

Timber Structures

Inspection and Maintenance planning of timber structures concerning climate change implementing Reinforcement Learning

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Timber

Timeless
Architectural Aesthetic
Long-term Durability
Strength

A vertical, close-up photograph of a piece of weathered wood. The wood has a dark, textured surface with numerous small, dark, irregular holes and indentations, likely caused by insect activity or decay. The wood grain is visible, showing a vertical orientation. The lighting is dramatic, with strong shadows and highlights that emphasize the texture and damage.

Timber

“Hygroscopic Material”

Sensitive to the environmental factors:

Temperature, Moisture, Light

Susceptible to biological factors:

Fungi, insects

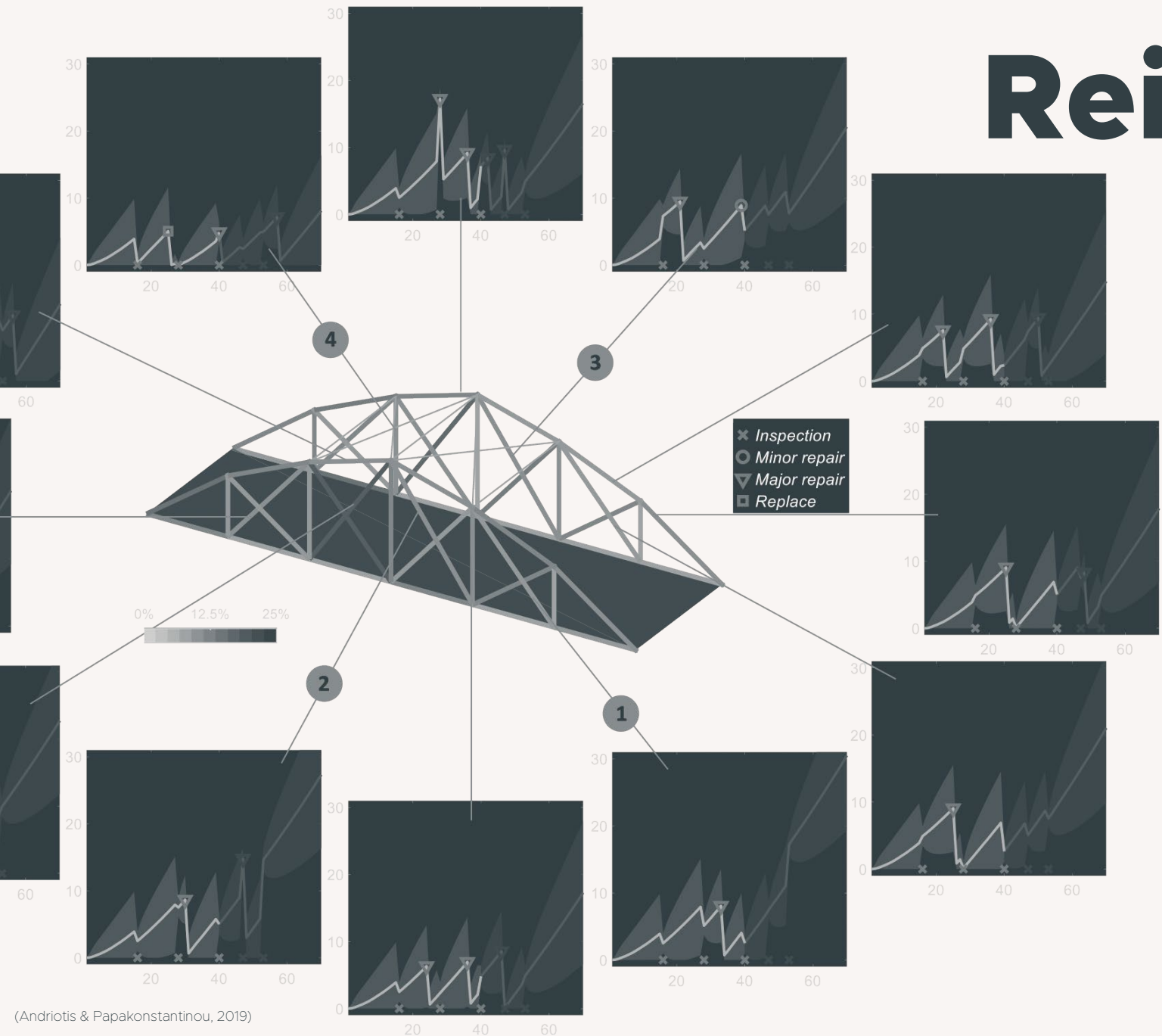
Decay over time



Climate Change

Dynamic change in:
Temperature
Moisture
Precipitation

Reinforcement Learning

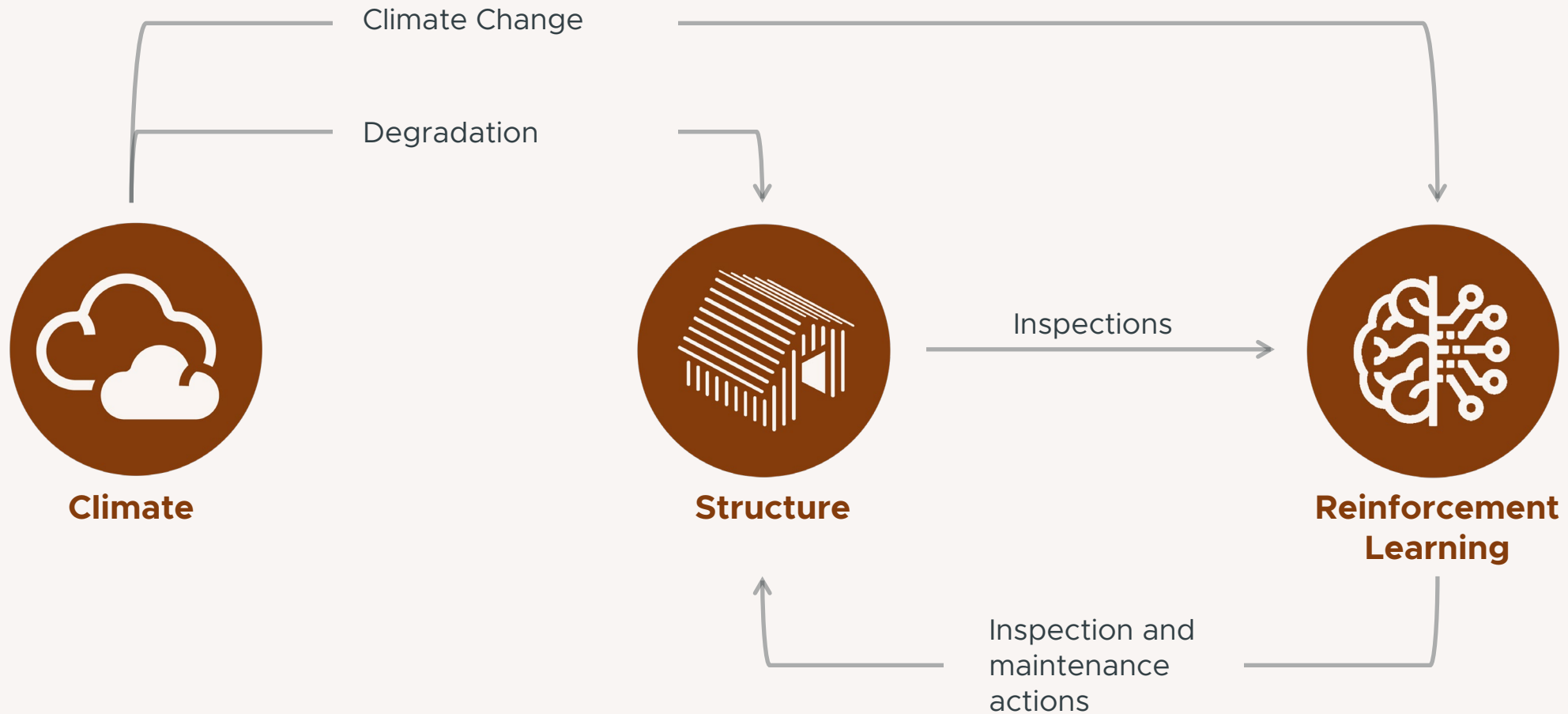


Shows the positive results in the large engineering infrastructure inspection and maintenance

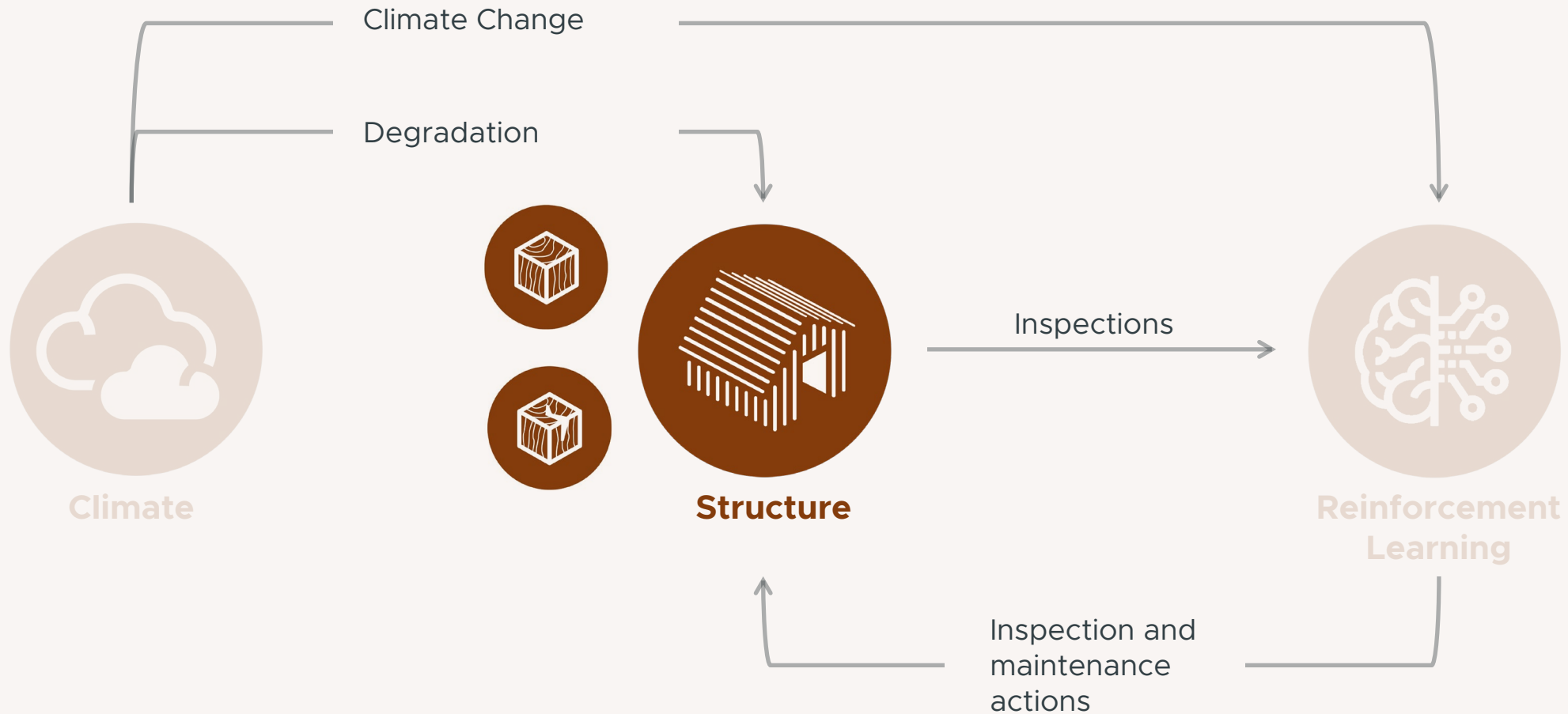
Research Questions

“How can reinforcement learning consider climate change effects to inform inspection and maintenance for timber structures?”

Framework dynamic policy under climate change

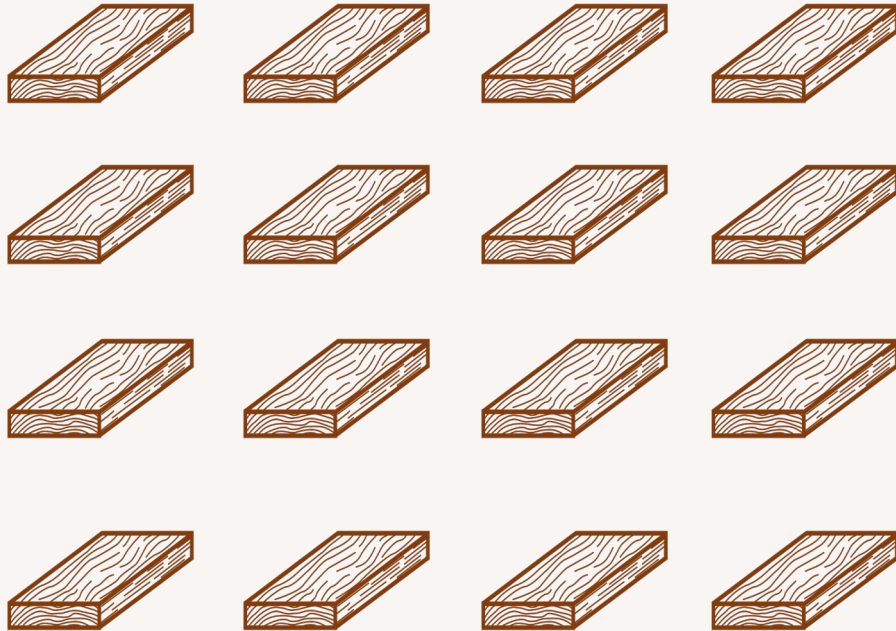


Framework dynamic policy under climate change

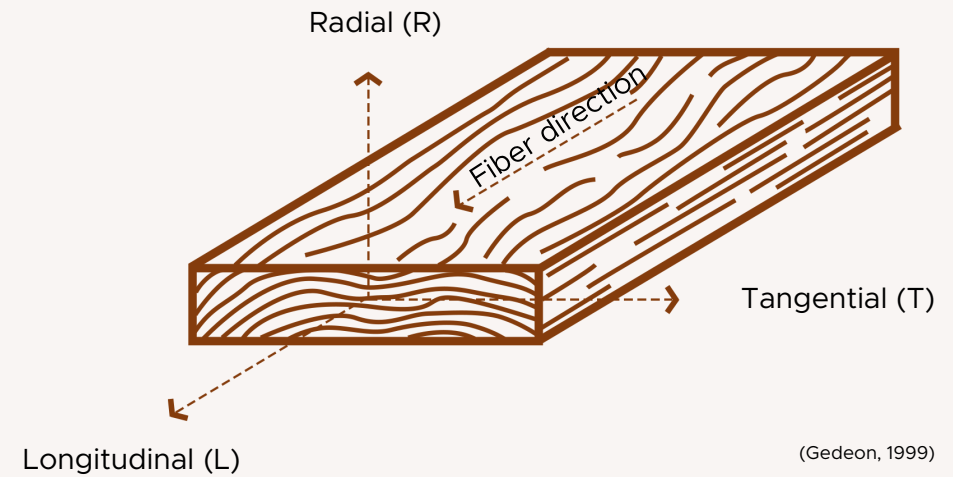


Timber Properties

Strength



Wood Species



Fiber Directions

Timber Properties

Factors that impact timber deterioration



Chemical and physical agents

Weathering:

- UV radiation
- Temperature
- Moisture & Humidity
- Rainwater

Fire



Biologic Degradation

Fungi

Insects



Degradation through time

Damage accumulation effect
(Duration of Load effect: DOL)

Chemical changes in wood
cells (Wood aging)

Timber Properties

Factors that impact timber deterioration



Relative Humidity



Temperature



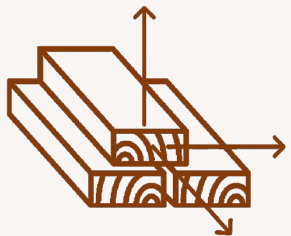
UV Radiation



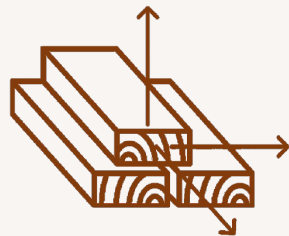
Fungi growth



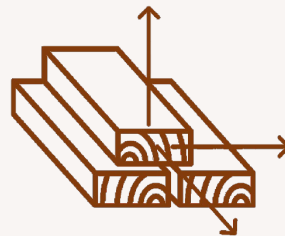
Time



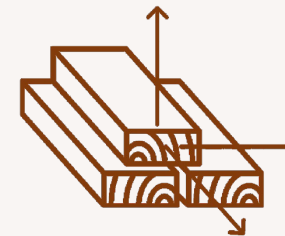
Wood Strength



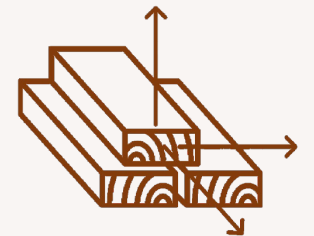
Wood Strength



Wood Strength



Wood Strength

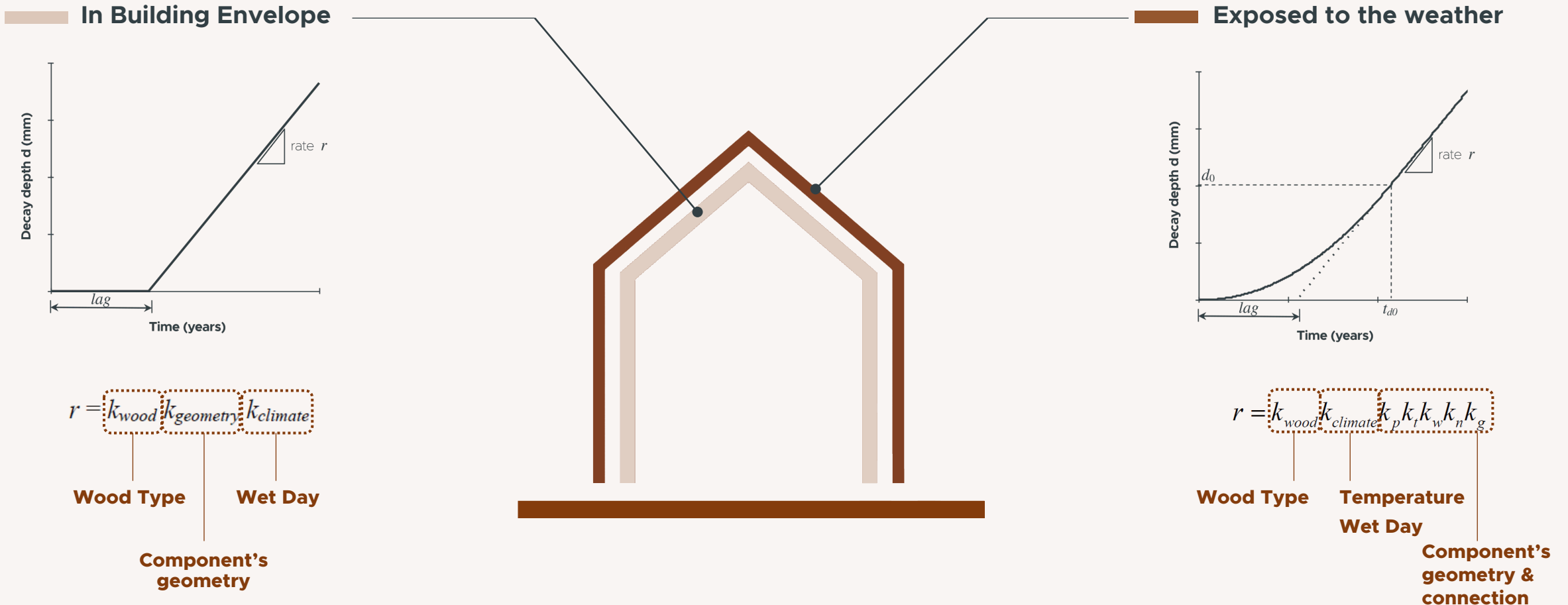


Wood Strength

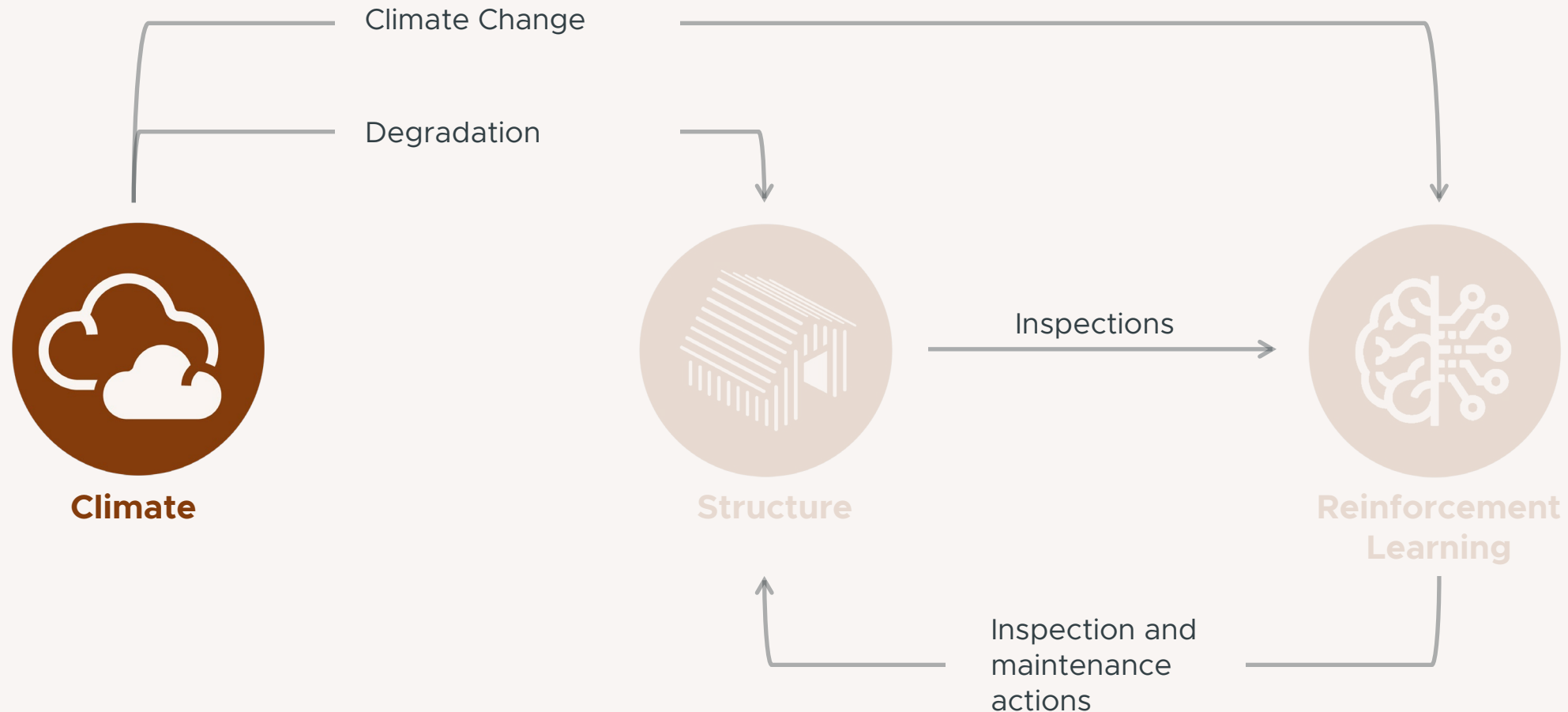


Timber Deterioration

Decay Fungi

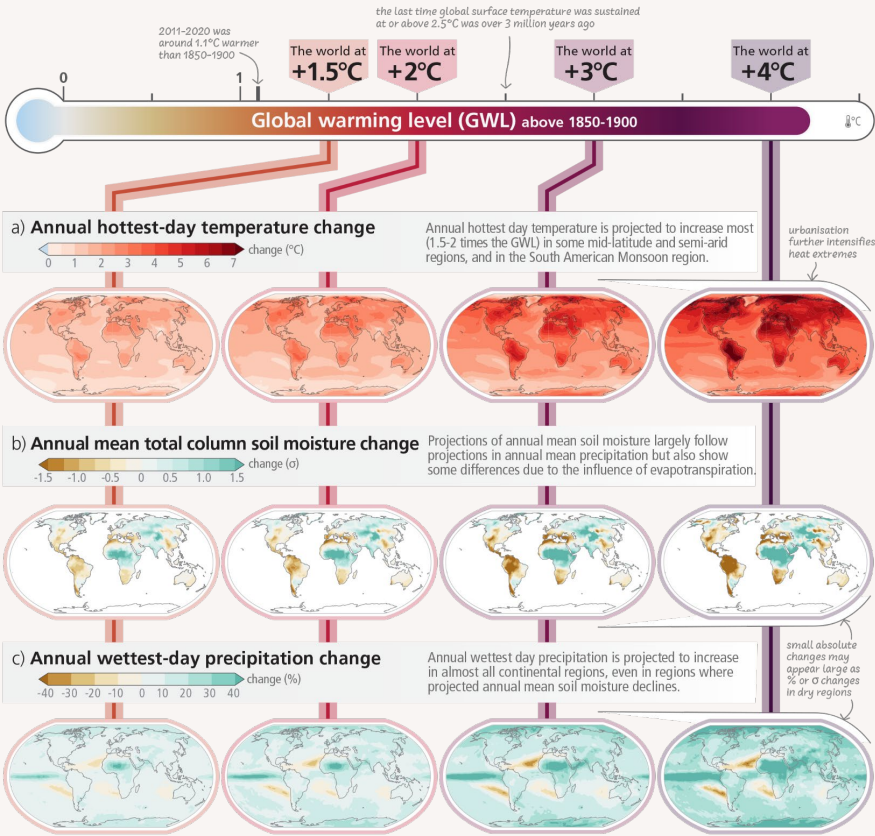
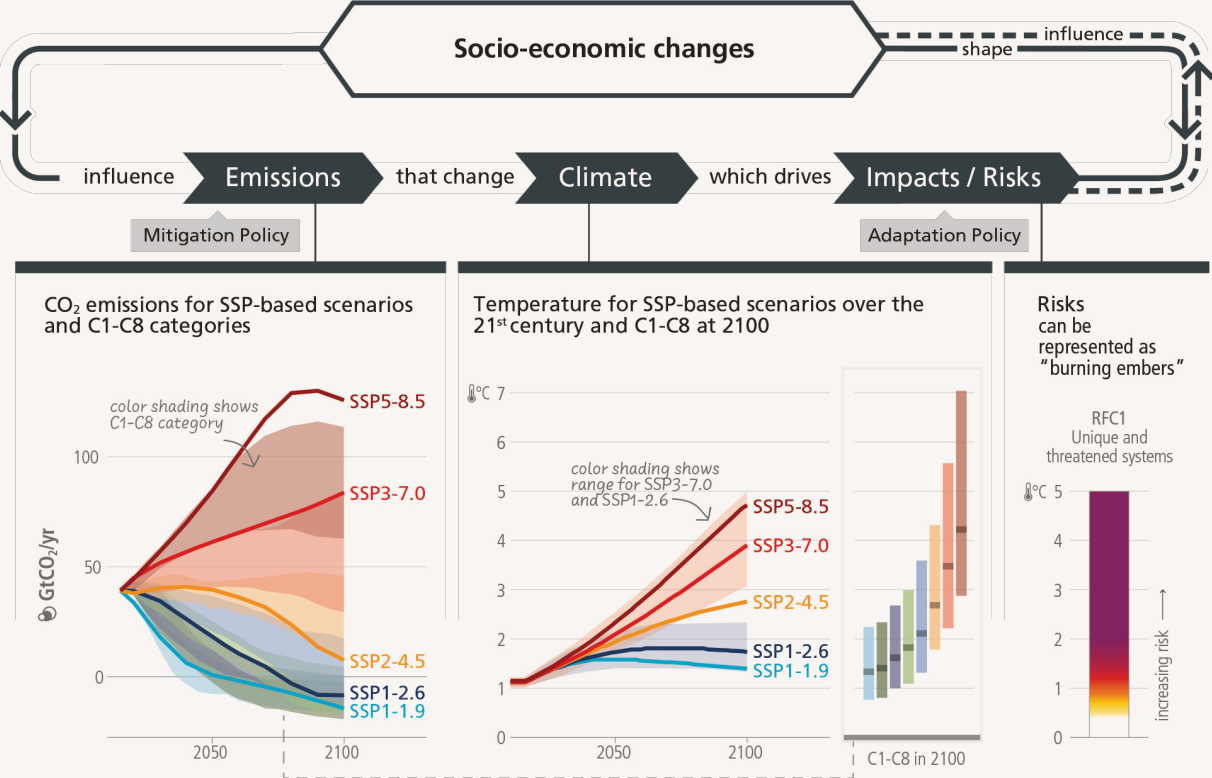


Framework dynamic policy under climate change



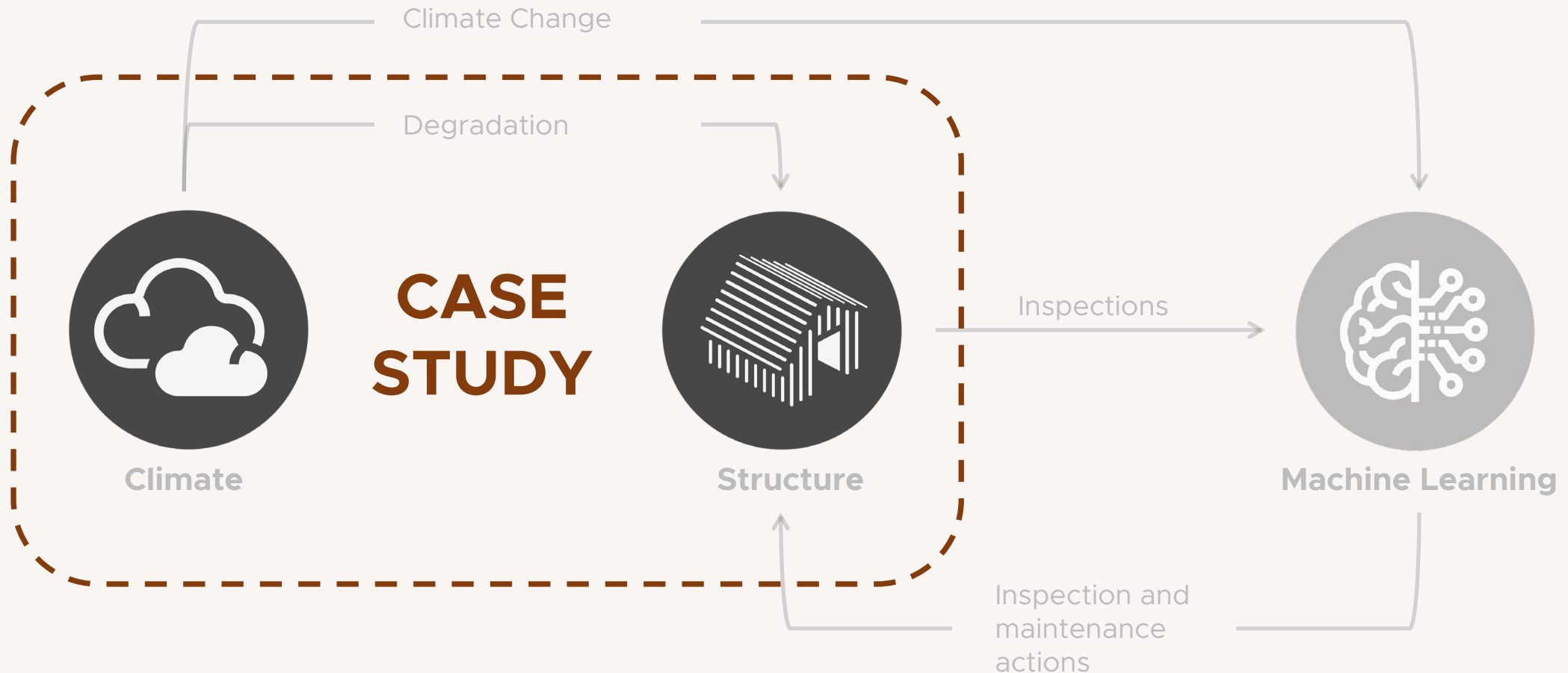
Climate Change

Climate scenarios



(IPCC, 2023a)

Framework dynamic policy under climate change





Case Study

Toshodai-ji Temple Kondo (Golden Hall): 8th century (1244 years)



Case Study

Toshodai-ji Temple Kondo (Golden Hall): location



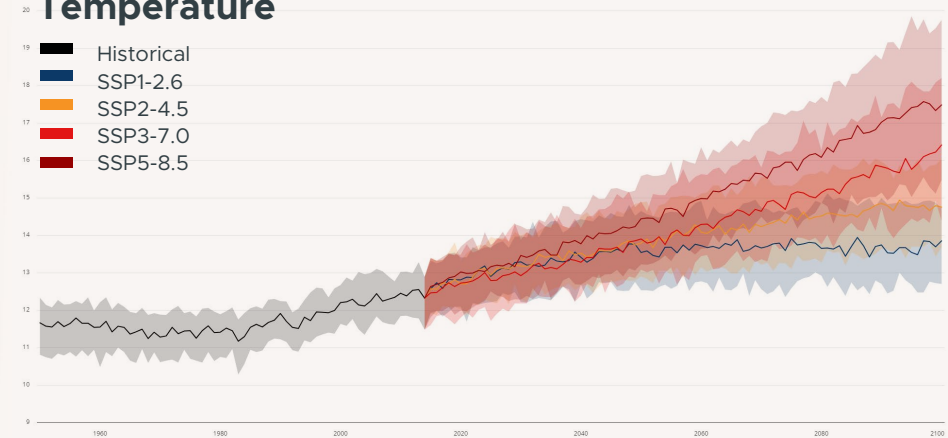
Case Study

Toshodai-ji Temple Kondo (Golden Hall): climate data

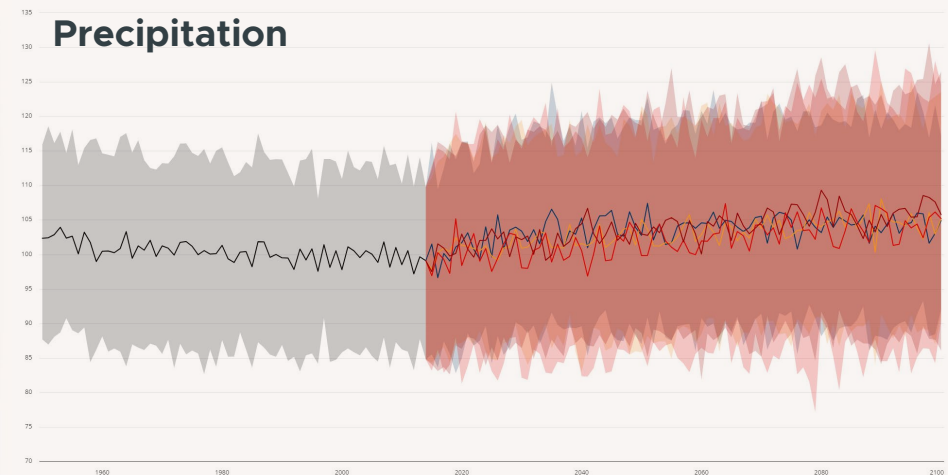


Temperature

Historical
SSP1-2.6
SSP2-4.5
SSP3-7.0
SSP5-8.5



Precipitation



Case Study

Toshodai-ji Temple Kondo (Golden Hall): wood type



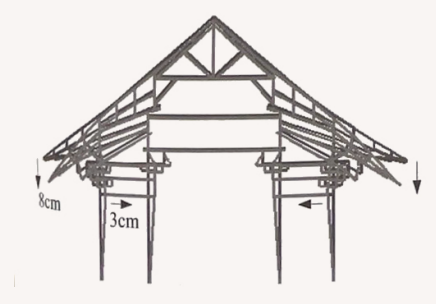
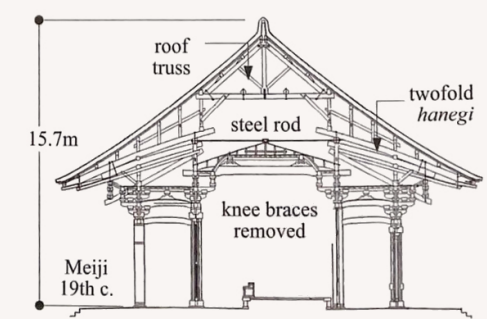
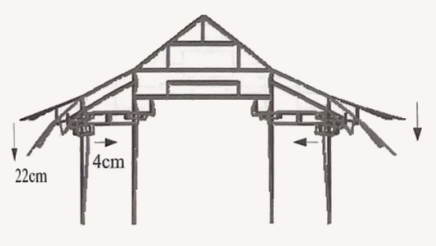
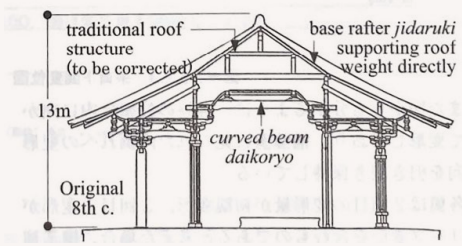
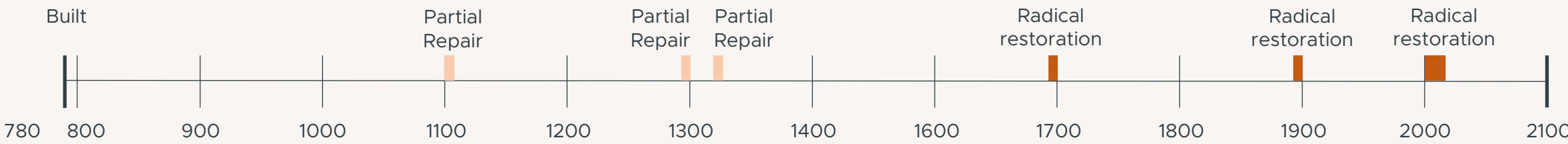
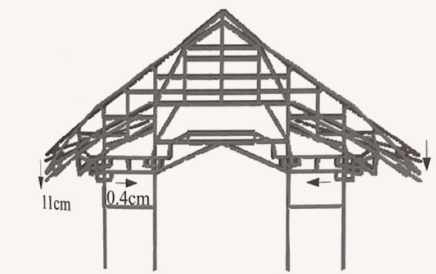
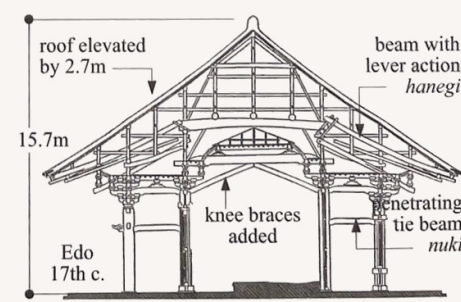
Japanese Cypress: Hinoki

“Chamaecyparis obtuse”



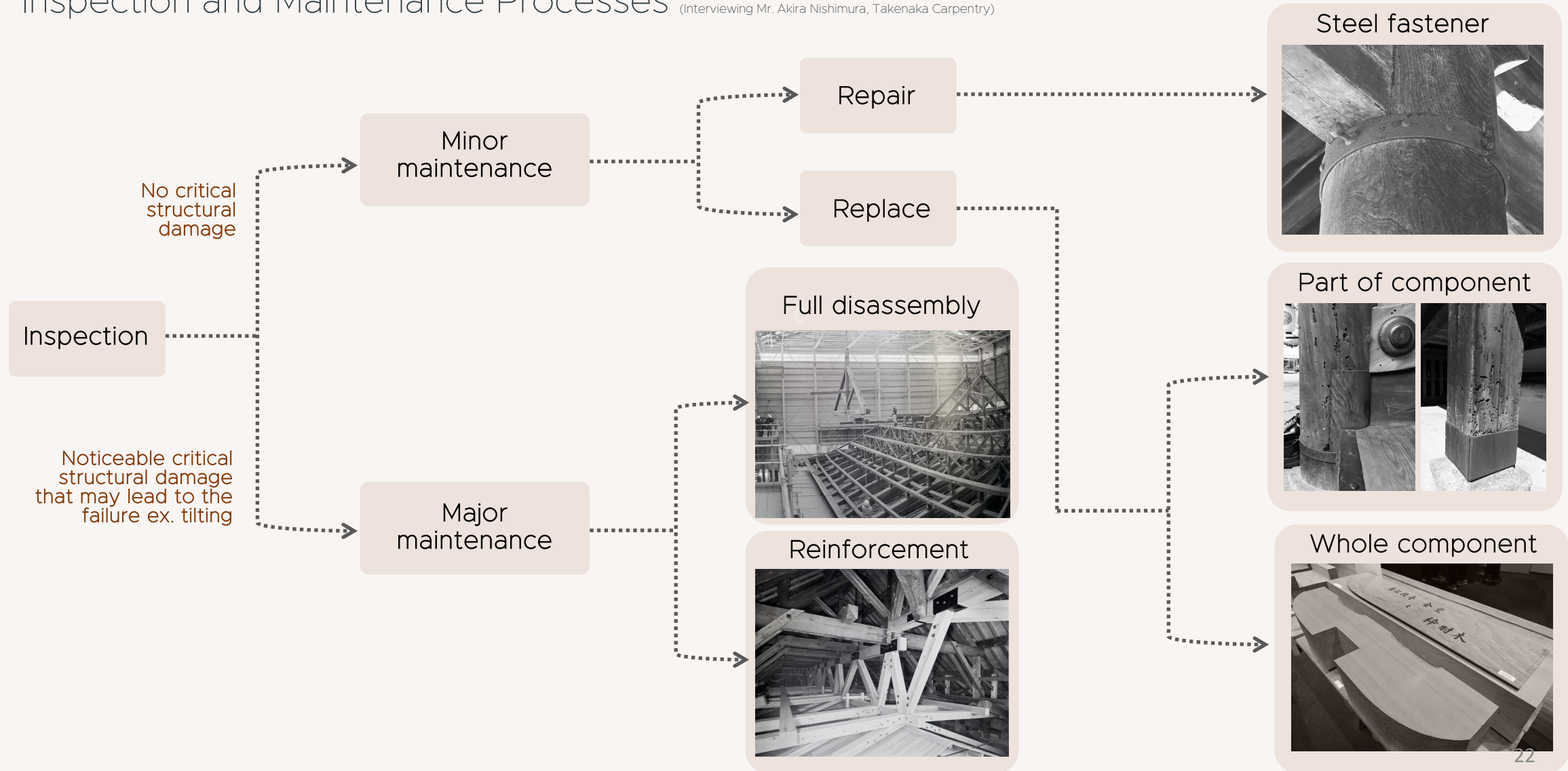
Case Study

Toshodai-ji Temple Kondo (Golden Hall): maintenance record



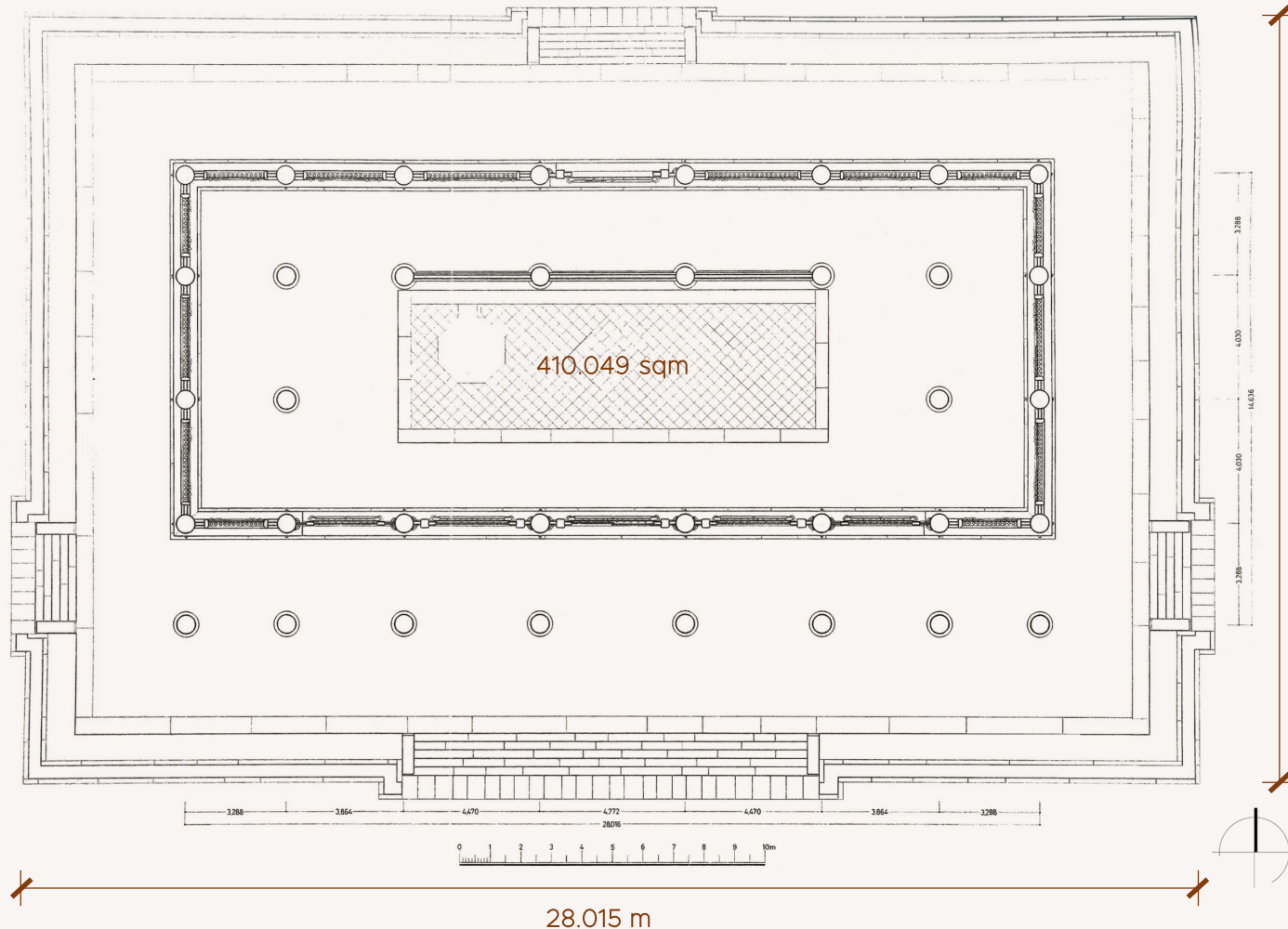
Case Study

Inspection and Maintenance Processes (Interviewing Mr. Akira Nishimura, Takenaka Carpentry)

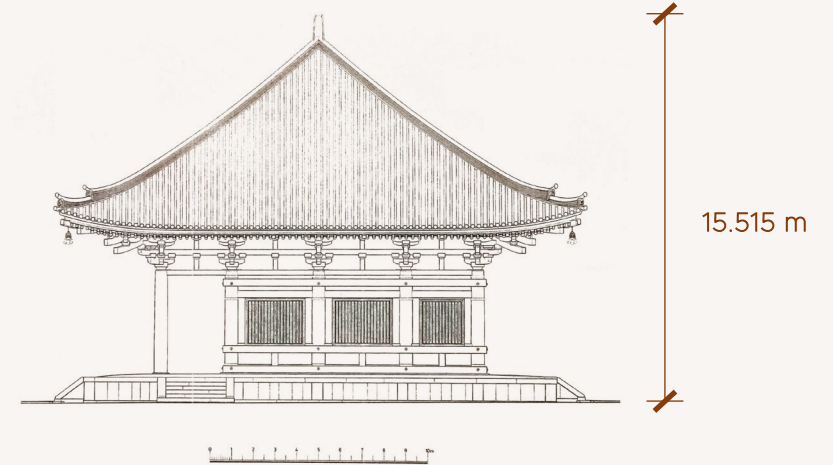


Case Study

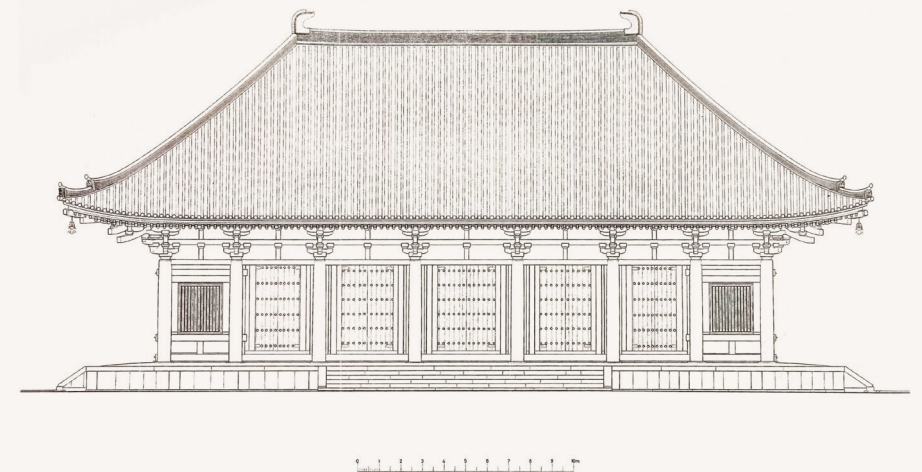
Toshodai-ji Temple Kondo (Golden Hall)



28.015 m
(Office of Cultural Assets Preservation, 2009)



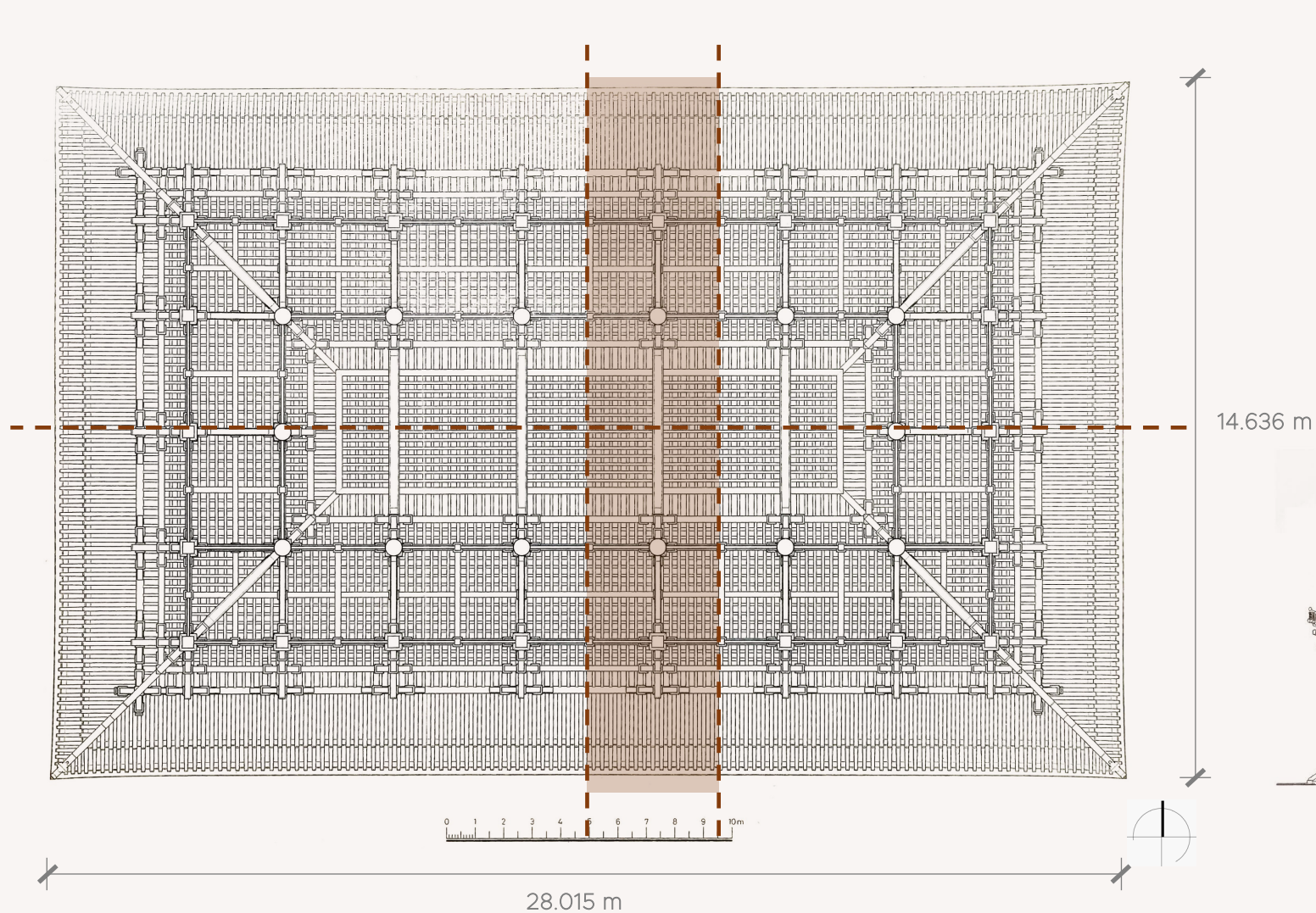
14.636 m



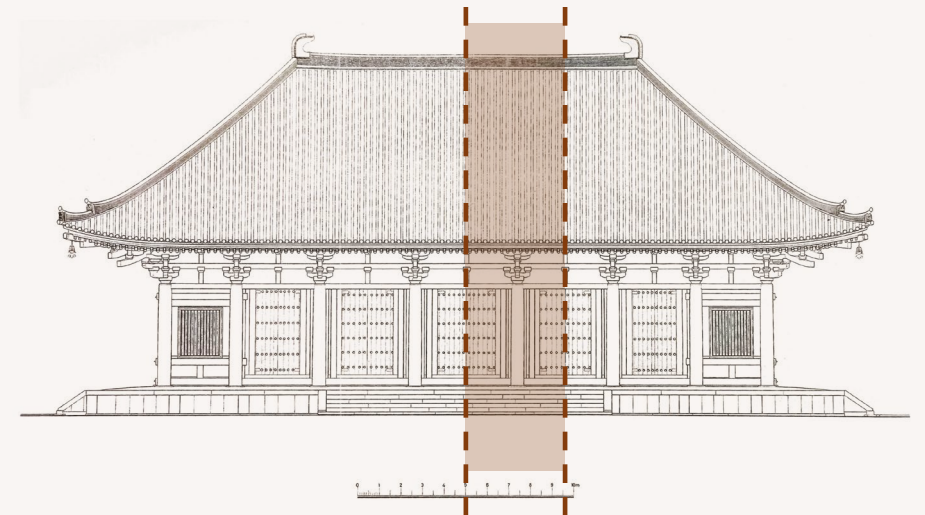
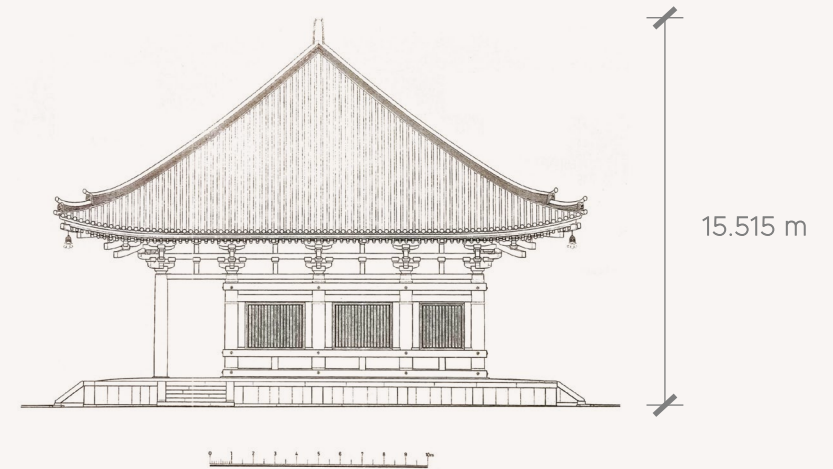
(Office of Cultural Assets Preservation, 2009)

Case Study

Toshodai-ji Temple Kondo (Golden Hall)



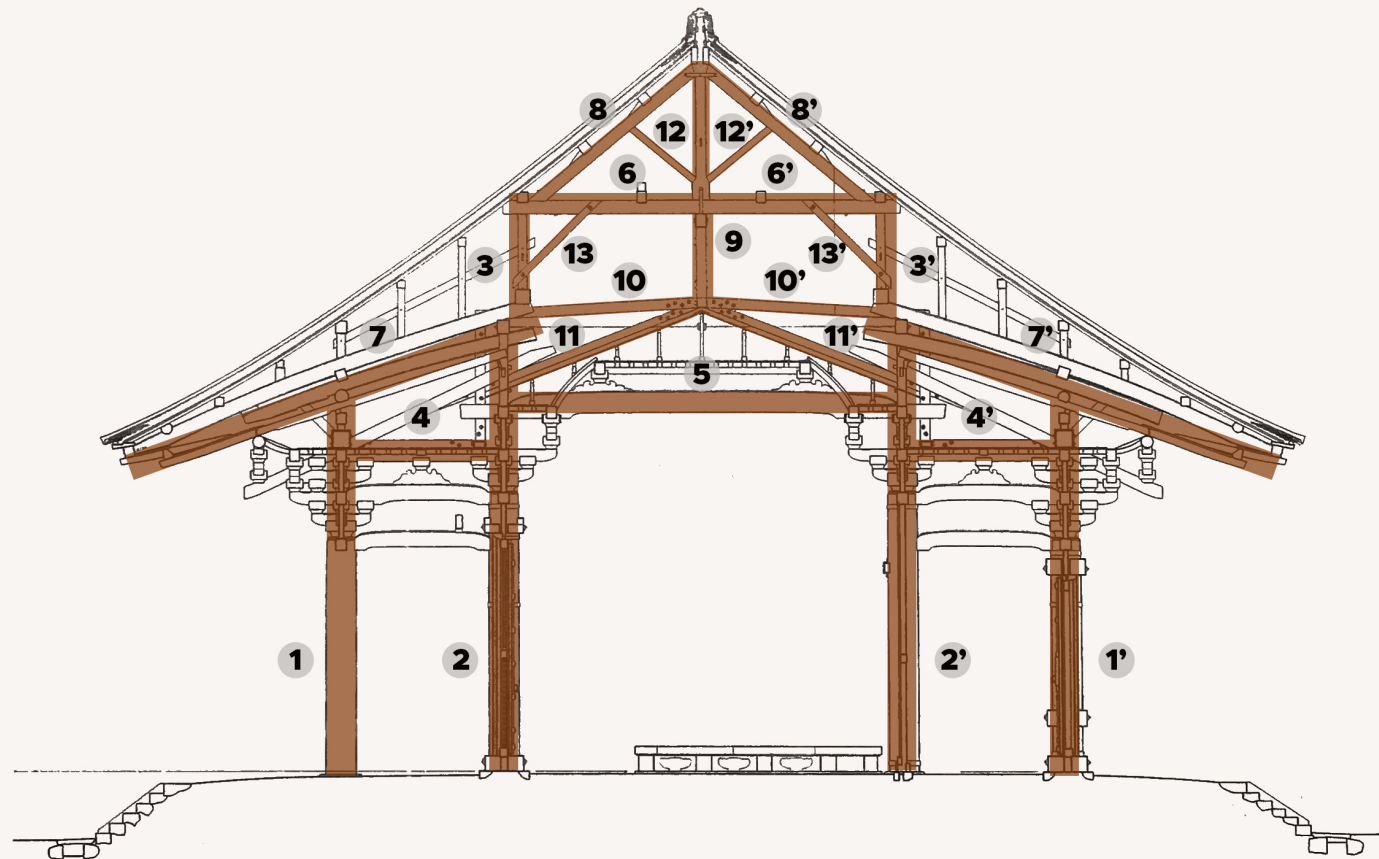
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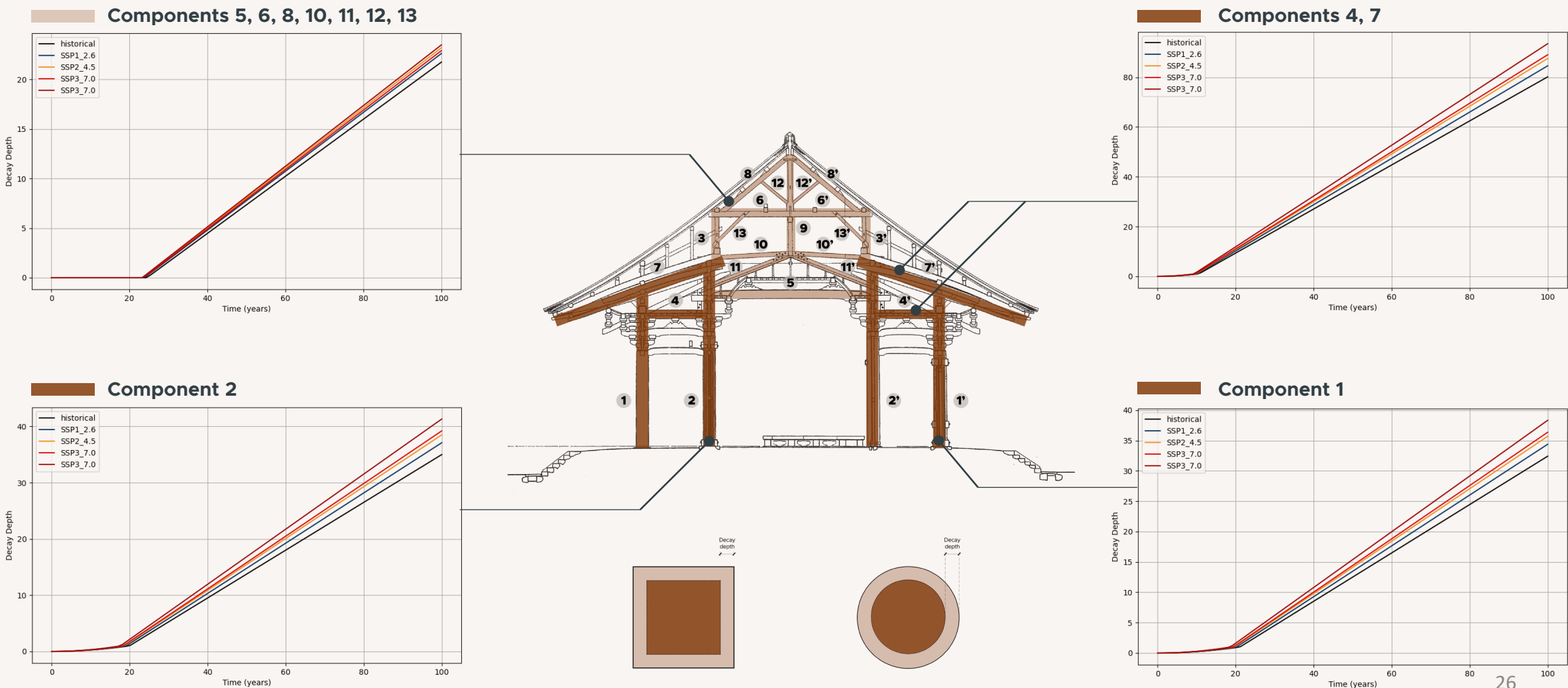
Case Study

Toshodai-ji Temple Kondo (Golden Hall)



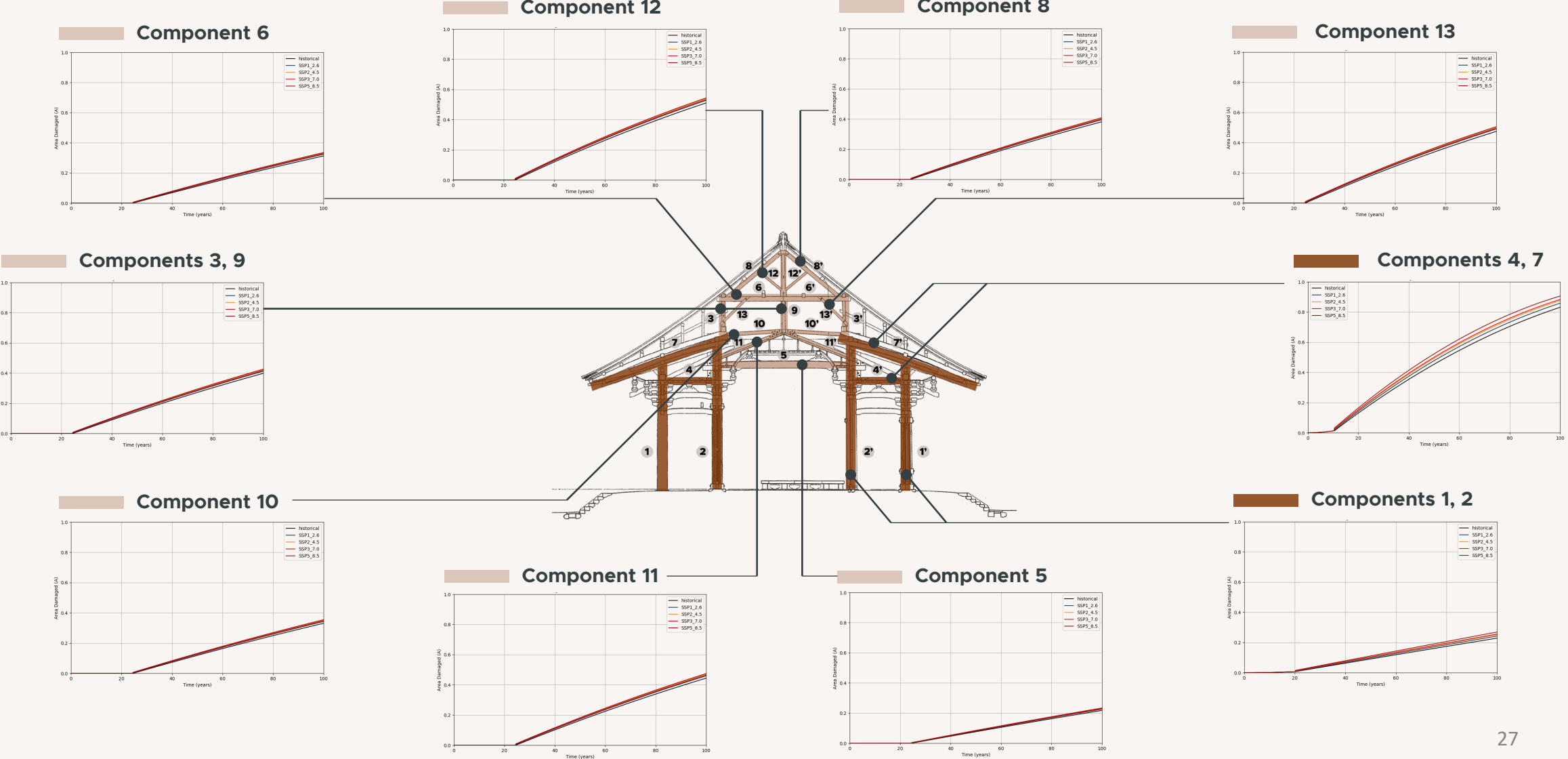
Case Study

Deterioration Model



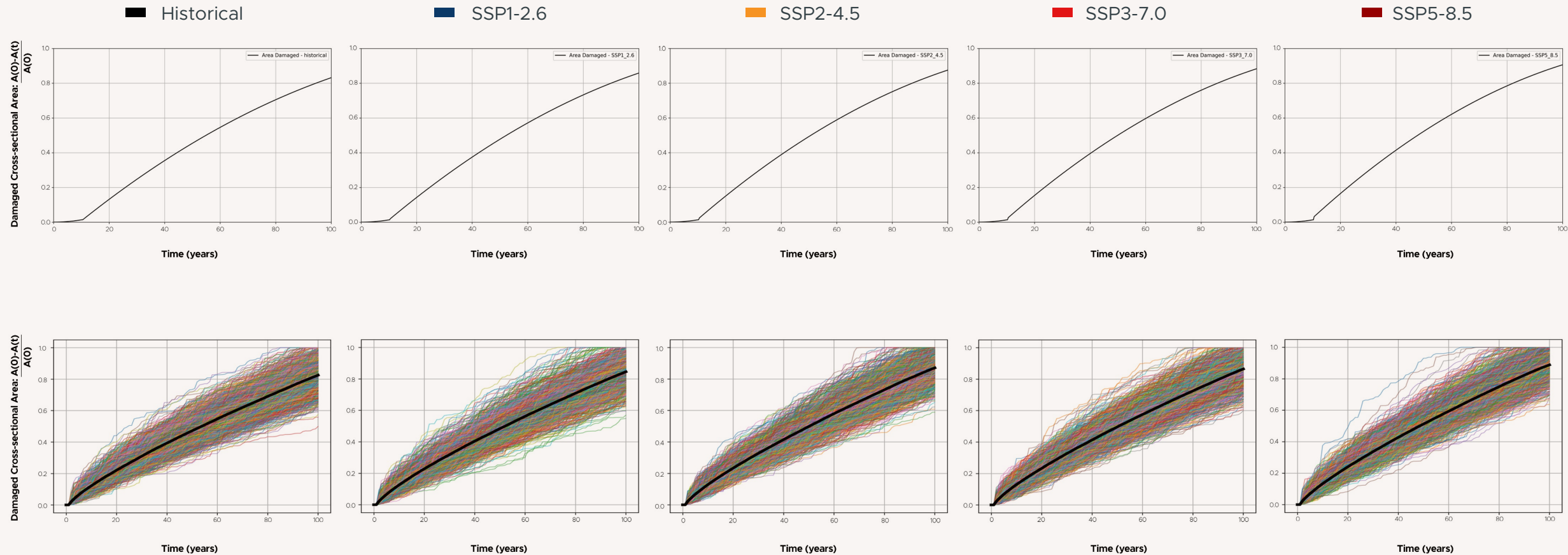
Case Study

Deterioration Model



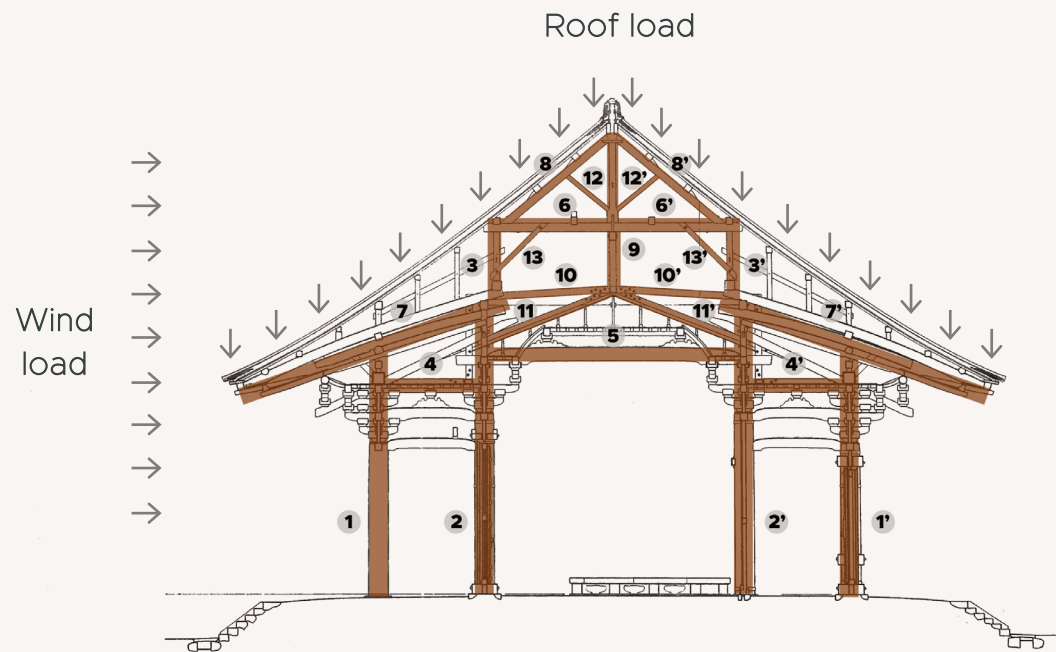
Stochastic Deterioration Process

Gamma Process

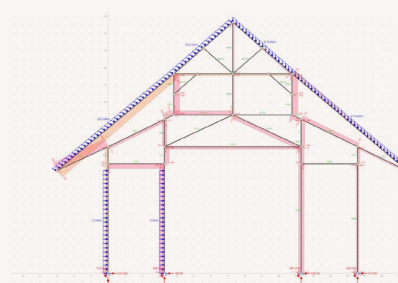


Case Study

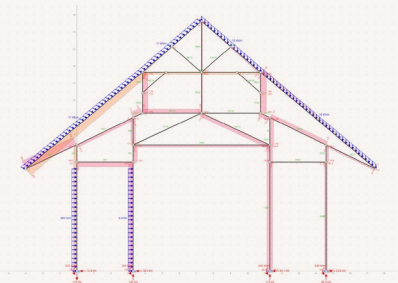
Structural Analysis



SLS



ULS



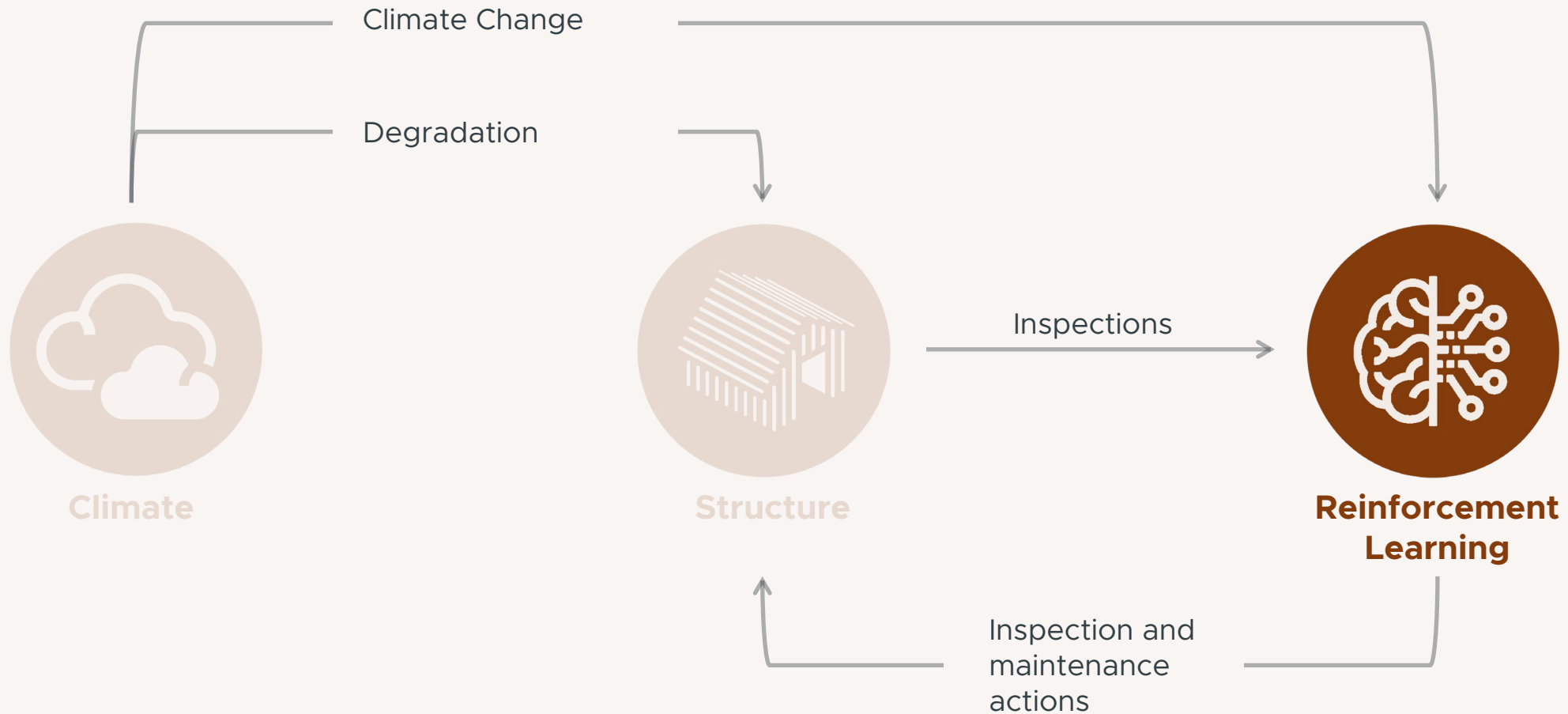
Stress

$$\sigma = \frac{F}{A}$$

Bending Moment

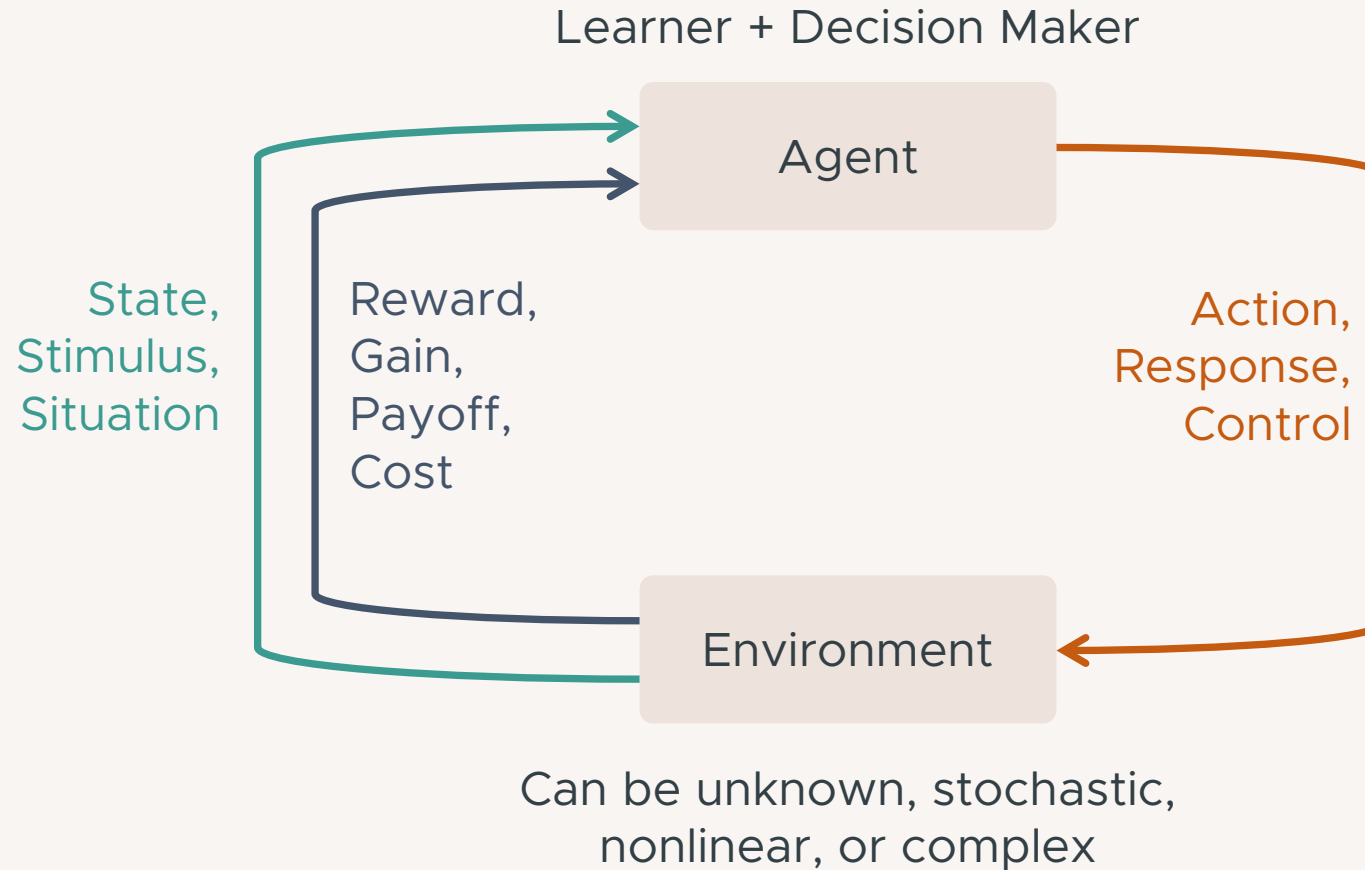
$$\sigma_m = \frac{My}{I}$$

Framework dynamic policy under climate change



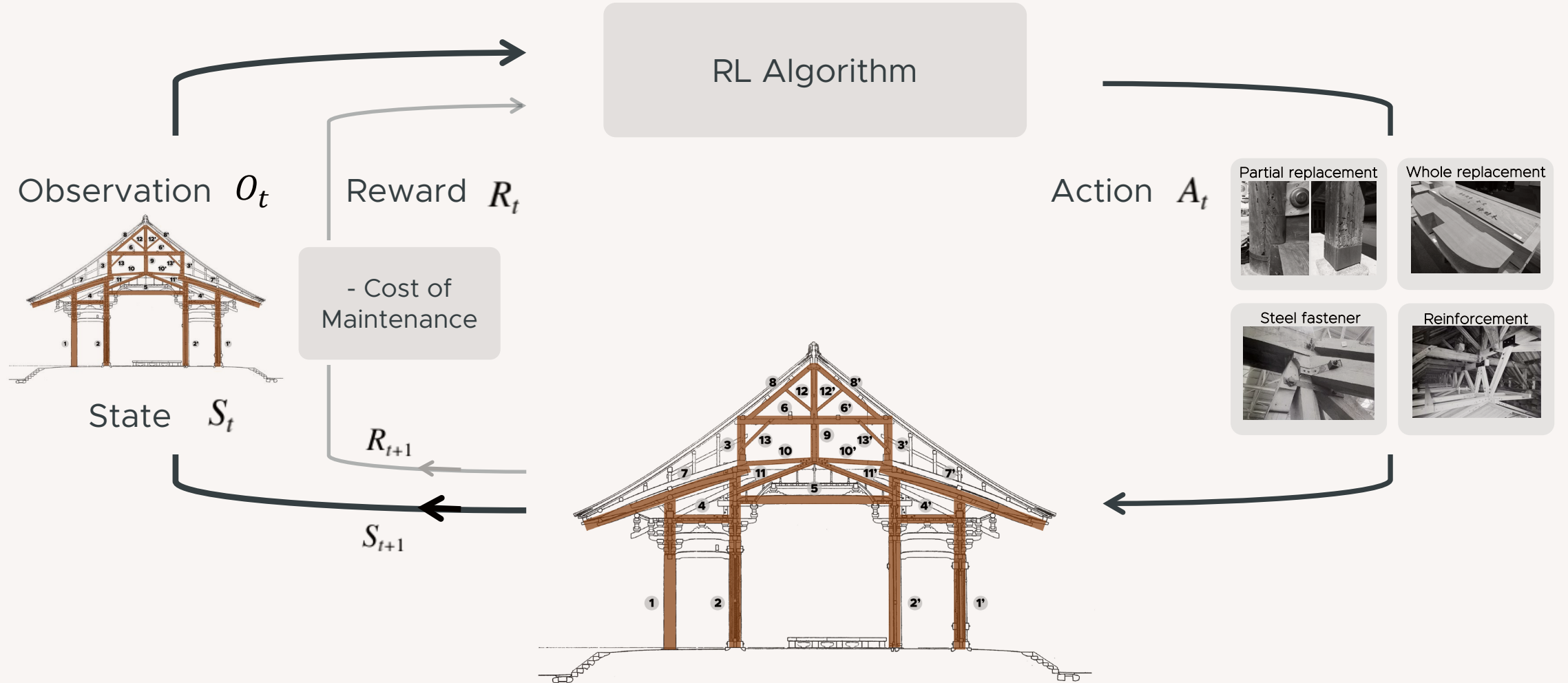
Reinforcement Learning (RL)

POMDP Framework



Reinforcement Learning (RL)

POMDP Framework



Reinforcement Learning (RL)

POMDP Framework

Belief States

Transition Probabilities

Observation Probabilities

Action Space

Reward Functions

Discount Factor

Reinforcement Learning (RL)

POMDP Framework

Belief States

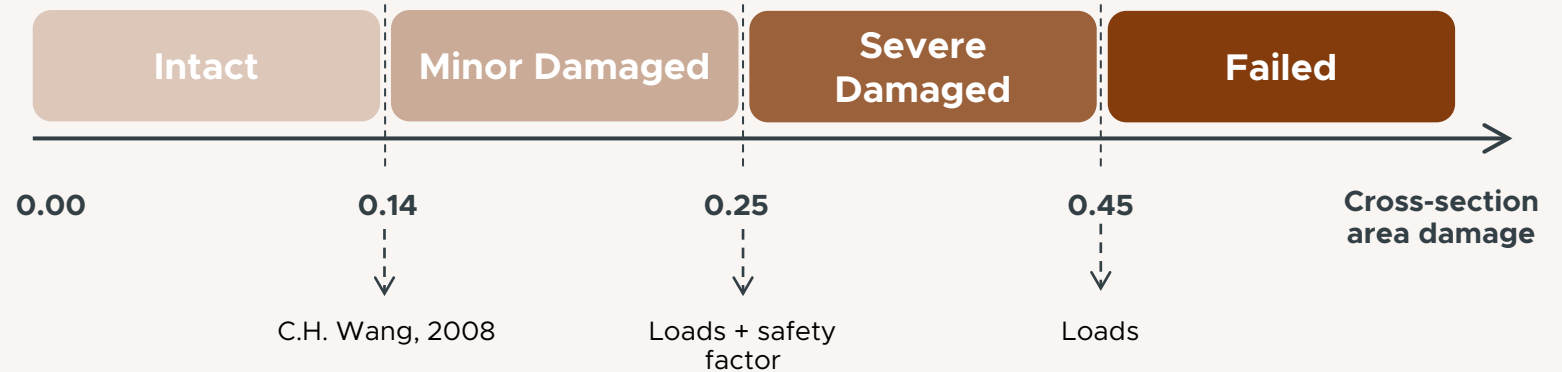
Transition Probabilities

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Reinforcement Learning (RL)

POMDP Framework

Belief States

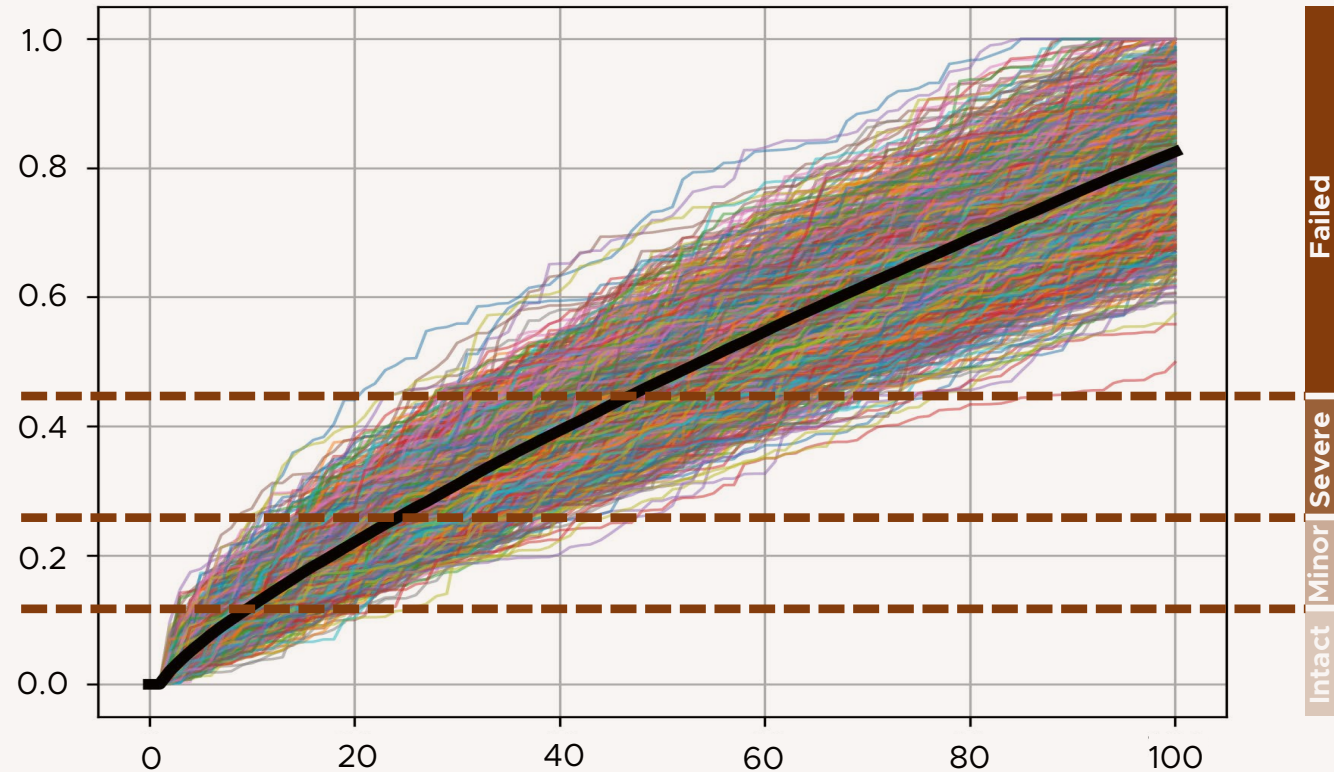
Transition Probabilities

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Reinforcement Learning (RL)

POMDP Framework

$$P(s_{t+1}|s_t, a_t) = \begin{bmatrix} p(s_0|s_0) & p(s_1|s_0) & p(s_2|s_0) & p(s_3|s_0) \\ 0 & p(s_1|s_1) & p(s_2|s_1) & p(s_3|s_1) \\ 0 & 0 & p(s_2|s_2) & p(s_3|s_2) \\ 0 & 0 & 0 & p(s_3|s_3) \end{bmatrix}$$

Belief States

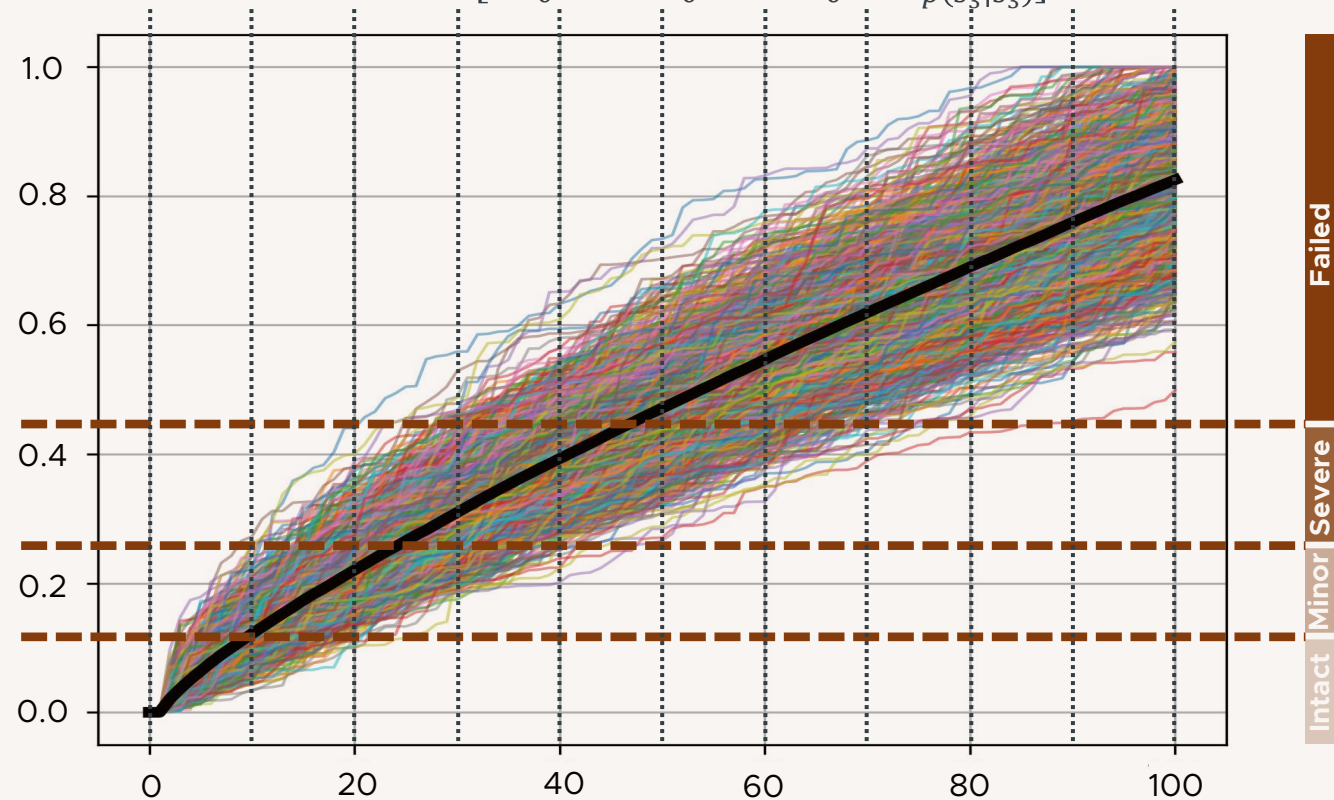
Transition Probabilities

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Action Space

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Reinforcement Learning (RL)

POMDP Framework

Belief States

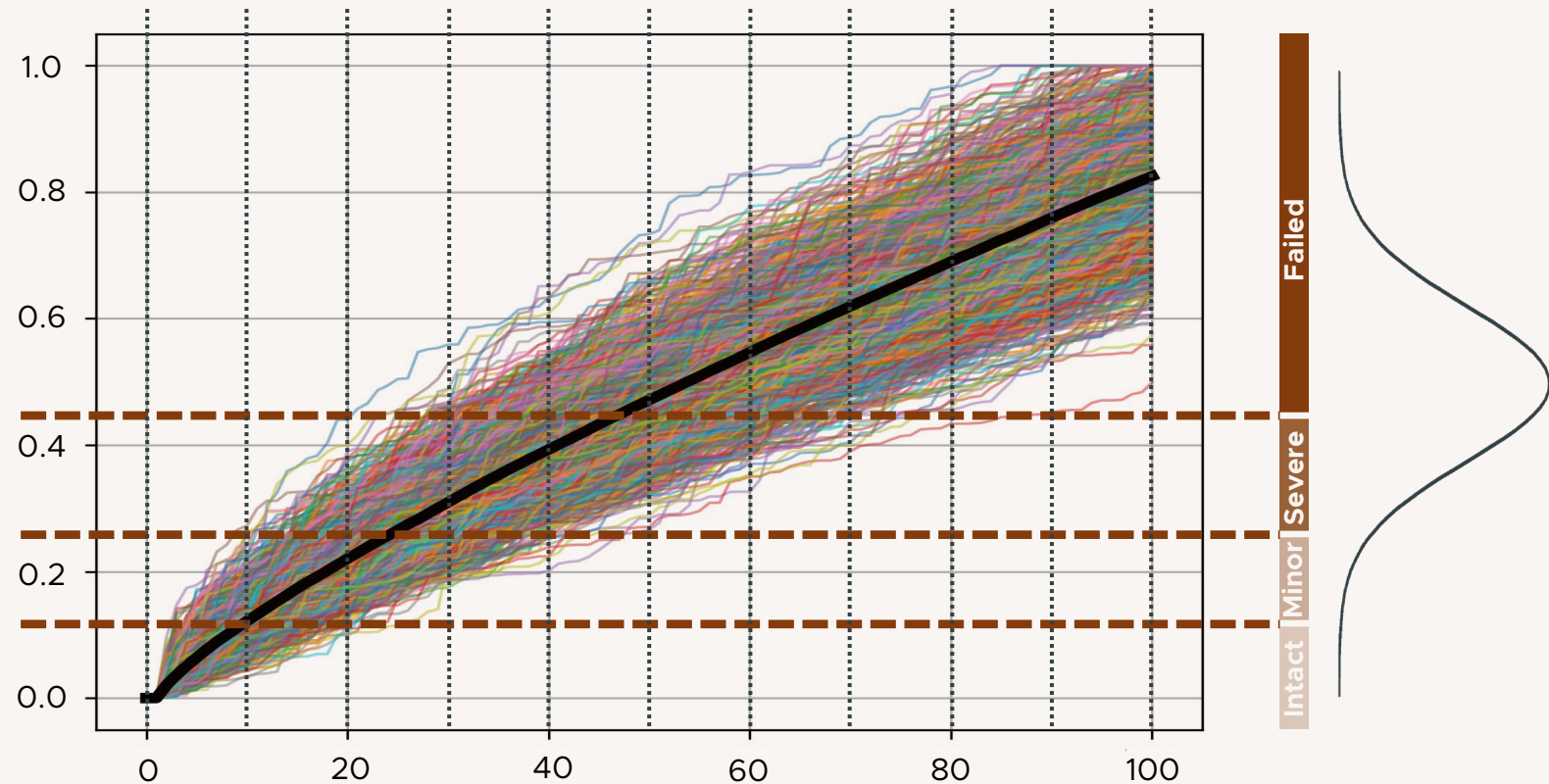
Transition Probabilities

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Reinforcement Learning (RL)

POMDP Framework

Belief States

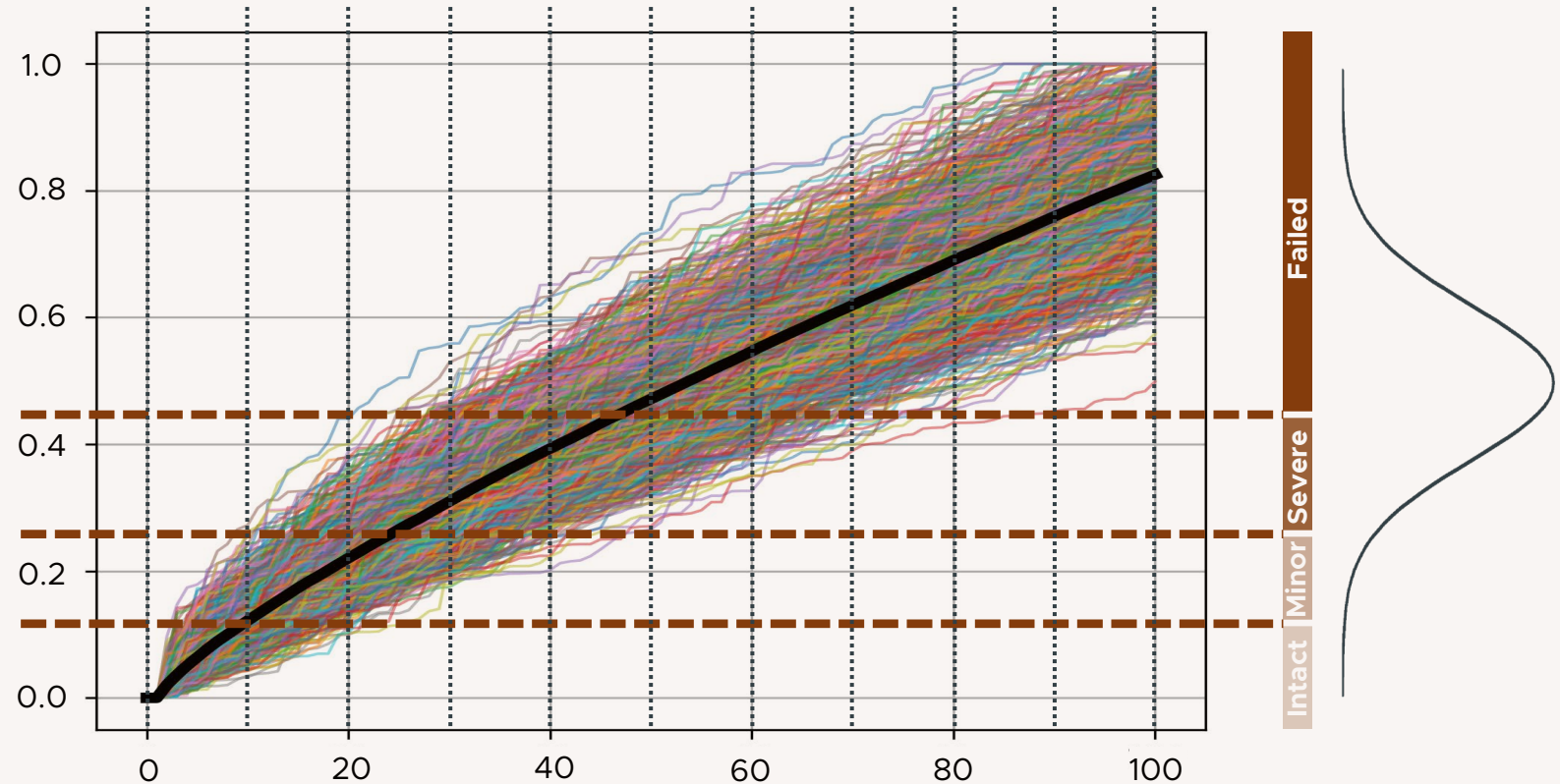
Transition Probabilities

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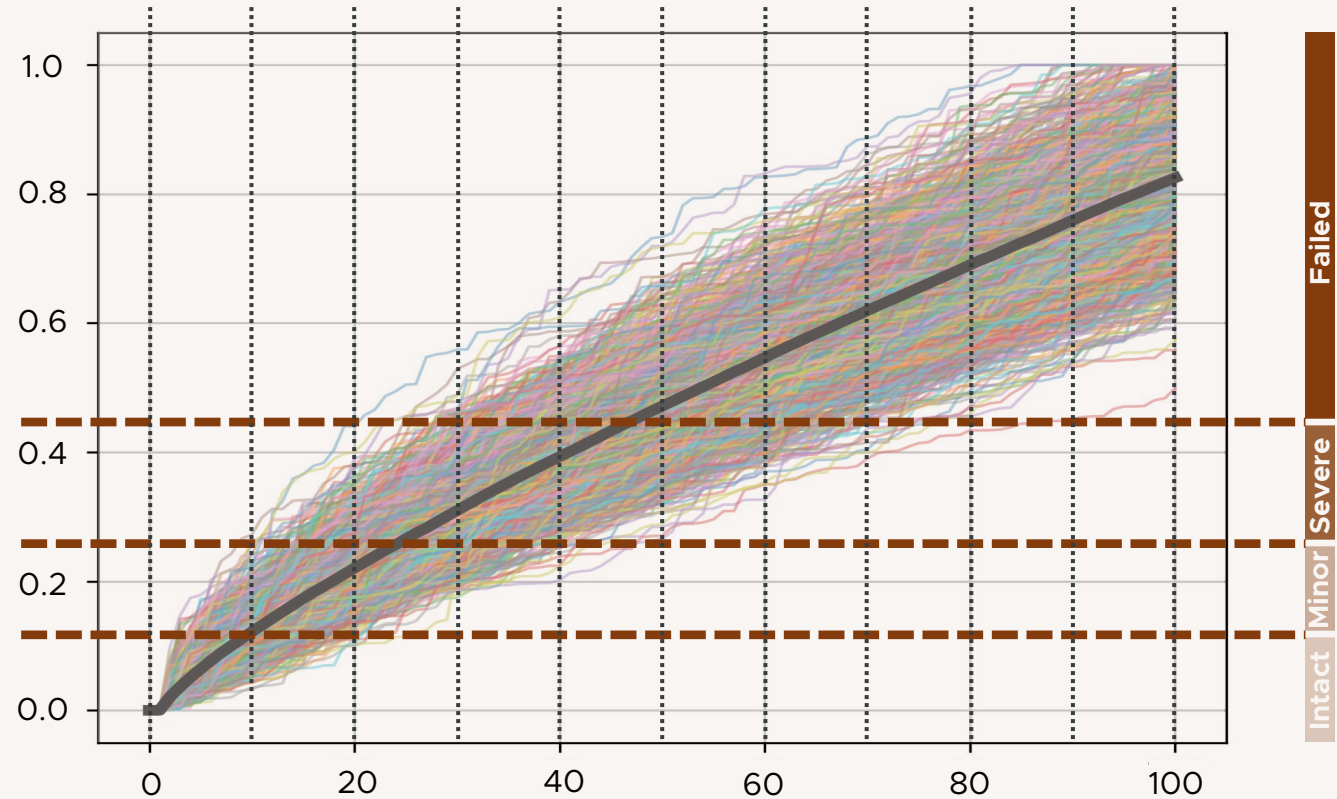


Reinforcement Learning (RL)

POMDP Framework

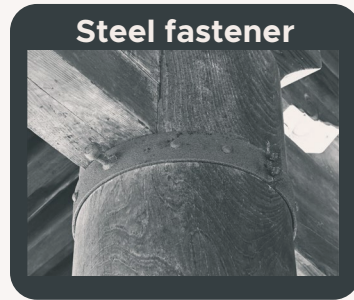


cost: 0.1 of replacement

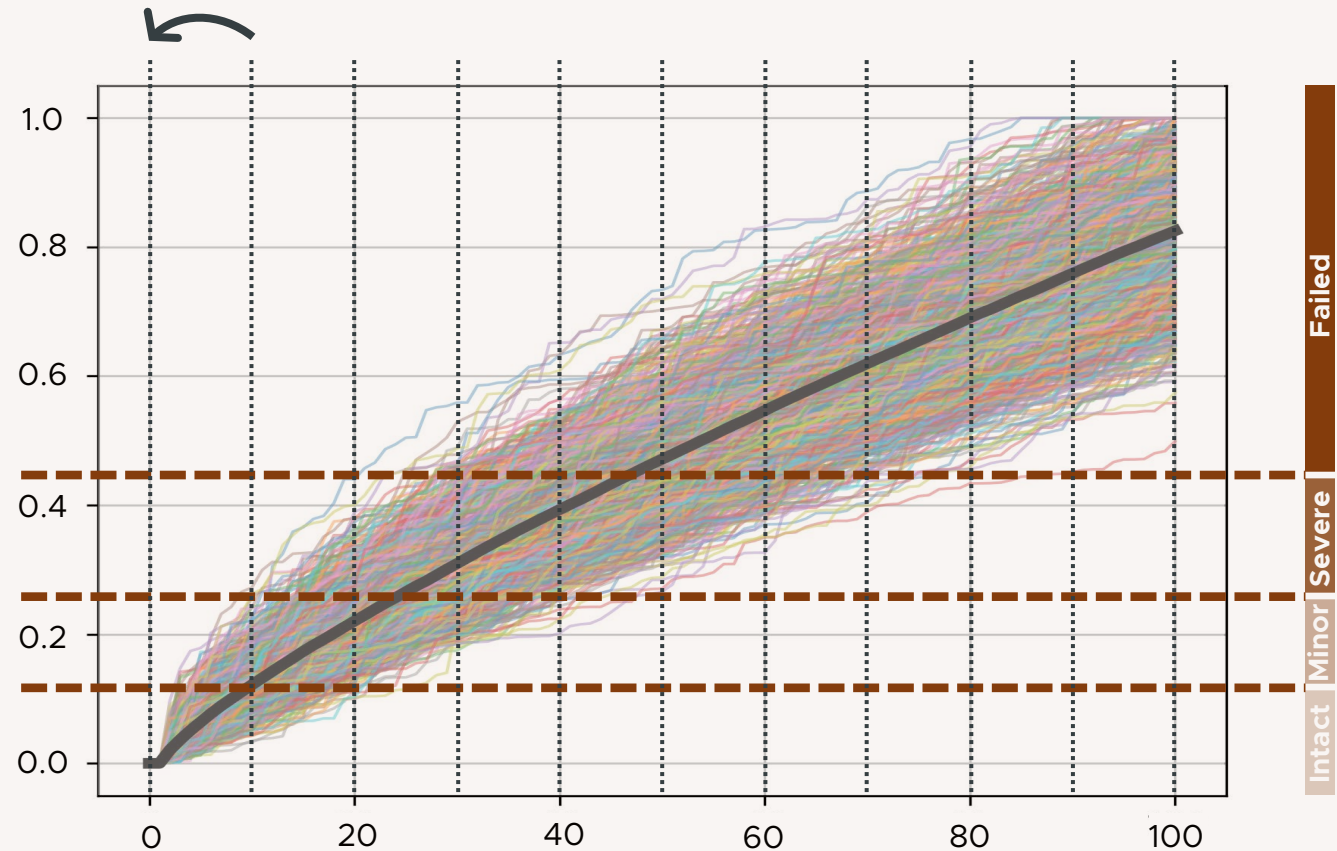


Reinforcement Learning (RL)

POMDP Framework



cost: 0.7 of replacement

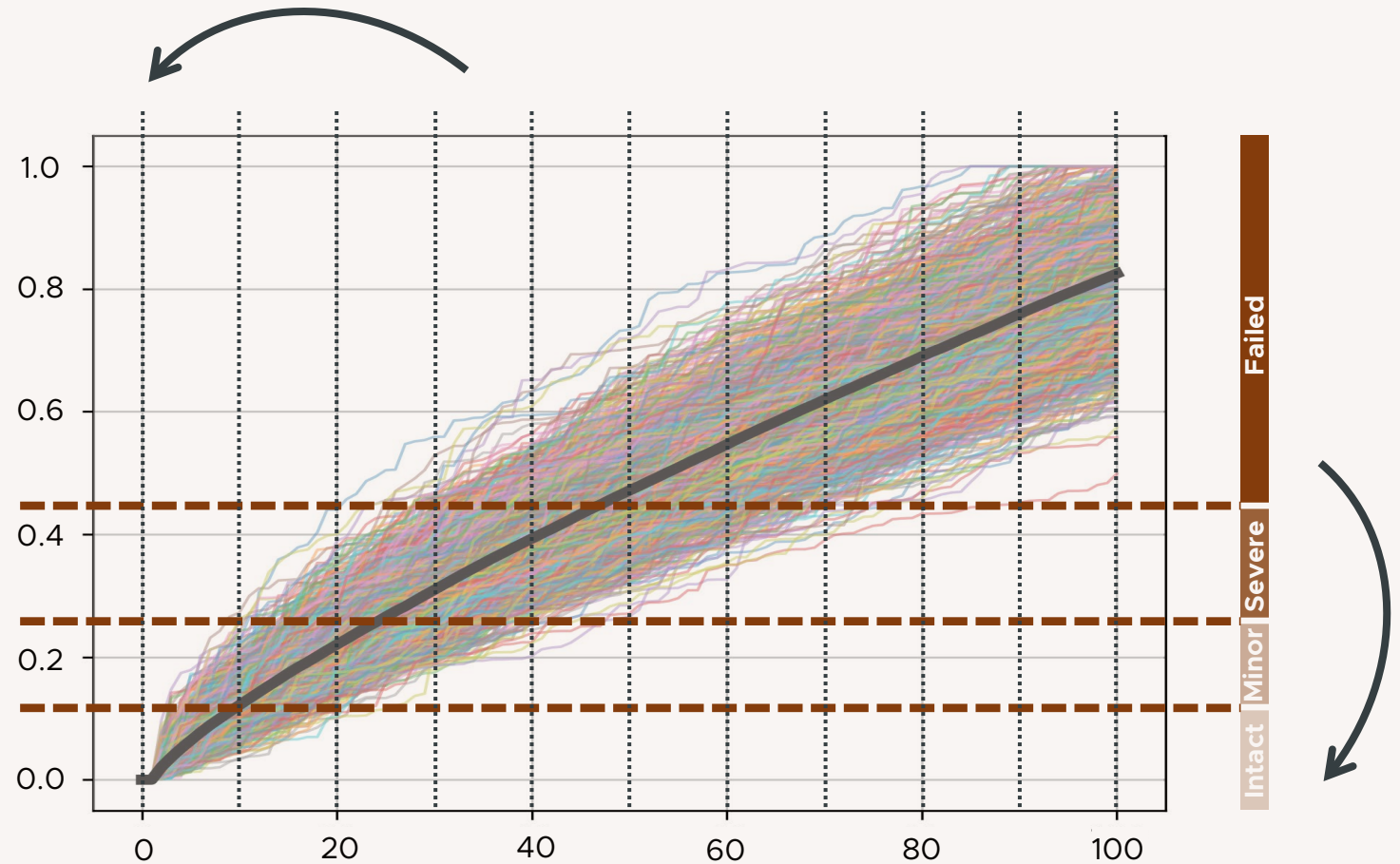


Reinforcement Learning (RL)

POMDP Framework

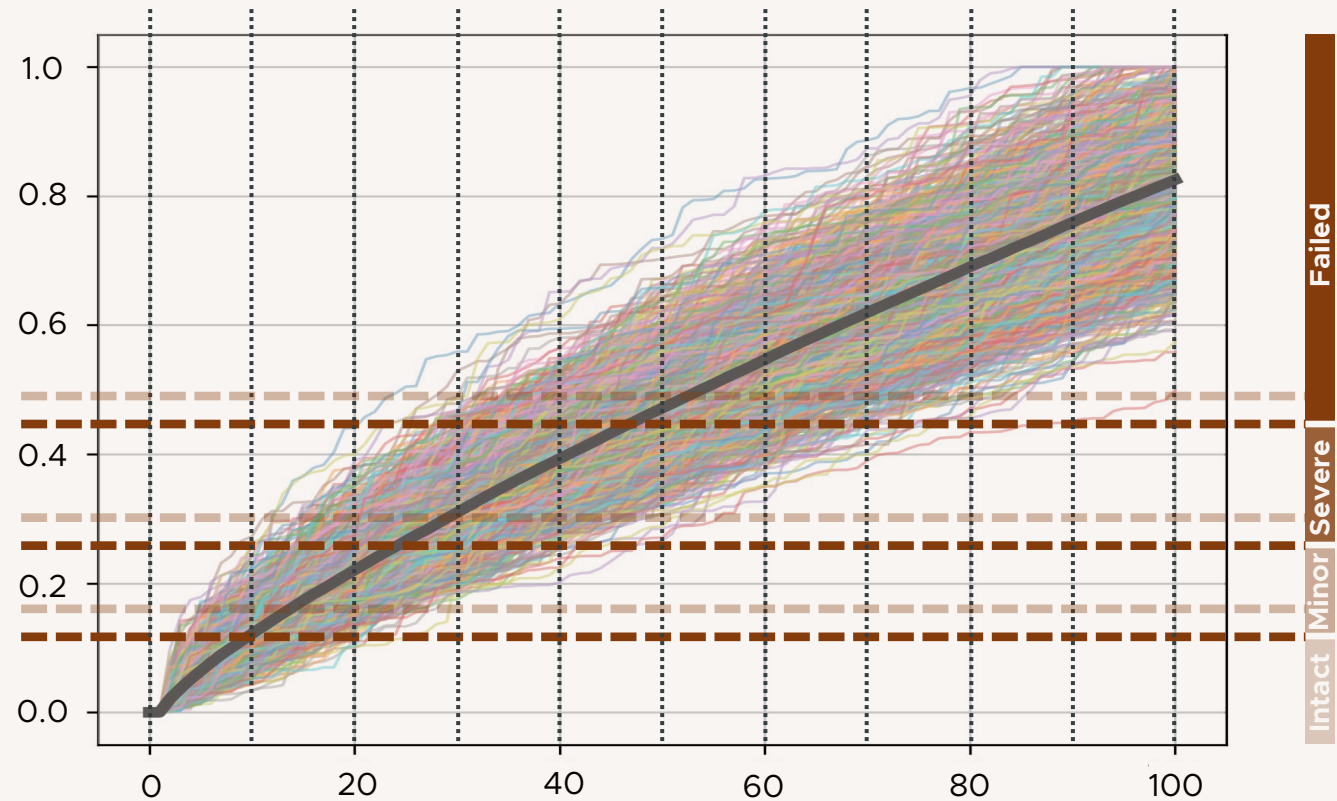


cost: 1.0 of replacement



Reinforcement Learning (RL)

POMDP Framework



Reinforcement Learning (RL)

POMDP Framework

Belief States

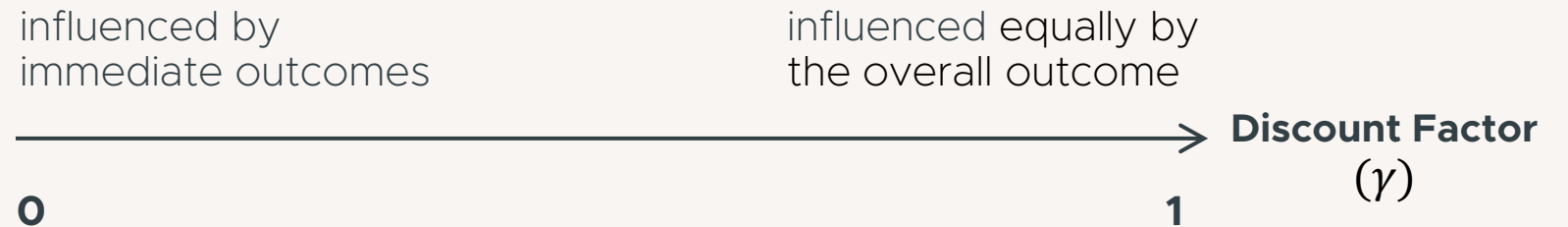
Transition Probabilities

Observation Probabilities

Action Space

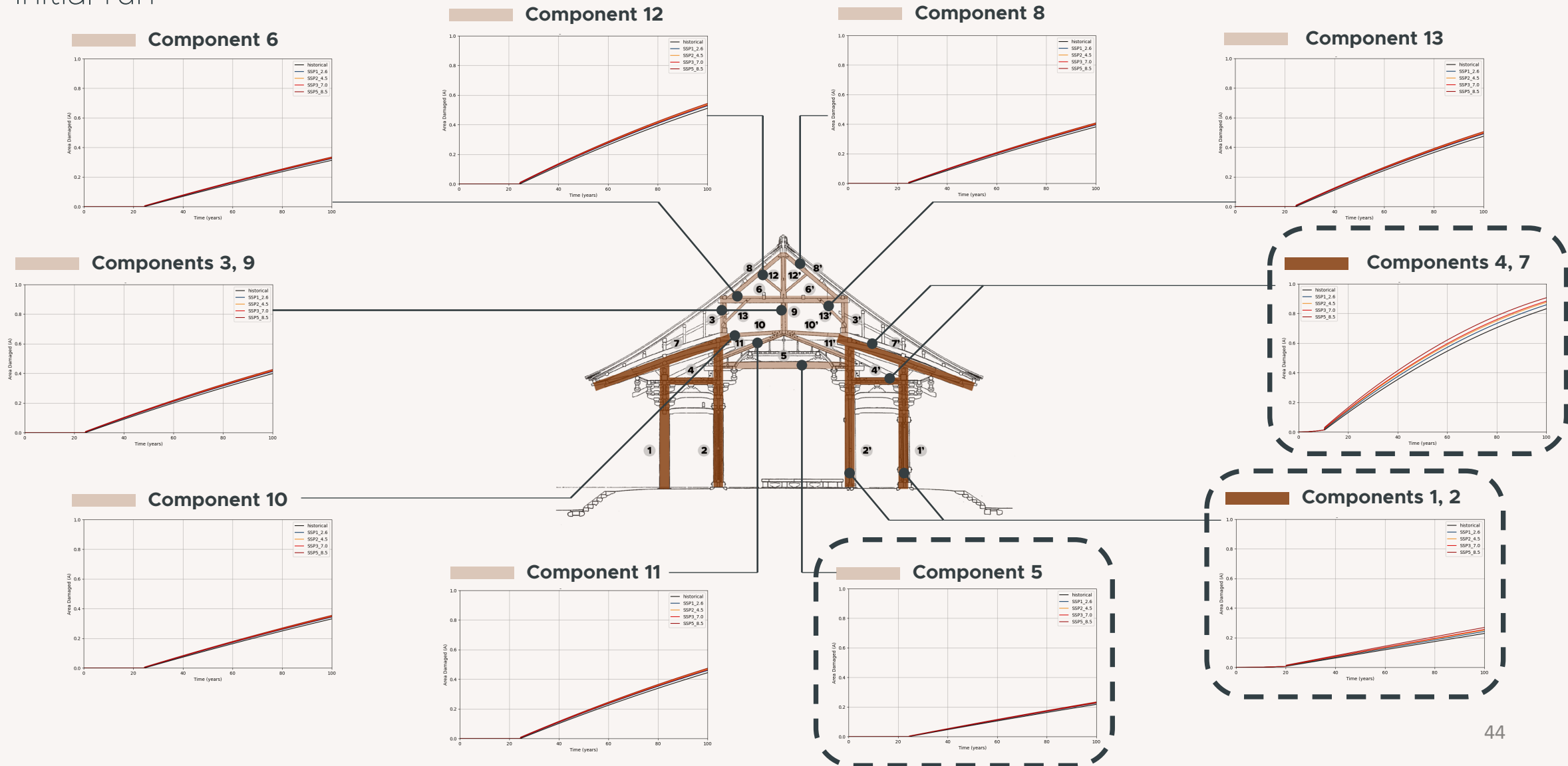
Reward Functions

Discount Factor



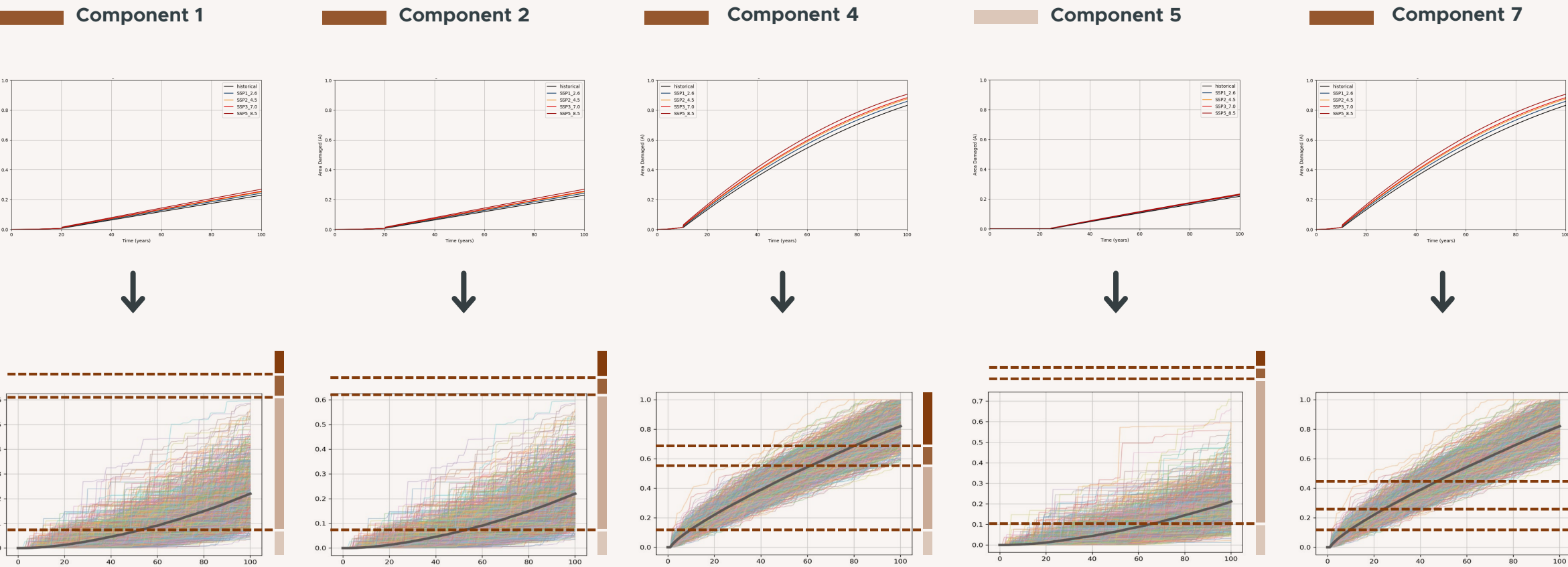
Reinforcement Learning (RL)

Initial run



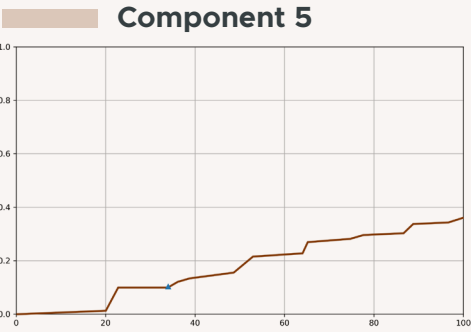
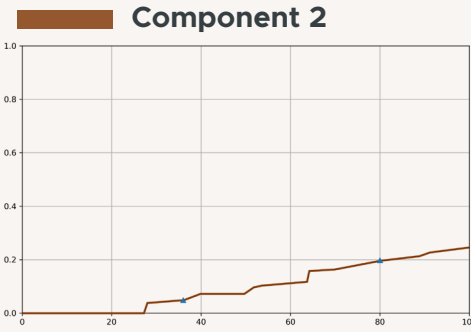
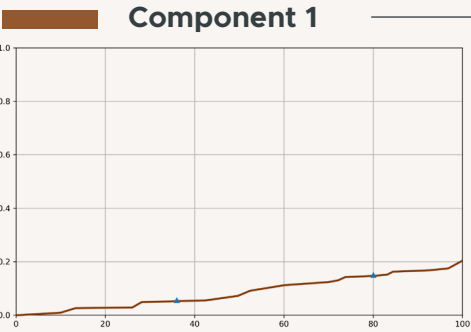
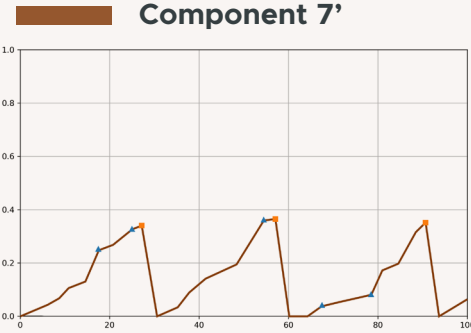
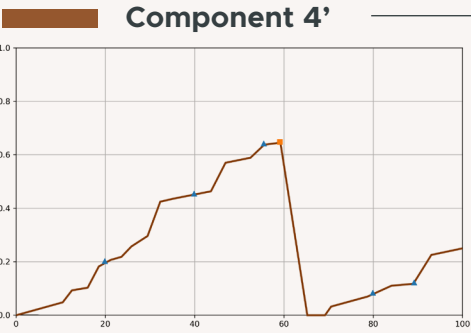
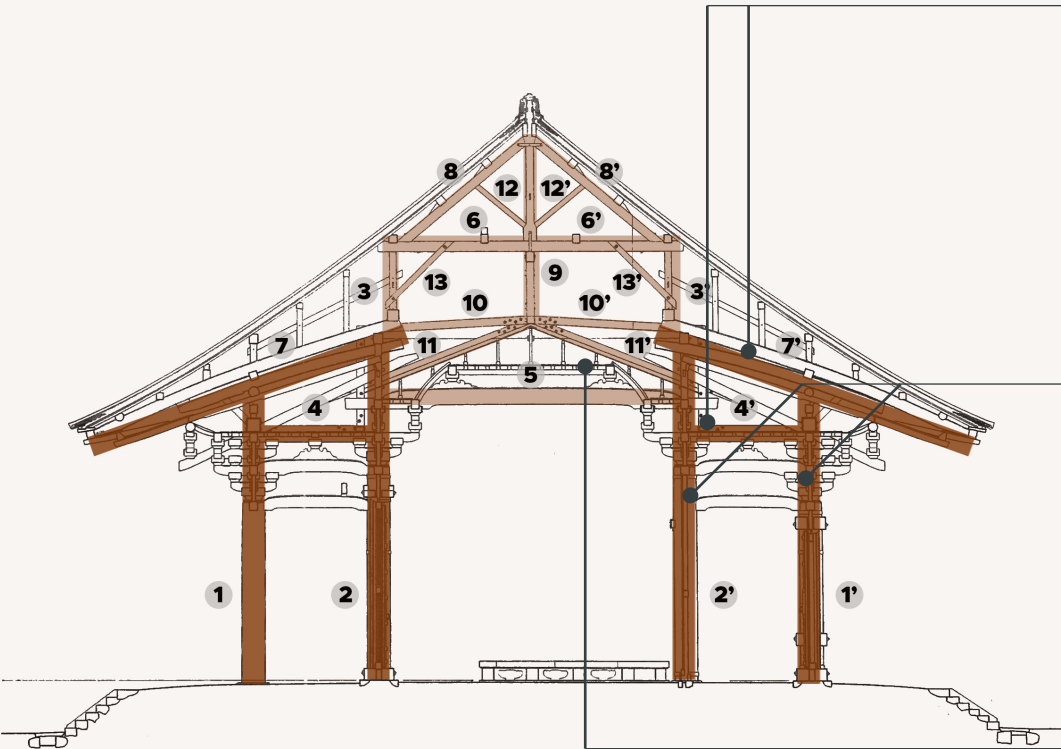
Reinforcement Learning (RL)

Initial run



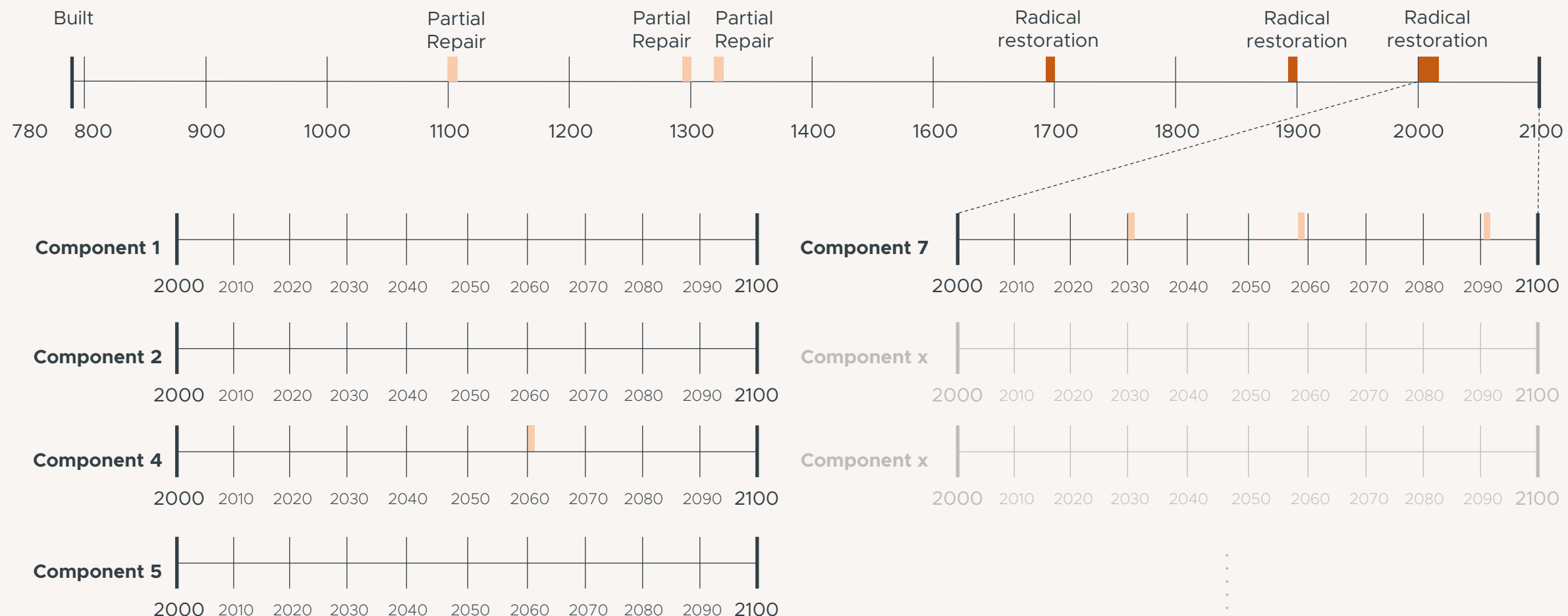
Inspection & Maintenance Policies

Initial run



- ▲ Inspect
- Repair
- Replace

Inspection & Maintenance Policies



Research Question

“How can reinforcement learning consider climate change effects to inform inspection and maintenance for timber structures?”

Framework

“How can reinforcement learning consider climate change effects to inform inspection and maintenance for timber structures?”



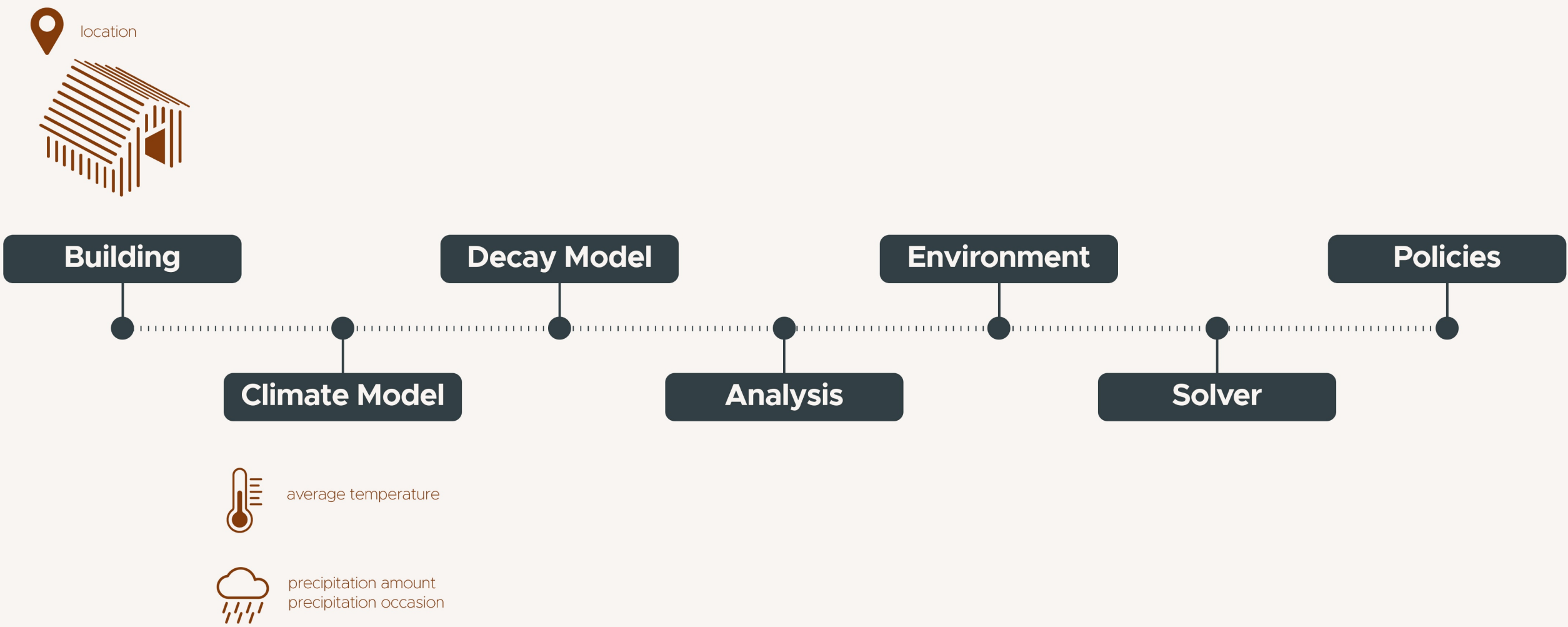
Framework

Required Information



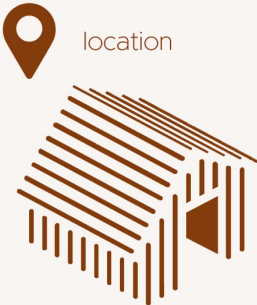
Framework

Required Information

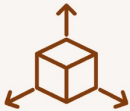


Framework

Required Information



wood durability



dimensions



connection types



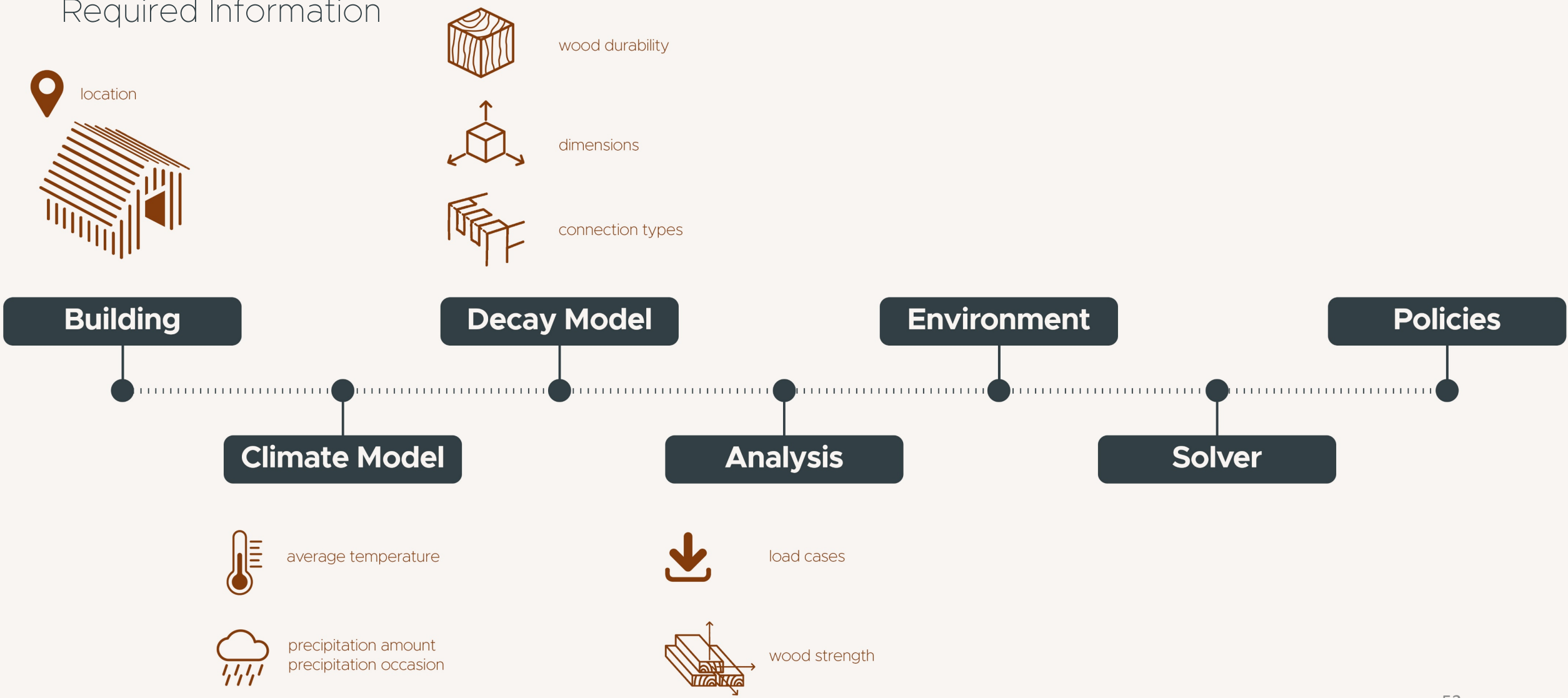
average temperature



precipitation amount
precipitation occasion

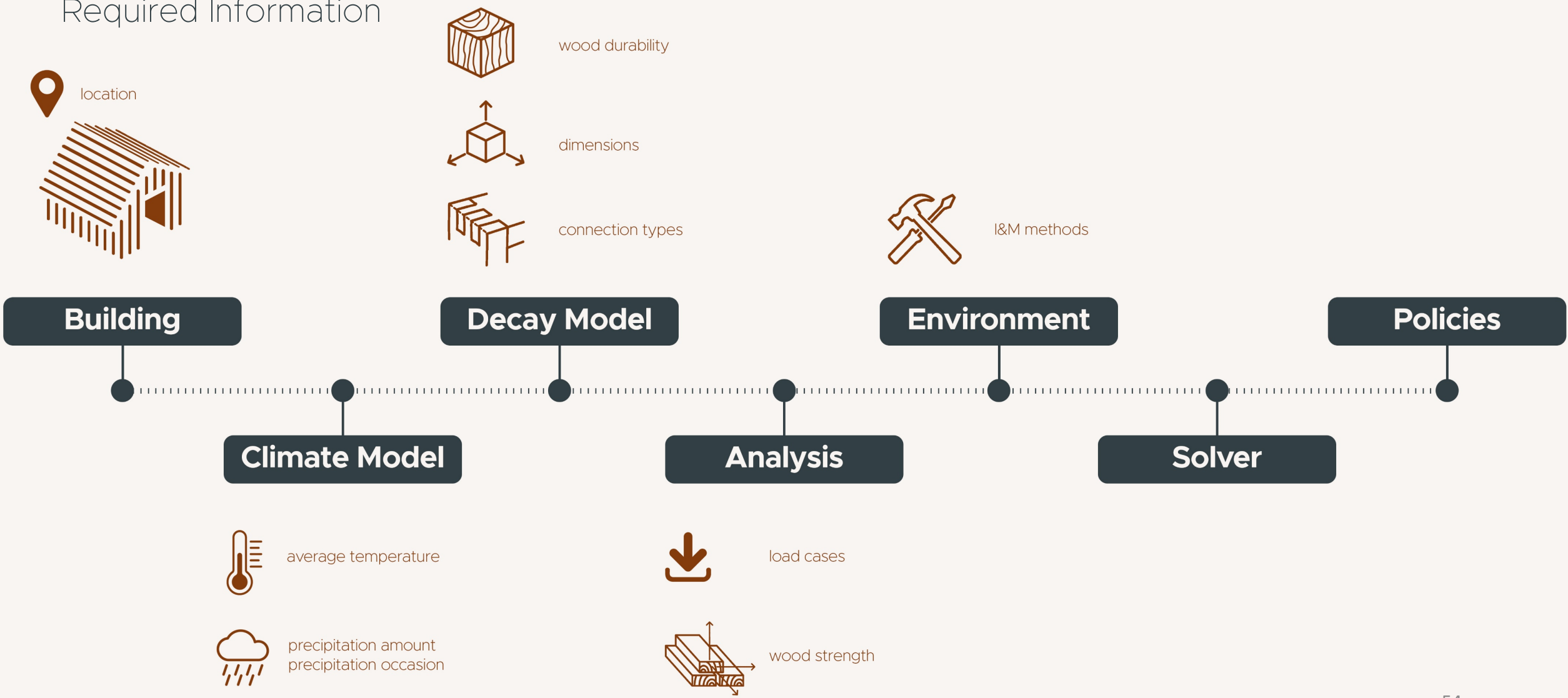
Framework

Required Information



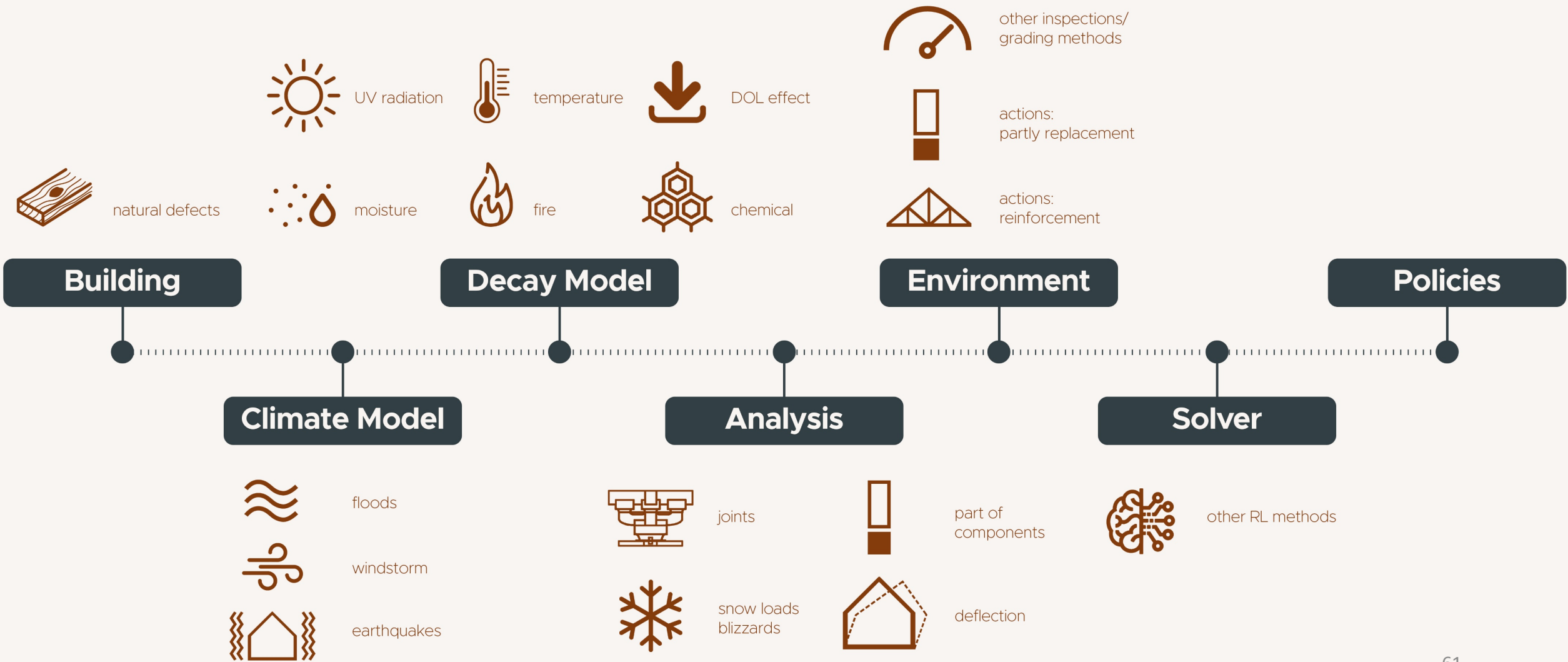
Framework

Required Information



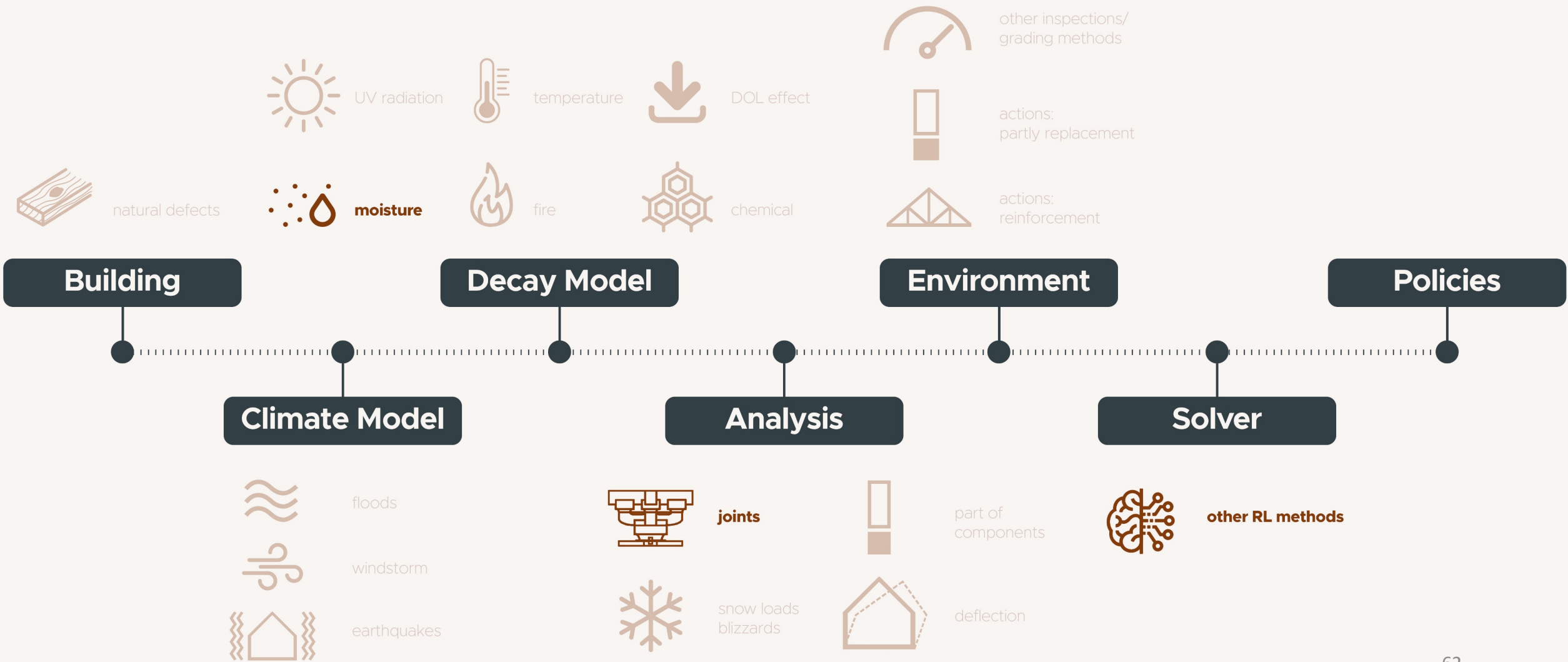
Reflection

Excluded Information



Further Development

Suggestions



Further Development

Suggestions

