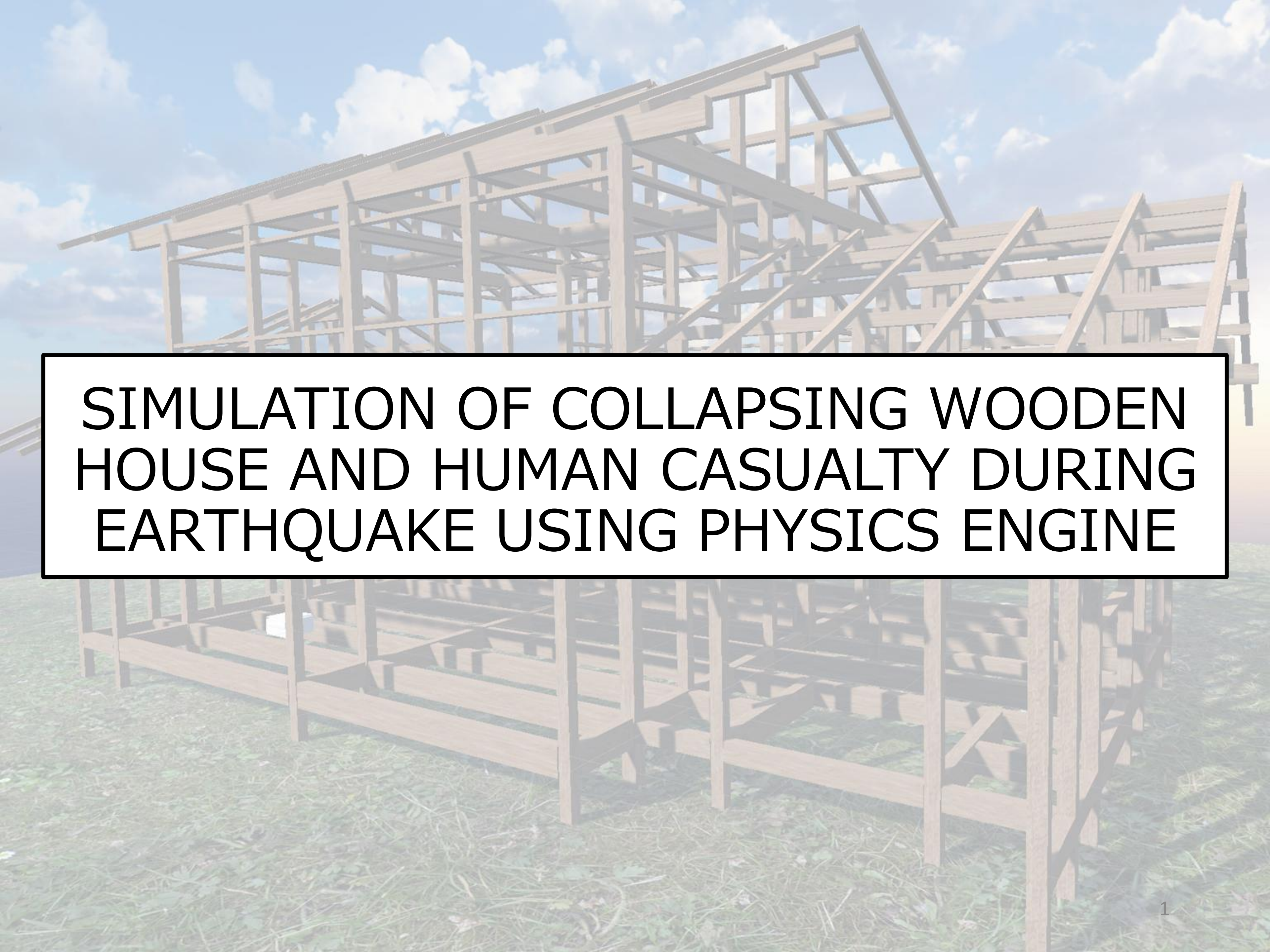


SIMULATION OF COLLAPSING WOODEN HOUSE AND HUMAN CASUALTY DURING EARTHQUAKE USING PHYSICS ENGINE

Background

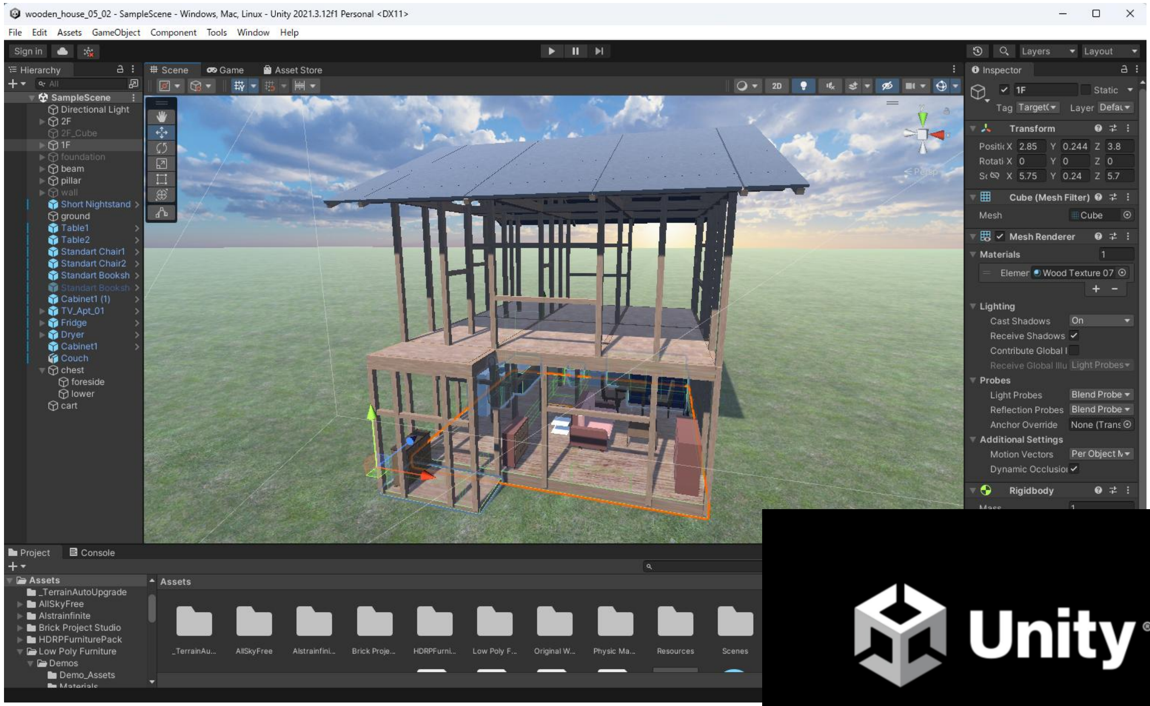
- In the 1995 Hyogo Prefecture Southern Earthquake that occurred in Japan, the total number of deaths was 6,433.
- 4,224 people were killed by collapsed houses.

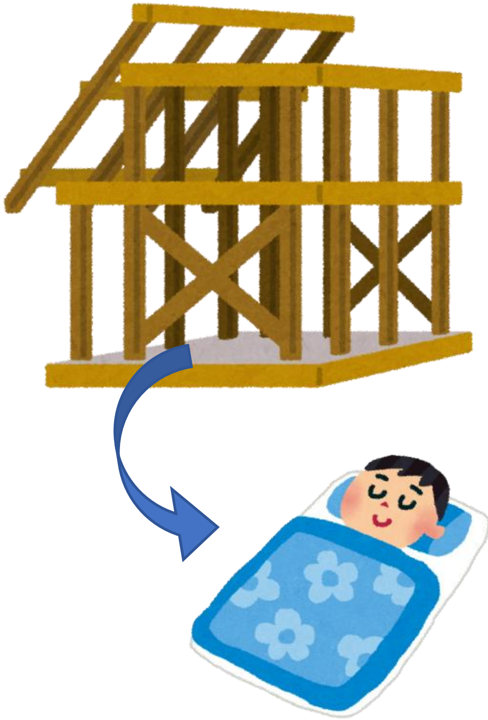
- In the 2016 Kumamoto Earthquake, 8,682 houses were totally collapsed.
- In Minamiaso Village, an apartment building collapsed, and 12 students were buried alive, three of whom died

- When investigating damage after an earthquake, only the final condition of the collapsed building can be ascertained
- It is difficult to understand the process of casualties and injuries caused by collapsed houses.

Objective

- We use a physics engine to construct wooden houses, furniture, and human body.
- By reproducing building collapse during an earthquake, we will elucidate the casualty process that is closer to the reality.

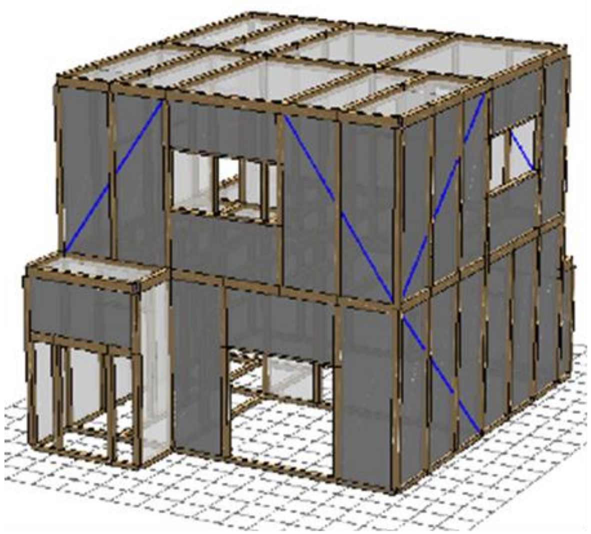




Seismic Response Analysis of Collapsing Wooden House

- Wallstat* is able to model a timber post and beam house using the discrete element method and analyze the damage and the collapse process of the house based on the time history response analysis.

- Two-story wooden building.
- The weight of the lower half of the first floor: 44.38 [kN]
- The weight of the lower half of the second floor and the upper half of the first floor: 119.2 [kN].
- The weight of the upper half of the second floor and the roof frame: 91.4 [kN].
- The height of each floor: 2.8 [m] for both the first and second floors.
- The frame was modeled using elasto-plastic rotation springs and elastic beam elements.
- The joints are rotary springs and elasto-plastic springs.
- The floor and walls were modeled by replacing the braces with truss springs.

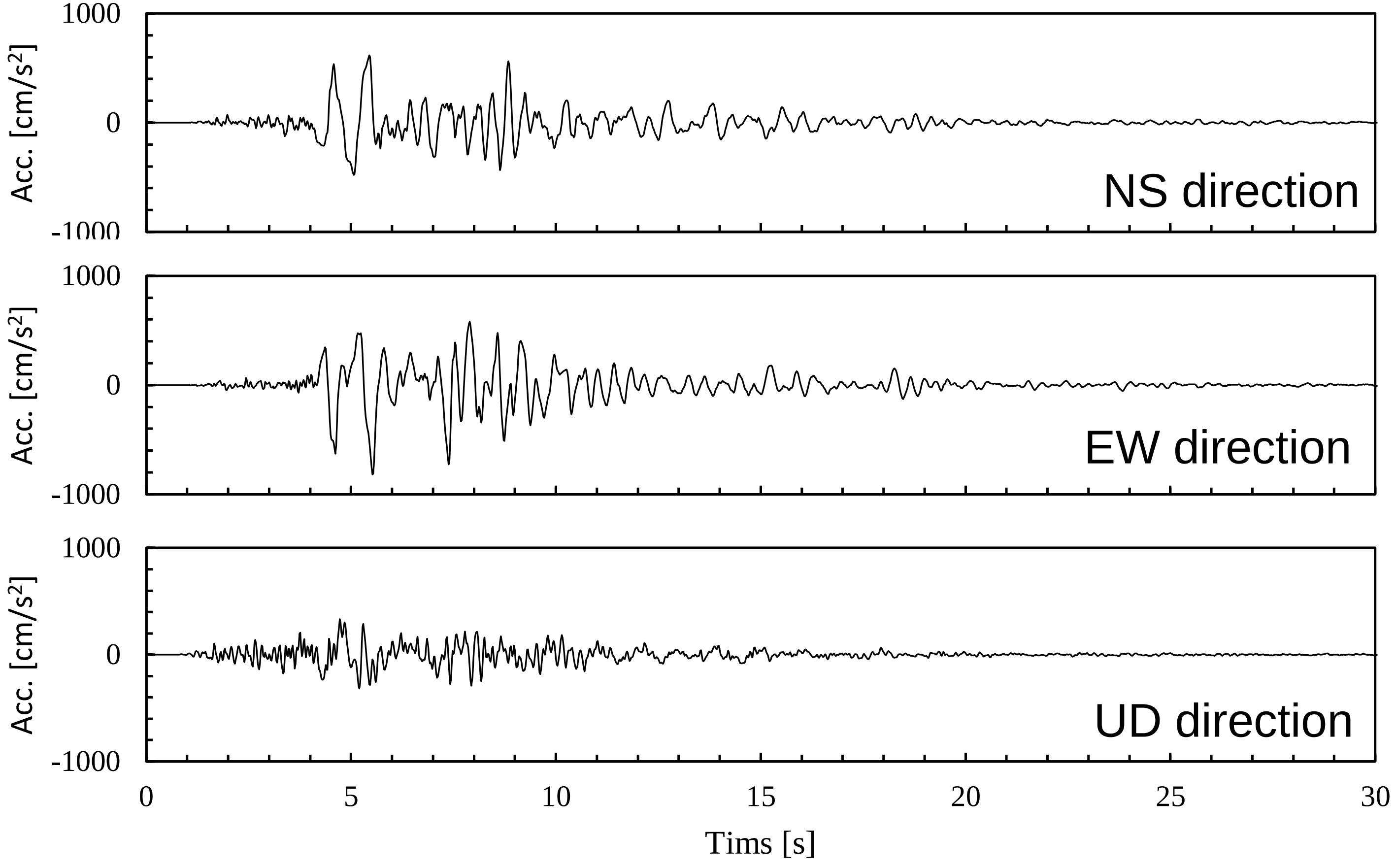


Analytical model

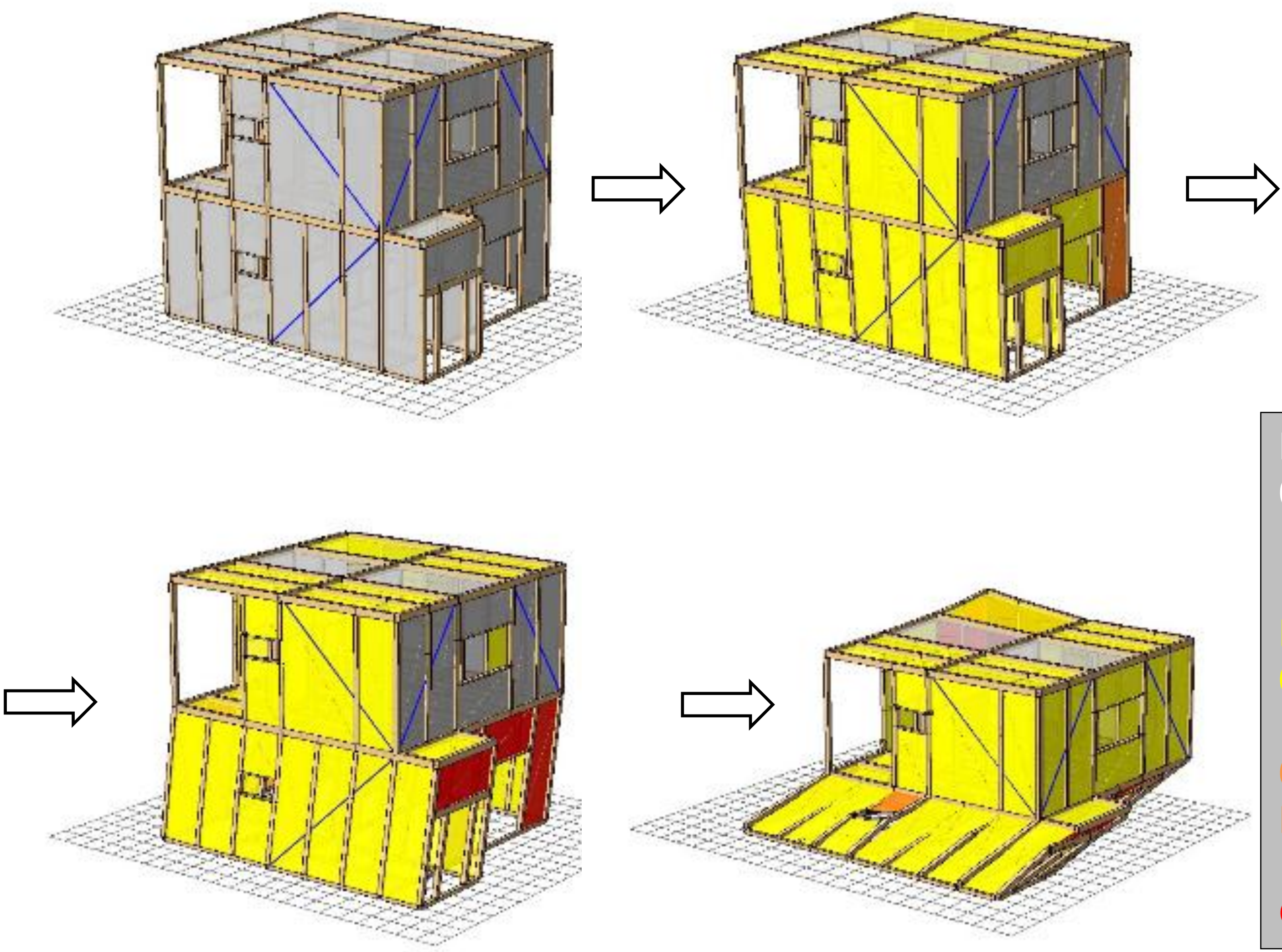
*The Building Research Institute in Japan

Input motion

- The strong motion record observed by Japan Meteorological Agency during the 1995 Southern Hyogo prefecture earthquake occurred in Japan (JMA Kobe)



Snapshots of the house collapse process



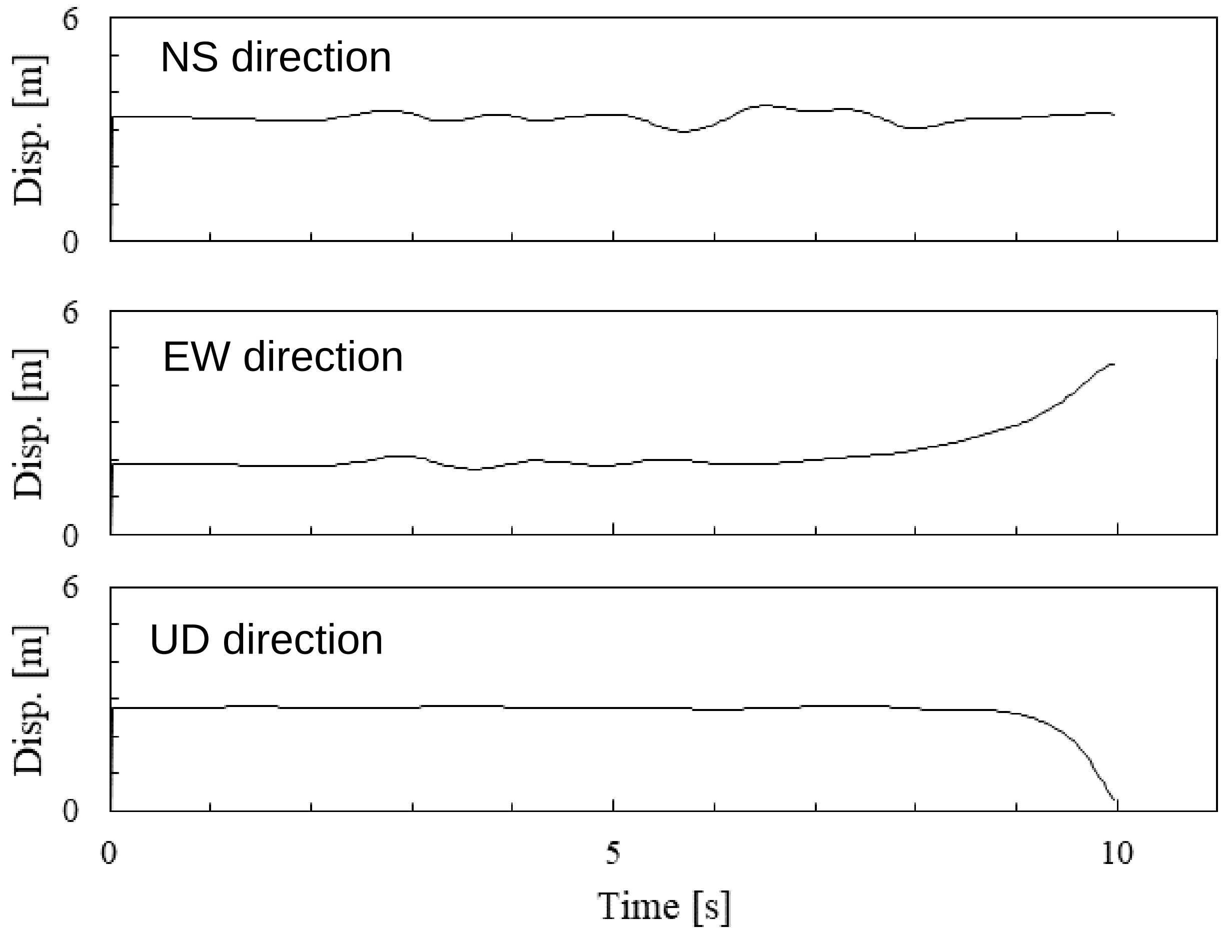
Deformation angle < 0.008 [rad]

0.008 [rad] ≦ Deformation angle < 0.033 [rad]

0.033 [rad] ≦ Deformation angle

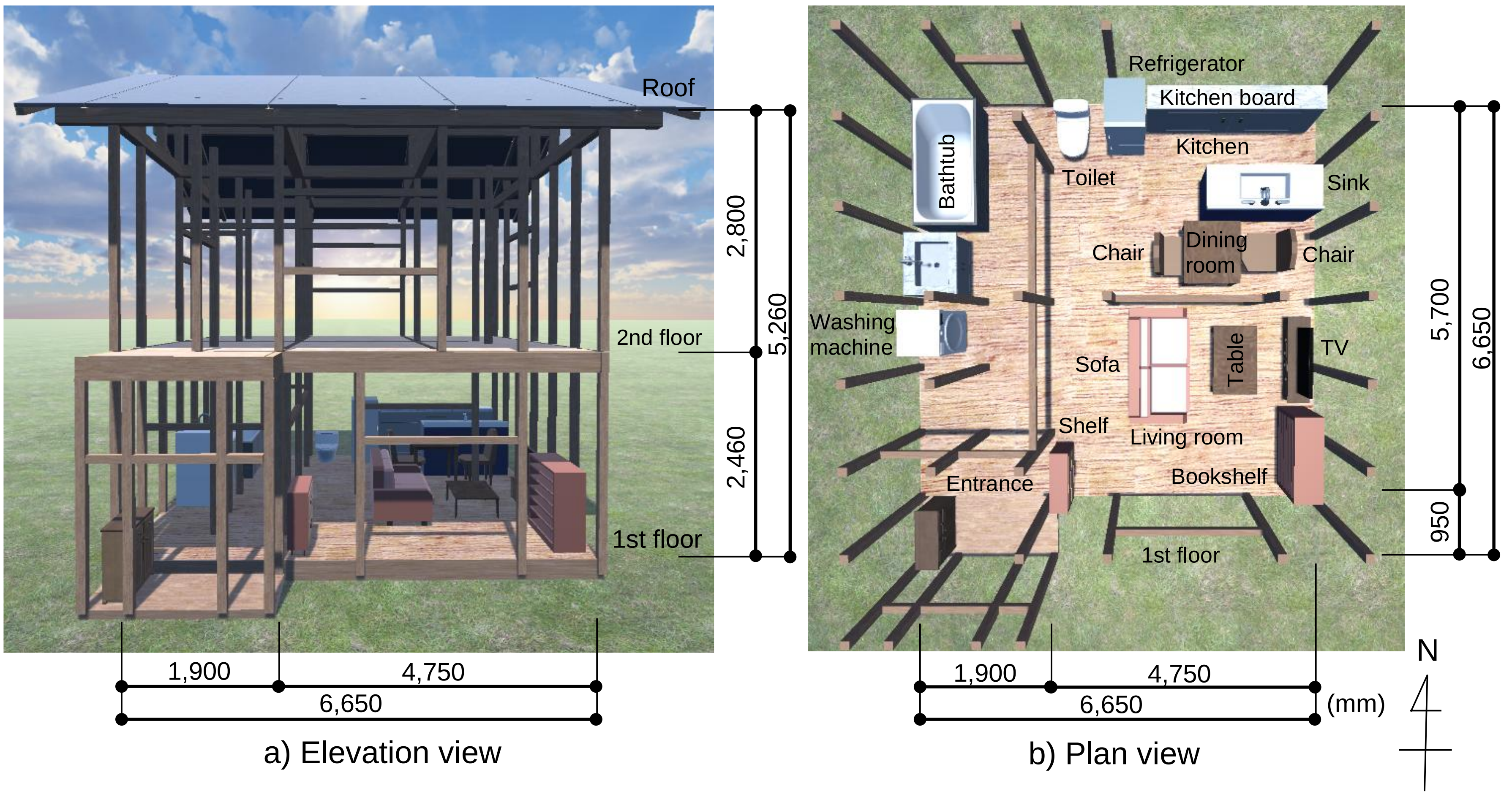
Collapsed

Results of collapse analysis of the wooden house



The results of this collapse analysis are input into a building model built using a physics engine to control the building behaviour.

Analysis model in physics engine



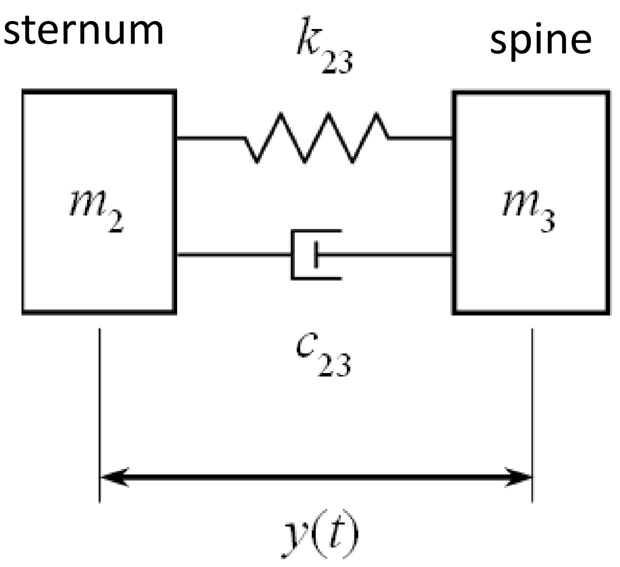
a) Elevation view

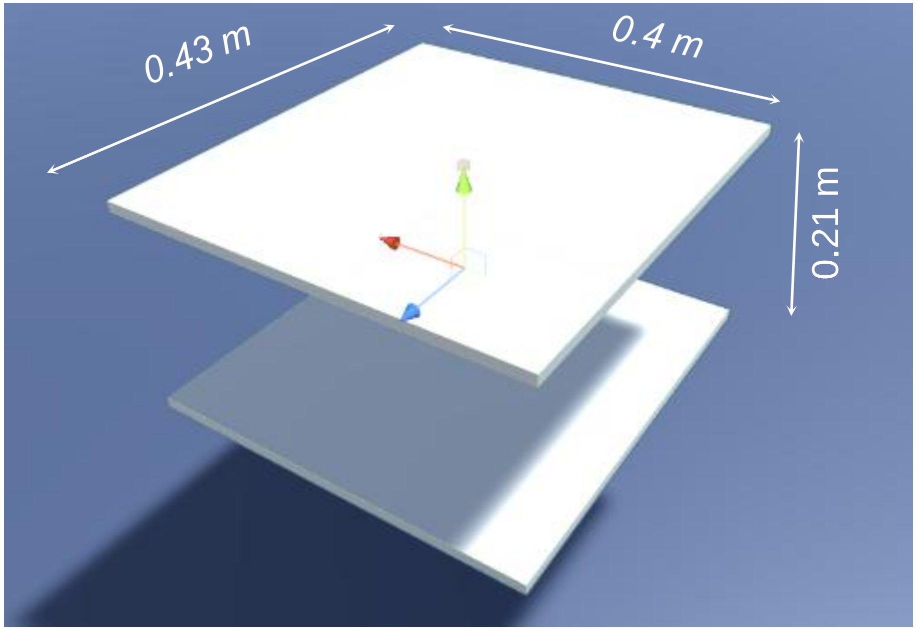
b) Plan view

Parameter of furniture

		Chair	Shelf	Sofa	TV	TV stand	Bookshelf	Table	Refrigerator	Microwave oven
Size (m)	Width	0.40	0.80	1.55	0.93	1.20	1.20	0.99	0.60	0.55
	Height	0.80	0.90	0.80	0.60	0.30	1.00	0.74	1.80	0.35
	Depth	0.45	0.30	0.80	0.05	0.40	0.40	0.74	0.60	0.35
Aspect ratio		0.500	0.333	1.000	0.083	1.333	0.400	1.000	0.333	1.000
Mass (kg)		6.0	20.0	40.0	5.0	20.0	35.0	45.0	130.0	10.0
Static friction coefficient		0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Dynamic friction coefficient		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Thorax Model of human body





Thorax model in physics engine

The values of each parameter of the model were set based on Korell*'s experimental conditions.
m2: 0.45 [kg], m3: 27.2 [kg]
k23: 26.3 [kN/m], C23: 0.52 [kNs/m]

*Korell, C.K., Scheider, D.C., Nahum, A.M. (1971), Impact Tolerance and Response to the Human Thorax, SAE Technical Paper 710851.

Anatomical conditions of each AIS score

- Thoracic injuries are highly correlated with thoracic deformation, which is the displacement of the sternum relative to the spine (Korell, 1971*).
- Thorax injuries are evaluated using the Abbreviated Injury Scale (AIS) (Baker 1974**).
- AIS evaluates the type of trauma and anatomical severity on a 6-point scale.

Anatomical conditions of each AIS score

AIS score	0	1	2	3	4	5	6
Injury level	No injury	Minor	Moderate	Serious	Severe	Critical	Fatal

$$AIS = -3.78 + 19.56 \times C_{max}$$

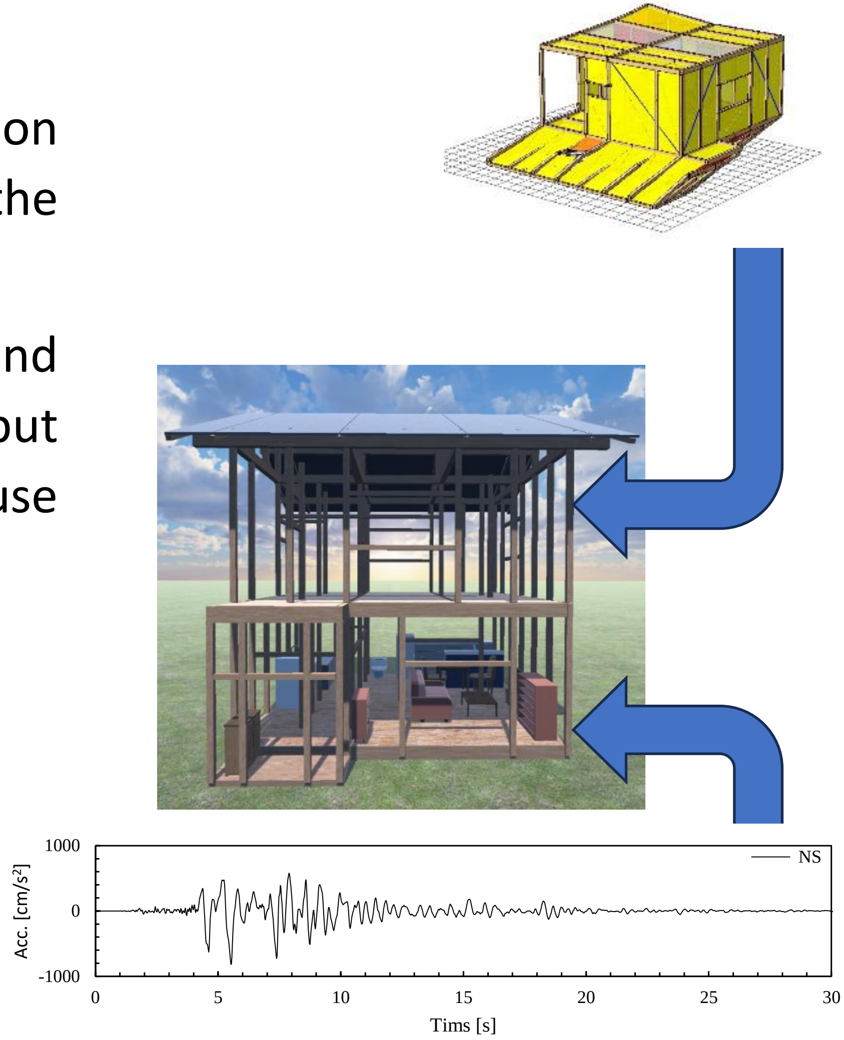
Cmax: the thorax maximum compressibility.
(The deformation of the thorax divided by the thorax thickness)

*Korell, C.K., Scheider, D.C., Nahum, A.M. (1971), Impact Tolerance and Response to the Human Thorax, SAE Technical Paper 710851.

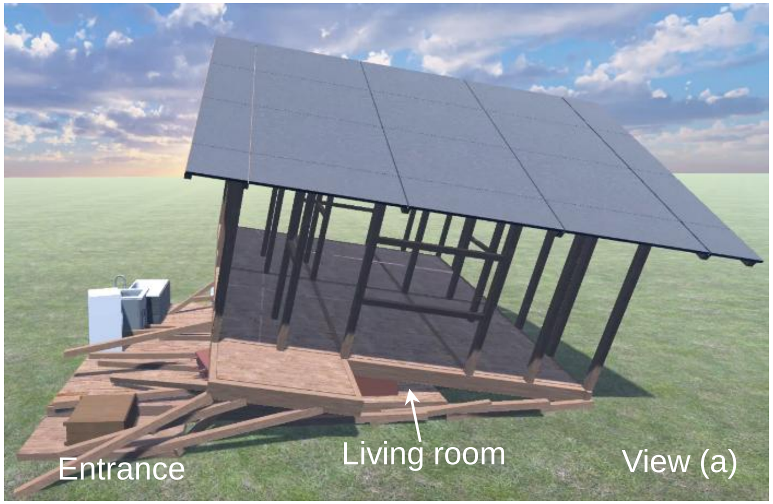
**Baker SP, O'Neill B, Haddon W Jr, et al. The injury severity score (1974), A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care. J Trauma, 14, 187-196.

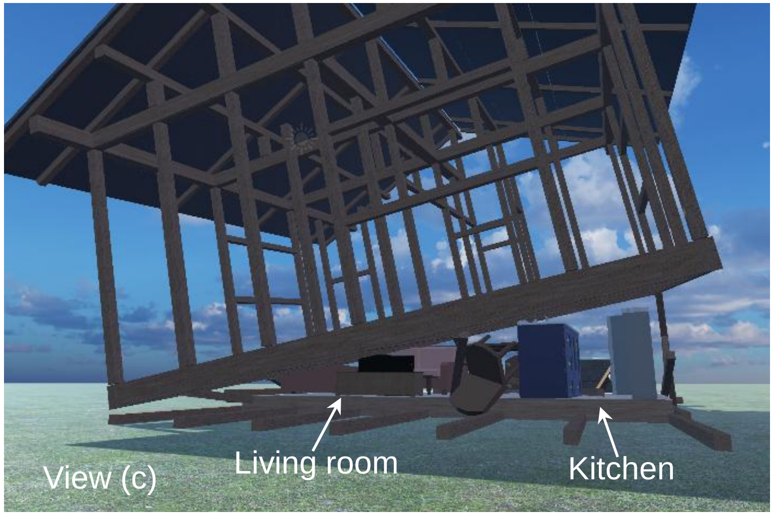
Analysis of Human Injury in Collapsing Wooden House

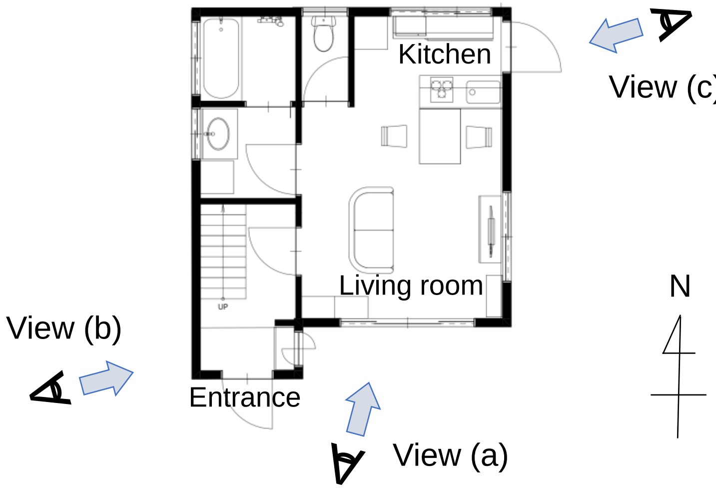
- The displacement waveform of strong motion record is input to the first floor of the wooden house model.
- The displacement waveforms of the second floor evaluated by the collapse analysis input to the second floor of the wooden house model.



Situation after the collapse of house

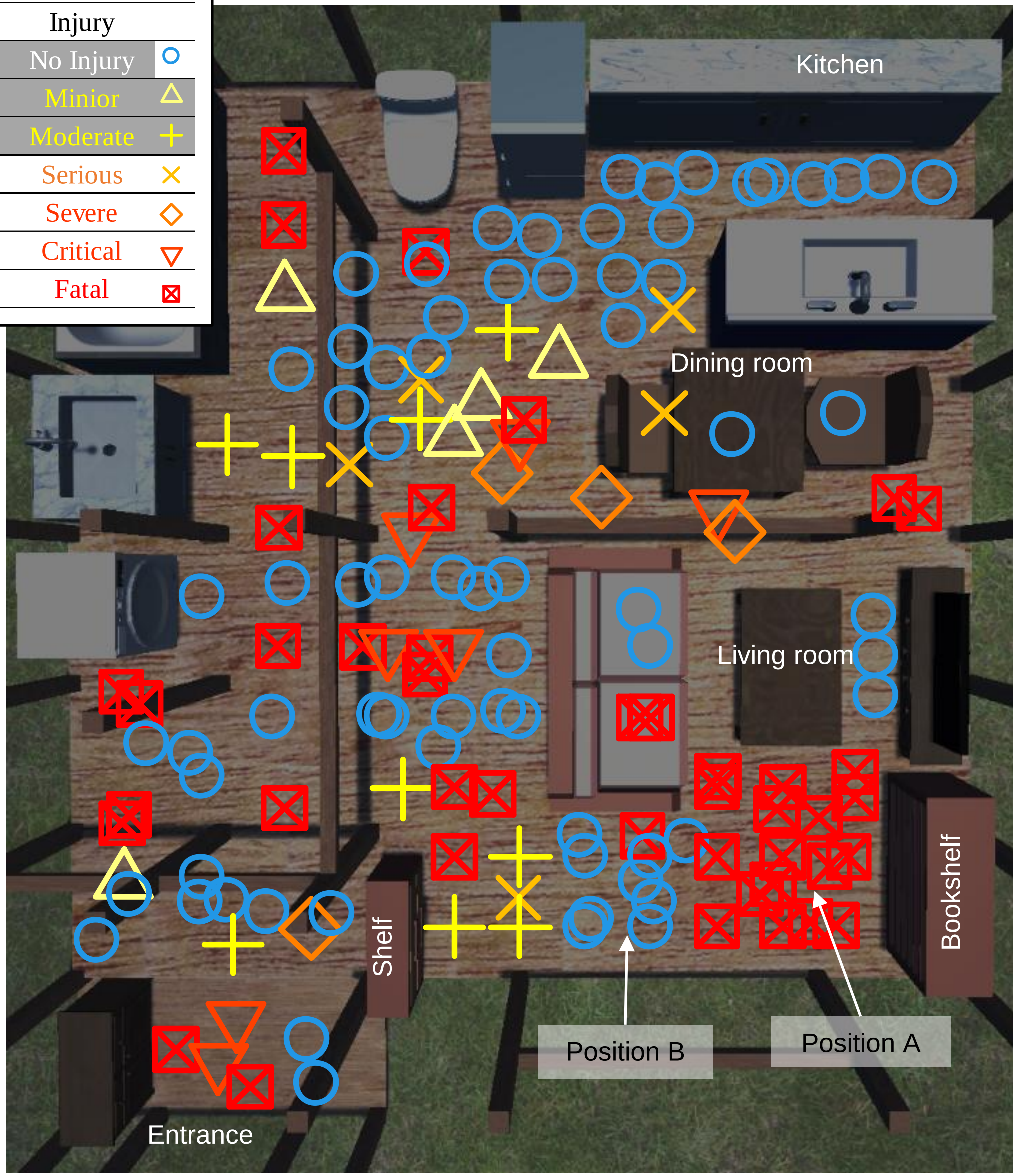






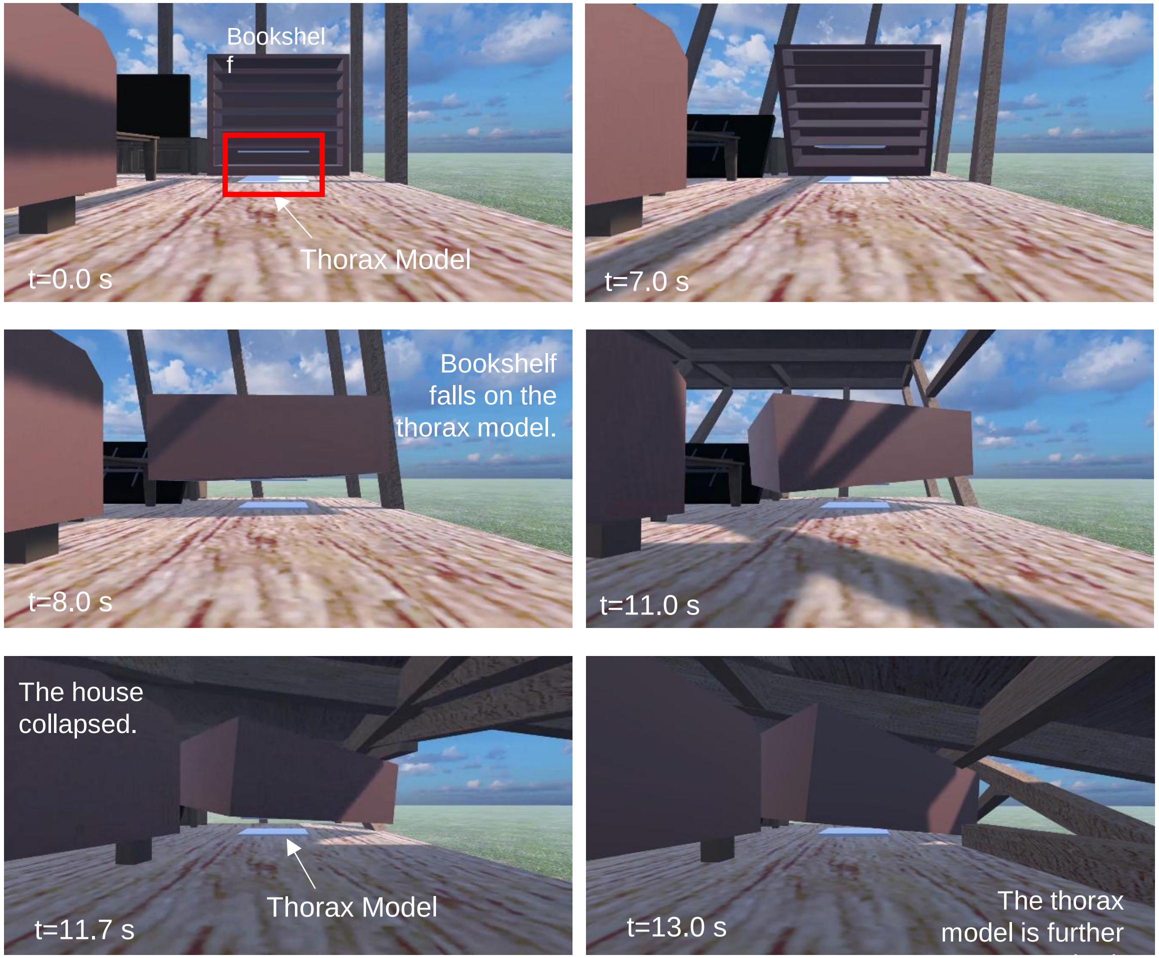
Distribution of AIS SCORE

AIS Score	Injury	
0	No Injury	○
1	Minior	△
2	Moderate	+
3	Serious	×
4	Severe	◇
5	Critical	▽
6	Fatal	⊠



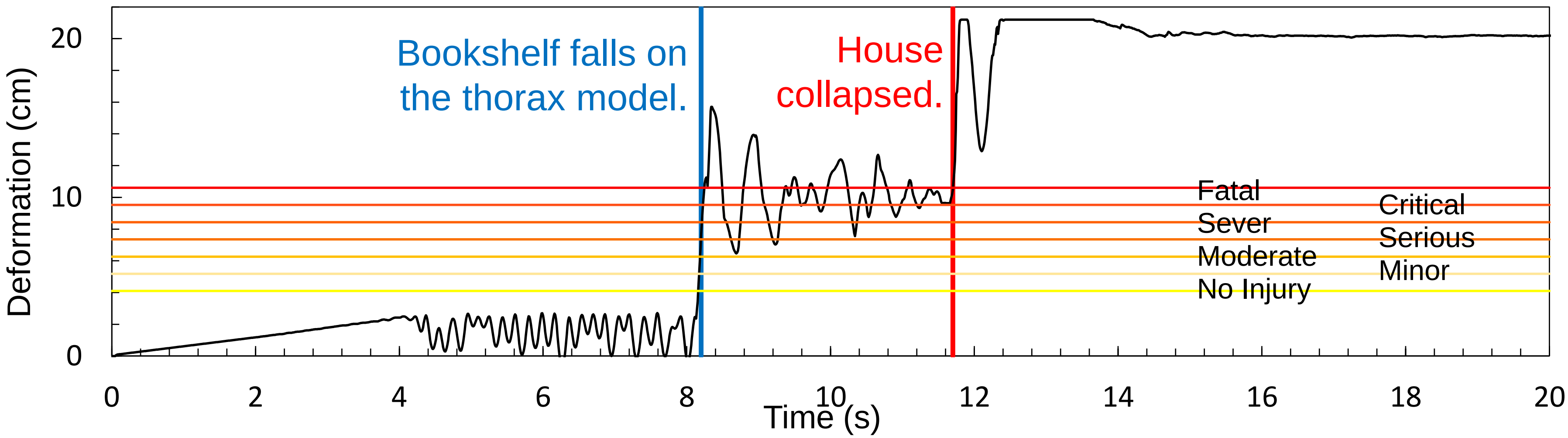
- The thorax model is placed in various positions on the first floor of the room.
- The AIS scores of the thorax model when it is compressed due to furniture falling over or the collapse of the house caused by shaking are obtained.
- The distribution of the AIS score in the room is investigated.

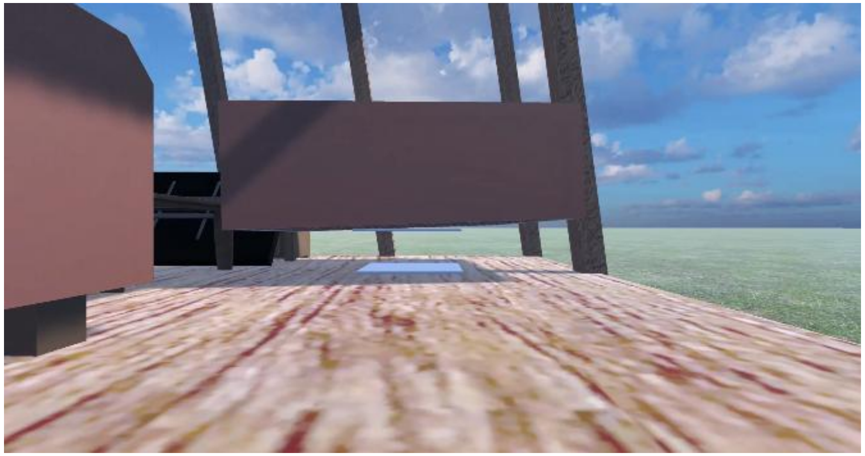
Snapshots at the position A (Fatal)

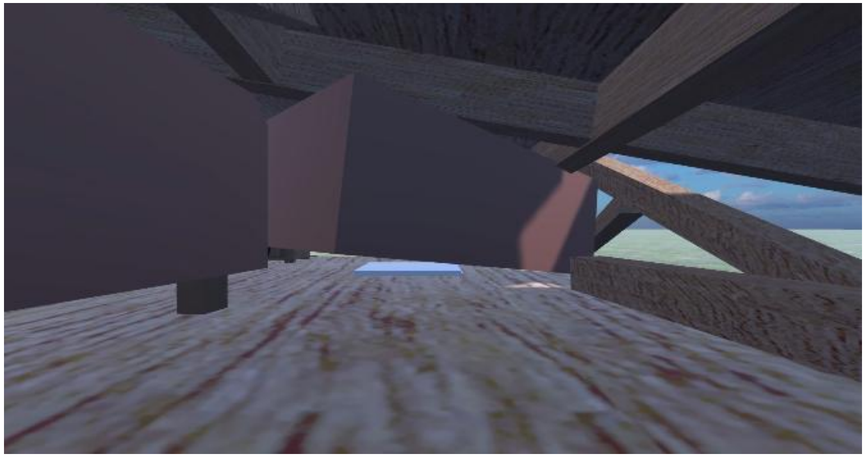


- The bookshelf tilted at 7 s, then it fell onto the thorax model at 8 s.
- The house significantly leaned at 11s, then the house collapsed at 11.7 s.
- The thorax model was further crushed by the falling second floor.

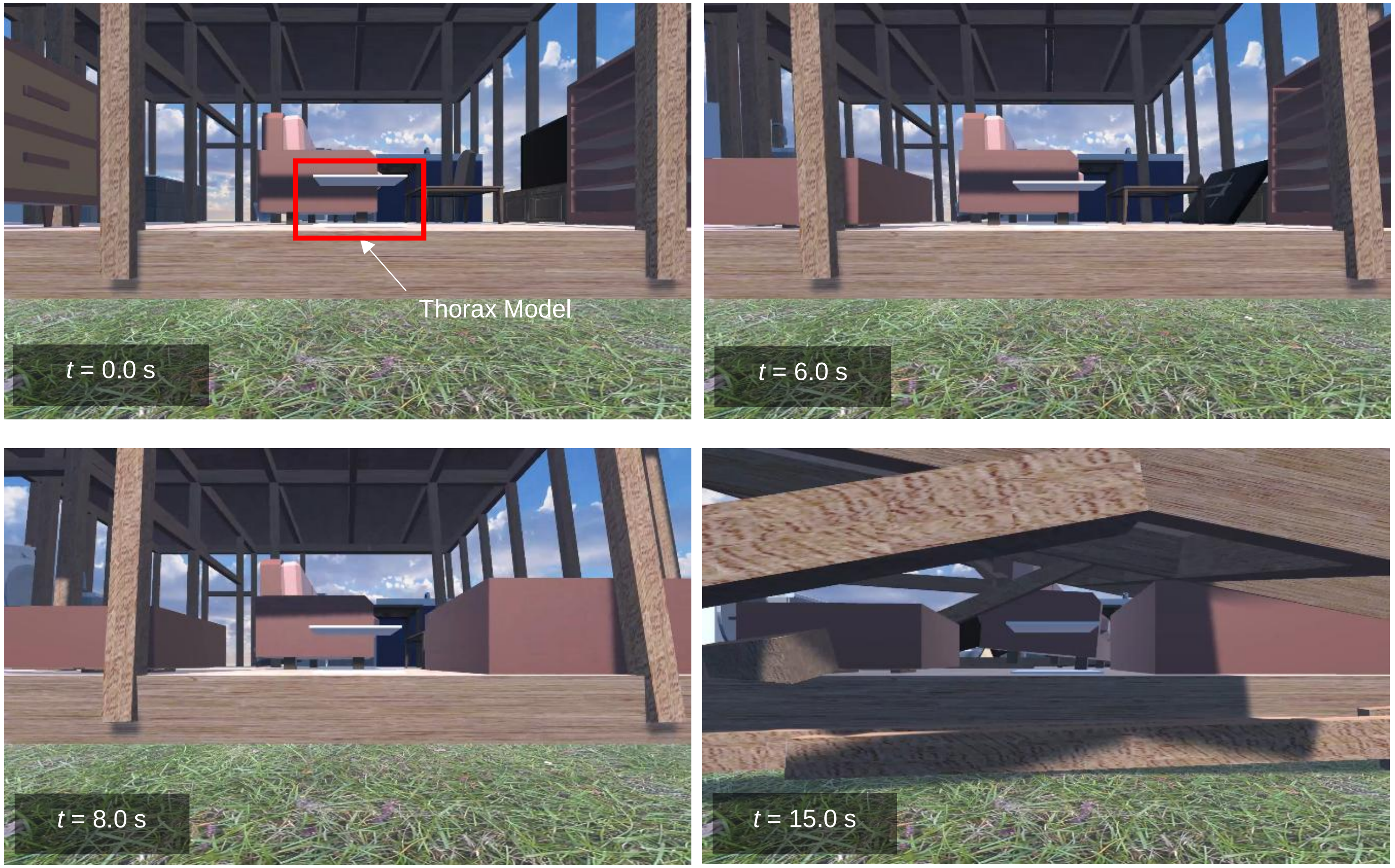
Time history of the thorax deformation







Snapshots at the position B (No injury)



- At around 8 seconds, the bookshelf placed on the right side of the thorax model fell over.
- The second floor fell at 15 seconds, but it was supported by the overturned shelves on both sides of the thorax model. The thoracic model did not be compressed.

Conclusion

- We investigated the human injury process by examining the thorax displacement associated with the collapse of a wooden house during an earthquake.

- If human was trapped under furniture and second floor fell on the furniture, the severity of injury according to the AIS score exceeded Fatal.

- If the first-floor collapses and the second-floor falls, human can avoid being crushed to death by staying between overturned furniture.

- By constructing a wooden house model using a physics engine, we can analyze not only the building behaviour but also the human damage during an earthquake.