Fundamentals of Panelized Walls and Modular Building Design

Woodworks Workshops

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Acknowledgements/Credits

Modular Building Institute
http://modular.org

University of Utah Integrated Technology & Architecture Collaborative
http://itac.utah.edu

University of Alberta Hole School of Construction Engineering
https://www.ualberta.ca/engineering/research/groups/construction-engineering

Woodworks Wood Products Council
http://woodworks.org
Who we are

• R&S Tavares was formed in 2002 by Ralph Tavares and his wife, Silvana, who have been personally involved with prefabricated and hybrid-fabrication models of construction since 1987, becoming some of the country’s foremost authorities on modular structures and fabrication processes. They have consulted with several internationally known corporations in bringing overseas prefabrication technologies to the US. Ralph currently holds professional engineering licenses in 43 States and Silvana is a New York Licensed Architect. Ralph is the recipient of the 2013 Outstanding Achievement Award of the Modular Building Institute and serves as Trustee on the Modular Building Institute’s Educational Foundation in order to promote and educate others on the advantages of modular construction.
Modular: a definition

Modular construction is construction of 3D volumes to IBC/IRC building codes with a high level of finish off-site, typically in a warehouse, yet at times in nothing more than a yard, that is shipped to a site in sections and then assembled into place utilizing a lifting mechanism. Once on-site, utility and structural connections as well as patching or finishing is completed between modules.

Modular construction is estimated to make up 3-5% of total US construction industry

- 3D-Volumetric modules
- IRC/IBC Building Code
- High level of finish performed off-site
- Shipped in sections
- Assembled into place via a lifting mechanism
- Utility, Structural and finishes typically finished on-site
- 3-5% of total US construction industry
Other types of Off-Site Construction

- ANSI code A119.5:
  - Park model trailers
  - Limited in total square footage
  - Allow loft spaces
  - Permanently attached to a chassis with axles
  - Has VIN # from DMV

- HUD Federal code:
  - Mobile/Manufactured housing
  - Federal-level code
  - Generally regulated to mobile home parks or jurisdictions w/o regulations

IBC/IRC “Flat pack” or “Panelized” building systems
Wall, floor and roof frames built in 2D sections and loaded onto carriers
Tilt-up erection on-site
Sometimes include rough-ins for MEP

- Wet core modules
  - Bathroom or kitchen pods
  - Widespread use in Europe and other areas
  - Gaining traction in US
  - Difficulty in US adoption due to ADA threshold challenges
Benefits of Modular Construction

• Resource efficient
• Controlled conditions
• Improved quality
• Precision
• Inherently “Green” processes

• Innovation needed
From 1985 to 2011 – 26 years
8000 stores – 70 million customers
Eastman KODAK
From 1888 to 2012 – 124 years

On January 8, 2012, Kodak shares closed over 50% higher after the company announced a major restructuring into two main divisions, one focused on products and services for businesses, and the other on consumer products including digital cameras. January 19, 2012: Kodak filed for Chapter 11 Bankruptcy Protection.
Traditional US Construction

**Challenges**

- Workers typically exposed to high levels of:
  - Noise
  - Dust/airborne particles
  - Adverse weather conditions
- Site compaction & soil erosion from construction equipment
- Material storage challenges
- Adverse weather conditions
- Unskilled labor force
Traditional Modular Construction in the US

Challenges
- Approval process / code challenges
- Design & engineering unfamiliarity
- Transportation limitations
- Inspectors & code official unfamiliarity
- Seismic area height challenges
- “Mobile home” stigma
Modular Construction in the US

• **Benefits**

• Reductions in:
  • Material waste
  • On-site air & water pollution
  • On-site dust & noise
Modular Construction in the US

- **Benefits**
- Fewer conflicts in work scheduling
- Reduction of On-site material storage
- Fewer losses/misplacement of material & tools
- Increased worker safety
- Retention of workforce talent
Benefits of Modular: Costs

- **Cost-Savings**
- Elusive Target
- Breakpoints in production
  - Economies of Scale possible with highly repetitive product
  - Many factories capable of building 4+ complete modules per day
- Realized cost savings:
  - General conditions
  - Construction financing
  - Time to occupancy/market
Benefits of Modular: Costs

- **Cost Considerations**
  - Manufacturer preferences
    - Hardware
    - Suppliers
    - Brands
  - Supply chain & purchasing power
    - Manufacturers buy in bulk
    - Spec materials from typical vendors
    - Lack of familiarity with custom materials
- State-level permitting
  - 35 states have modular programs
  - Time & cost of state permits often significantly less than local jurisdictions with heavy regulatory environments
- Prevailing Wage
  - Typically not required for off-site components
- Union Labor
  - Often avoided for off-site components
## Benefits of Modular: Costs

### Key Findings: Quantitative Analysis

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<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>16% Savings</td>
</tr>
<tr>
<td><strong>Schedule</strong></td>
<td>43% Savings</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>5.4 Average Change Orders</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>0.25 Average Safety Incidents</td>
</tr>
</tbody>
</table>
Benefits of Modular: Costs

Key Findings: Return on Investment

<table>
<thead>
<tr>
<th>Schedule Reduction</th>
<th>Average Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>$5.81/SF</td>
</tr>
<tr>
<td>50%</td>
<td>$10.93/SF</td>
</tr>
</tbody>
</table>
Benefits of Modular: Time

Compressed project schedules

- Components manufactured off-site while: Foundation built
- Utilities ran
- Site work completed

Compressed project schedules

- State-level approvals and inspections via 3rd party approval agencies
- No local inspections for off-site product
Benefits of Modular: State Approvals

- State Program Approvals by Third Party:
  - Less Complicated
  - Generally Faster

- State Program **Inspections** also by Third Party:
  - Inspections for off-site components performed at Factory vs. On-Site

- Local Jurisdiction-led Approvals & Inspections
  - Burdensome
  - Often backlogged
  - High level of turnover in large jurisdictions
    - Inexperienced plan checkers and inspectors
  - At times due to factors such as
    - Unions/Labor
    - Previous cycle building codes
    - Lack of flexibility for new materials & methods
  - Local Jurisdictions may hold control of Site & Fire and Life Safety Issues
Advances in Modular Technology: Europe
Advances in Modular Technology: Japan
Advances in Modular Technology: Japan
Hilton Palacio del Rio, San Antonio

- 21-Story Modular Hotel
- Completed 1968
- Modular construction chosen due to schedule
- 50 years until the next Modular high-rise in the US
Brooklyn Yards Modular Tower

- Tallest Modular Building in the World
- 32 Stories
- 4 years to build. One of the longest tower construction projects in NYC
- Group reorganized as Full Stack Modular and will continue building modular projects
Herron Project, Nashville
Three on Abbott, San Diego
Three on Abbott, San Diego
Appalachian State University
Shipping Constraints

- **Width:**
  - Up to 16’-0” most places
  - Breakpoints at 12’ & 14’
  - TX up to 18’-0”

- **Length:**
  - Typically around 72’-0”
  - Dependent on factory layout

- **Height:**
  - 17’-0” including trailer in many jurisdictions
  - 16’-0” Elsewhere. Location specific
Shipping Constraints

- Mods of the same width can be loaded on the same trailer up to maximum shipping length.
- Manufacturers typically set up to serve 500’ mile radius.
- We often estimate $10/mile/shipment for standard shipments.
Mid Rise Construction

- Senior Living
- Apartments/Condos
- Mixed Use
- Student Housing
- Affordable Housing
- Hotels

Where Wood is a viable option, it’s likely the most appropriate choice.
Raised Foundation
watch for sill plates and bolts
TYP. HOLDDOWN STRAP @ EXT. WALL (TOP MOD TO BELOW)

1 1/2'' = 1'-0"

TYP. HOLDDOWN @ CORRIDOR (TOP MOD TO BELOW)

1 1/2'' = 1'-0"
Only (5) full height comp. studs this side, need (5) each side of rod @ first floor.

Note, module width is 14'-10" however grid line to grid line is 15'-0", GC to dimension from grid line to anchor bolts.

6" projection needed per Simpson
Need to connect the modules
Need to connect the modules
Diaphragm continuity

CAD & Revit Details: www.woodworks.org
Mod to Mod Connections @ Mate Lines

ACCESS OPENING w/ FIELD INSTALLED FASTENING

SHTG SEE PLAN & SHEAR PANEL SCHEDULE

PLYWOOD STOPS @ 2"

FLOOR TRUSSES PER PLAN

2x12 FIELD INSTALLED SEE 11 / S6.1(F)

ADDITIONAL RIM JOIST WHERE CALLED FOR ON PLAN

RIM JOIST PER PLAN SEE 2/S5.0(M) FOR OTHER NOTES

1 1/4" COMPRESSION STRIP

PLYWOOD STOPS @ 2"

MATE LINE @ WALL LOCATIONS

1 1/2" = 1'-0"
Shear transfer
Belly Bands

Shrinkage
Zone of Movement

Shrinkage occurs primarily in horizontal members
- Wall plates
- Floor/rim joists

Be aware of cumulative shrinkage.
Door and Window Considerations

Sealant joint sized to allow shrinkage of wood frame and expansion of brick (typically $\frac{1}{4}''$ to $\frac{1}{2}''$ per floor)

Flexible membrane flashing detailed to maintain positive slope after frame shrinkage.
Modular UL listed assemblies

- UL Listed Assemblies available for modular components:
  - Fire rated
  - STC/IIC rated
  - Floor/Ceiling
  - Mateline/Mateline
  - Floor/Crawlspace
- General excellence in STC/IIC qualities due to redundancy in framing and air gaps
Shear Walls – Panelized

1. Solid or Segmented Walls
2. Perforated Walls
3. Force Transfer Around Openings Walls
MODULE 101
61'-0" x 11'-11"
BEDROOM BATH

DRAWING INDEX

P0.0- TITLE BLOCK
P1.0- MODULE 101 - FLOOR PLAN, CHASE & WALL NOTES
P1.1- MODULE 101 - FLOOR FRAME
P1.2- MODULE 101 - ROOF & CEILING FRAME
P1.3- MODULE 101 - ROOF & CEILING BEAM
P1.4- MODULE 101 - CEILING PLAN
P1.5- MODULE 101 - HOLD DOWN
W1.0- MODULE 101 - WALL #1 SIDEWALL FRAME AND GRAB BAR ATTACHMENT
W1.1- MODULE 101 - WALL #2 SIDEWALL FRAME
W1.2- MODULE 101 - WALLS FRAME END WALLS
W1.3- MODULE 101 - WALLS FRAME
W1.4- MODULE 101 - WALLS FRAME

*THESE STRUCTURAL SHOP DRAWINGS SHOULD BE USED IN CONJUNCTION WITH THE APPROVED CONSTRUCTION DOCUMENTS. THESE DRAWINGS SHOULD BE READ AND COORDINATED WITH ALL OTHER CONTRACT DRAWINGS. IN THE EVENT OF DEVIATIONS, DISCREPANCIES, CONFLICTS OR UNCLEAR CONDITIONS THE CORRAO NEEDS TO BE NOTIFIED THROUGH THE RFI PROCESS.
BEDROOM BATH FLOOR PLAN

WALL NOTES:
1. ONE (1) BOTTOM PLATE & TWO (2) TOP PLATES
2. WALL HEIGHT IS 9'-0", STUD HEIGHT IS 8'-7 1/2"
3. "X" FOR STUD, "O" FOR JACK, "F" FOR STUD ON FLAT
4. △ INDICATES WALL NUMBER DARK PART SHOWN IS TO INDICATE THAT GYP BOARD IS ON THIS SIDE
5. ALL GWB IS 5/8 TYPE X, UNLESS NOTED OTHERWISE (UNO)
6. (S.W.) SHEAR WALL RATED WOOD SHEATHING IS 15/32 OR 7/16
7. WALL 11 TO BE TACKED IN PLACE
8. SEE P1.5 FOR FLOOR FASTNER SCHEDULE
FLOOR NOTES:

1. PRE-ENGINEERED 11 7/8" x 11'-3 1/2" FLOOR TRUSSES @ 24" O.C.
2. LSL 1 1/4" x 11 7/8" - PERIMETER WITH (3) LSL’S
3. ALL EXPOSED LSL RIM JOISTS ON EXTERIOR 1ST FLOOR BLDG AND BALCONIES PERIMETER SHALL BE TREATED WITH ZINC BORATE
4. APPLY JOIST HANGER @ LSL’S
5. 1 1/8" RATED WOOD SHEATHING ON FLOOR FRAME BLOCKED DIAPHRAGM WITH 10d NAILS @ 2 1/2" BOUNDARY, 6" EDGE AND 12" FIELD

NAIL PATTERN FOR LSL AT FLOOR
1. SEE DETAIL LSL AT FLOOR

PLUMBING FIXTURES

<table>
<thead>
<tr>
<th>FIXTURE</th>
<th>X</th>
<th>Y</th>
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<tbody>
<tr>
<td>WC1</td>
<td>25-8</td>
<td>7 7/8</td>
</tr>
<tr>
<td>WC2</td>
<td>35-4</td>
<td>5 7/8</td>
</tr>
<tr>
<td>TUB 1</td>
<td>19-8</td>
<td>1-9 1/8</td>
</tr>
<tr>
<td>TUB 2</td>
<td>41-3</td>
<td>7 7/8</td>
</tr>
</tbody>
</table>
ROOF FRAME NOTES:

1. 2x6 x 11'-1 1/2" HF#2 CEILING JOISTS @ 16" O.C. • SOLID BLX'G @ MID SPAN
   2x6 x 11'-1 1/2" HF#2 ROOF JOISTS @ 24" O.C.

2. (1) 2x6 PERIMETER RBM & (1) 2x8 PERIMETER RBM @ DOUBLE LAYER OF 3/4" PLYWOOD BEAM (5 PLY/5 LAYER)

3. (1) LAYER 5/8" TYPE C GWB @ CEILING
   (1) LAYER 5/8" PLYWOOD @ ROOF • BLOCK @ PLYWOOD SEAMS
   (1) LAYER 1/4" DENS DECK OVER ROOF SHEATHING

4. BLOWN IN INSULATION • COMPLETELY FILLED

FASTENER SCHEDULE:

1. ROOF • 10D NAILS @ 6" EDGES/12" FIELD

2. CEILING • SEE DETAIL 16/A/730 IN DETAIL BOOKLET

5/8"-C.S.- COMPRESSION STRIP DIAGRAM

3 1/2"
5 1/2" C.S. 3 1/2"
5 1/2"

MODULE 101
ROOF & CEILING FRAME
REFER TO P1-3
FOR PLYWOOD BEAM & PARAPET
1 ROOF AND CEILING BEAM

2 ROOF FRAMING @ END WALL

MODULE 101

REFER TO P1.2 FOR FRAME

3 NOTES

ROOF FRAME NOTES:
1. 2x8 11'-1 1/2" HF@2 CEILING JOISTS @ 16" O.C. - SOLID BKG @ MID SPAN
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FASTNER SCHEDULE:
1. ROOF • 10D NAILS @ 6" EDGES/12" FIELD
2. CEILING • SEE DETAIL 16A/730 IN DETAIL BOOKLET
CEILING FRAME NOTES:

1- 2x6x11-5/8" HF #2 CEILING JOISTS @16" O.C.

2- (2) 2x6 PERIMETER RIM

3- (2) LAYER OF 5/8" TYPE C GWB

1 1/4" C.S. - COMPRESSION STRIP DIAGRAM+

C. S. - CORRIDOR WALLS

BLOCKING 2x6 @ 24" O.C.

CUT BACK GWB 10" 2 BAYS

33-11 1/2"

11'-11"

16'-0"

18'-8"

WINDOW RIM @ CEILING TO BE CUT ON SITE AFTER SET-UP REMOVE GWB

2x6 PLATES ON FRAME

1 1/4" C.S. - COMPRESSION STRIP DIAGRAM+

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2- WALL HEIGHT IS 9'-0". STUD HEIGHT IS 8'-7 1/2"
3- "X" FOR STUD, "O" FOR JACK, "F" FOR STUD ON FLAT
4- INDICATES WALL # (NUMBER) WITH DARK PART TO SHOW GWB SIDE
5- ALL GYP.BO. IS 5/8" TYPE X, UNLESS NOTED OTHERWISE (UNO)
6- NAILING - 7" O.C. W/ 6D CEMENTED COATED NAILS 1 7/8" LONG 0.0915 IN.
   SHANK DIAM. & 1/4" DIAM. HEAD OR #6 BUGLE HEAD DRYWALL SCREWS
   1 7/8" LONG (TYP. FOR ONE HOUR FIRE RATED WALLS)
Off-site Finishing Capabilities
Financing

- Many banks nervous
- Factories typically require 100% payment before product leaves yard and may require as much as 50% to get started
  - Large amount of interest reserve used early in project
  - Construction should wrap up shortly after arrival of mods
  - Typical draws before mods arrive for site work/utilities and foundation
Finding Modular Consultants

• Modular Building Institute Member Finder (Commercial Projects)  
  http://modular.org/Finder/Default.aspx
• Modular Home Builders Association Member Finder (Residential)  
  https://modularhousing.com/Finder/Default.aspx
• Be wary of paid ads on google and other searches
  • Paid SEO ≠ quality consultants
Additional Resources

1. Advancing the Competitiveness and Efficiency of the US Construction Industry, NIST/NRC, National Institute of Standards and Technology and National Resource Council, 2010
2. Improving Construction Efficiency & Productivity with Modular Construction, Modular Building Institute
4. Woodworks “Putting the Pieces Together”
Additional Resources

Mid Rise Design: Opportunity and Implementation
Ralph M. Tavares, PE
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