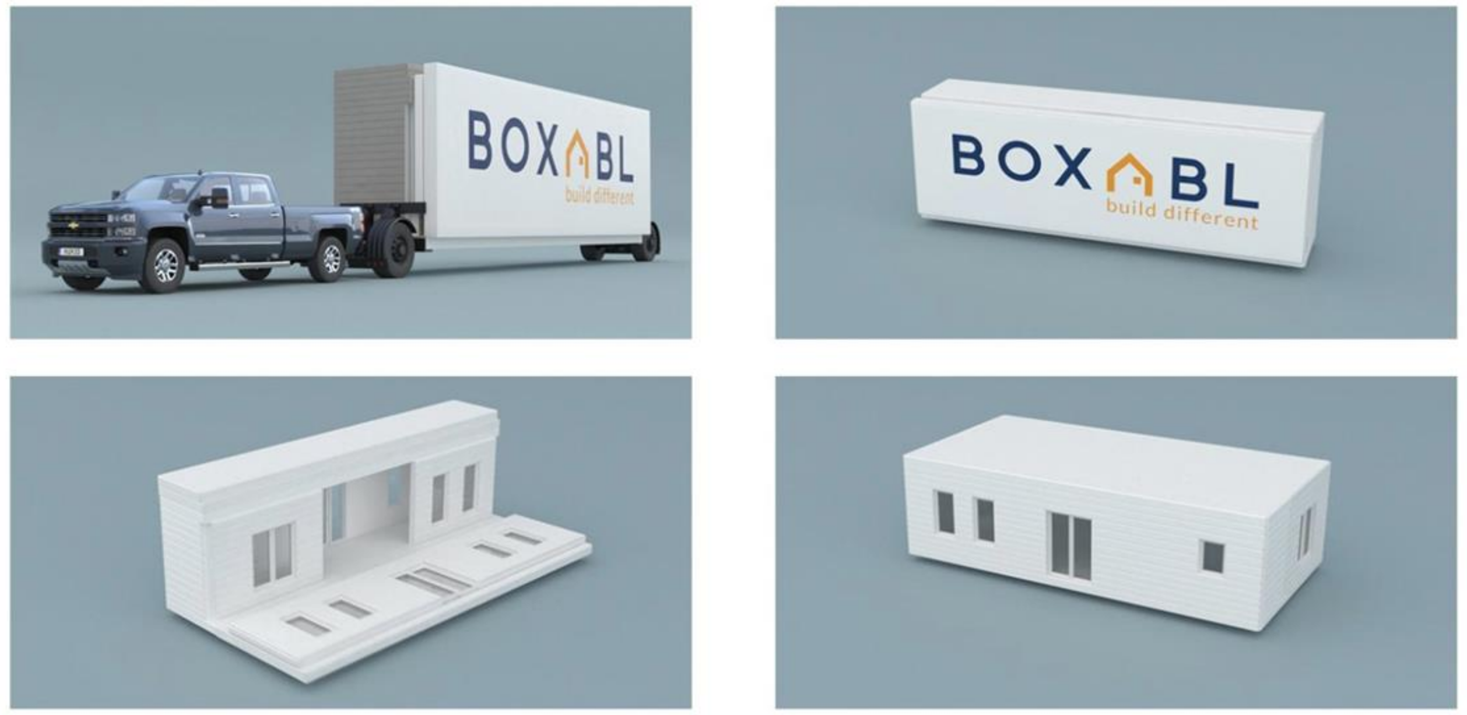
Boxabl - Technology Breakthrough

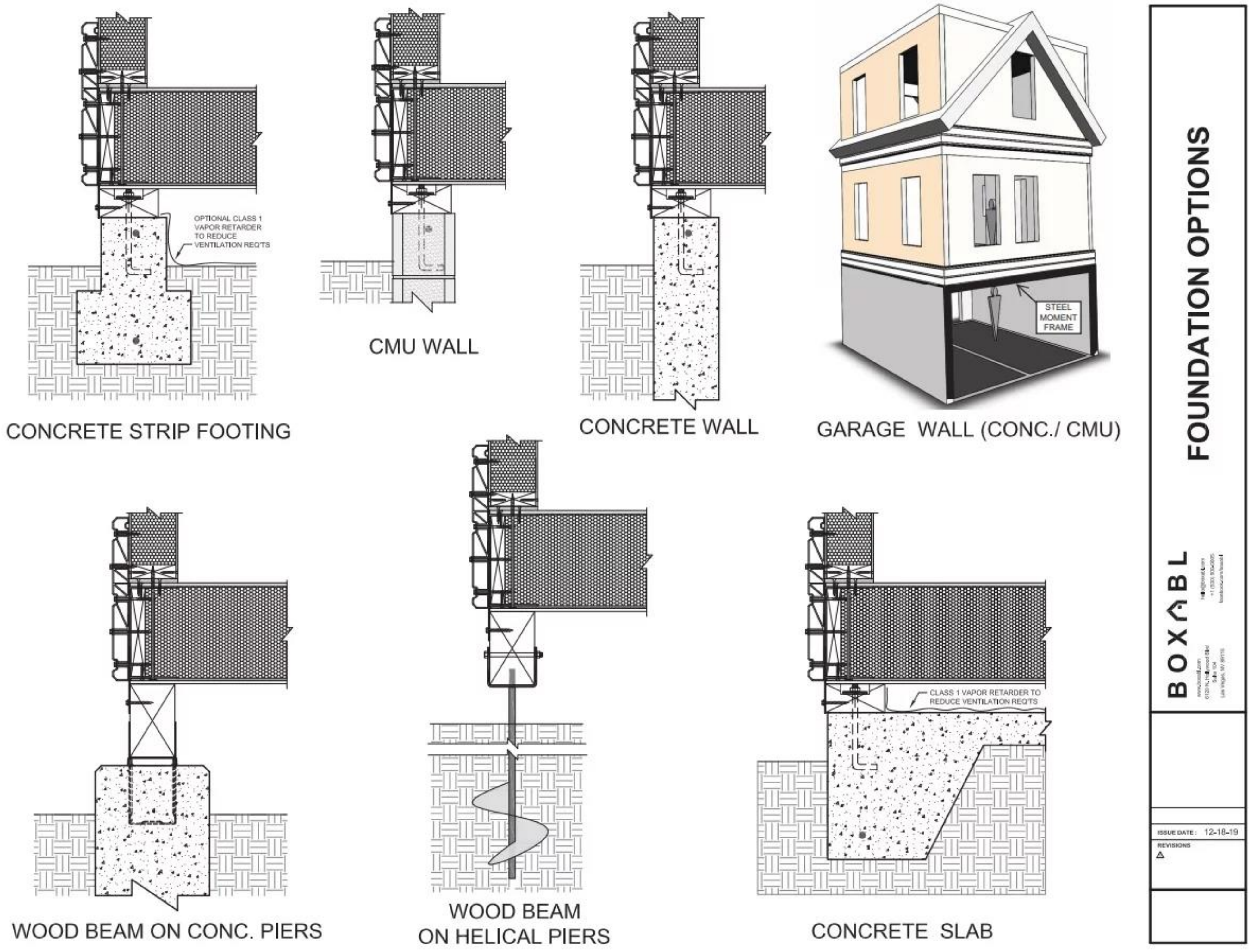
- Transportation
  - Standardized sizes
  - Each room can be packed in on itself and towed behind a regular sized pickup truck for quick affordable shipment
- Materials
  - Boxabls are made from steel, concrete and EPS foam. These building materials don't degrade and will last a lifetime.
  - The walls, floor and roof are structurally laminated panels that are much stronger than the average building.
- Compatible with any Foundation
  - Boxabl includes the Connector Plates



TECH - Transport

BOXABL





https://invest.boxabl.com/invest/regd-offering?investorid=14899&declared_accreditation_status=0
https://www.boxabl.com/foundation-options

Boxabl - Multi-story Home

Photo Credit; https://www.sohu.com/a/489870781_204826

Boxabl - Served as Emergency Architecture

- When Immediate relief needed
  - Boxabl can be pre built, inventoried, and filled with supplies.
  - The room is fold down to 8.5 feet wide and can be transported by trucks, trains, sea and air
- Once the emergency passes
  - They can be converted into high quality upscale permanent housing and used to rebuild communities.

https://www.boxabl.com/disaster

Application and Future Trend

Modular Construction and Infrastructure Renovation

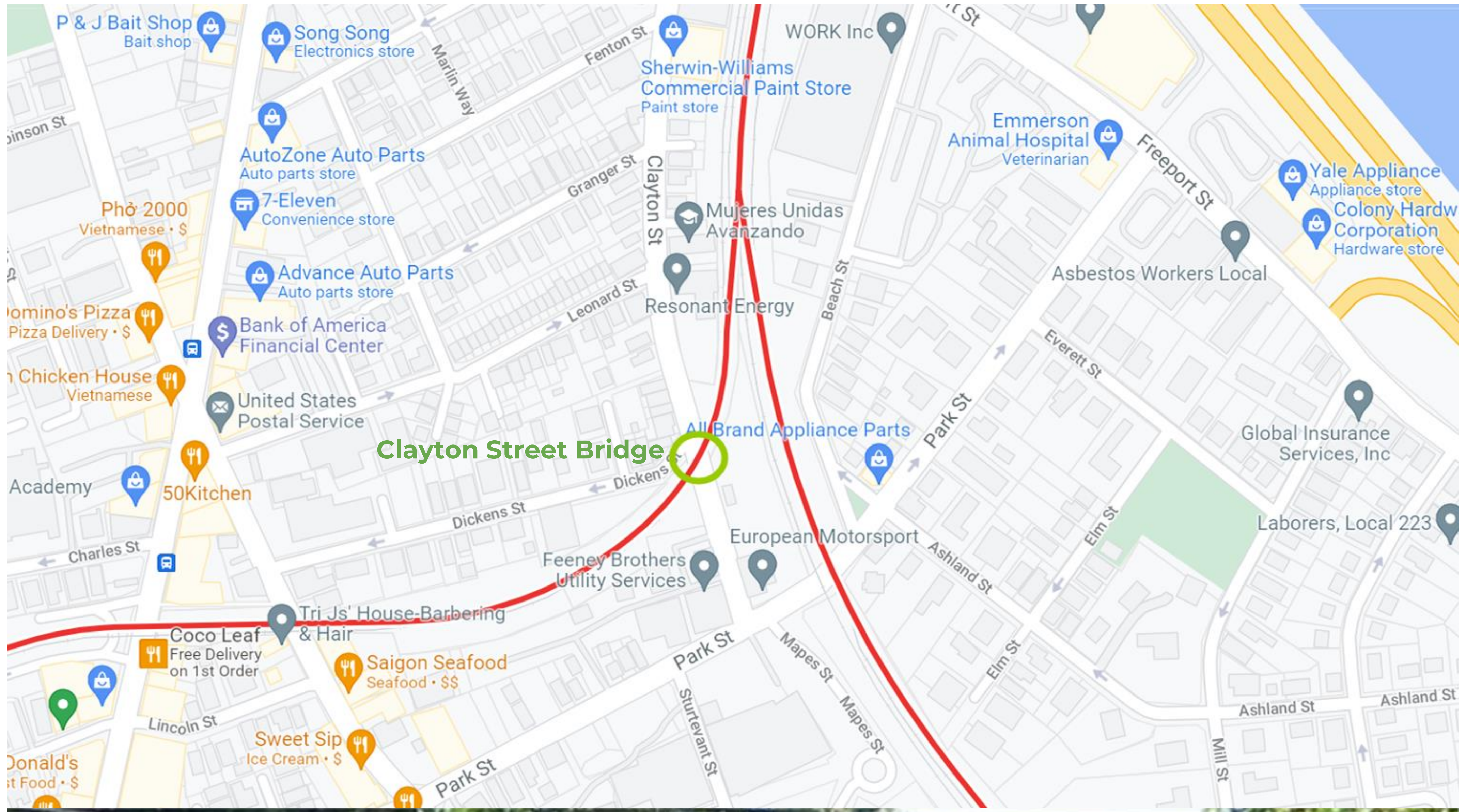
- Demands
  - The nation’s infrastructure earned a C- in the 2021 Infrastructure Report Card
  - New York faces infrastructure challenges of its own. For example, driving on roads in need of repair in New York costs each driver $625 per year, and 9.9% of bridges are rated structurally deficient. The state’s schools have an estimated capital expenditure gap of $2.91 billion.
- Challenges
  - Renovation will cost a lot of money.
  - The infrastructure is under use so that renovation may cause inconvenience for people’s livings.

https://infrastructurereportcard.org

Modular Construction and Infrastructure Renovation

The Clayton Street Bridge Replacement

- Background
  - Locates in Dorchester, Massachusetts
  - Old bridge built in 1911
  - Serve as part of MBTA Ashmont Red Line (subway)
- Issues of Old Bridge
  - Steel showed signs of deterioration
  - Original 13’-10” clearance was not sufficient for truck traffic under the bridge, causing truck collision damage
  - Steel bents blocking roadway caused hazards for motorist
- Challenges
  - MBTA Red Line trains could not be shut down on weekdays
  - Limited number of possible Red Line weekend shutdowns
  - Residential area cross the street from the bridge



https://www.americaninno.com/boston/mbta-red-line-clayton-st-bridge-project/
https://bc.mbta.com/business_center/bidding_solicitations/awarded_contracts/?cnumber=B00CN01
https://www.louisberger.com/our-work/project/clayton-street-transit-bridge-replacement-boston-ma-us

Modular Construction and Infrastructure Renovation

The Clayton Street Bridge Replacement

- Who
    - Owner: Massachusetts Bay Transportation Authority (MBTA)
    - MBTA contract number: B00CN01
    - Designer: Louis Berger Corp.
    - General contractor: Barletta Heavy Division, Inc.
- Cost
    - Project Value: $8.7 million
      Lowest Bid: $5.48 million
      Actual Cost: $5.5 million
    - Without costing MBTA millions of revenue.
- Timeline
  (*Traditional: may need 30 months)
    - Design completed on September 2012
    - Demolition and replacement completed on November 2013 during Veteran's Day weekend.

Old

New

https://www.americaninno.com/boston/mbta-red-line-clayton-st-bridge-project/
https://bc.mbta.com/business_center/bidding_solicitations/awarded_contracts/?cnumber=B00CN01
https://www.louisberger.com/our-work/project/clayton-street-transit-bridge-replacement-boston-ma-us

Modular Construction and Infrastructure Renovation

The Clayton Street Bridge Replacement

Phase 1

Construct temporary utility bridge to relocate MBTA power, signal and communication cable for the bridge.

Phase 2

Place 85 foot long tie backs through the hundred year old concrete abutment to strengthen the abutment.

https://www.youtube.com/watch?v=3YVUxDYj4QQ
https://youtu.be/5pRMLCAjJDE

Modular Construction and Infrastructure Renovation

The Clayton Street Bridge Replacement

Phase 3

Place micropile through the concrete abutment to increase stability of soil.

Phase 4

The replacement bridge superstructure was preassemble in the factory to ensure proper fitting and shipped in segment to a nearby site for assembly.

https://www.youtube.com/watch?v=3YVUxDYj4QQ
https://youtu.be/5pRMLCAjJDE

Modular Construction and Infrastructure Renovation

The Clayton Street Bridge Replacement

Phase 5

Demolish the existing bridge. Remove and replace back wall, new bearing. SPMT move the new bridge in place with very high precision.

New Bridge Description

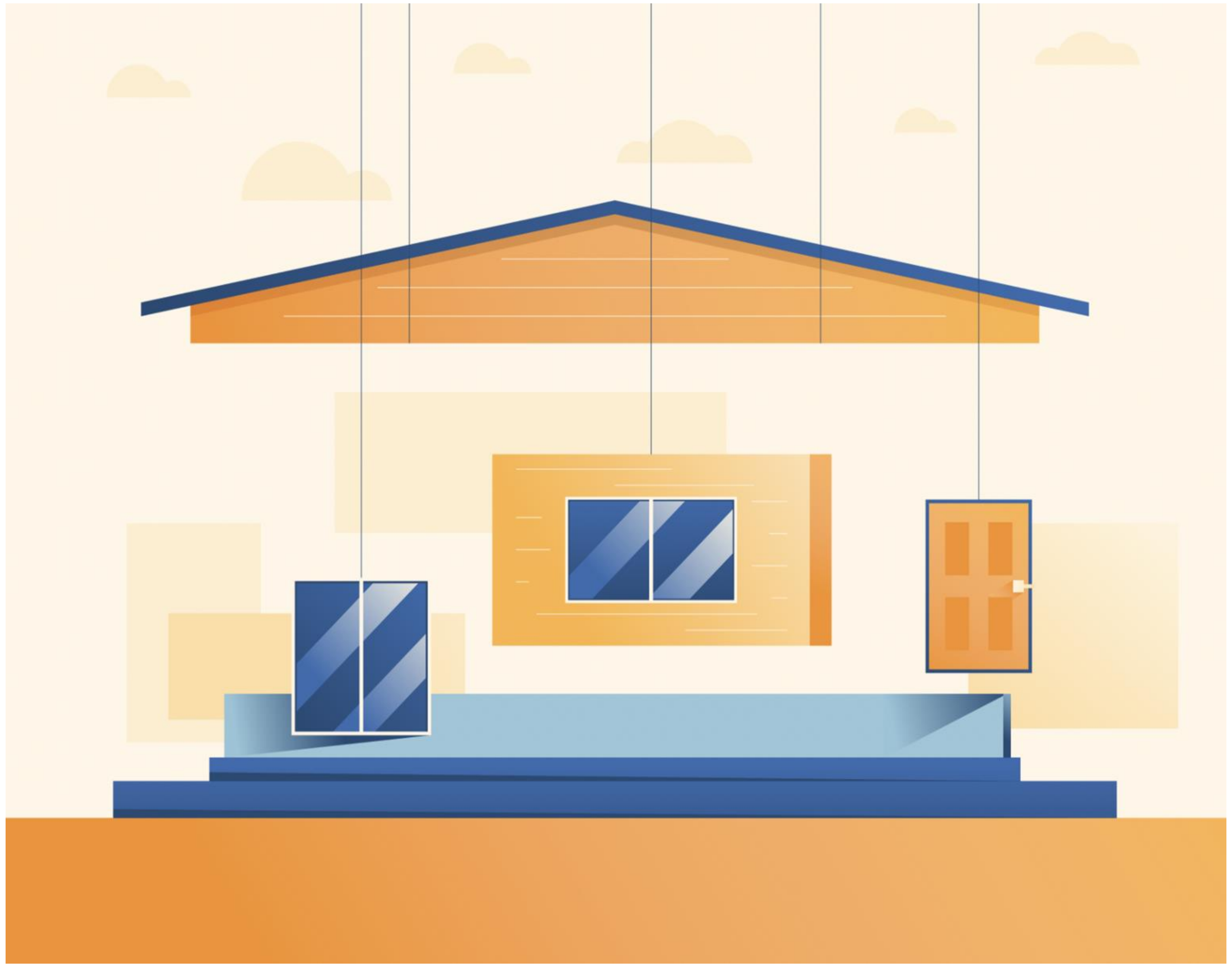
- 14' clearance
- Added new formliner and lightings for esthetics
- New sidewalks were constructed

https://www.youtube.com/watch?v=3YVUxDYj4QQ
https://youtu.be/5pRMLCAjJDE

Sustainability In Modular Construction

How Modular Buildings Provide Sustainable Construction Solutions

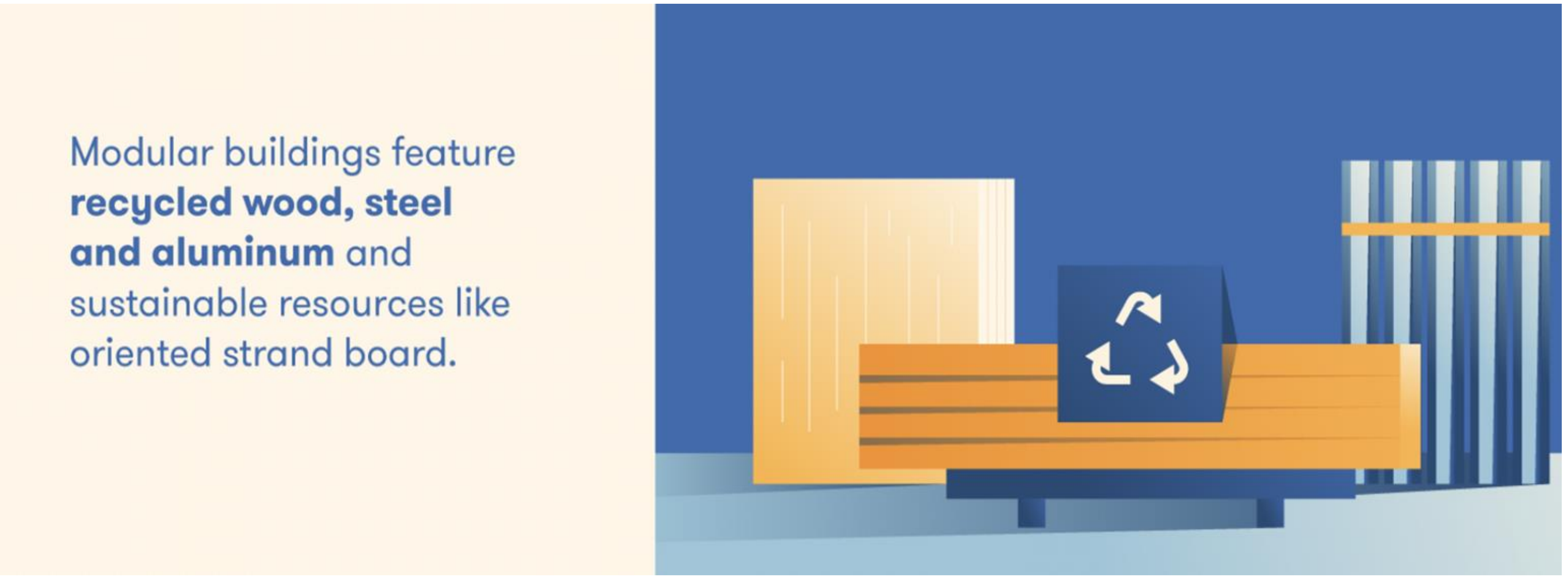
1. Decreases construction waste
2. Uses recycled materials
3. Decreases Energy Consumption During Construction
4. Reduces Emissions
5. Uses Insulation That Reduces Energy Needs
6. Integrates Solar Panels
7. Features Green Fixtures and Finishes
8. Built to Last — and to be Reused



BigRentz, Inc. “How Modular Construction Benefits the Environment.” *BigRentz*, 23 Feb. 2021, https://www.bigrentz.com/blog/modular-construction-

1. Decreases Construction Waste

Because multiple modules are being constructed simultaneously, materials that would be discarded on a normal construction site can be reused for other projects in a modular construction facility. Traditional construction generates around 56 million tons of debris every year, and reducing this amount would have huge environmental benefits.



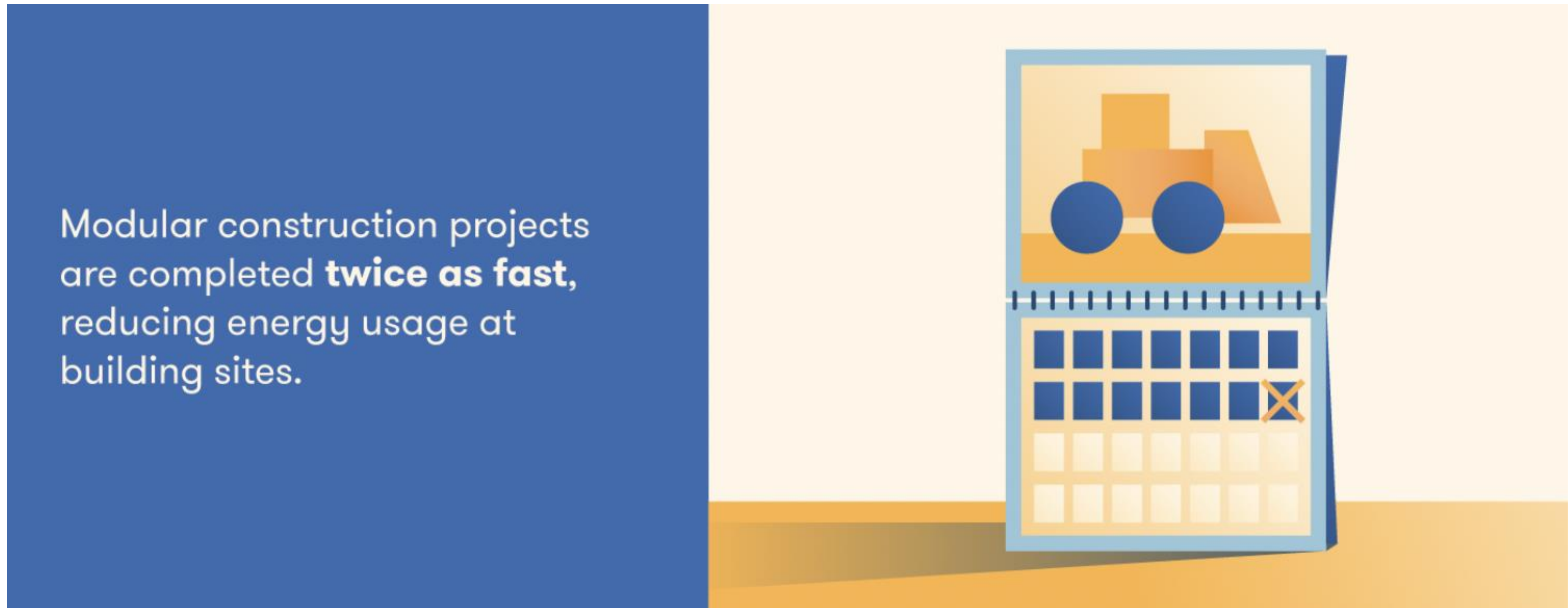
2. Uses Recycled Materials

Modular buildings use a variety of sustainable materials, and many of those materials are recycled, including wood, steel and aluminum, which can be used to form siding, frames and roofs. Some modular construction companies use innovative materials like oriented strand board (OSB), which is made from fast-growing, sustainably sourced wood. Modular design professionals are getting increasingly creative with materials in their buildings, like the Wikkelhouse, a structure made entirely of recycled cardboard, expected to last 100 years.

BigRentz, Inc. "How Modular Construction Benefits the Environment." *BigRentz*, 23 Feb. 2021, https://www.bigrentz.com/blog/modular-construction-

3. Decreases Energy Consumption During Construction

Since construction happens in a controlled factory setting rather than on site, overall energy use is decreased in the course of making a modular structure. During construction, energy usage is optimized using machine learning to create an environmentally sound building process. Additionally, on-site energy expenditures are significantly lower, as construction times are substantially decreased with modular buildings.



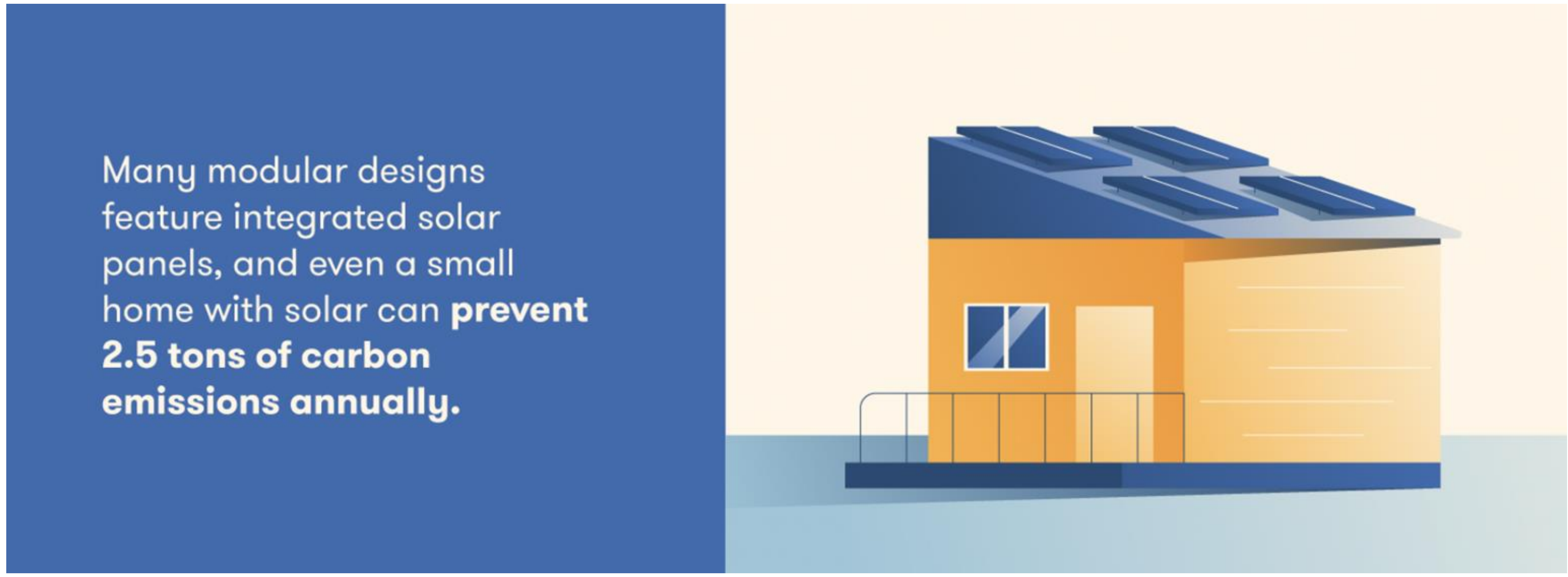
4. Reduces Emissions

A United Nations report found that 39 percent of global carbon emissions result from the construction field, and much of that is the result of inefficient transportation of labor, equipment and materials. By reducing overall transportation needs and optimizing the delivery of modules, modular construction is able to reduce total deliveries to building sites by 90 percent, which has an enormous effect on total emissions.

BigRentz, Inc. "How Modular Construction Benefits the Environment." *BigRentz*, 23 Feb. 2021, https://www.bigrentz.com/blog/modular-construction-

5. Uses Insulation That Reduces Energy Needs

Modular construction frequently includes a variety of features that reduce overall energy usage. One extremely beneficial design choice is the use of “structural insulated panels” (SIPs), which combine two exterior layers with insulated foam, creating a seal that is 15 times more airtight than fiberglass insulation. As a result, modular buildings maintain their temperature very well and require less heat or air conditioning.



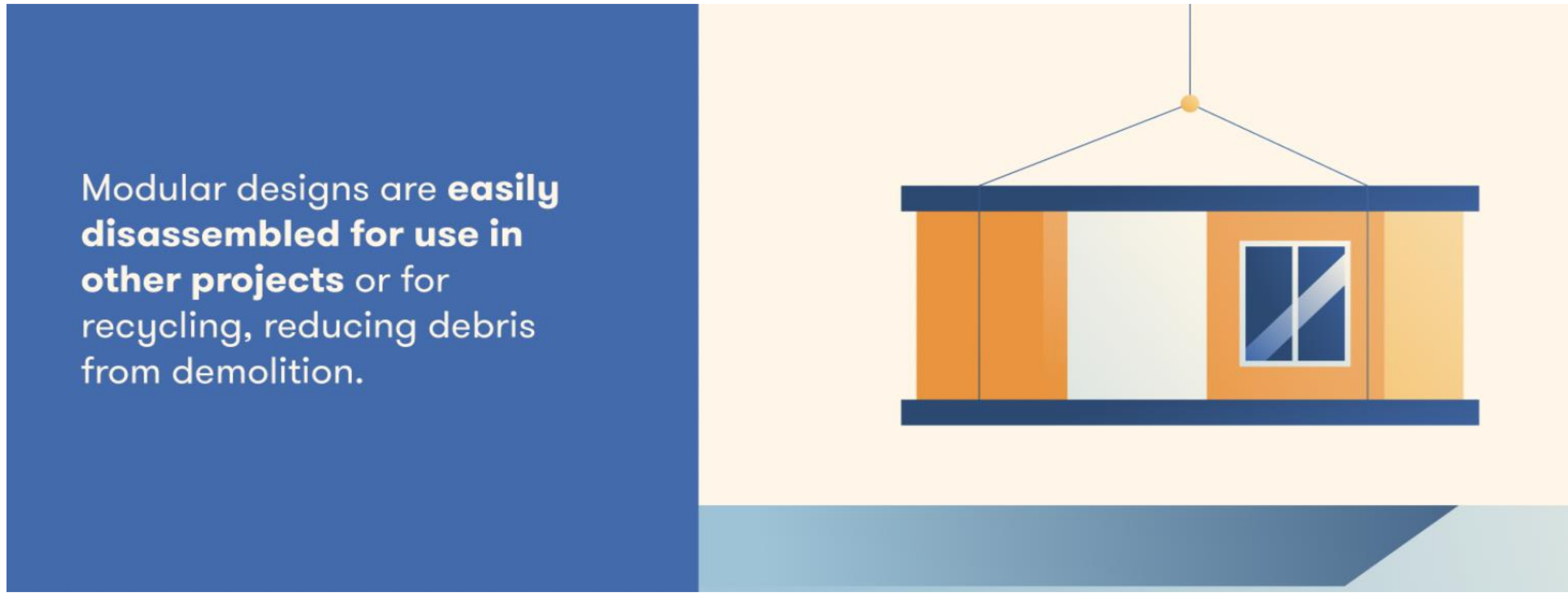
6. Integrates Solar Panels

Many modular buildings are designed with solar energy in mind. Combined with excellent insulation, solar panels can power the modest energy needs of a well-designed modular structure, as is the case with the KODA, which has sleek solar panels included on its roof. A simple solar set up can prevent 2.5 tons of carbon emissions annually.

BigRentz, Inc. “How Modular Construction Benefits the Environment.” *BigRentz*, 23 Feb. 2021, https://www.bigrentz.com/blog/modular-construction-

7. Features Green Fixtures and Finishes

Modern modular designs include a slew of eco-focused features, like dimmable LED lighting, solar water heaters, occupancy sensors, batteries for energy storage, triple-paned windows and electric carports. Innovative companies like PlantPrefab put environmentally sustainable features first, using materials with no volatile organic compounds (VOCs) and natural airflow technology to create designs that are healthier for humans and the planet.



8. Built to Last — and to be Reused

One of the distinct advantages of modular construction is that the designs aim for resilience and long lifespans, but this is also true of many traditional buildings. Unique to modular buildings, however, is the ease with which they can be disassembled — either to be reused in other locations and configurations or recycled for new projects. When considering long-term sustainability, modular building has distinct advantages, especially in helping to reduce debris generated by demolition, which accounts for more than 500 million tons of waste each year.

BigRentz, Inc. "How Modular Construction Benefits the Environment." *BigRentz*, 23 Feb. 2021, https://www.bigrentz.com/blog/modular-construction-

Sustainability in Modular Construction

T30 - Hotel

Background:

- Location: Xiangyin, Hunan, China
- Construction Company: Broad Group
- Manufacturer: Broad Group
- Construction Duration: 15 days
- Project value: $17 million
- Project size: 183,000 sqft

  30 stories, 358 hotel rooms

"China Broad Group Constructs 30 Story Building in 15 Days." *NextBigFuture.com*, 7 Apr. 2017, https://www.nextbigfuture.com/2012/01/china-broad-group-constructs-30-story.html.

Sustainability in Modular Construction

T30 - Hotel

Sustainable Characteristics:

- 5 times more energy efficient

  15 cm glass curtain wall insulation

  4-paned window

  External solar shading

  Heat recovery ventilation system
- 20 times purer air

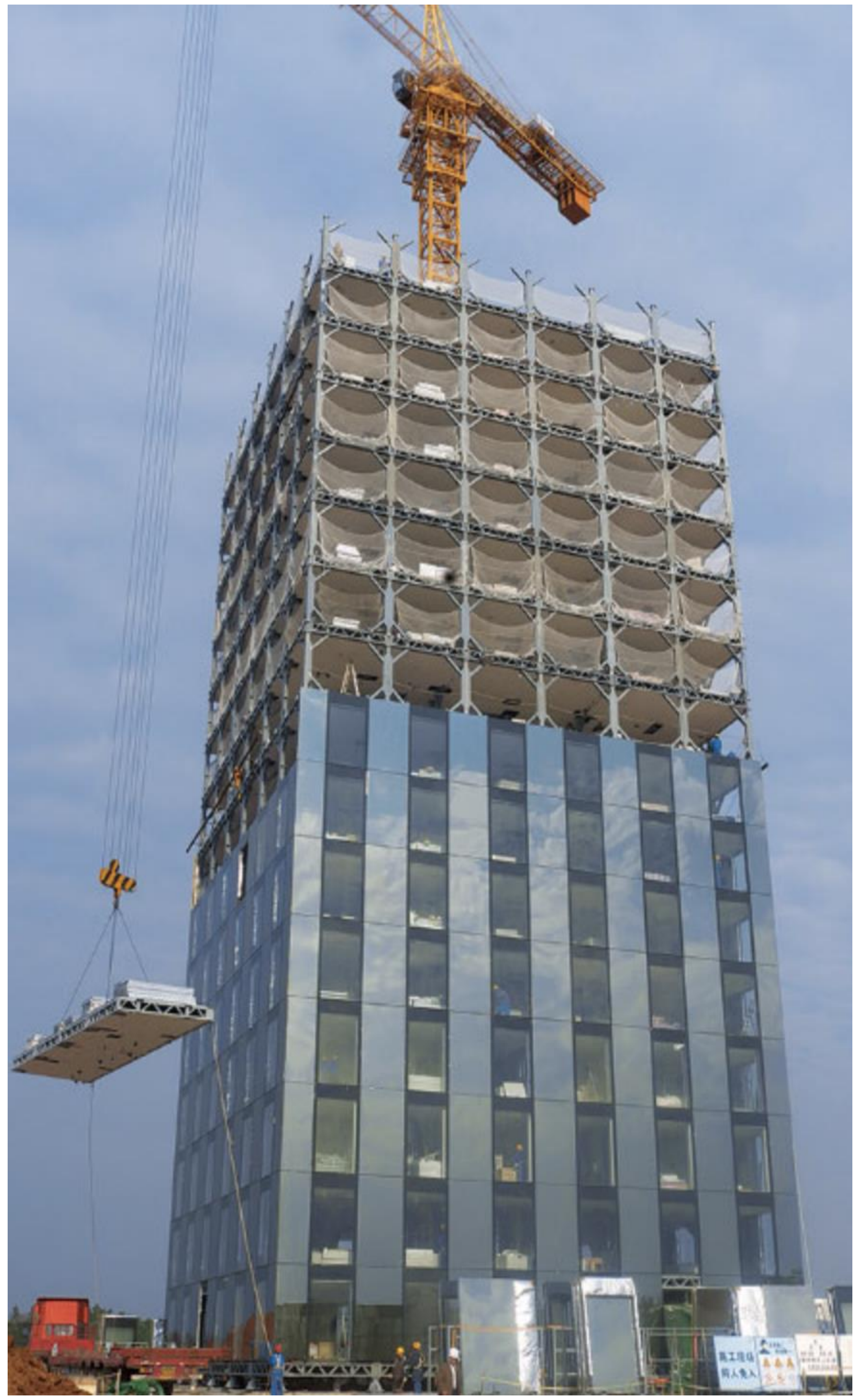
  3-stage air filtration
- Less construction waste

  99% reduction in construction waste

  80% reduction in concrete consumption

  10% reduction in steel consumption

  No construction dust and water consumption in site



"China Broad Group Constructs 30 Story Building in 15 Days." *NextBigFuture.com*, 7 Apr. 2017, https://www.nextbigfuture.com/2012/01/china-broad-group-constructs-30-story.html.

Sustainability in Modular Construction
T30 - Hotel

Heat recovery ventilation system

Heat recovery ventilation (HRV), also known as mechanical ventilation heat recovery (MVHR), is an energy recovery ventilation system which works between two sources at different temperatures. Heat recovery is a method which is increasingly used to reduce the heating and cooling demands of buildings. By recovering the residual heat in the exhaust gas, the fresh air introduced into the air conditioning system is pre-heated (pre-cooled), and the fresh air enthalpy is increased (reduced) before the fresh air enters the room or the air cooler of the air conditioning unit performs heat and moisture treatment. A typical heat recovery system in buildings consists of a core unit, channels for fresh air and exhaust air, and blower fans. Building exhaust air is used as either a heat source or heat sink depending on the climate conditions, time of year and requirements of the building. Heat recovery systems typically recover about 60–95% of the heat in exhaust air and have significantly improved the energy efficiency of buildings.

“China Broad Group Constructs 30 Story Building in 15 Days.” *NextBigFuture.com*, 7 Apr. 2017, https://www.nextbigfuture.com/2012/01/china-broad-group-constructs-30-story.html.

“Heat Recovery Ventilation.” *Wikipedia*, Wikimedia Foundation, 31 Oct. 2021, en.wikipedia.org/wiki/Heat_recovery_ventilation.

Challenges and Recommendations

- Challenges
  - Rent of Factory & On-site Workplace
  - Transportation & Supply-Chain
  - Policy & Standard Rules
  - Financial Issues
  - Technical Issues

Challenges & Recommendations

- Recommendations
  - Policy

    The approvals process can be complicated. No matter how they are constructed, all projects must meet federal, state and local laws and codes. However, the codes that are applicable change based on method. Some states and local jurisdictions are more favorable to modular production than others. Ideally, the modules are made subject to state codes (such as Pennsylvania Industrialized Housing Act) and can be inspected and completed at the factory with only connections and work performed on site subject to local inspection. On the contrary, states like Maryland require local inspections of systems preventing walls from being closed and finishes applied until on site. In places with strong union influence, how contractors navigate trade relationships can further complicate both the approval and execution phases.

Challenges & Recommendations

- Recommendations
  - Supply Chain

    Additionally, you're concentrating execution risk for the project into one or a few suppliers. Modular manufacturers have mostly focused on making single-family homes as their bread-and-butter products. While the number of companies producing commercial and multifamily products is growing, it's still very limited in those that are interested, capable and have the financial capacity to deliver. Buyers, whether they're owners or general contractors, must perform full diligence on companies before entering into an agreement that puts all their eggs in one basket. And, they must continue to be diligent following up throughout their work. Even if bonded, it would have to be a huge disaster to switch to another manufacturer in the middle of a project.

Challenges & Recommendations

- Recommendations
  - Financial

    Other than very high investment, there are other challenges involving financing. Since modular construction requires purchasing and making things on a faster timeline, the bills are usually much larger earlier in the construction period than investors and lenders may be used to seeing and paying. Therefore, take time to work with the manufacturer and contractor to understand the amounts and timing of anticipated funding (create a projection by month) and update it as the project unfolds. This will help to make sure that adequate monies are available to keep the job going and prevent mechanic's liens. A related item is that someone representing the contractor, owner and bank should plan to visit the factory at stages of production to make sure that funds are being invested into your modules and not into somebody else's (this is applicable for any type of funding of stored materials and pre-fabricated purchases).

Challenges & Recommendations

- Recommendations
  - Technical

    Modular construction demands that more decisions and greater design and engineering be completed up front in the process. It requires architects, engineers and contractors to be familiar with the intricacies of the modular fabrication and erection stages. For instance, the taller the building (higher modules stacked) the more attention is needed to how they are connected together to be aligned and how both modules and the exterior skin will allow for compression.

CONCLUSION

Modular construction methods utilize technological advancements like robotization and 3D-printing to increase productivity without having negative impacts on the environment. Modular construction embraces the concept of reusing and controlled construction spaces to decrease the wastage of raw materials without compromising the integrity of the building.

Digitization is making the current modular construction trend a constant in additional markets worldwide. The advancement of digital tools has drastically changed the intricacies of modular construction proposition. The whole process of designing different modules, coordinating the processes within the construction facility, and the optimization of the logistics to assemble the modules on site are some of the enhancements that are making modular construction a compulsion on our way to a sustainable future.

https://www.designingbuildings.co.uk/wiki/Modular_buildings