

# Pathology of Wood: Working With Nature



2007 Association for Preservation Technology International Conference  
San Juan, Puerto Rico

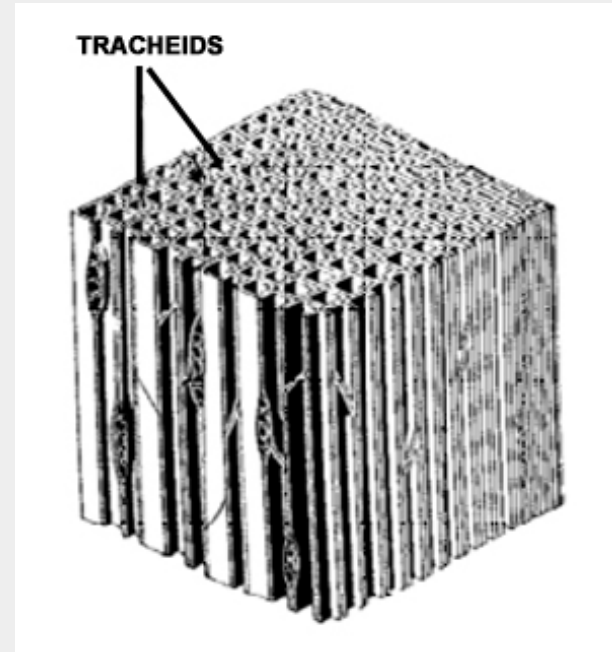
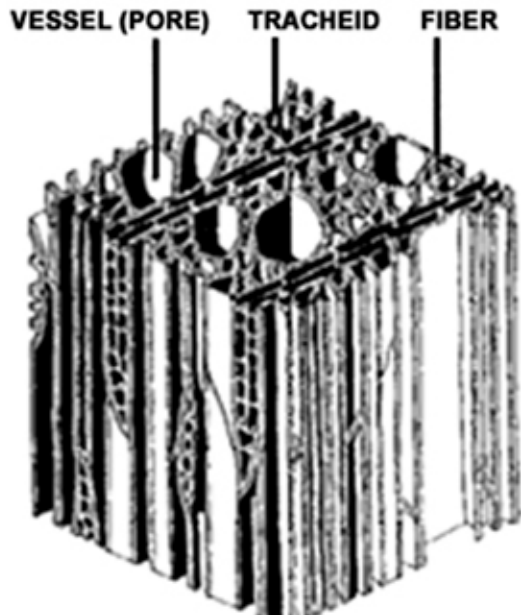


# Presentation Goals

1. Refresh our understanding of the nature of wood
2. Review techniques of analysis of wood deterioration
3. Understand options for arresting wood deterioration and repair techniques
4. Learn methods of documentation for construction contracts.

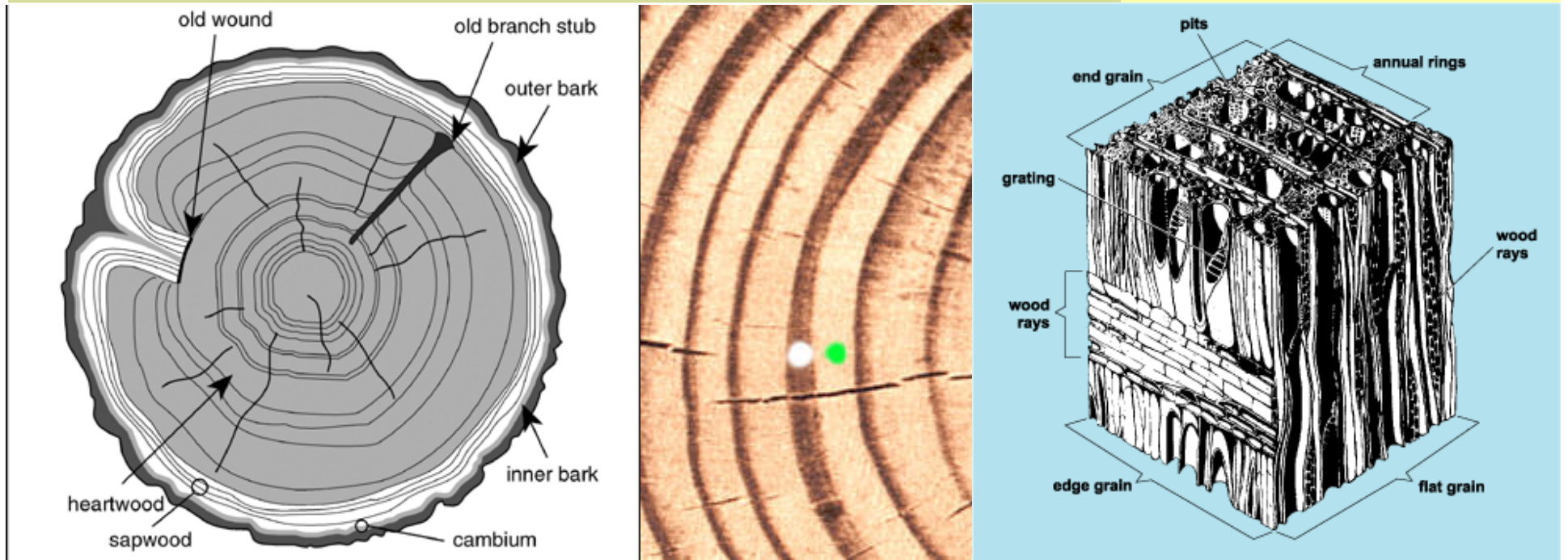


# Characteristics of Wood



- **The Basics**
  - Organic
  - Variability in color, density, strength, porosity, etc.
  - Rate of deterioration varies, even amongst the same species
- **Hardwood vs. Softwoods**
  - 12 types of softwoods (fir, pine, redwood, hem-fir, etc.)
  - 3 or 4 types of temperate hardwoods available (such as oak and maple) in the US
  - Thousands of types of hardwoods available – over 6,000 in the Philippines alone!
  - Pop Quiz! What is the basis of Classification of hardwoods and softwoods?

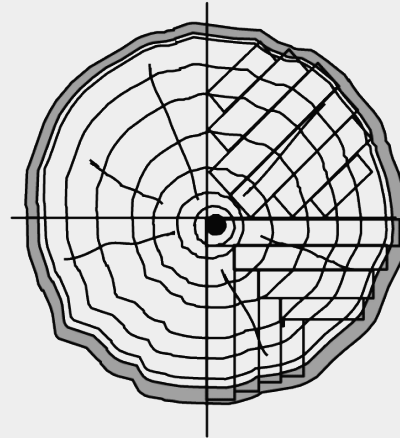
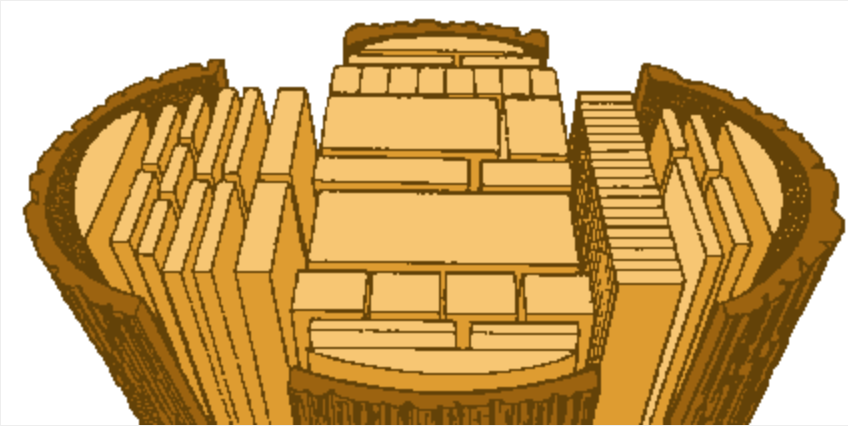
# Characteristics of Wood



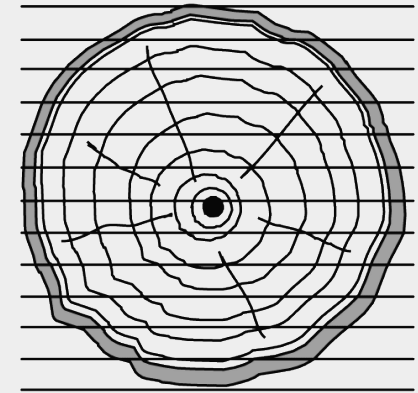
- **Growth Rings**

- Temperate zone trees have growth rings – distinct zones of seasonal growth
- Early wood is the soft zones developed during rapid spring growth, not as strong as late wood
- Late wood is the hard zones slow growth over the winter seasons
- Early wood is not as strong as late wood because it's not as dense

# Characteristics of Wood



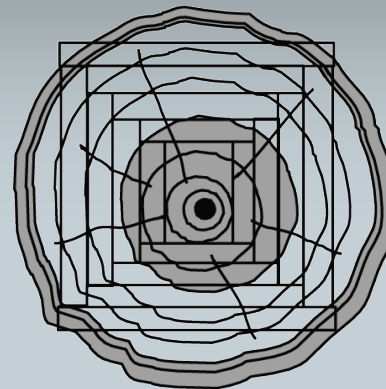
Quartered conversion, showing  
2 different ways (radial boards)



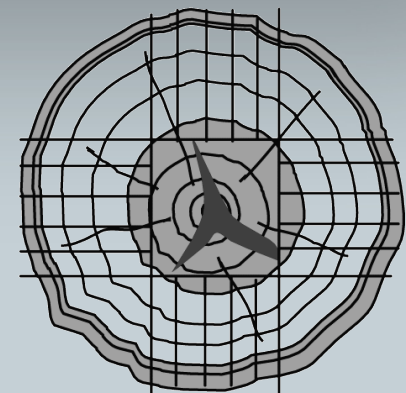
Through and through conversion.  
(tangential and some radial boards)

- **Log to Lumber**

- Different source locations affect:
  - How it will perform over time
  - How it will react to moisture



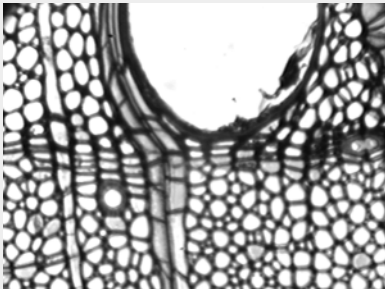
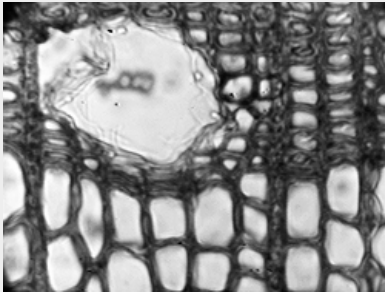
tangential cuts



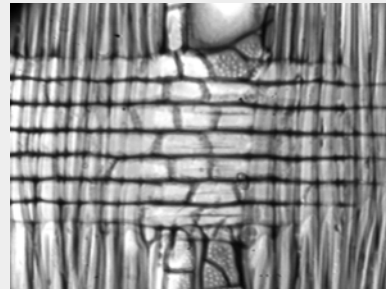
boxed heart  
(usually old oak)

# Characteristics of Wood

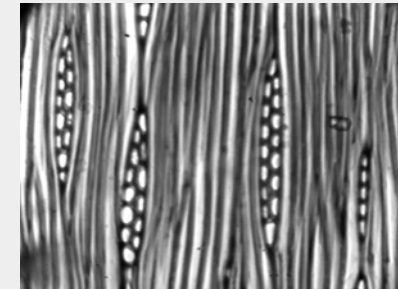
**End Grain**



**Radial**



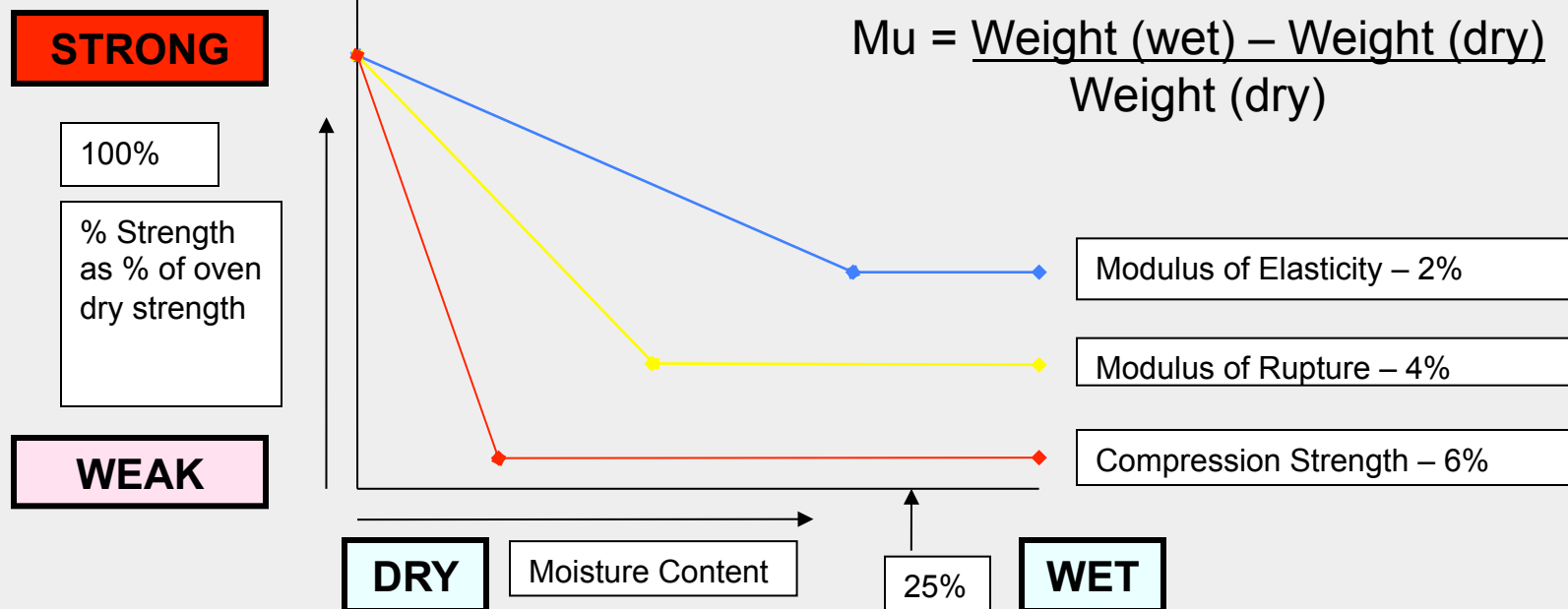
**Tangential**



- **3 faces of wood:**
  - End grain
  - Tangential (rays)
  - Radial
- **Soft Wood (Conifer): Pinus Ponderosa (Ponderosa Pine) (top)**
- **Hard Wood (Deciduous): Angiosperm Wood (bottom)**

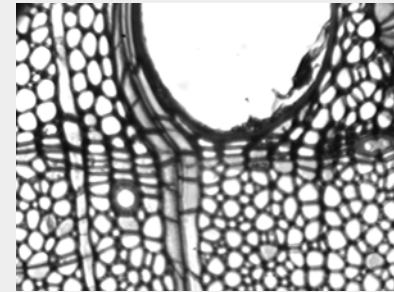


# Characteristics of Wood



- **Moisture Content Defined**
- **Moisture Content Calculation**
- **Affects of moisture on wood:**

# Characteristics of Wood



**Table 1. EMCs at Different Humidities for 30 to 90°F**

RH	10	20	30	40	50	60	70	80	90
EMC	2-3	4	6	7-8	9-10	10-11	12-13	15-16	10-21

- **Equilibrium Moisture Content**

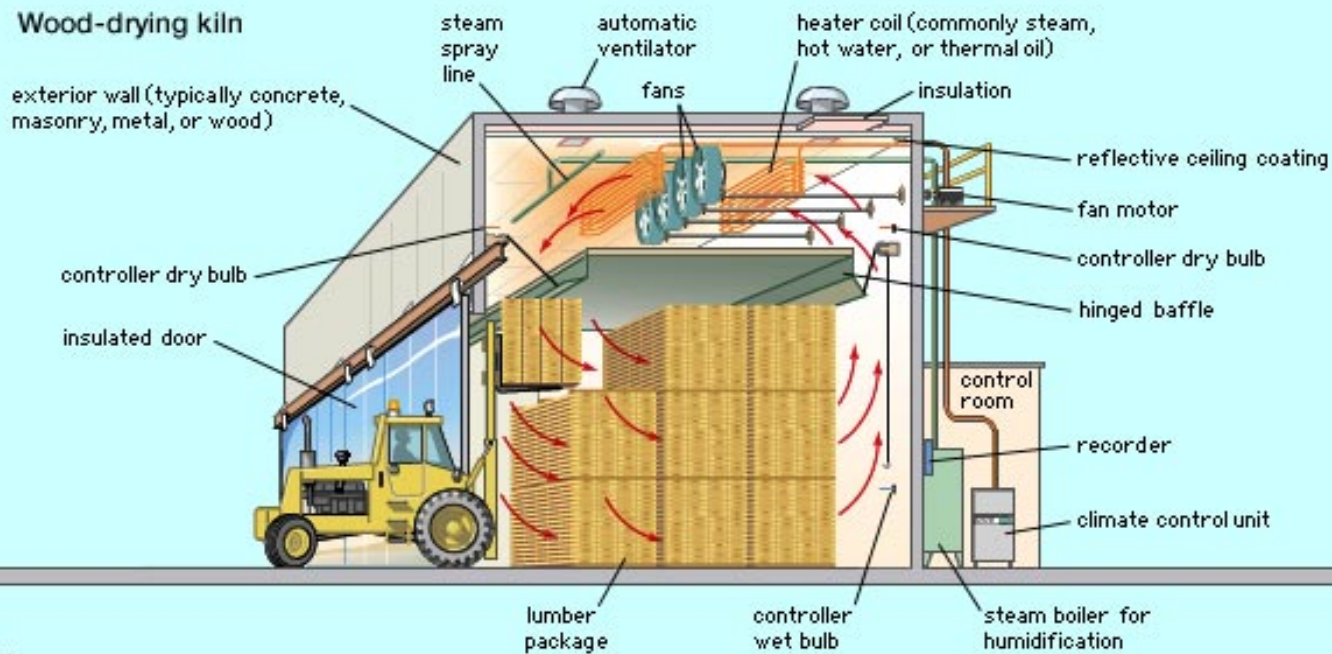
- Definition: The point at which wood is in equilibrium with the relative humidity of the environment it is in.
- Equilibrium Moisture Content varies with Relative Humidity

- **Fiber Saturation Point**

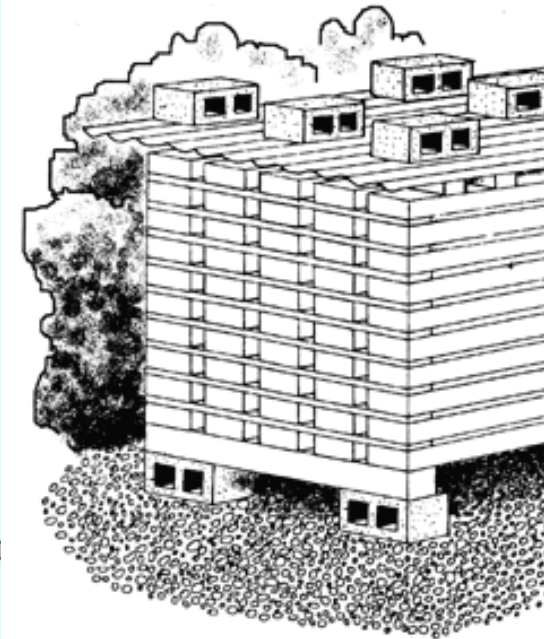
- Definition: Water completely fills cell walls, but not vessels. No “free” water in vessels.

# Characteristics of Wood

## Wood-drying kiln



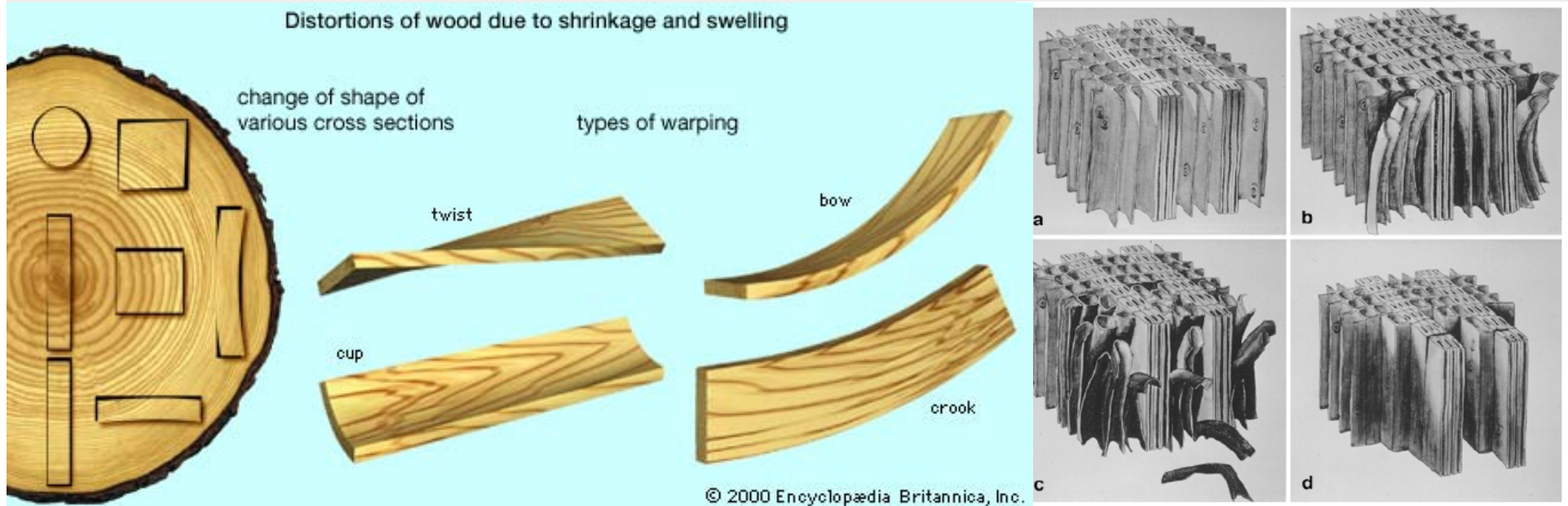
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- **Drying Wood**

- Does not require heat, but the Relative Humidity of the air must be less than the Equilibrium Moisture Content of the wood
- Stack with spaces, cover wood materials, blow air through with a fan – that's it!
- Note – denser wood takes longer to dry!

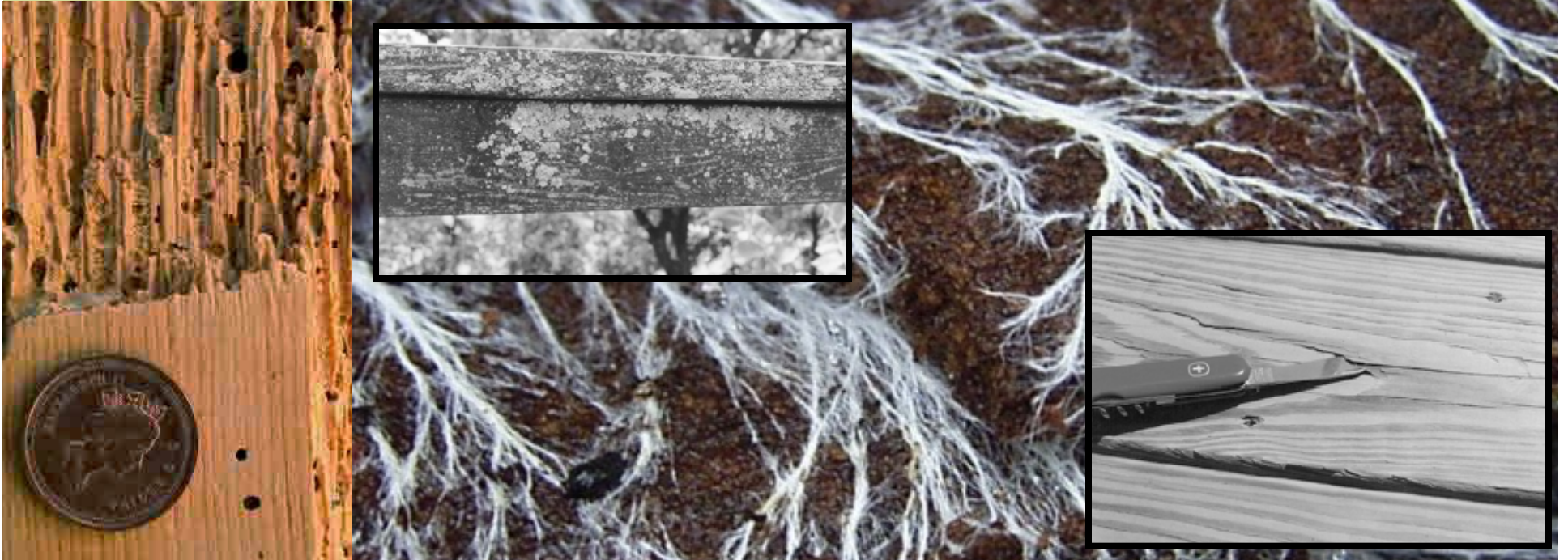
# Failure of Wood Materials



- Natural defects in milled wood
- Non-natural Modes of Deterioration



# Failure of Wood Materials



- **Failed alterations**
- **Structural Failure (Tension, compression failure)**
- **Biological deterioration**
- **Herbivorous failure**
- **Rot**
- **And....**

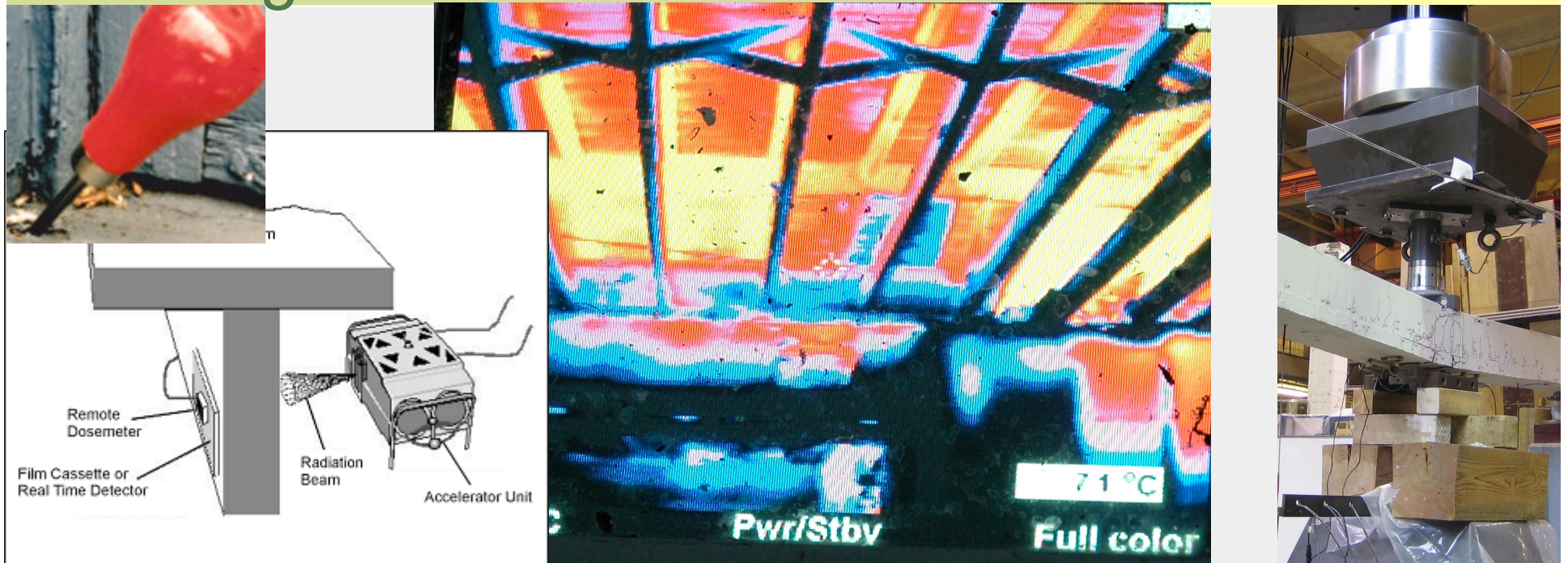


# Failure of Wood Materials





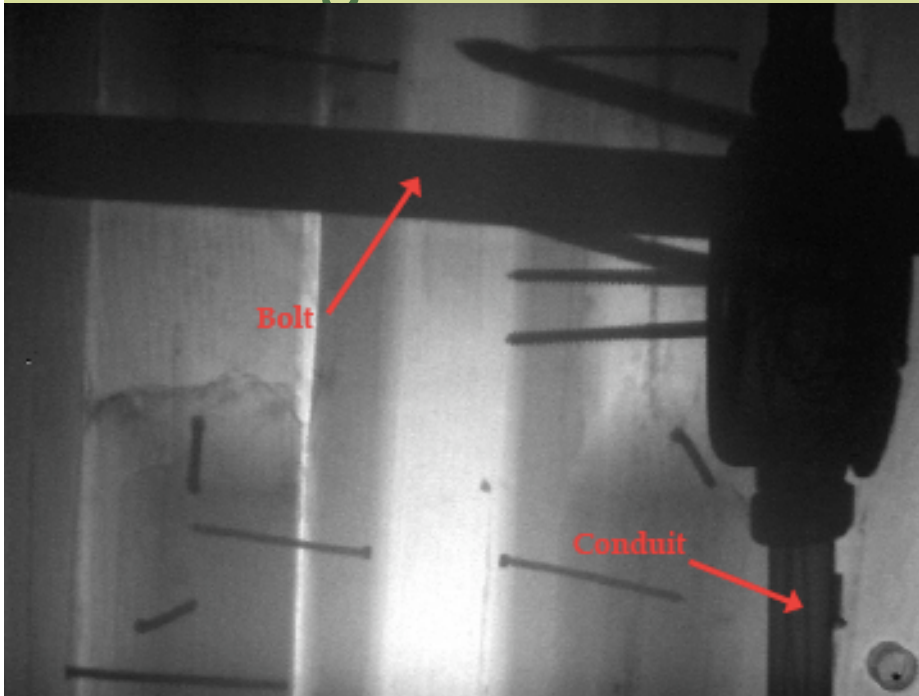
# Investigation of Wood Deterioration



- **Non-Destructive Testing and Detection methods**

- Eyeballs!
- Ice pick or sharp knife
- Thermography (thermal imaging)
- Density drilling
- Radiography
- Infra-red imaging
- Load Testing – in situ

# Investigation of Wood Deterioration



Center for Wood Anatomy Research  
USDA Forest Service, Forest Products  
Laboratory

One Gifford Pinchot Dr.  
Madison, WI 53726-2398

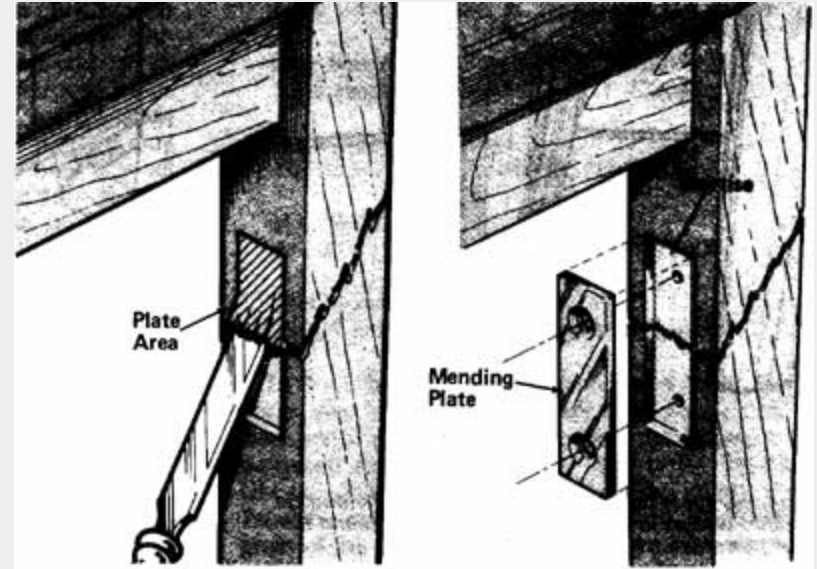
[woodidentification@fs.fed.us](mailto:woodidentification@fs.fed.us)

<http://www.fpl.fs.fed.us/>

- Radiography
- Unknown wood species



# Wood Repair Techniques



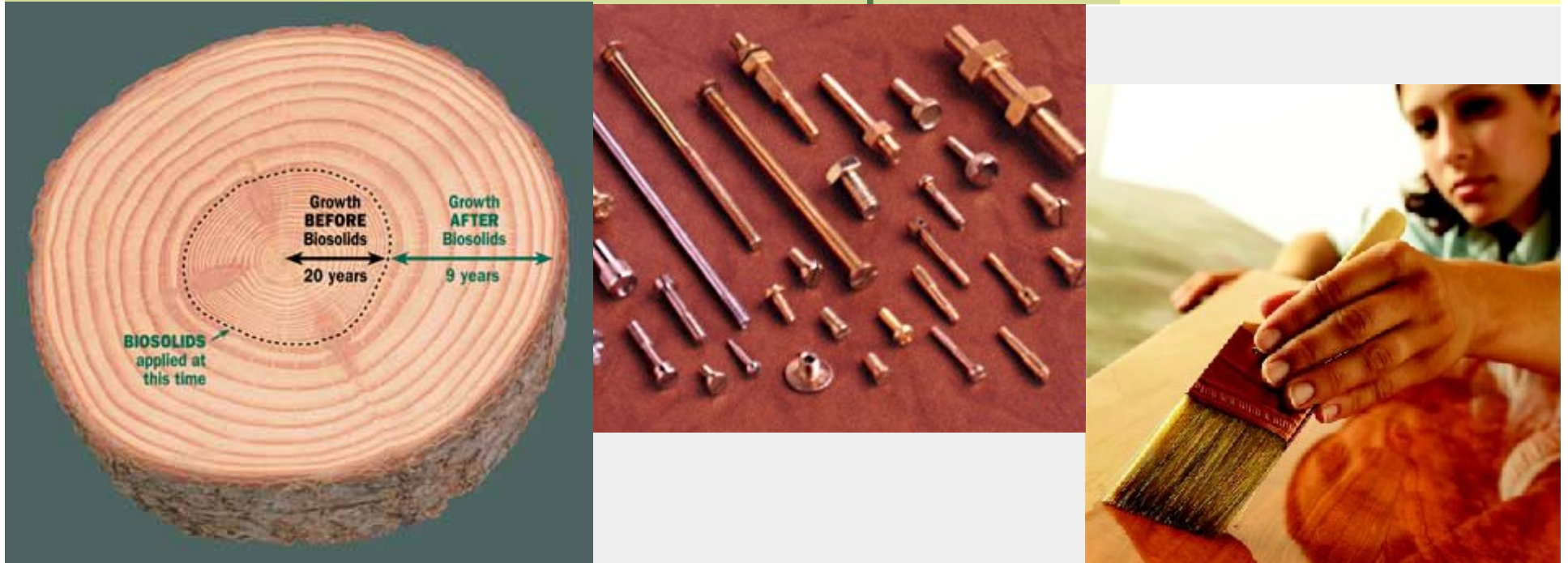
- **Repair techniques**
  - Structural
  - Moisture
  - Biological
  - Critter
  - Fire

# Defensible Documents - Specifications



- **Part 1:**
  - Contractors: Level of Prequalification commensurate with quality of project
  - Documentation/Cataloging of existing materials

# Defensible Documents - Specifications



- **Part 2: Materials**
  - Specify number of growth rings for wood
  - Screws and fasteners: Specify diameter and length
  - Hierarchy for use of deteriorated materials
  - Recommendations for finishes

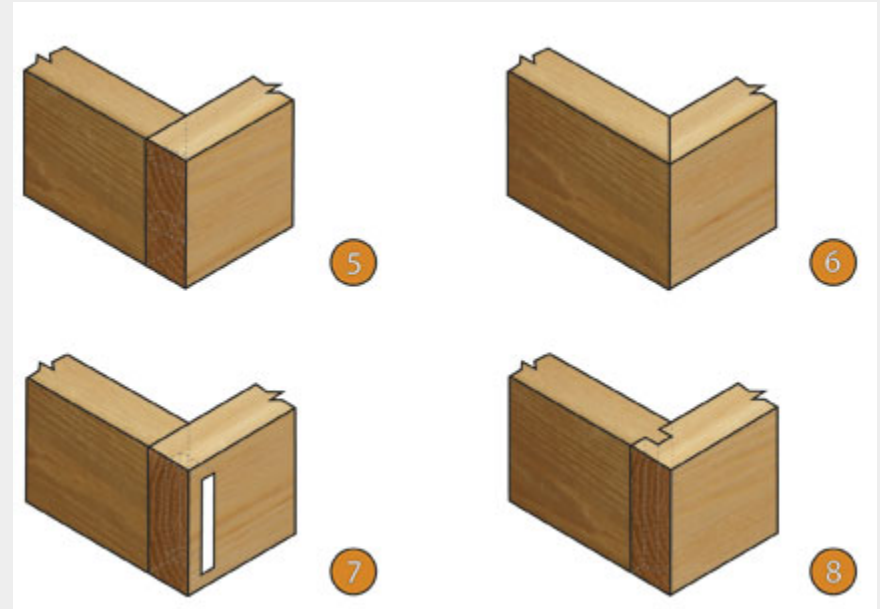
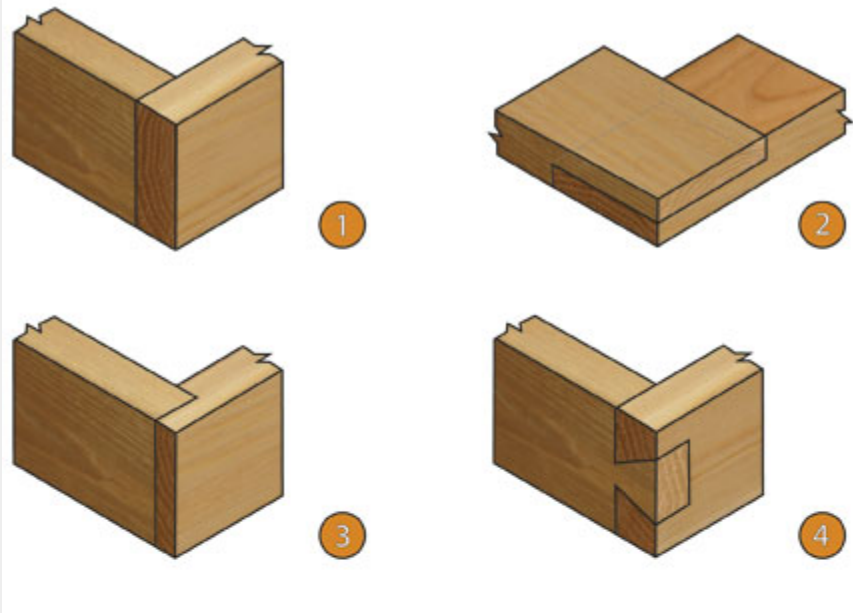
# Defensible Documents - Specifications



- **Part 3:**
  - Cleaning
  - Marking and measuring
  - Means & Methods



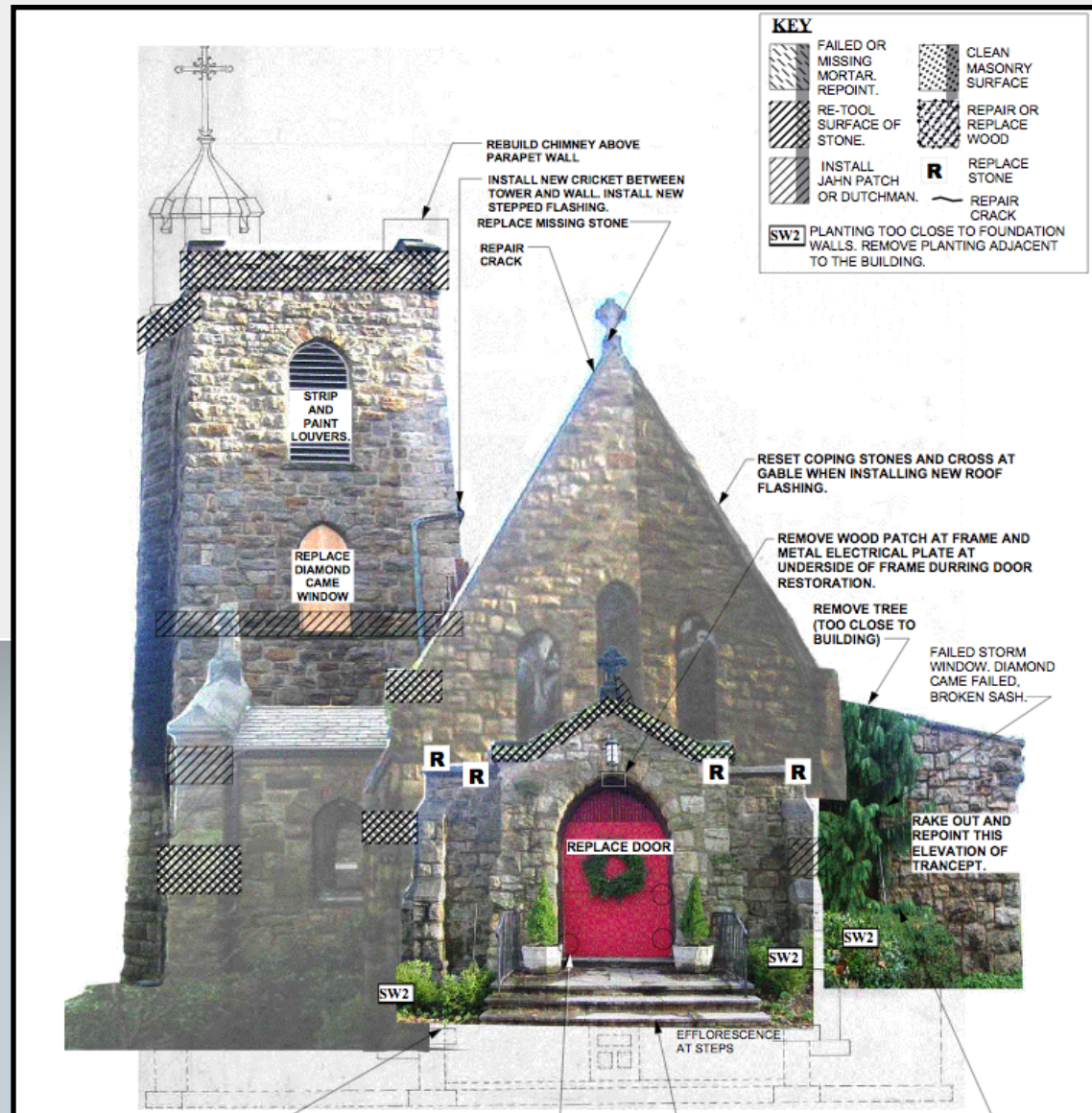
# Defensible Documents - Drawings



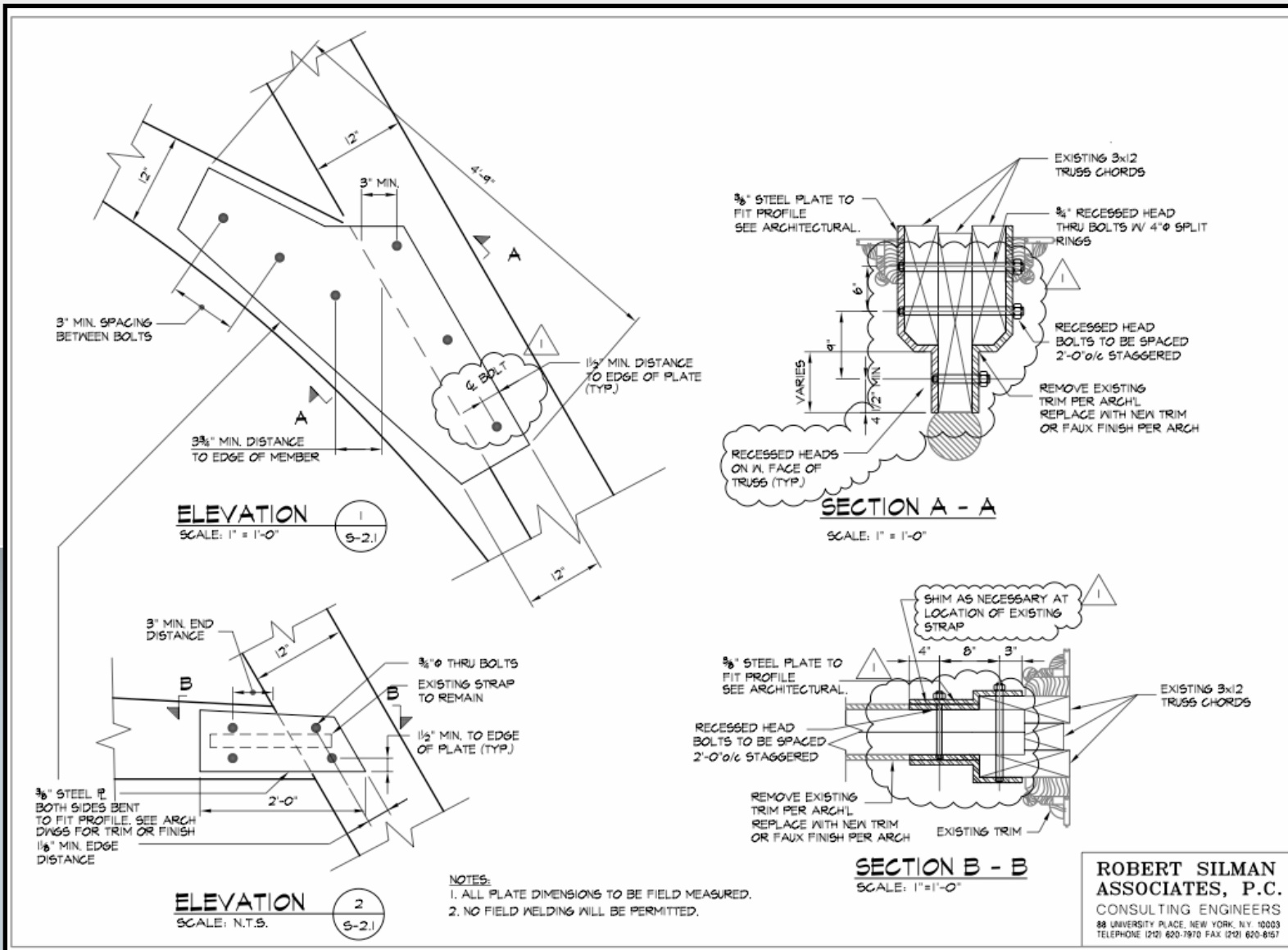
- **Wood Joint Designs – Basic Joints**

- Lap, Half lap
- Rabbet
- Dovetail
- Mitered
- Mortise & Tenon
- Dado
- Not shown: Finger joint, Scarf joint, dovetail miter, shoulder miter, splinted miter

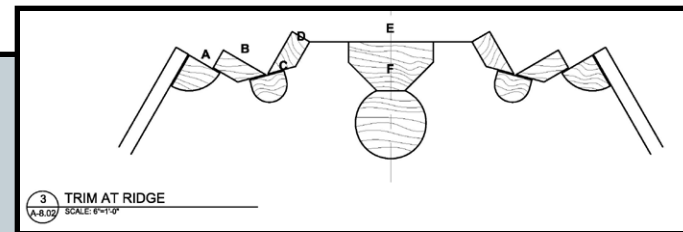
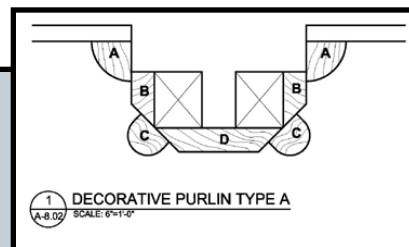
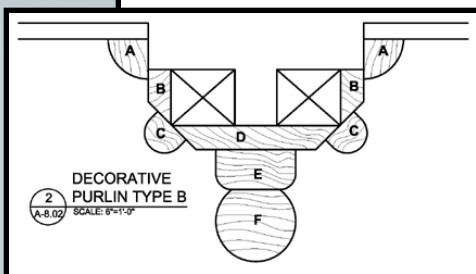
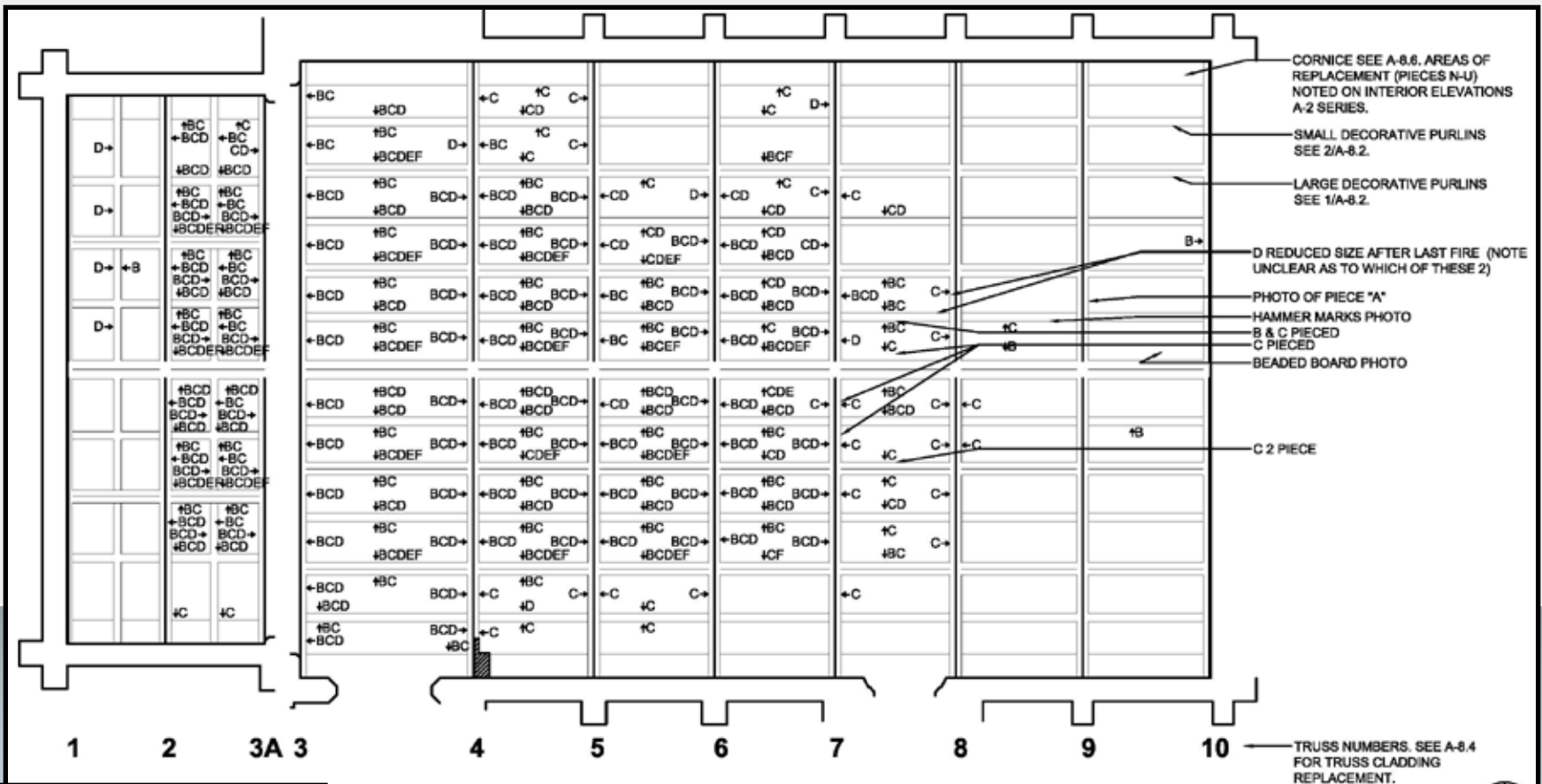
# Defensible Documents - Drawings



# Defensible Documents - Drawings

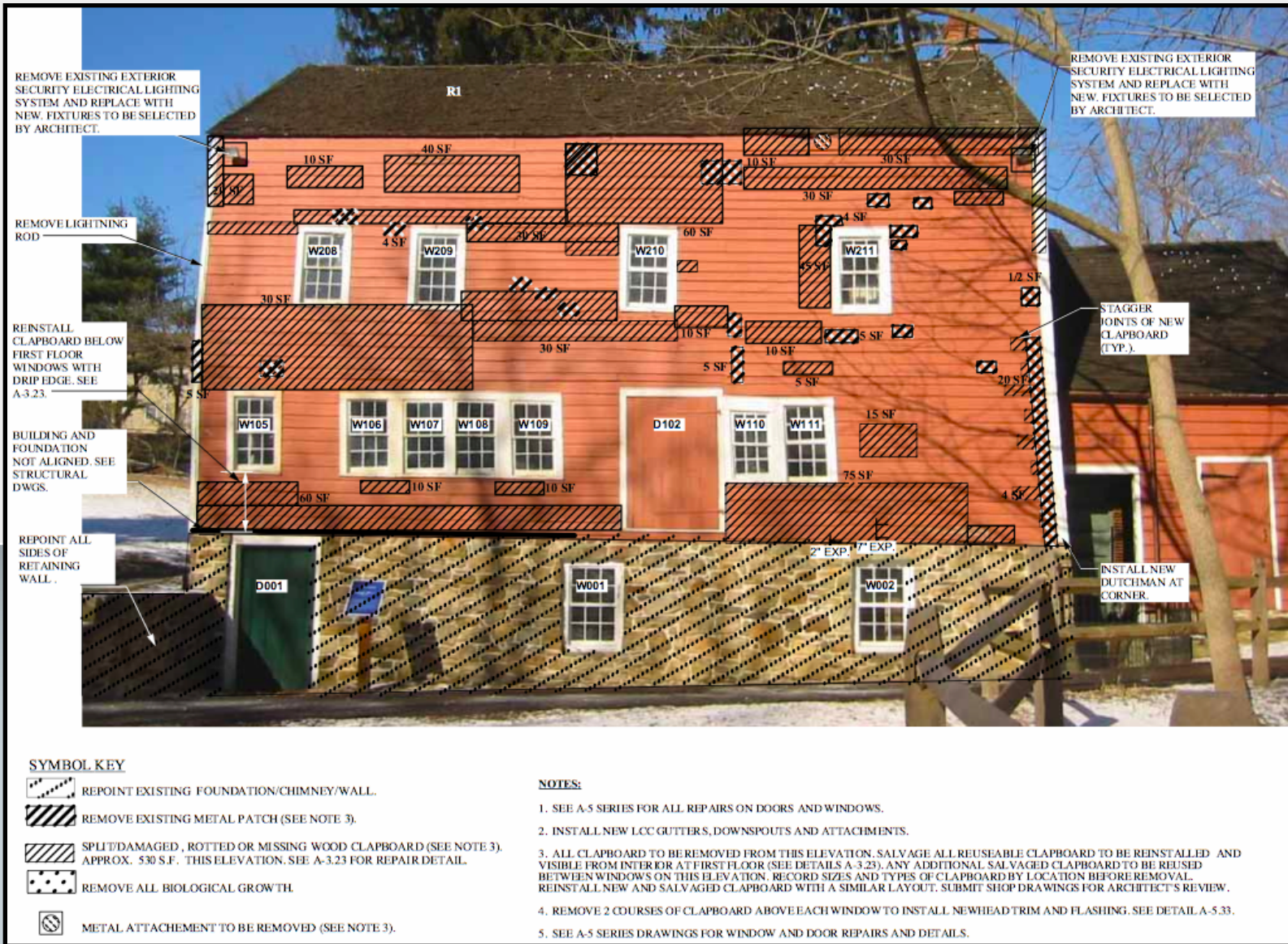


# Defensible Documents - Drawings

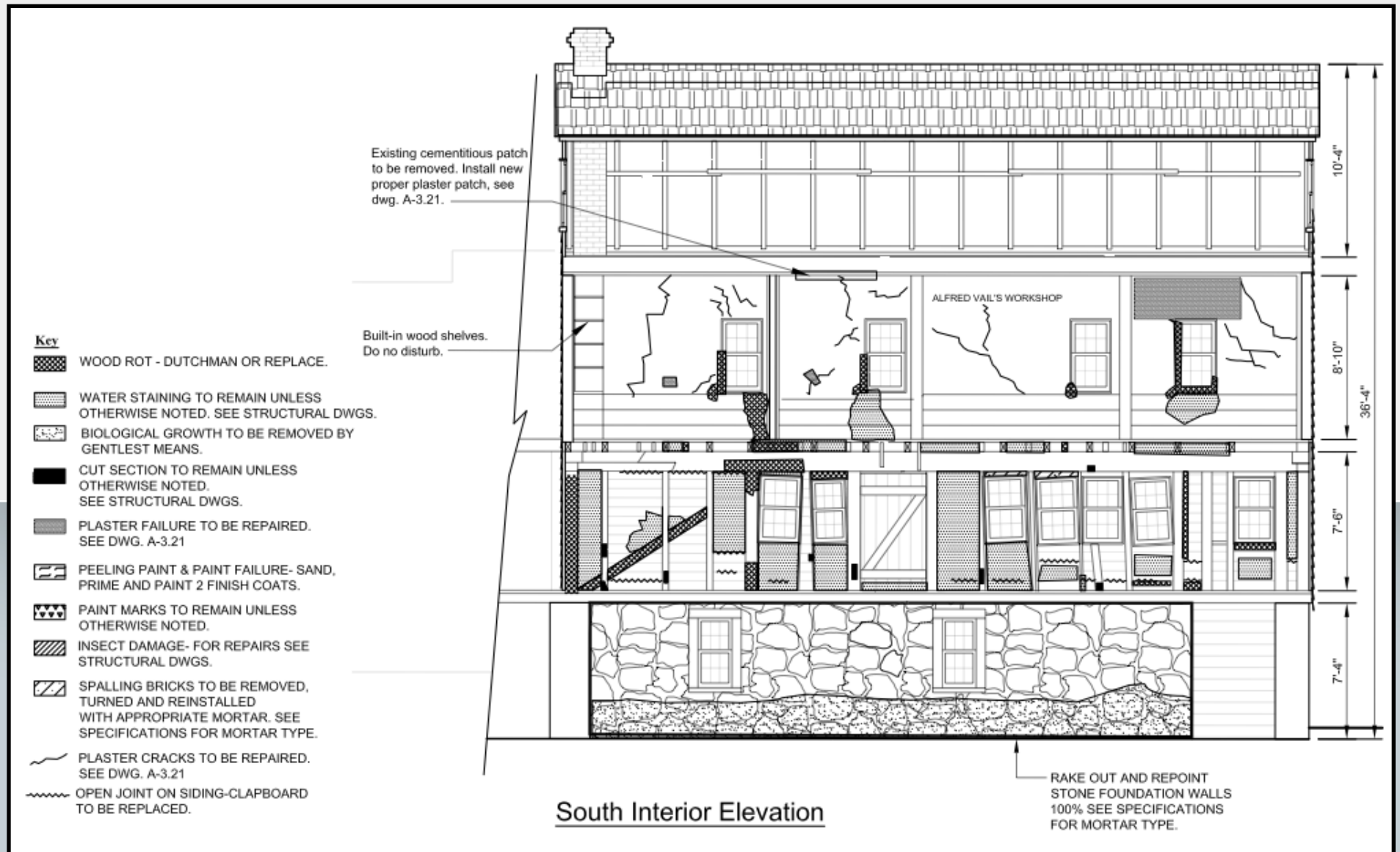




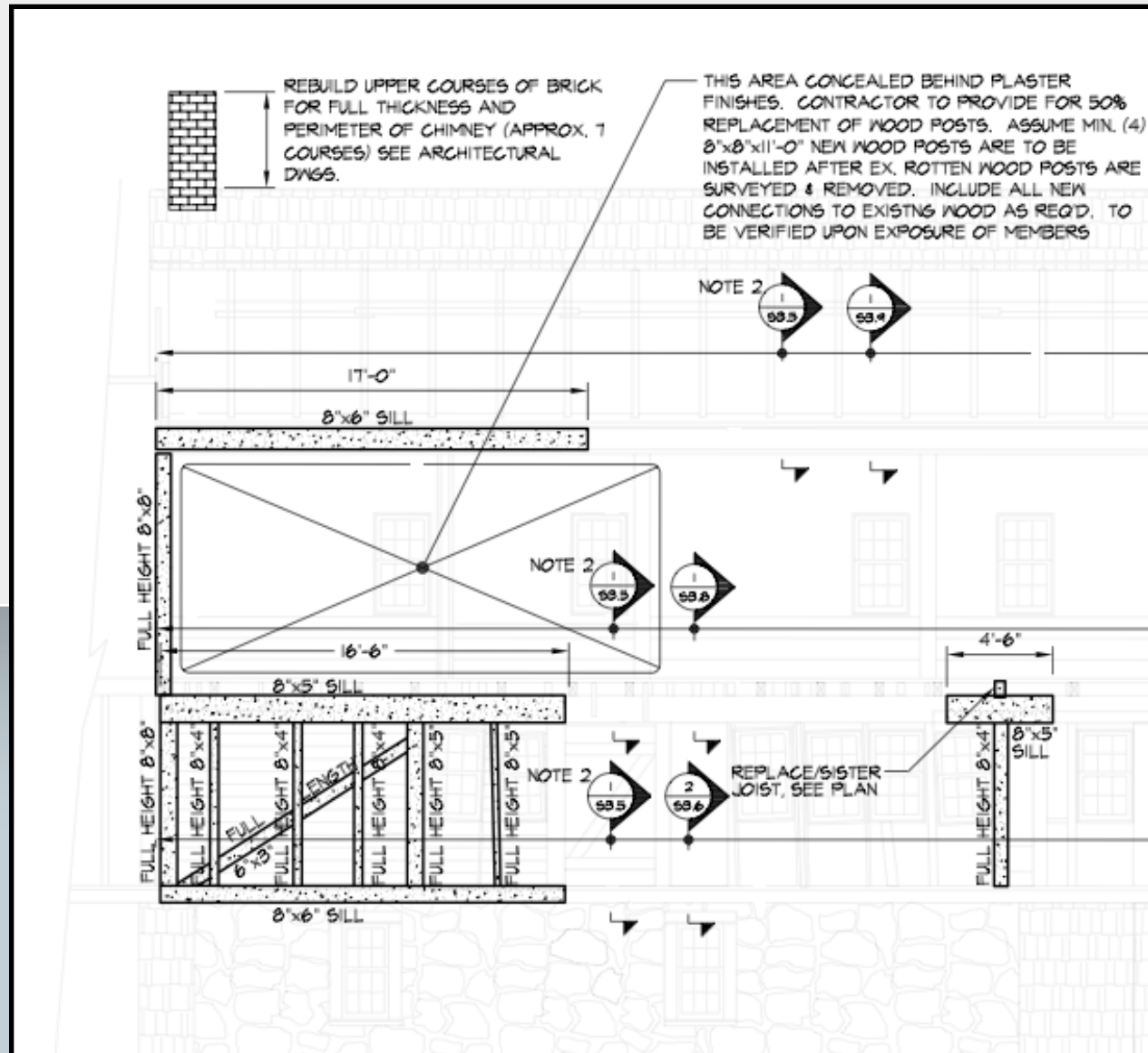
# Defensible Documents - Drawings



# Defensible Documents - Drawings



# Defensible Documents - Drawings





# Defensible Documents - Drawings

extensive hammer marks on interior of sash below latch.

WINDOW NUMBER	SW	GLASS	WOOD REPAIRS	CASEMENT ADJUSTER					LATCH & ESCUTCHEON	HINGES	NOTES		
				R	T	B	N	C				S	
W01	1	0	C	Ok	Ok	Rp	Ok	Rp	Ok	1:Complete	H1:2 S:NA	Weather stripping to remain. Furniture in front of storm window.	MOCK-UP WINDOW W01 Mock-up to include frame, sill and casement.
W02	1	2		Bl	Bl	Rp	Ok	Rp	Rp5	1:Complete	H1:2 S:NA	Window to be made operable, care is to be taken to correct reason for not opening. Weather stripping to remain.	
W03	1	0	C (sill)	Ok	Ok	Rp	Ok	Rp	Rp1	1: L:Ok, E:Ok, S:Rp2	H1:2 S:NA	Window to be made operable, care is to be taken to correct reason for not opening. Weather stripping to remain.	
W05	1	1	C	none					contemporary hook	(2)5 butt w/balls top&bottom. 3S		Remove contemporary hook. replace with historically accurate latch. Review installation w/ Architect in the field.	
W06	1	0	X	Ok	Rp	Ok	Ok	Rp	Rp1	1: L:Ok, E:Ok, S:Rp1.	H1:2 S:NA	Weather stripping to remain. Remove staples from sash & sill.	
W07	1	0	X	New replacement: no provision for cap screw. All flat head screws.					1: L:Ok, E:Ok, S:Rp3.		H1:2 S:Ok	Window to be made operable, care is to be taken to correct reason for not latching properly. Weather stripping to remain.	

**KEY**

- (C) Consolidate rotten wood.
- (D) Replace/dutchman severely rotten wood.
- Replace broken glass.



# Defensible Documents - Drawings

**FIRST FLOOR WINDOWS**

**SPRING LATCH**  
 PHOTO TAKEN AT W101. ALL WINDOWS ARE TO BE MADE OPERATIONAL: UPPER SASH FIXED IN PLACE, LOWER SASH WITH 2 NOTCHES AT RIGHT SIDE AND CUSTOM MADE SPRING LATCHES AT RIGHT SIDE. (AVAILABLE FROM BALL AND BALL 1-800-257-3711 WWW.BALLANDBALL.COM). FOR QUANTITIES SEE A-5.01.

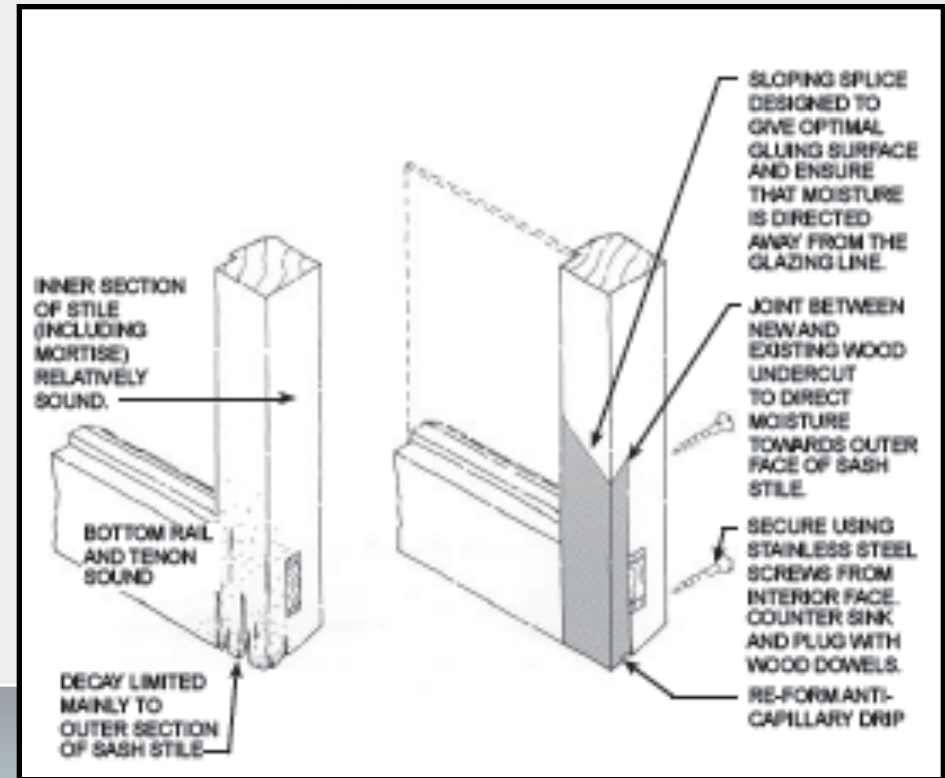
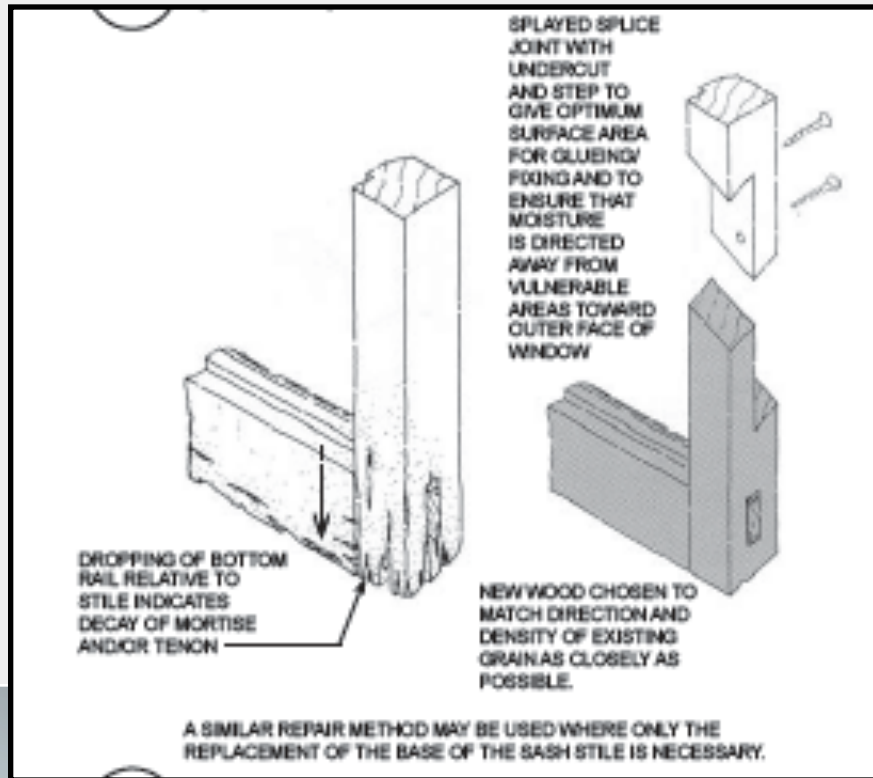
**FOR SPECIFIC WINDOW REPAIRS SEE WINDOW SCHEDULE, DWG A-5.01**

**SECOND FLOOR WINDOWS**

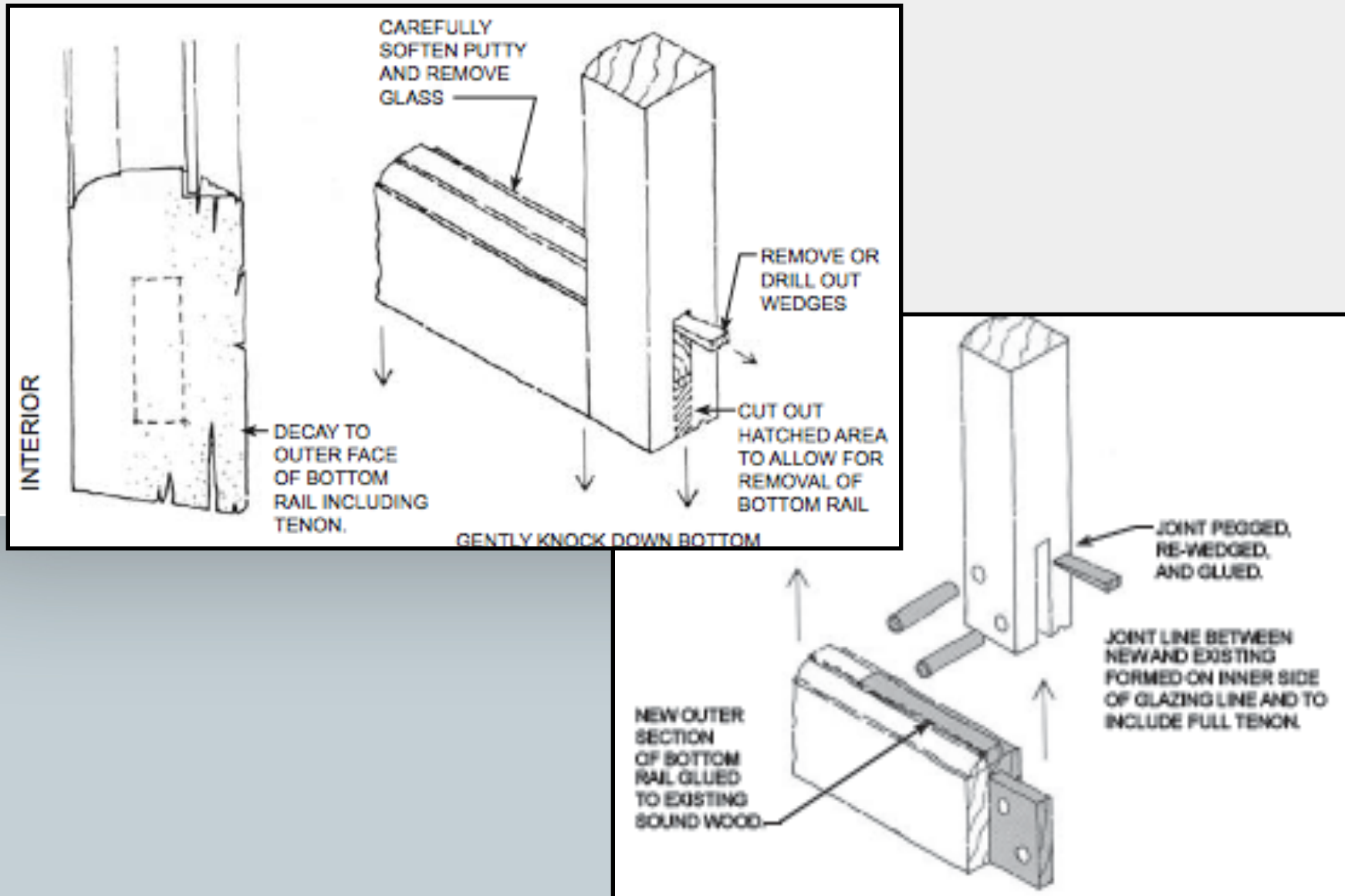
**WINDOW COMPONENTS:**

- ① SILL SUPPORT
- ② EXTERIOR SILL
- ③ INTERIOR SILL
- ④ INTERIOR FRAME
- ⑤ STOPS (RIGHT, LEFT, TOP)
- ⑥ SASH (UPPER AND LOWER)
- ⑦ EXTERIOR TRIM (UPPER SASH "SITS" ON THIS TRIM)
- ⑧ EXTERIOR FACE TRIM
- ⑨ HEAD TRIM
- ⑩ INTERIOR FACE TRIM (RIGHT, LEFT, TOP, BOTTOM)

# Defensible Documents - Drawings

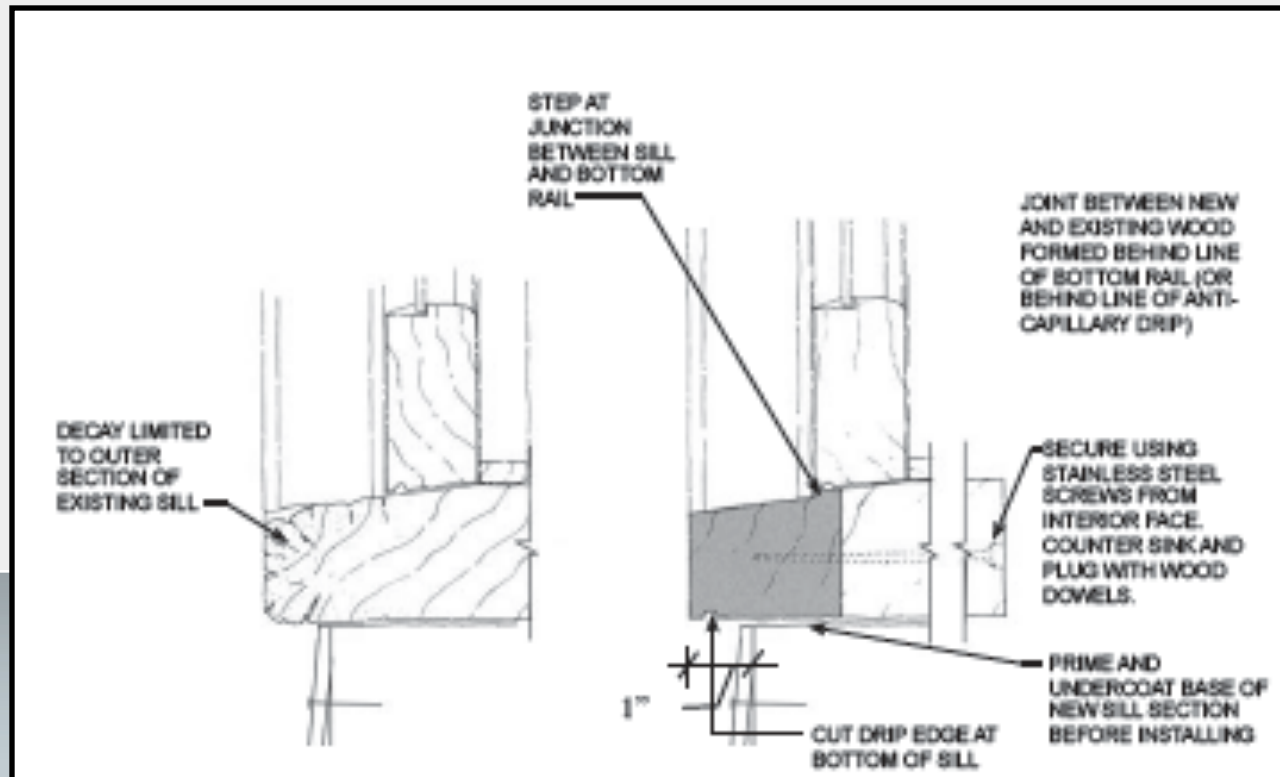


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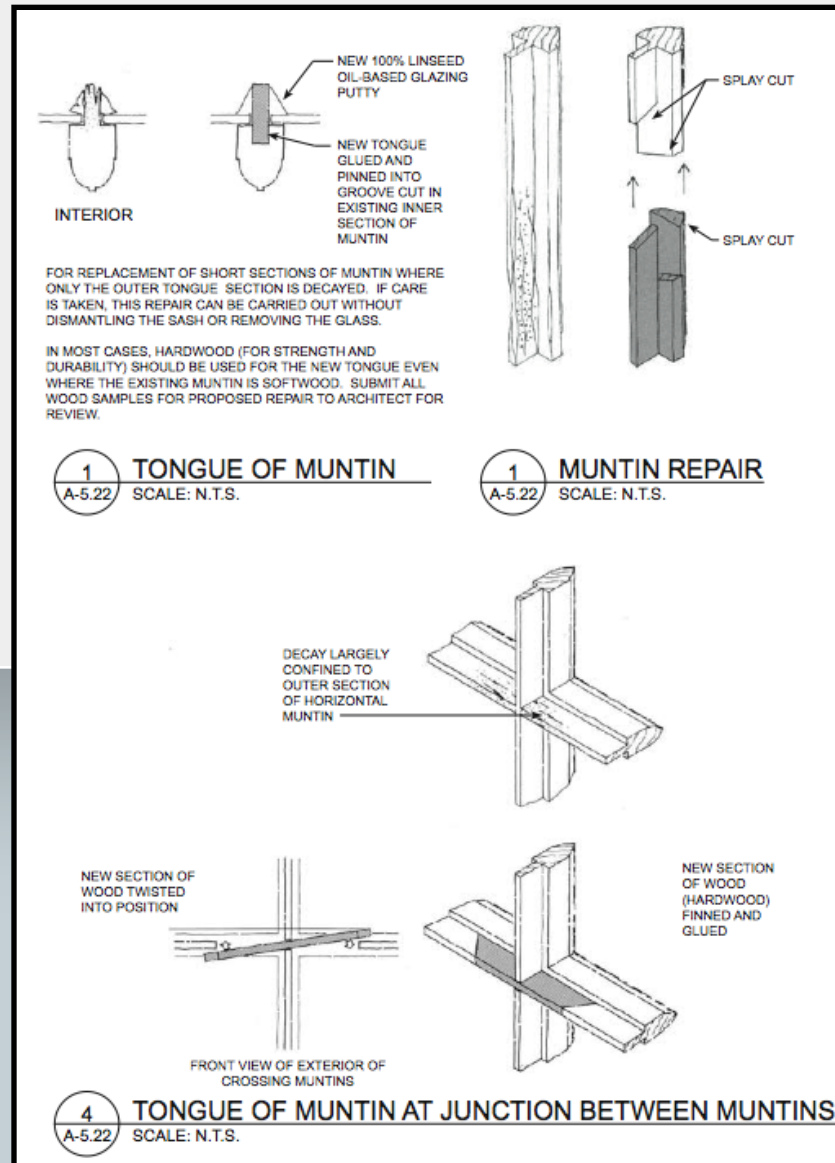




# Defensible Documents - Drawings



# Defensible Documents - Drawings



# Defensible Documents - Drawings

DOOR SCHEDULE								
door #	photos	Location	Size	Hardware				Notes
				lock	latch	hinges	other existing	
D001	A-5.10	South	3'-10"X6'-10"	New Deadbolt	New Exterior Latch and Push Plate	New Butt Hinges	slide bolt: R/R	Rehang door to swing outward. Adjust and rehang screen door at interior. See A-5.41.
D003	NA	Elec. Closet	2'-10"X6'-10"	New Deadbolt	New Latch	New Butt Hinges		
D101	A-5.10	West	2'-11 1/2"X5'10 1/2"	New Deadbolt	New Exterior Latch and Push Plate	C/R butt hinges	Padlock hardware: R/R	Remove existing hardware and repair wood. reinstall with left swing out.
D102	A-5.11	South	4'-1 1/2"X6'	New Slide bolt		C/R painted to match door.		Construct new door similar to existing to fit entire opening. Paint Exterior and edges of door to match clapboard. New sill and blocking for deeper wall covering. See detail A-5.33. Install Plexiglas barrier and hold at W111 sill. See A-5.36.
D103		Closet	2'-1"X5'-11 1/2"				All hardware: R/R	Remove door and closet. Salvage wood. Possibly reuse door as D002.
D201	A-5.11	Stair	3'-5"X6'-4"		C/R	C/R	Padlock hardware: R/R	
D202	A-5.12	Closet	2'-5"X6'-6"	New Deadbolt	New Latch		Hasp and screw eye: R/R	
D203	A-5.12	Wheel	2'-2 3/4"X6'-3 5/8"	none			Slide bolt: install new handle	No other repairs.
D204		Stair (gate)		New padlock				No repairs.

**Hardware repair codes:**  
 C/R clean and reinstall - paint black U.O.N.  
 R/R remove existing hardware, repair door.

**New Hardware** (all to be dark iodized satin finish U.O.N.):  
 Deadbolt (interior and exterior): New BEST lock 83T-7-K-STK-613-2\*\*\*. Keying must be coordinated with MCPC. Confirm door thicknesses before ordering.

**Interior Hardware:**  
 Hinges: Ives Full Mortise 3 knuckle hinges (2 per door).  
 Latch: Ball and Ball X505-B25 Suffolk Latch factory finish.

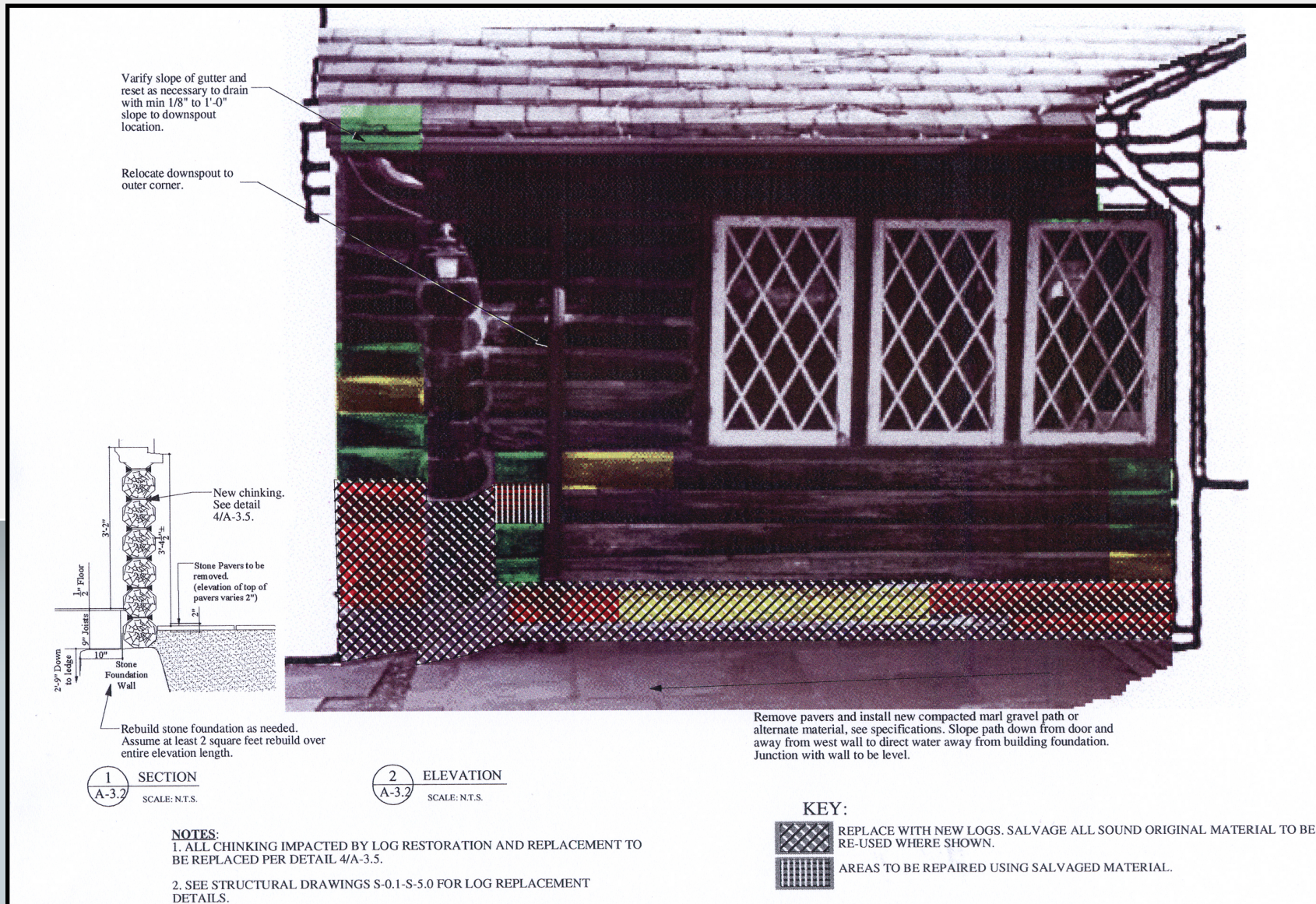
**Exterior Hardware:**  
 Hinges: Ives Spring Hinge 3SP1-613 - 2 per door.  
 Exterior Latch: Ives RL32 roller latch - 2 per door.  
 Push Plate: Crown City Hardware 42c Wrought Iron push plate.  
 Reattach existing pull on exterior-remove all paint and paint flat black. Prepare mockup for architect's review of successful operation of hardware.

NOTE:  
CONSOLIDATE TOP AND BOTTOM EDGES  
OF ALL 3 EXTERIOR DOORS.

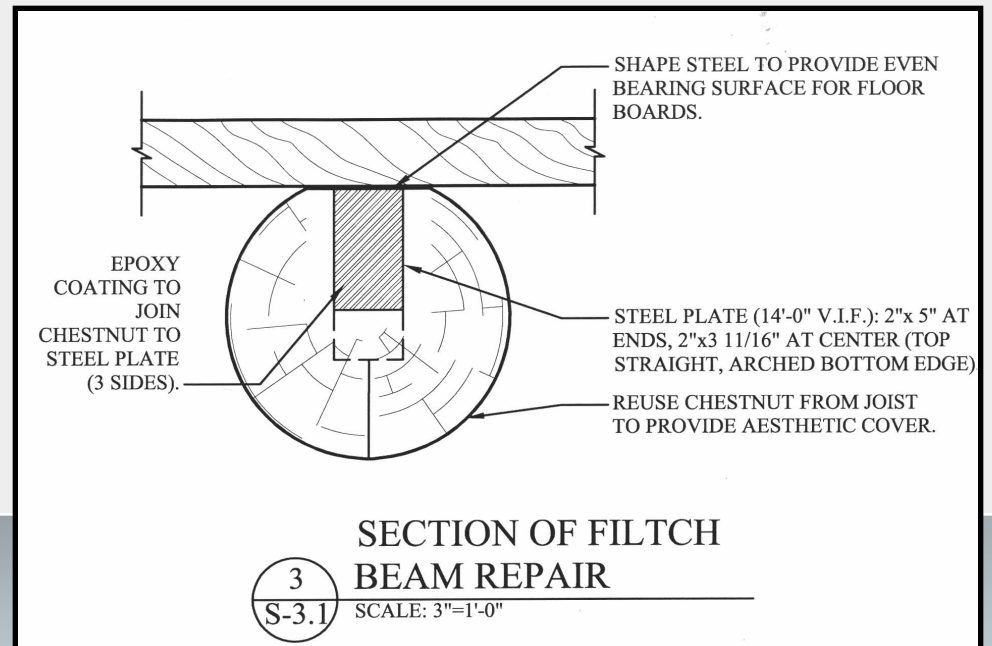
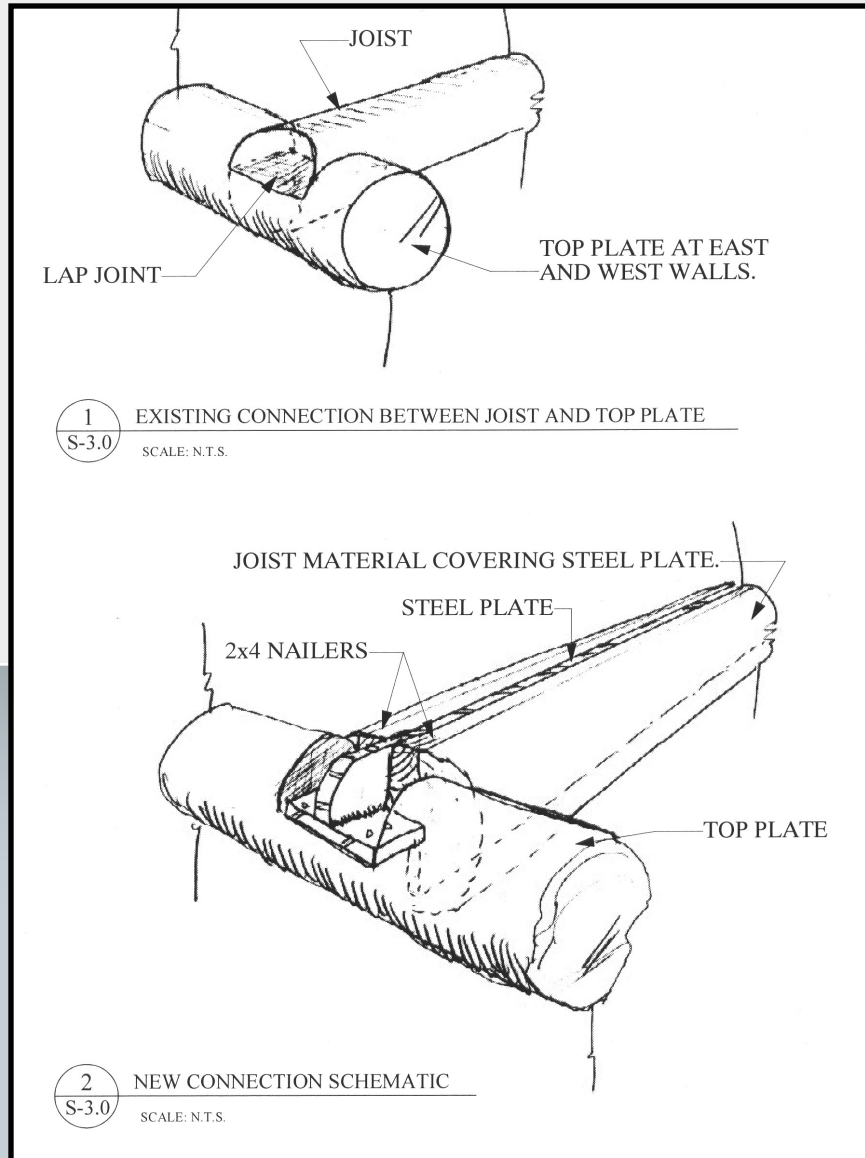




# Defensible Documents - Drawings

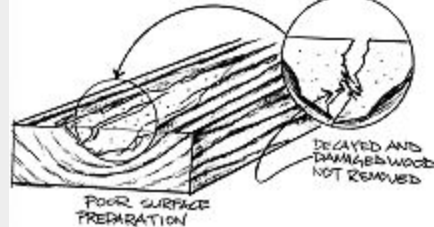
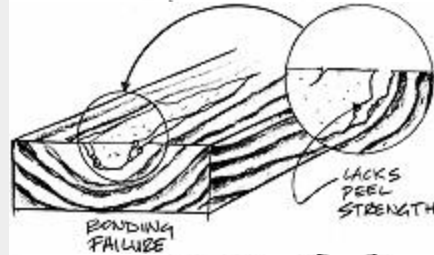
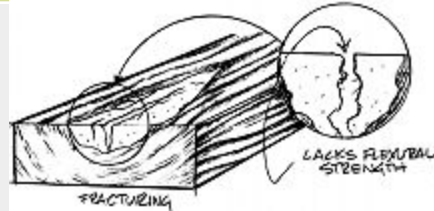


# Defensible Documents - Drawings





# Random Thoughts – Going with the Grain



- **Wood Fillers**
  - Latex (Acrylic), Polyurethane, Epoxy
- **Wood Consolidants**
  - Polyurethane
- **Failure of Wood Repair materials**
  - Bond strength, repair material strength/flexibility, substrate preparation



# Random Thoughts – Going with the Grain



Durra Panel Cross-Section

**POLYSEAL**  
**SOY FOAM INSULATION**  
~saving more than energy~

**The insulation of choice for the educated consumer**

- **New wood materials**
- **Composite wood products**
- **New Directions in Wood – Cellulosic materials**
  - Integrated Biomass Technologies (IBT)
  - Bio-based Resources

# Resources



- Association for Preservation Technology International (<http://www.apti.org/>)
- Japanese Joinery books
- ACS Symposium #845: Wood Deterioration and Preservation: Advances in Our Changing World by [Catherine P. Palmer](#)
- Forest Products Laboratory (<http://www.fpl.fs.fed.us/index.html>)
  - Wood as an Engineering Material. General Technical Report 113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 463 p.
- Wood Work Institute (<http://www.wicnet.org/>)
- Woodweb (<http://www.woodweb.com/>)
- APA – The Engineered Wood Association (<http://www.apawood.org/>)
- USDA Bio-Preferred Catalog (<http://www.biopreferred.gov/>)



## Special Thanks To:



- **Annabelle Radcliffe-Trenner, Historic Building Architects, NJ**
- **Ron “The Wood Guy” Anthony, Anthony Associates, CO**
- **Jose “Pepe” Izquierdo-Encarnacion, PE, FACI, Puerto Rico**
- **Francisco Gutierrez, Master Carpenter, Puerto Rico**





Thank You!

# Pathology of Wood: Working With Nature



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San Juan, Puerto Rico



# Presentation Outline

- 1. Material Characteristics**
- 2. Defects in Wood**
- 3. Modes of Deterioration**
- 4. Non-Destructive Testing and Detection methods**
- 5. Repair techniques**
- 6. Contract Documentation**
  - Specifications
  - Drawings
- 7. Resources**

# Characteristics of Wood



- **The Basics**
  - Organic
  - Variability in color, density, strength, porosity, etc.
  - Rate of deterioration varies, even amongst the same species



# Characteristics of Wood



**1620**



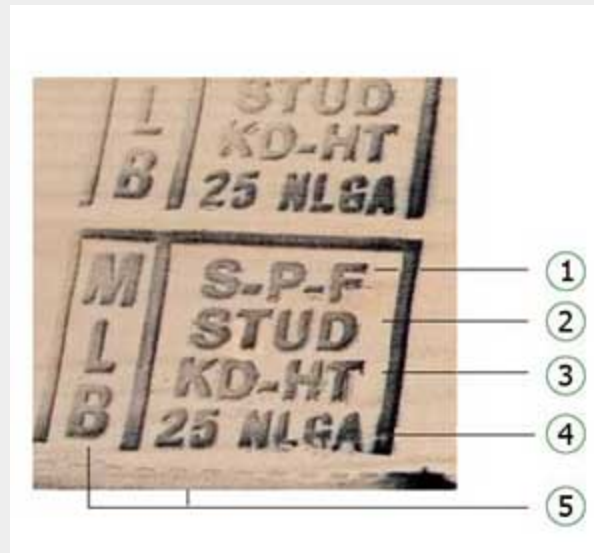
**1850**



**1990**

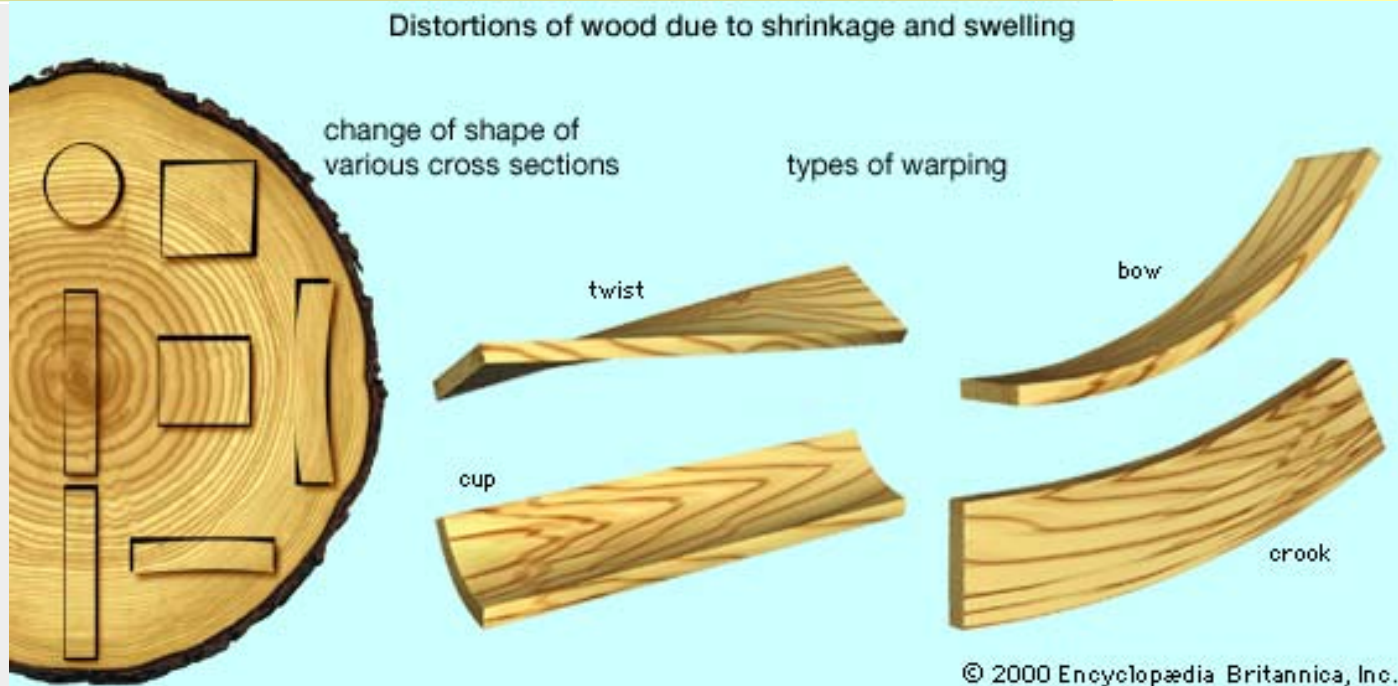
- **Old Growth Forests**
  - What old growth forests?
  - What's the difference?

# Characteristics of Wood



- **Design strength of wood is effected by:**
  - Species
  - Grade (number of defects allowed)
  - Use (indoor vs. outdoor)
  - Direction of loading (radial, tangential, longitudinal)
  - Type of Load (compression vs. tension – or both)
  - Moisture Content

# Failure of Wood Materials



- **Natural defects in milled wood**

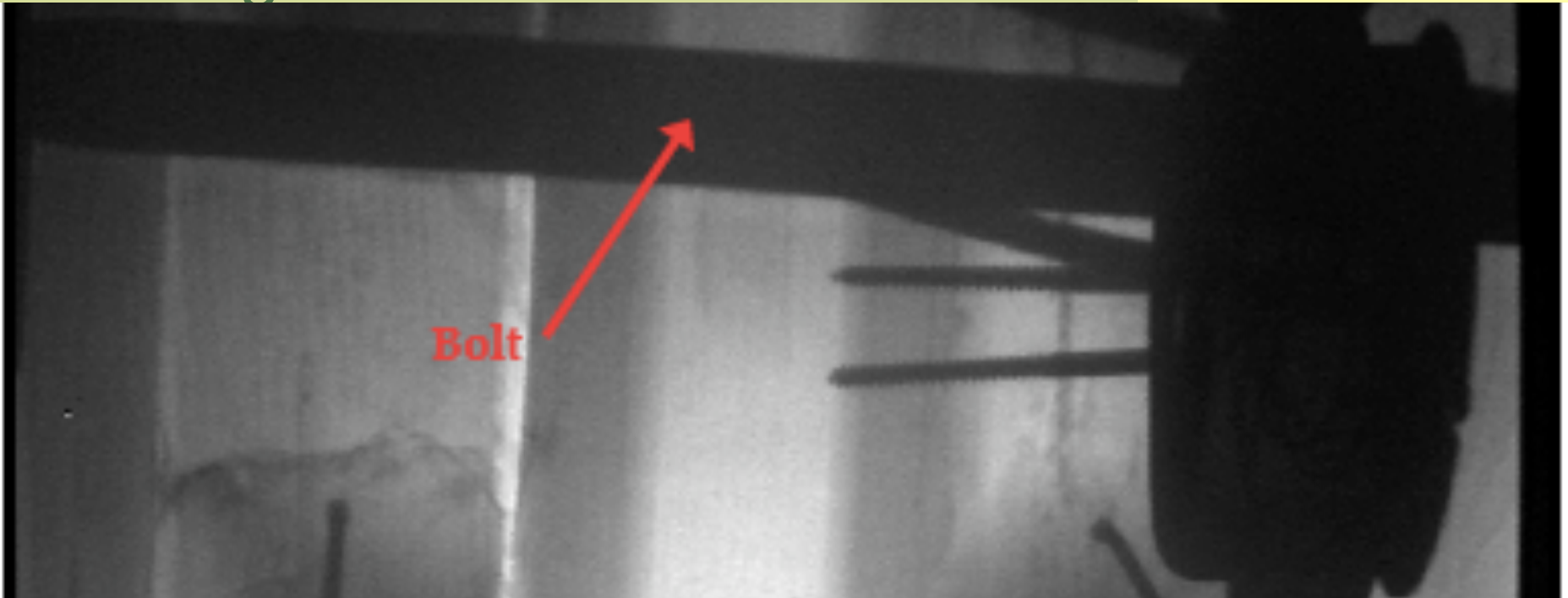
- Warping
- Splits
- Checks
- Knots
- Etc...



# Failure of Wood Materials

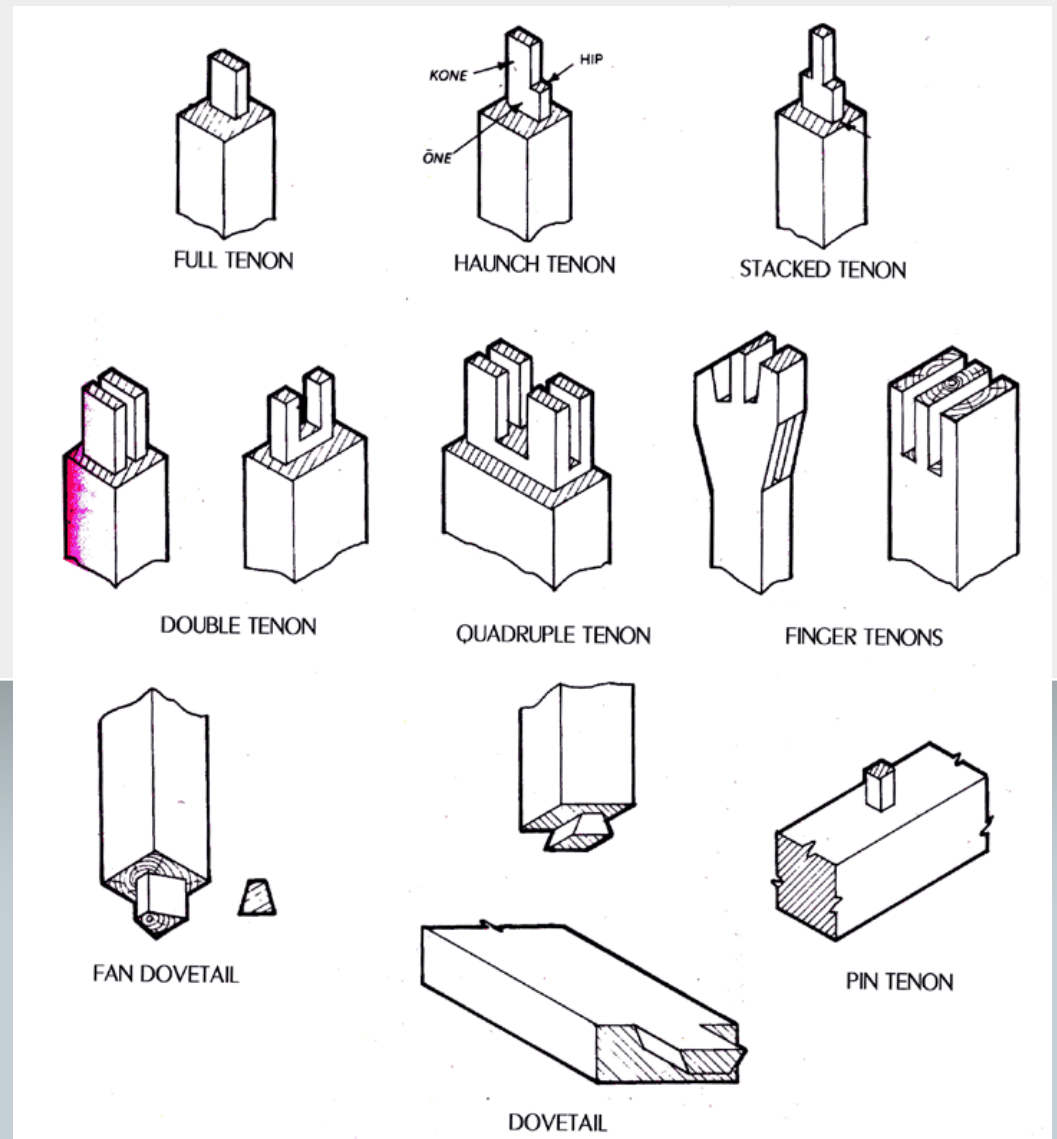
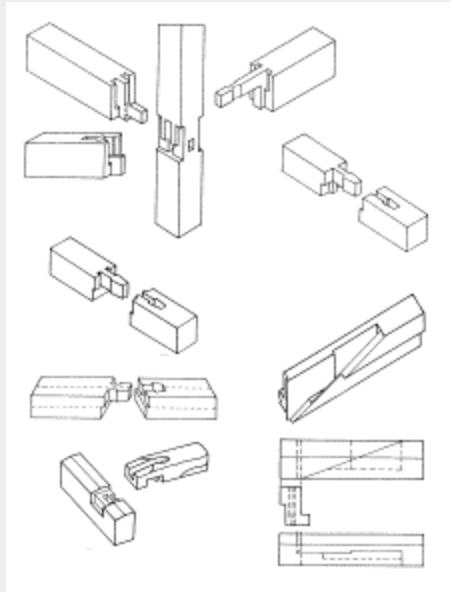


# Investigation of Wood Deterioration



- **Non-Destructive Testing and Detection methods**
  - Radiography

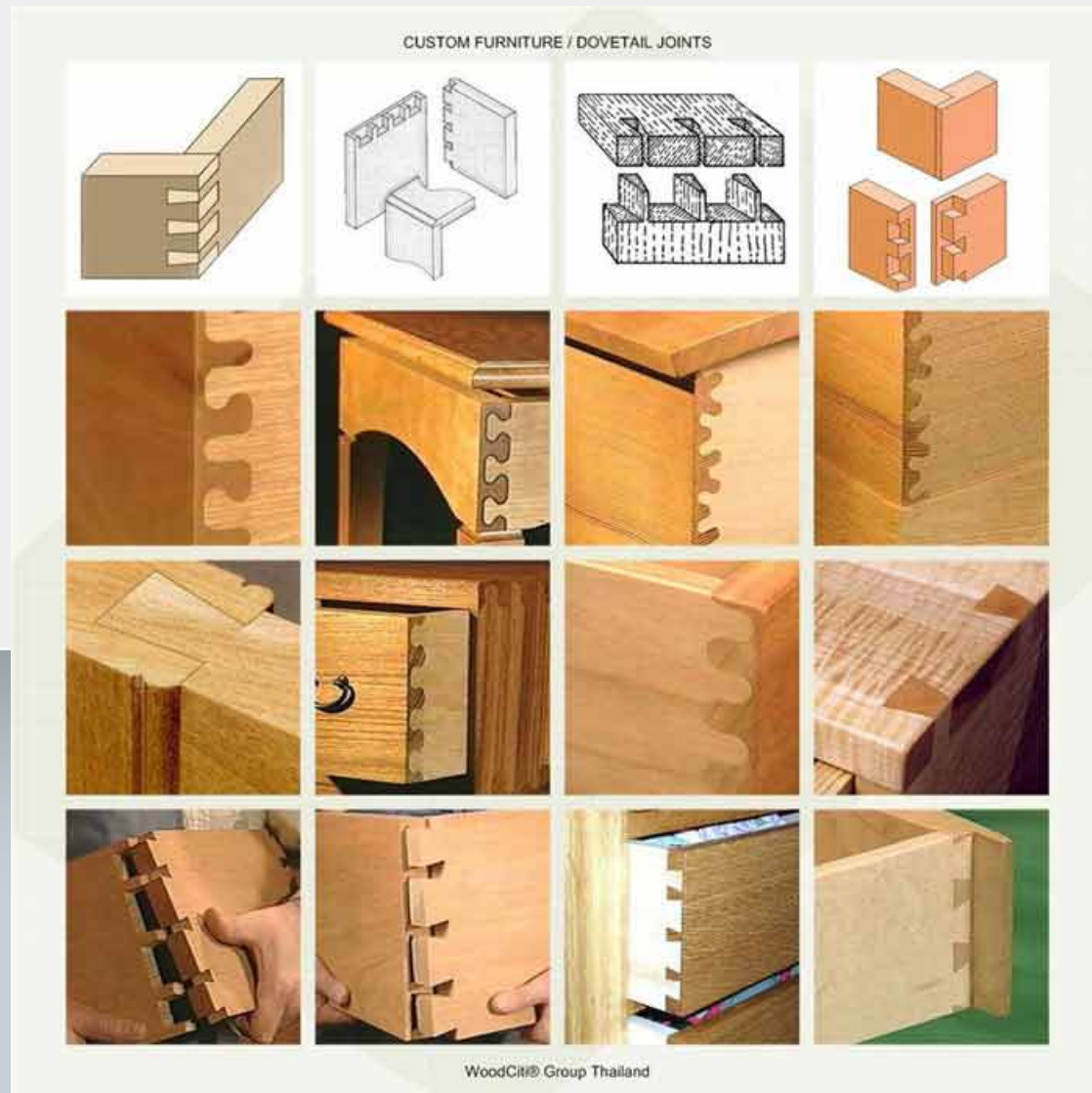
# Defensible Documents - Drawings



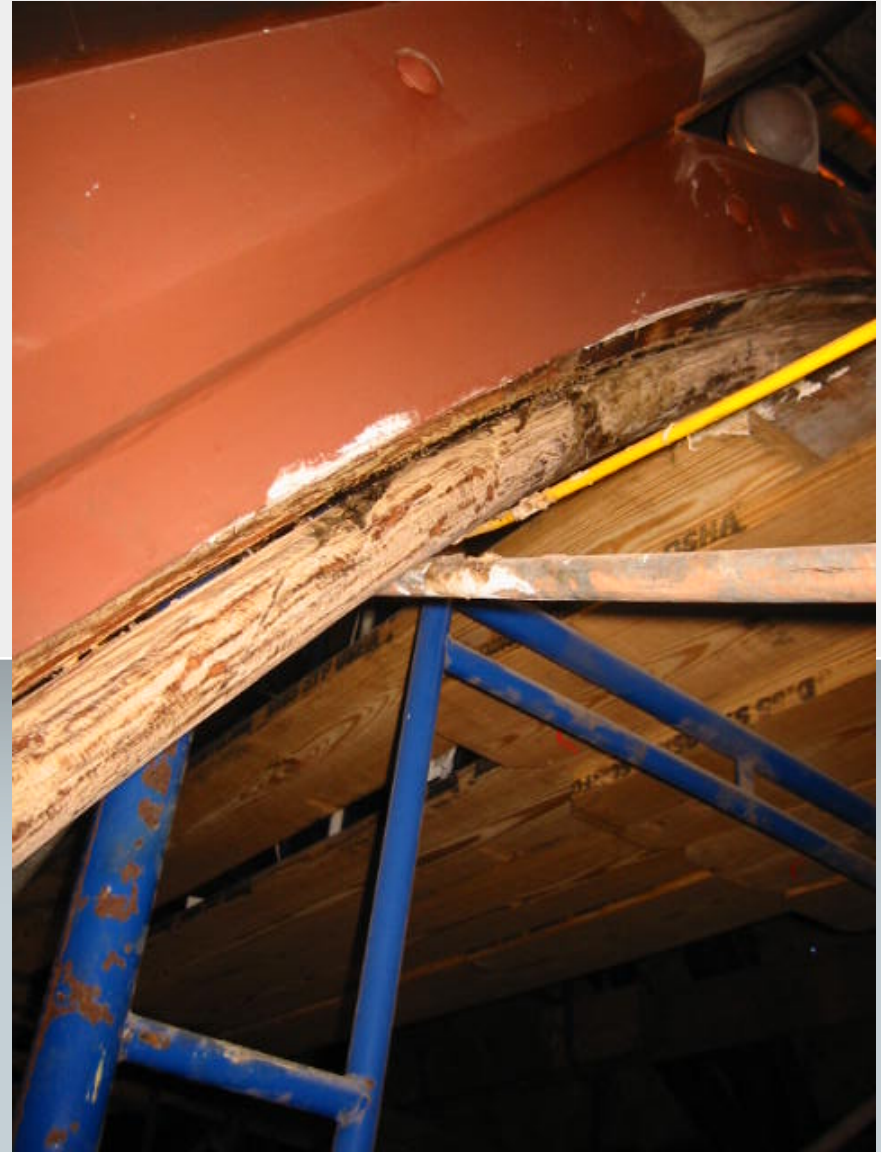
- Wood Joint Designs



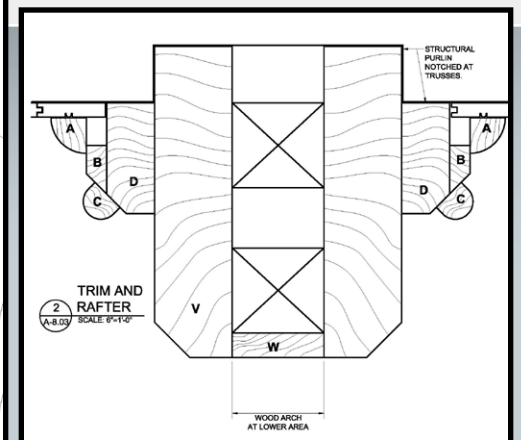
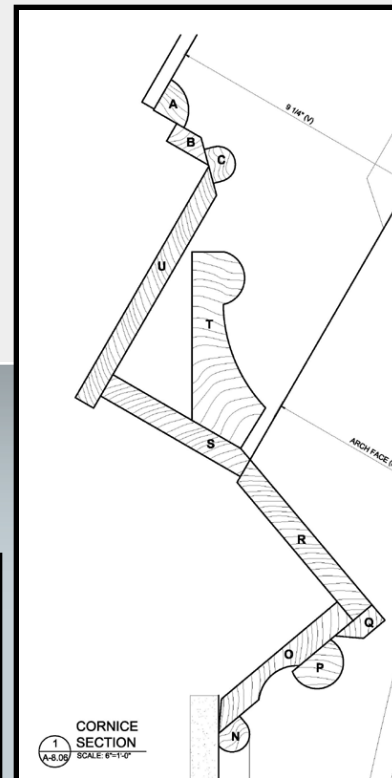
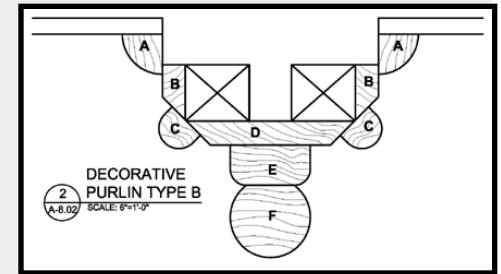
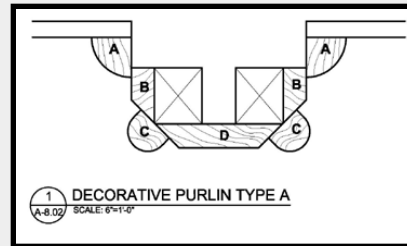
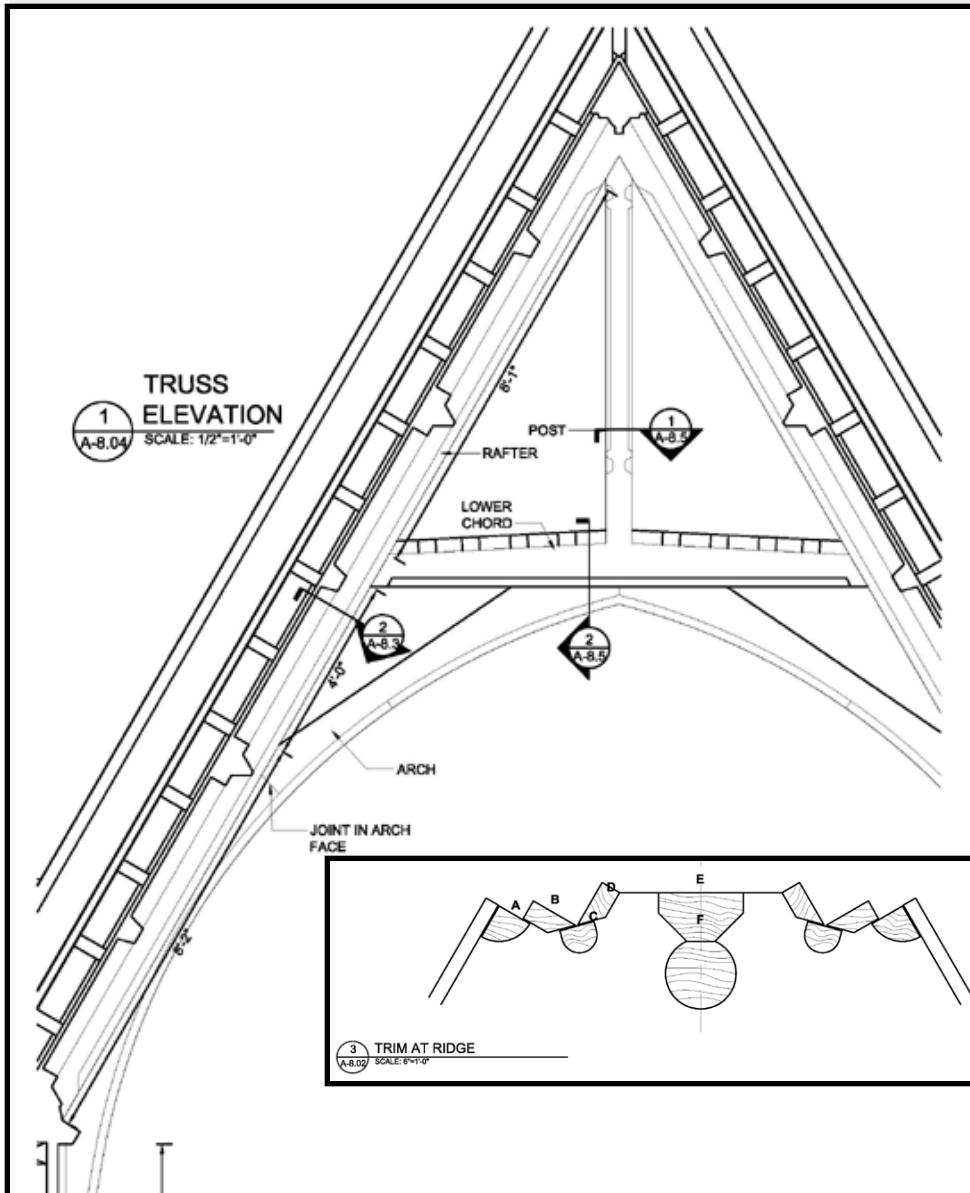
# Defensible Documents - Drawings



# Defensible Documents - Drawings

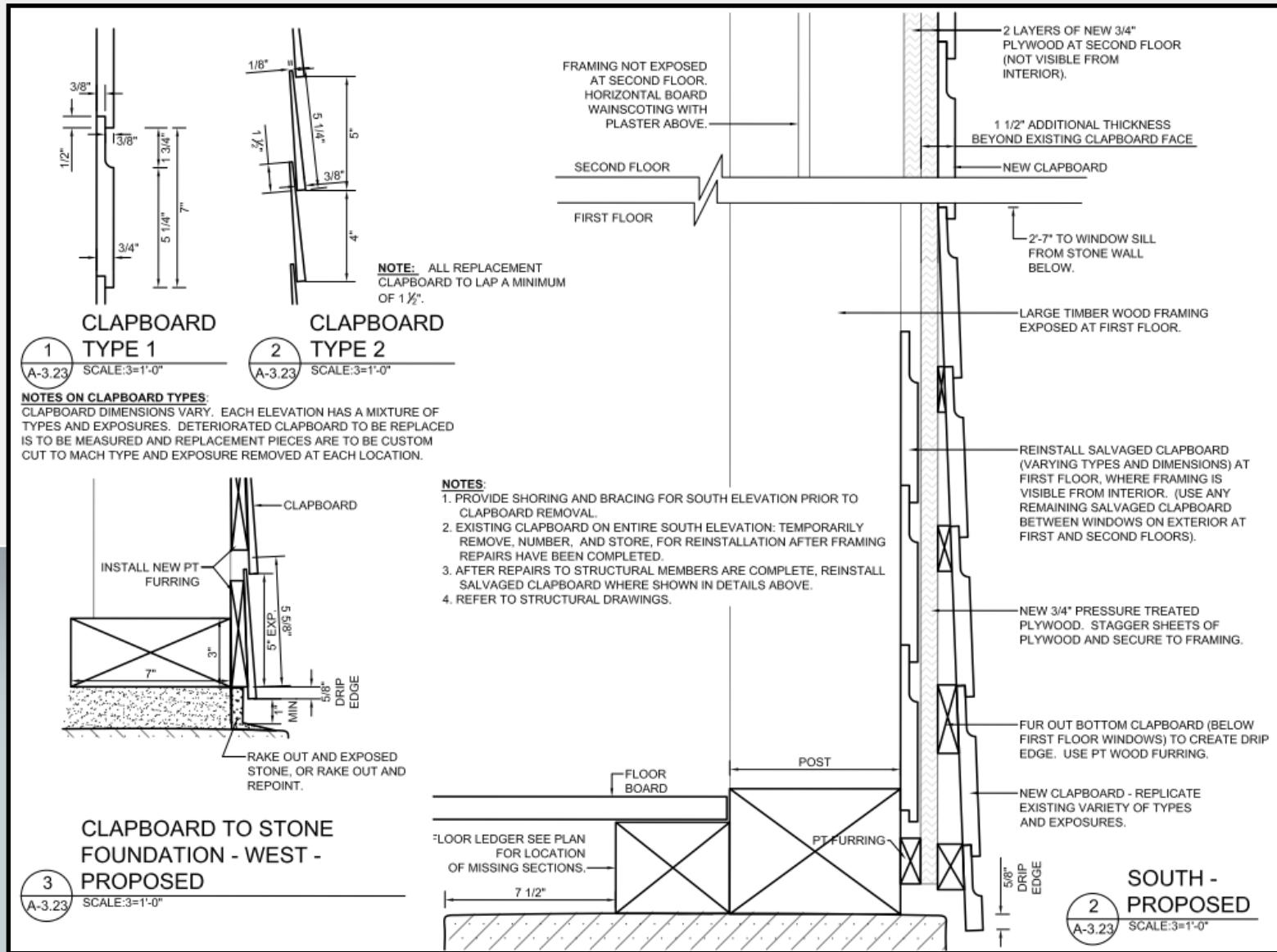


# Defensible Documents - Drawings

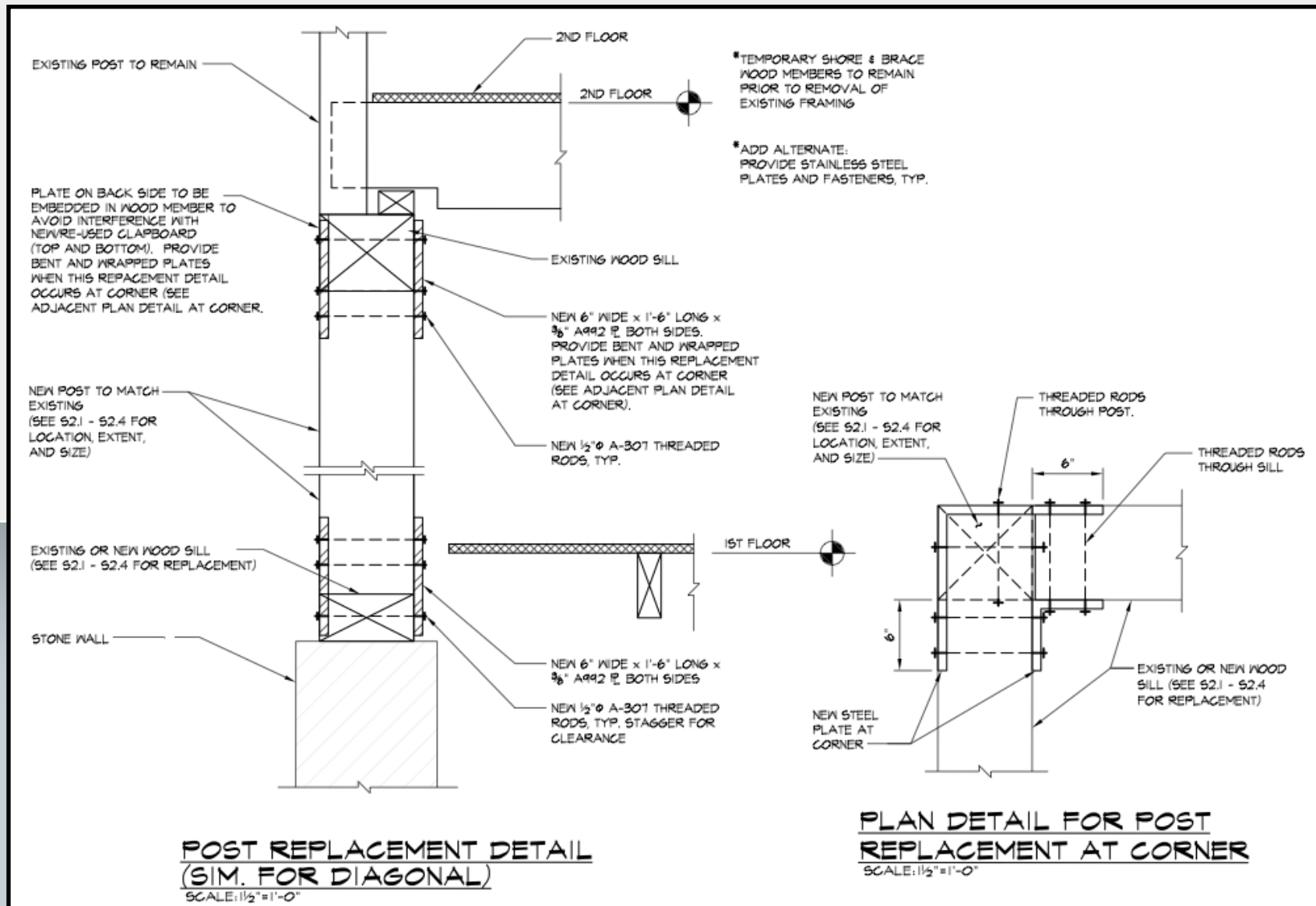




# Defensible Documents - Drawings



# Defensible Documents - Drawings

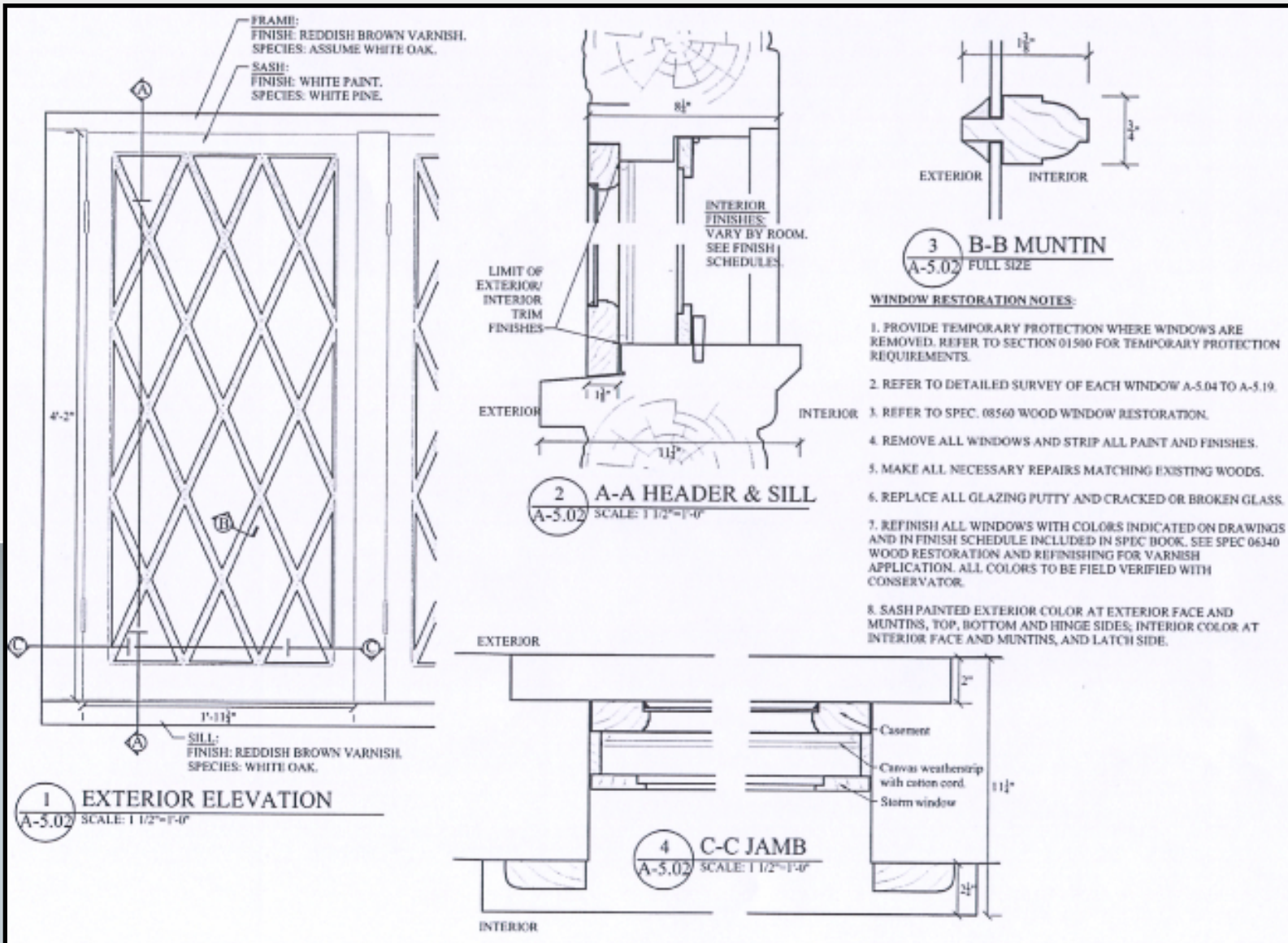


# Defensible Documents - Drawings

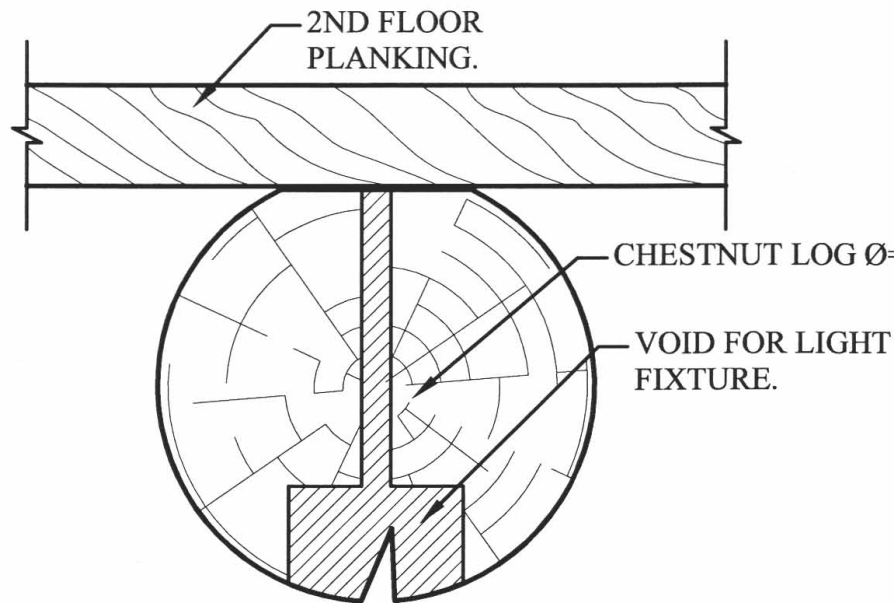




# Defensible Documents - Drawings



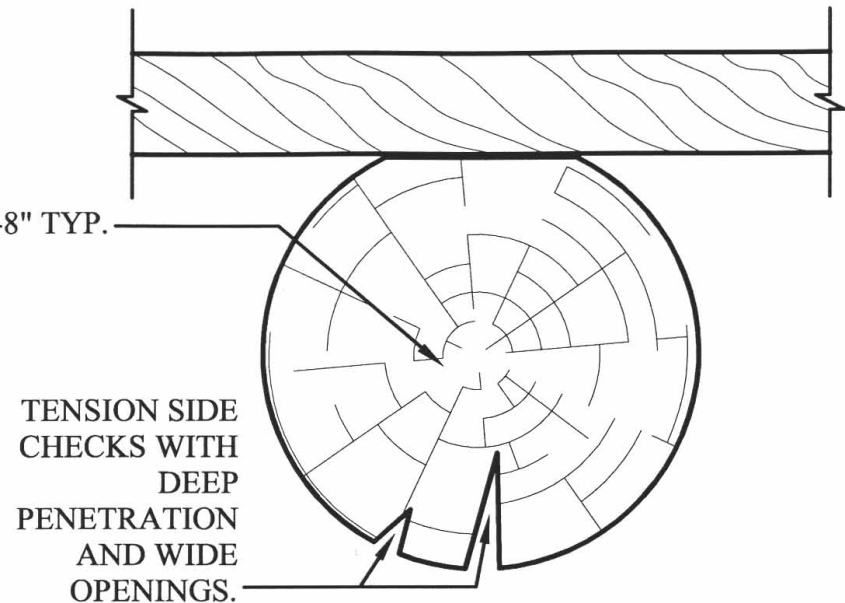
# Defensible Documents - Drawings



1 TYP. EXISTING CONDITION  
AT LIGHT FIXTURE

S-3.1

SCALE: N.T.S.



2 TYP. EXISTING CONDITION  
NOT AT LIGHT FIXTURE

S-3.1

SCALE: N.T.S.



# Defensible Documents - Drawings

