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CHRONOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF CONVENTIONAL TIMBER FRAME CONSTRUCTION TECHNIQUES OBSERVED IN EXISTING HOUSES IN MIE PREFECTURE, JAPAN

Wakana Matsumoto[1], Chikako Tabata [2], Yoshito Tomioka [3]

ABSTRACT: This study aims to understand the diversity of conventional construction methods for timber houses in Mie Prefecture, Japan. These methods, which have evolved over time to accommodate local conditions, exhibit distinct chronological and geographical distributions. A questionnaire survey was conducted among inhabitants of timber houses in six districts: Hokusei, Chusei, Iga, Nansei, Shima, and Higashikishu area. The survey data were collected on foundation, floor, wall, and roofing to identify the patterns of adoption and regional variations. Comparative analysis with Kanto-region revealed distinct patterns in the adoption of modern materials and techniques. Kanto showed gradual transition to modern construction methods, whereas Mie rapidly adopted them after 2000. Exterior finish and roofing materials retained traditional elements and regional variations in Kanto and Mie, thereby indicating that these elements preserve local architectural characteristics.

KEYWORDS: questionnaire investigation, inhabitants, detached house

1 – INTRODUCTION

The objective of this research is to clarify the chronological characteristics of conventional timber frame construction methods in Mie Prefecture and to examine the geographical differences observed through these characteristics by comparing them with those in Kanto-region.

Wooden frame construction, primarily composed of columns and beams, has long been used in Japan and remains the predominant method for wooden houses today. This construction technique, which utilizes relatively small cross-section timber members, offers advantages in earthquake resistance due to its lightweight structure and low dead load. In addition, it is cost-effective, as it does not require large-scale factory processing or production. Furthermore, this method is characterized by high adaptability to diverse floor plans, flexibility for partial renovations and expansions, and a tendency to reflect geographical characteristics in building production.

2 – BACKGROUND

Nationwide studies on the transition of timber frame houses in Japan include a series of reports by Shinkai (1955) [1] and a survey conducted by Watanabe [2] in the 1970s. Both studies were large-scale, multi-year projects conducted by the Building Research Institute under the Ministry of Construction at the time. Since then, several reports have been published by the Uchida-Sakamoto Laboratory at the University of Tokyo and related research groups.

The authors have been conducting surveys and reports—primarily questionnaire surveys targeting architects and designers [3] —continuously since around 2000. In addition, Mori et al. [4] conducted a questionnaire survey targeting inhabitants, which was presented at WCTE 2016. Based on the study by Mori et al., this study conducted a questionnaire survey among residents of Mie Prefecture in 2021. This paper presents the results, analysis, and key insights through a comparative study with Kanto-region report by Mori et al.

[1] Wakana Matsumoto, B.Eng., Graduate Student, Division of Architecture, Graduate School of Engineering, Mie University, Tsu-city, Mie, Japan. wakana.mieuniv@gmail.com

[2] Chikako Tabata, Associate Professor for timber structure and construction, Division of Architecture, Graduate School of Engineering, Mie University, Tsu-city, Mie, Japan, tabata@arch.mie-u.ac.ip, https://orchid.org/0000-0003-1326-741X

[3] Yoshito Tomioka, Architect, Dr. Eng., Professor for architectural design, Division of Architecture, Graduate School of Engineering, Mie University, Tsu-city, Mie, Japan. tomioka@arch.mie-u.ac.ip, https://orchid.org/0000-0002-1077-7636

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3 – PROJECT DESCRIPTION

The left side of Fig. 1 shows the locations of Mie Prefecture and Kanto-region, which was the survey area in the report by Mori et al. on a map of Japan. Mie Prefecture is situated near the geographic and cultural boundary that divides Japan into eastern and western regions. Kanto-region comprises one metropolis and six prefectures: Tokyo Metropolis, Kanagawa, Chiba, Saitama, Ibaraki, Gunma, and Tochigi.

The right side of Fig. 1 illustrates Mie Prefecture, the survey area, divided into six regions: Hokusei, Chusei, Iga, Nansei, Shima, and Higashikishu, based on administrative divisions. Hokusei area is part of the Nagoya Metropolitan Area. Iga, with strong historical ties to the Kansai region, has good access to Osaka and is partially included in the Kinki region. Nansei area is home to the famous Ise Jingu, while Shima area has numerous scattered fishing villages. Higashikishu area has a history of direct transportation and trade of building materials, such as timber, and food products, such as fruits, to Edo (present-day Tokyo) during the Edo period when marine transportation was well-developed.

Given these distinct historical, cultural, and economic characteristics, the survey was conducted evenly across the prefecture. Two or three towns were selected from each region, and around 450 questionnaires were distributed per region. Densely populated residential areas that appeared historically established were chosen, while newly developed housing areas were excluded. The questionnaires were mailed to single-family homes across each town, with a total of 2,710 questionnaires distributed. Table 1 presents the breakdown and response rates. Responses from houses with 2 × 4, reinforced concrete, steel-frame, or mixed construction were excluded from the analysis. Consequently, only responses from residents of detached timber frame houses were analyzed, resulting in 272 valid responses (collection rate: 10.0%). According to Mori et al. [4], Kanto-region survey was conducted in 2015, with 3,258 questionnaires distributed and 9.9 valid responses received.

For this analysis, responses containing missing data, illegible content, or apparent errors were excluded as necessary. In addition, to ensure comparability with the Kanto survey, responses other than the "others" option were excluded, though their number was small.

The questionnaire conducted in Mie Prefecture collected various types of information, categorized into three groups, as shown in Table 2. This paper reports and analyzes the results of Category 3. The questions in Category 3 were designed to match those in the Kanto survey in both content and wording. However, for the exterior wall finish question, different options were included to reflect regional circumstances.

Multiple responses were allowed for questions regarding exterior wall and roofing materials. As a result, the number of analyzed responses varies across graphs. To account for this, the total number of responses (N) is indicated within each graph.

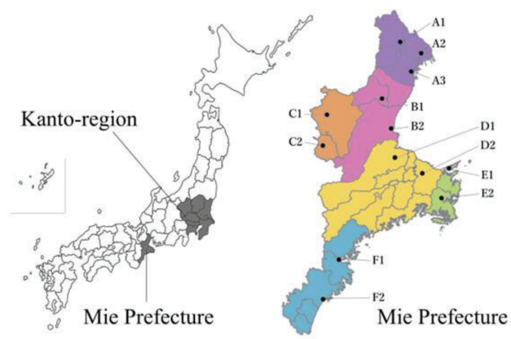


Figure 1. Mie prefecture, and six areas with port of selected towns.

Table 1: Valid Responses rate

<Mie prefecture, 2021>

Area and Marker of selected town in Fig.1			Valid response rate (%)	
	Hokusei	A1	16/163 (9.8)	36/442 (8.1)
		A2	11/125 (8.8)	
		A3	9/154 (5.8)	
	Chusei	B1	16/226 (6.6)	45/431 (10.2)
		B2	29/205 (14.1)	
	Iga	C1	25/243 (10.3)	47/460 (10.4)
		C2	22/217 (10.1)	
	Nansei	D1	26/230 (11.7)	45/460 (9.8)
		D2	19/230 (8.3)	
	Shima	E1	19/209 (9.1)	57/471 (12.1)
		E2	38/262 (14.5)	
	Higashikishu	F1	30/245 (12.2)	42/446 (9.4)
		F2	12/201 (6.0)	
Total			272/2710 (10.0)	

<Kanto-region>

Total	323/3258 (9.9)

Table 2: Question items and Categories

Categories		Question items
1)	Building specifications	(a) Completion year (b) Building address (c) Rehabilitation history etc.
2)	History of seismic diagnosis and reinforcement	(a) Year of reinforcement (b) Owner’s knowledge (c) Cost etc.
3)	Construction methods	(a) Foundation (b) Wall (c) Floor (d) Roof

4 – RESULTS

4.1 FOUNDATION

The foundation of Japanese houses has evolved from isolated foundations to footing foundations and, more recently, to raft foundations. Isolated foundations support columns at discrete points, whereas footing foundations distribute the building load continuously along a linear path. Raft foundations, which provide the highest earthquake resistance, are particularly effective on soft ground due to their integrated, planar structure.

Fig. 2 presents the survey results on the foundation types of conventional houses. The results for Mie Prefecture are shown on the left, while those for Kanto-region are on the right. To facilitate comparison with the previous study on Kanto-region, houses were classified by construction year in 10-year intervals, with all responses prior to 1970 grouped together.

The foundation types were categorized into three groups: isolated foundation (green), footing foundation (red), and raft foundation (blue). Unanswered and unclear responses were excluded. As a result, the number of valid responses (N) shown in Fig. 2 is 164 for Mie Prefecture and 213 for Kanto-region. The numbers within the bars indicate the response count for each category.

In Mie Prefecture, from 1981 to 2000, the adoption of isolated foundation considerably declined, whereas footing foundation became the predominant choice. Raft foundation was adopted at a rate of approximately 20% from the outset, particularly as a measure against soft ground, with no notable regional bias. After 2000, the adoption rate of raft foundations increased sharply, accounting for approximately 90% of all foundations.

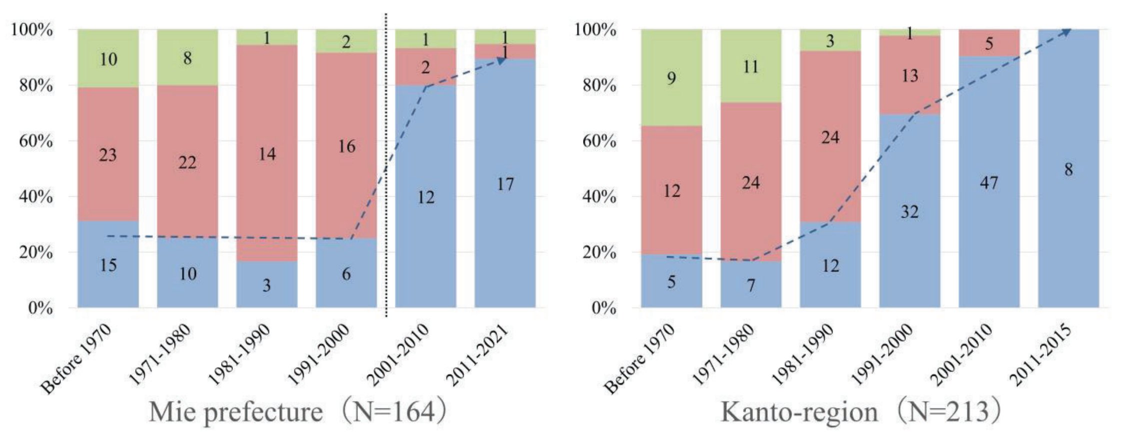
In Kanto-region, the adoption of raft foundations began increasing in the early 1990s and continued to rise gradually thereafter. After 2001, raft foundations became the dominant type, similar to the trend in Mie Prefecture. However, while both regions transitioned from isolated and footing foundations to raft foundations, differences were observed in the timing and pace of adoption. In Kanto-region, the shift from footing foundation to raft foundation was gradual, beginning in the 1990s, whereas in Mie Prefecture, raft foundations spread rapidly after 2001. This suggests that Mie Prefecture lagged behind Kanto-region in adopting raft foundations by approximately 10 years.

4.2 FLOOR

Traditionally, floor frames in Japanese wooden houses consisted of narrow wooden boards. However, in recent years, plywood has increasingly replaced wooden boards to enhance construction efficiency and structural performance.

Fig. 3 presents the survey results on floor frame materials in Mie Prefecture and Kanto-region. Floor frames were classified into two types: wooden board (red) and plywood (blue).

In Mie Prefecture, the utilization rate of plywood remained around 40% until the early 1990s but increased sharply after the 2000 revision of the Building Standards Act, reaching approximately 70% by 2001. However, after 2001, its adoption showed a declining trend, dropping to around 55% by 2011. Meanwhile, the use of wooden board has remained between 50% and 60%. Given that wooden board represents an older construction method, it is unlikely that their share will increase in the future. Considering that respondents were



Isolated foundation Footing foundation Raft foundation

Figure 2. Trends in Adoption Rates by Foundation Type

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not construction specialists, some may have mistakenly identified wooden board as finishing flooring materials. Further detailed investigations are needed to accurately assess the adoption of plywood in floor frames.

In contrast, the adoption of plywood in Kanto-region has shown a steady, linear increase across all construction periods. By 2011, its usage had reached approximately 90%.

4.3 WALL

4.3.1 SHIN-KABE AND O-KABE

Fig. 4 compares the chronological adoption trends of Shin-kabe (red) and O-kabe (blue) between Mie Prefecture and Kanto-region.

In Mie Prefecture, the adoption rate of O-kabe remained between 10% and 20% until 1990, with Shin-kabe being the predominant style. However, after 1991, the adoption of O-kabe increased, reaching a turning point in 2001 when it surpassed Shin-kabe for the first time. Since then, the adoption rates of both types have remained nearly equal, at around 55%. Regionally, the O-kabe adoption rate is particularly high in Hokusei and Iga area, especially in Hokusei area, where it exceeds 50%. In other areas, Shin-kabe continues to be adopted at relatively higher rates.

In Kanto-region, the adoption of O-kabe has followed a steady upward trend since the 1970s, reaching 100% by 2011.

Both regions exhibit a transition from Shin-kabe to O-kabe, but with notable differences in timing. In Kanto-region, the shift to O-kabe was gradual, and in recent years, it has become the standard for all buildings. In contrast, the transition in Mie Prefecture started slightly later, and even in recent years, Shin-kabe continues to be adopted in approximately half of the houses. In addition, Mie Prefecture lagged Kanto-region for adopting O-kabe by approximately 20 years.

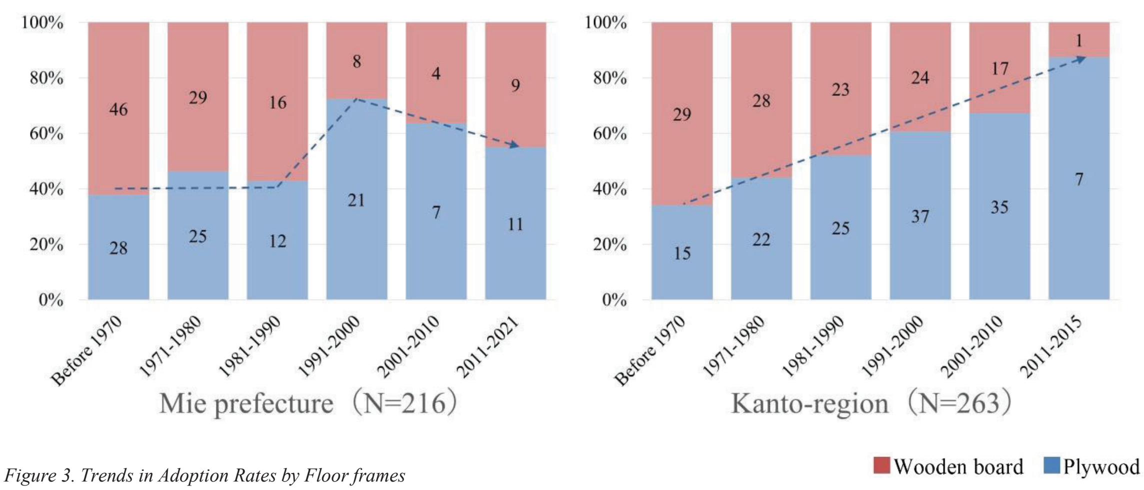

Figure 3. Trends in Adoption Rates by Floor frames

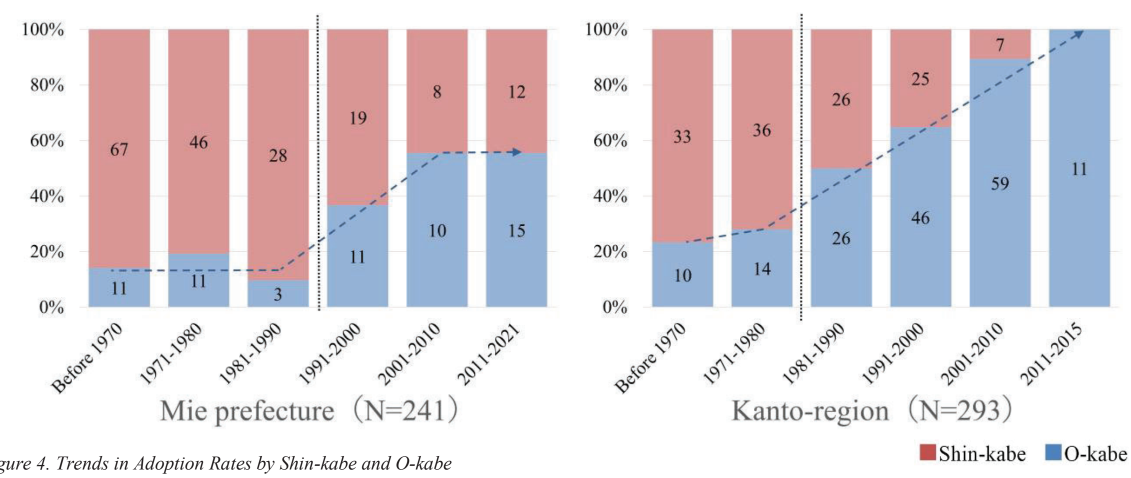

Figure 4. Trends in Adoption Rates by Shin-kabe and O-kabe

4.3.2 SHEAR WALLS

Traditionally, the shear walls of Japanese wooden houses were constructed using penetrating ties and mud walls, with bracing later becoming the predominant method. However, in recent years, the use of structural plywood has increased due to growing demands for improved seismic performance and shorter construction periods. Fig. 5 illustrates the chronological changes in the adoption rates of different shear wall types in Mie Prefecture and Kanto-region. Shear walls are categorized into three types: only bracing (green), only structural plywood (red), and a combination of both (blue).

In Mie Prefecture, the use of only bracing accounted for a high percentage (70%–80%) until 2000. The adoption of only structural plywood was minimal, while the use of both bracing and structural plywood remained relatively high at around 20%. Since 2001, the adoption of only bracing has sharply declined, while the use of both bracing and structural plywood has rapidly increased to approximately 60%. However, the adoption of structural plywood alone has remained low. Regionally, approximately 30% of respondents in the Iga area reported using structural plywood, either alone or in combination, indicating a higher adoption rate compared to other regions. In addition, in Nansei area, the adoption of structural plywood was particularly high during the periods 1971–1980 and 2001–2010.

In Kanto-region, bracing remained the predominant method from the 1970s to 2000, and similar to Mie Prefecture, the adoption of structural plywood alone was low. From 1980s, the use of both bracing and structural plywood gradually increased, with the adoption rate exceeding 50% in recent years.

While both Mie Prefecture and Kanto-region show an increasing trend in the adoption of structural plywood, it is primarily used in combination with bracing rather than as a standalone material, indicating the continued widespread use of bracing. In addition, when compared with the adoption trends of O-kabe shown in Fig. 4, the use of structural plywood for shear walls in Mie Prefecture increased approximately 10 years later.

4.3.3 EXTERIOR WALL FINISH

Traditional Japanese construction used plasterwork and wooden panel boards for exterior wall finish with mud walls as a substrate. Around 1970, mortar became the predominant choice nationwide. However, in recent years, there has been a transition toward siding due to its enhanced durability and construction efficiency. Fig. 6 illustrates the chronological changes in exterior wall materials, categorized into four types: plasterwork (purple), wooden panel board (green), mortar (red), and siding (blue).

In Mie Prefecture, the adoption rate of siding was slightly high, remaining around 40% until 1990 before increasing to 80% after 2001, making it the most common exterior wall finish today. The adoption rate of mortar remained at approximately 20% throughout the study period but has fallen below 10% since 2011. A distinctive feature in Mie is the presence of wooden panel board, which accounted for around 30% of homes before 1970 and have since maintained a share below 20%. Plasterwork, the most traditional method, temporarily increased from 1971 to 1980 before gradually declining, though it remains in use even from 2011 to 2021. Regionally, the adoption of siding is higher in Nansei and Shima areas. The Iga area shows a slightly higher adoption of mortar, primarily in houses from the 1970s. In addition, in Iga

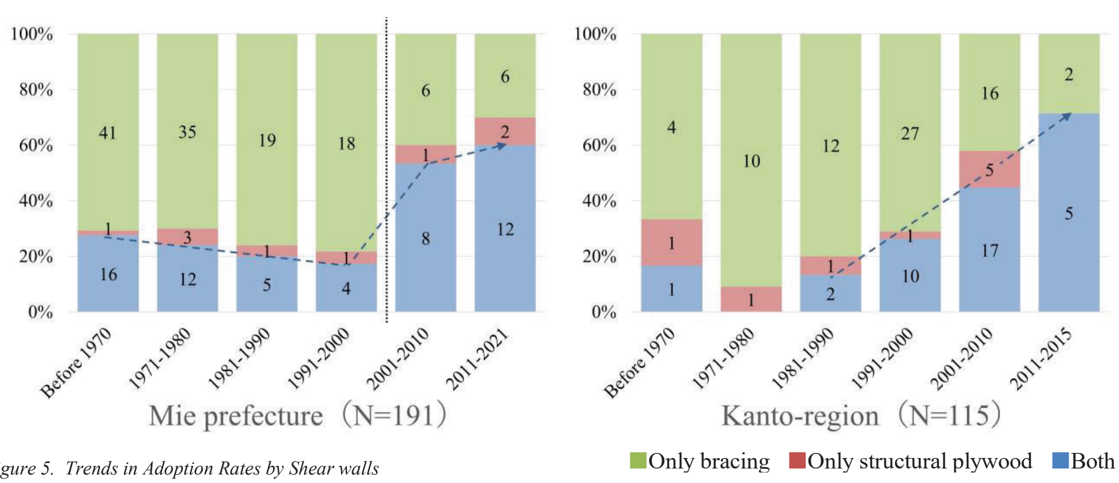

Figure 5. Trends in Adoption Rates by Shear walls

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area, the adoption rates for plasterwork and wooden panel board are higher than in other regions, with wooden panel board particularly common in Shima area.

In Kanto-region, siding has also gained popularity, but its adoption has been more gradual, ultimately reaching only about 60%. Mortar, in contrast, has maintained a significant share of over 30%, indicating continued demand. The adoption of plasterwork has gradually declined, with no confirmed responses after 2011.

As described above, siding has become the dominant exterior wall material in both regions, though its adoption is slightly higher in Mie Prefecture. However, Kanto-region continues to maintain a notable share of traditional mortar construction. Meanwhile, in Mie Prefecture, wooden panel boards remain in use, and plasterwork, the most traditional method, has persisted beyond 2011. These findings suggest that regional factors significantly influence exterior wall finish preferences.

4.4 ROOF

4.4.1 ROOF-BASE MATERIALS

Similar to floor frames, traditional Japanese wooden houses originally used wooden boards for roof-base materials. However, in recent years, there has been a shift toward plywood, which offers improved structural integrity and construction efficiency. Fig. 7 illustrates the chronological changes in roof-base materials in Mie Prefecture and Kanto-region. The materials are classified into two types: wooden board (red) and plywood (blue).

In Mie Prefecture, the adoption rate of plywood for roof-base materials remained stable at approximately 20% until 1990. However, after 1991, its use gradually increased, surpassing that of wooden board in 2001 and stabilizing at around 70% thereafter. Regionally, the Higashikishu area showed a distinct pattern, where wooden board continued to dominate, and the adoption of plywood remained minimal.

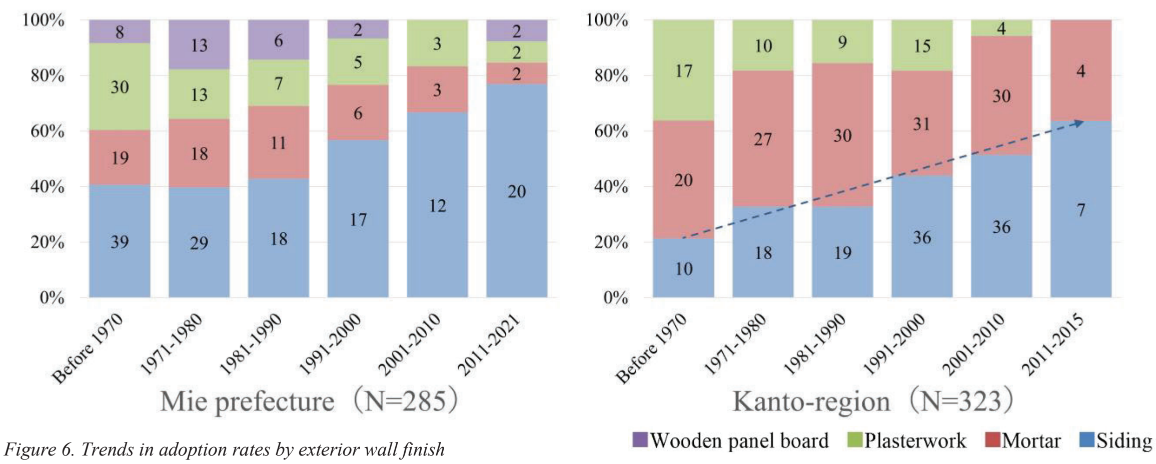

Figure 6. Trends in adoption rates by exterior wall finish

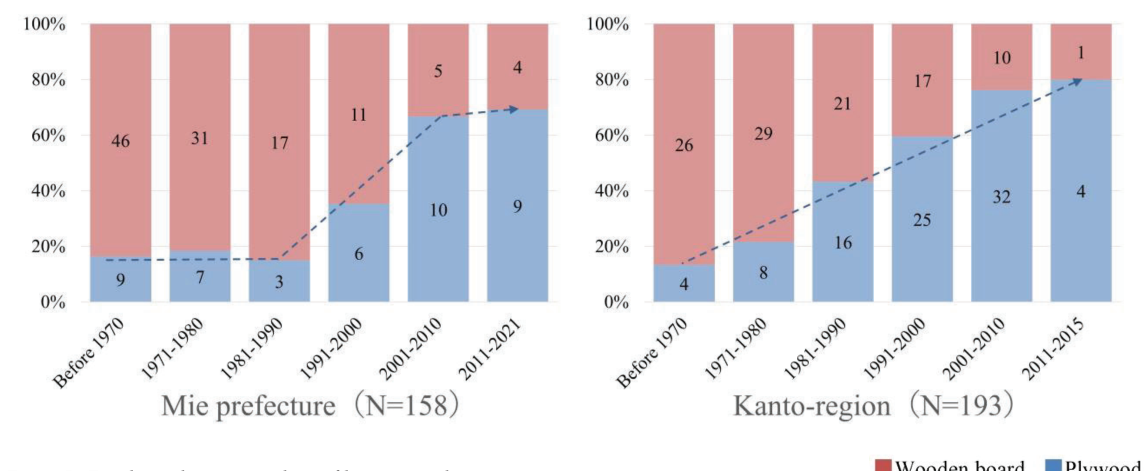

Figure 7. Trends in adoption rates by roof-base materials

In Kanto-region, the transition to plywood followed a steady, linear increase from 1971 onward. In recent years, the adoption rate has reached approximately 80%.

These findings confirm a general shift from wooden board to plywood in both regions. However, while the transition in Kanto-region was gradual and began earlier, Mie Prefecture experienced a more abrupt shift after 1991. Furthermore, when comparing the adoption timeline of plywood in shear walls and floor frames, it is evident that in both regions, plywood spread first in floor frames, followed by near-simultaneous adoption in shear walls and roof-base materials.

4.4.2 ROOFING MATERIALS

Traditionally, Japanese roof tiles were the predominant roofing material in Japan. However, in recent years, there has been a shift toward slate and metal sheets to reduce construction time and overall roof weight.

Fig. 8 illustrates the chronological changes in roofing materials over time. The roofing materials are categorized into four types: slate roof (blue), Japanese roof tile (red), Western roof tile (green), and metal sheet roof (purple).

In Mie Prefecture, Japanese roof tiles maintained a high adoption rate of approximately 80% until 2000. Although this proportion has declined since 2001, they still hold a 40% market share today.Slate roofing consistently remained around 10%, but between 2001 and 2010, its adoption surged to 40%. However, since 2011, it has stabilized at around 20%. The adoption of metal sheet roofing was around 10% until 1970, after which it saw minimal use. However, its adoption began to rise around 2000, reaching 30% since 2011. Western roof tiles have maintained a consistently low adoption rate throughout the observed period. This study found no significant regional variations within Mie Prefecture.

In Kanto-region, Japanese roof tiles accounted for more than 50% of roofing materials until 1980s. During the 1970s and 1980s, the use of slate roofing increased, eventually exceeding Japanese roof tiles. Western tile roofing saw a temporary increase, reaching about 20% between 2001 and 2010. The adoption of metal sheet roofing gradually declined until 2000, stabilizing at around 10% between 2001 and 2010. Notably, slate roofing showed a continuous upward trend, reaching 100% adoption after 2011.

In summary, Mie Prefecture exhibited an exceptionally high adoption rate of Japanese roof tiles until 2000, but in recent years, the adoption rates of Japanese roof tiles, slate, and metal sheets have become more balanced. In contrast, Kanto-region demonstrated a diverse range of roofing materials until 1990. However, in recent years, demand for slate roofing has sharply increased, leading to the near-complete phase-out of other materials.

5 – CONCLUSION

This study presented a comparative analysis of the chronological evolution of conventional wooden-framed houses in Mie Prefecture and Kanto-region of Japan. In Kanto-region, there has been a gradual and steady transition toward modern materials and construction methods. By 2011, an almost complete shift had occurred, except for exterior wall finishes and roofing materials. However, mortar remains widely used for exterior wall finishes in recent years, indicating some continued preference for traditional methods.

In contrast, Mie Prefecture underwent a rapid transition

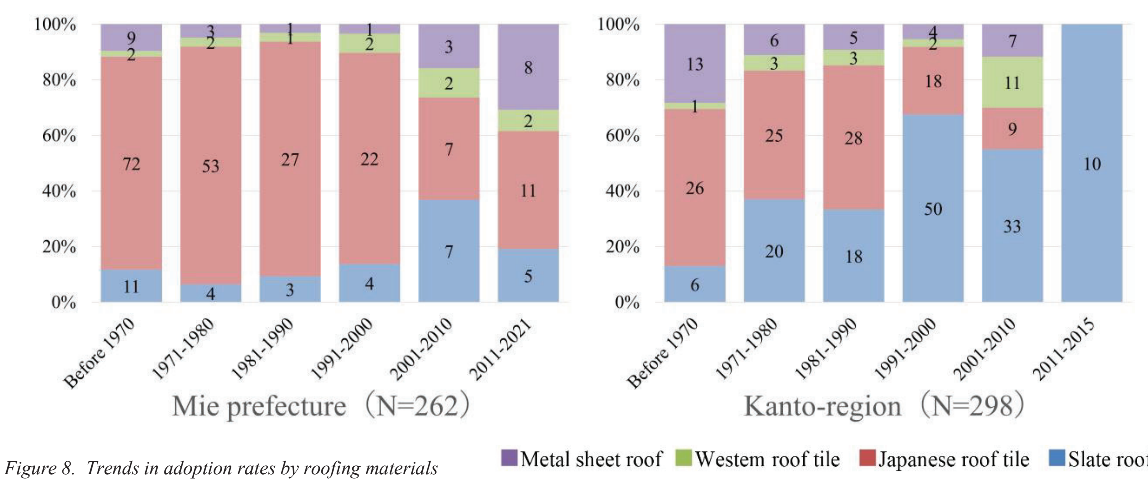

Figure 8. Trends in adoption rates by roofing materials

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to modern materials and construction techniques around 2000, largely in response to revisions to the Building Standards Act. However, Mie Prefecture's adoption of raft foundation lagged behind that of the Kanto region by approximately 10 years, while the adoption of O-kabe lagged by about 20 years. In addition, traditional materials and methods continue to be used for exterior wall finishes. Notably, exterior wall finish and roofing materials demonstrated distinct regional and chronological variations, suggesting that these elements may more strongly reflect and maintain regional architectural characteristics compared to other building components.

It is important to note some limitations of this study: Kanto-region dataset is only available up to 2015. Certain items include responses from partial age groups with a limited sample size. For Mie Prefecture, the survey allowed multiple responses for exterior walls and roofing materials, which may introduce variability in the findings.

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