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# Spatial composition and building techniques of farmhouses prone to windstorms: a case study in Arakawa Village, Shiga Prefecture, Japan

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## ABSTRACT

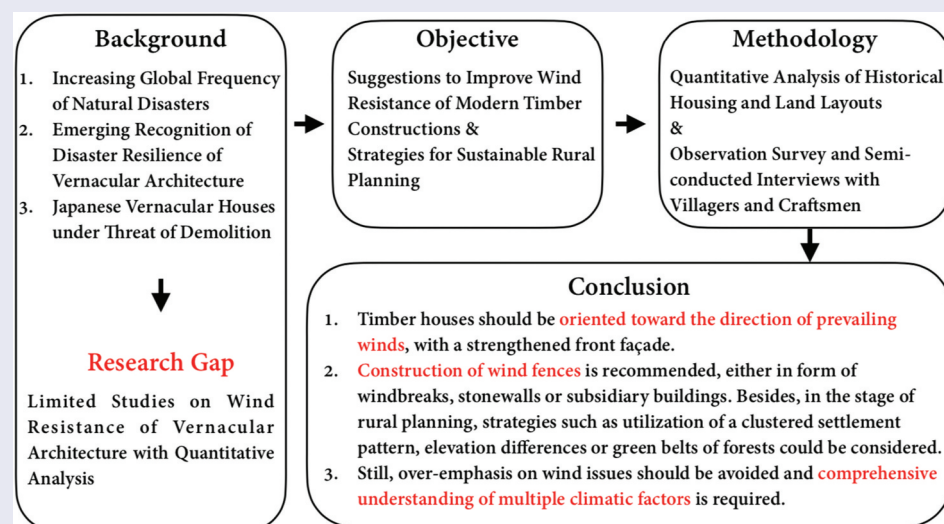
In Arakawa Village, the strong Hira downslope windstorm blowing from the Hira Mountains toward Lake Biwa, poses a great challenge for timber housing structures, which are prone to deformation. To understand the countermeasures applied in local farmhouses to mitigate the effect of wind attacks, features of historical housing and land lot layouts from the Meiji Era (1868–1912) were studied and interviews with local villagers and craftsmen were conducted. It was found that a significant majority of houses were built along the wind direction, with a closed front façade. Contrariwise, subsidiary structures, such as storage buildings and retirement houses, were placed perpendicularly to the wind direction, forming wind fences to protect the front yards, which served as agricultural workspaces. The features of spatial composition have been explained by local craftsmen as technical countermeasures; according to them, farmhouses were built on an incline of about 3–5 cm into the wind direction to mitigate deformation of timber structure. The study suggests that spatial composition of vernacular farmhouses and building techniques could offer effective strategies for sustainable rural planning and be employed to enhance the wind resistance of modern timber constructions, especially for regions prone to powerful prevailing winds worldwide.

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## KEYWORDS

Vernacular architecture; climate adaptation; wind resistance; spatial composition; downslope windstorms; the Meiji Era



## 1. Introduction

### 1.1. Background

In recent decades, global frequency of natural disasters has been clearly increasing, especially the climatological events (e.g. wildfire) (Abatzoglou and Williams 2016), meteorological events (e.g. tropical storm) (Mendelsohn, Emanuel, and Chonabayashi 2011), and hydrological events (e.g. flood) (Tabari 2020), under the impact of climate change. “The heterogenous effects of climate change are pushing architecture to recover its

vernacular gaze.” (Wiegand and Simonetti 2020) As a result, UNESCO published a guidebook to explain lessons learned from seismic performance of non-engineered buildings with the traditional manner of construction (Arya, Boen, and Ishiyama 2014); flood-proof housing design was published under inspiration of vernacular architecture in the Philippines (Ham 2018). In Japan, the study of vernacular architecture has also gained increasing attention in recent times, to help enhance the disaster resilience of modern timber constructions against earthquakes (Kitahara et al. 2002), floods (Aoki and Kuroyanagi

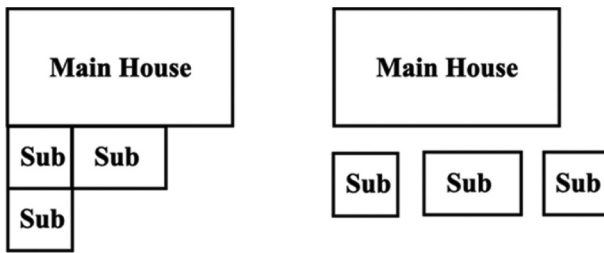


Figure 1. Two patterns of housing layouts.

2015), and winds (Ando, Kuroyanagi, and Nakamura 1999). This paper focuses on features of vernacular farmhouses in rural Japan against the backdrop of the Hira downslope windstorms.

However, Japanese vernacular housing structures are under threat of demolition, driven mainly by the “scrap-and-build” scheme fueled by the market economy (Uchida 2018). Historical records are, therefore, valuable sources to study vanishing folk houses. Yet, the studies on historical records tend to explain either village forms in relation to watercourses (Hata and Sakurai 2012), or village features under specific political conditions (Ito, Sasayama, and Watanabe 2010), and discuss natural hazards less often.

Therefore, this study provides a new perspective of quantitative analysis on historical records to understand the specific spatial composition of the farmhouses in areas that are prone to windstorms. This is further supplemented with technical explanations of underlying building techniques.

## 1.2. Existing studies

Ever since 1945, the effects of windbreaks were studied by many western scholars, under the impacts of periodic monsoons, from a meteorological perspective (Yoshino 1975). Yet in recent decades, various vernacular building techniques were studied as well, such as orientation of houses according to prevailing wind direction in Denmark (Daibaieh and Eybye 2016), utilization of short eaves in the Philippines (Shih 2019), or the storm-resistant traditional wood joint system in Vietnam (Nguyen 2013). Meanwhile, the wind-resistance of a hipped roof has been promoted in several studies worldwide, whether in Fiji (Caimi 2017), in the Philippines (Shih 2019) or in Vietnam (Truong 2014), as it could be better sealed with less traction force.

Japan is a mountainous country with complex topography and various wind types, such as downslope windstorms and gap winds, among which at least 28

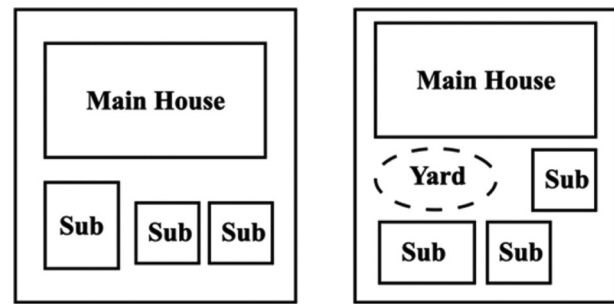


Figure 2. Two patterns of land lot layouts.

local winds are known by name (Kusaka and Fudeyasu 2017). Therefore, the relationship between winds and livelihoods has been a popular topic among researchers in the country. However, regarding wind-resistant techniques, most studies have tended to focus on stonewall construction (Miyake and Shono 2005) and windbreaks (Furukawa and Yamada 1997), whereas only limited studies focused on features of housing and land lot layouts, or local building techniques that were developed in response to wind issues. Ando et al.’s study (1999) revealed compact settlement patterns of fishing villages against wind attacks, and the research of Muramatsu (1943) indicated that farmhouses in Omiya of East Japan were built along the wind direction. However, most of those exiting international or domestic studies were only based on qualitative analysis.

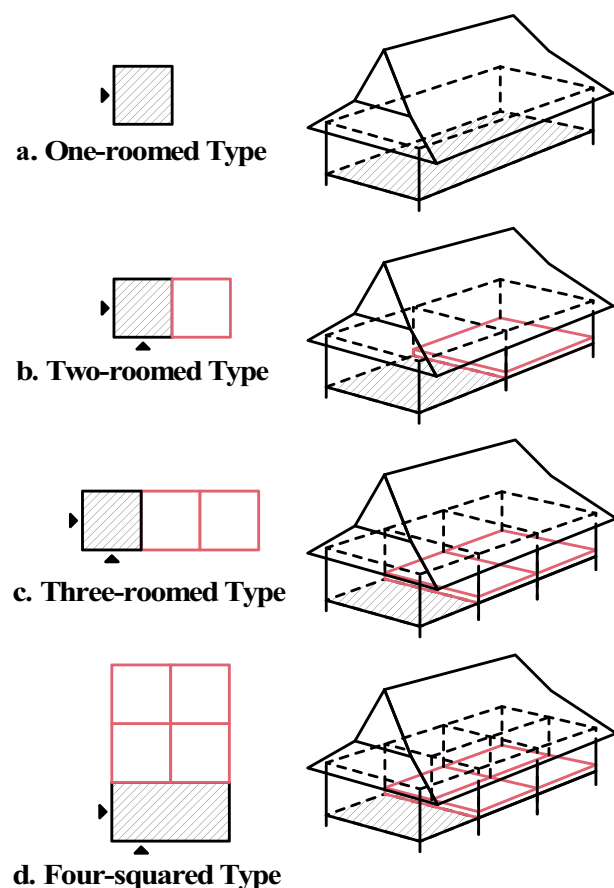
A brief introduction about basic features of Japanese farmhouses was given as follows. Studies regarding climate adaptation of rural settlements in Japan originated in the field of human geography (Saiki 1986). The geographer Sato (1962) found that there were two patterns of housing layouts *madori*<sup>1</sup> and land lot layouts *yashiki-gamae*,<sup>2</sup> depending on different geographical locations. In regard to housing layouts, a so-called main house *omoya*<sup>3</sup> tended to have all substructures directly attached to it in the northeastern regions of rural Japan, due to lower temperatures, whereas a main house in the southwestern regions tended to be a building isolated from substructures (Figure 1). As for land lot layouts, the size of spare space between a main house and its substructures also varied in different regions (Figure 2).<sup>4</sup> Sometimes, little spare space was allocated, as agricultural activities were mainly carried out indoors, while in other regions, large spare space was allocated as an open agricultural workspace (Sato 1962). The classification was found adoptable for farmhouses in Arakawa Village, which was explained in detail in section 3.3.

<sup>1</sup>*Madori* indicates the room plan of a house and is translated as “housing layout.” In the paper, it refers specifically to the room plan of a main house.

<sup>2</sup>In contrast to *madori*, *yashiki-gamae* indicates the spatial composition of a land lot and is translated as “land lot layout.” It focuses on the features of the relative positions between a main house and its substructures.

<sup>3</sup>*Omoya* indicates a main house where family members lived and carried out daily activities; in contrast, substructures, such as storages, warehouses, and cowsheds, were separate building unites with various specific purposes.

<sup>4</sup>The two diagrams aim to explain the concept without corresponding to the exact position and proportion of houses and substructures in reality.



**Figure 3.** Four typologies of housing layouts. (a) One-roomed type. (b) Two-roomed type. (c) Three-roomed type. (d) Four-squared type.

Besides, Swiss researcher Egenter (1992) defined four typologies of typical housing layouts of a main house, based on the transformation process of farmhouses. They originated from a one-roomed type with an earth floor (Figure 3(a)) and expanded to a two-roomed type with a dwelling space set on an elevated floor and separated from the earth-floored area (Figure 3(b)). This was followed by a three-roomed type, with an expanded dwelling space divided into two rooms (Figure 3(c)), and finally, a four-squared type, with expanded dwelling space divided into four rooms (Figure 3(d)). This categorization offered a foundation of research methodology to classify housing layouts in Arakawa Village in section 2.3.

Locally, two official studies have been conducted to record the features of vernacular housing structures remaining throughout the Shiga Prefecture (Shiga Prefecture Board of Education 1969 & 1998). Sections and floor plans of each targeted house have been duly presented based on measurement surveys, briefly introducing the house location, roof style, materiality, and certain technical details. However, researchers have focused mainly on thatched-roof houses that

were well maintained; thus, only a limited number of houses with recognized high conservation value were covered in the reports. Consequently, no houses were selected in Arakawa Village. Villages that confronted natural hazards, essentially, tended to be neglected due to the necessity of frequent renovations. Moreover, the two studies merely focused on structural features of each building, with little consideration, if any, of the overall village form and the climatic context.

### 1.3. Study objective

By examining countermeasures adopted in vernacular farmhouses from Japan, the study aims to provide effective strategies for sustainable rural development and suggestions to improve wind resistance of modern timber constructions, for regions prone to powerful prevailing winds worldwide. The significance of the study is to provide a methodology to integrate both qualitative and quantitative study of vernacular building techniques and gain further understanding of feasible countermeasures to enhance disaster resilience of modern society.

## 2. Methodology

A case study in Arakawa Village, Shiga Prefecture of Japan was conducted, where strong windstorms were observed since centuries due to its specific geographic conditions (Shiga Town Kido Elementary School 1874). A detailed outline of Arakawa Village was explained below, which was followed by an introduction of research methodologies. Initially, historical housing and land lot layouts were interpreted through a literature review of a land register from the Meiji era. Then a quantitative analysis regarding the spatial composition of both housing and land lot layouts was conducted. Lastly, field surveys were made to verify the findings of the previous analysis with underlying building techniques.

### 2.1. Outline of the study area

Arakawa Village belongs to the former Shiga Town<sup>5</sup> (hereafter, Shiga Town) in the northeast district of Otsu City, Shiga Prefecture, situated on the western side of Lake Biwa. In total, there are nine agricultural villages under Shiga Town, with a land area of 71.73 km<sup>2</sup>, measuring 15.9 km from north to south and 7.3 km from east to west (Figure 4). Due to its unique geographic location between the Hira Mountain Range on the west and

<sup>5</sup>The former Shiga Town served as an independent administrative unit from 1955 to 2006, which was abolished when the villages were united into the city of Otsu until today.



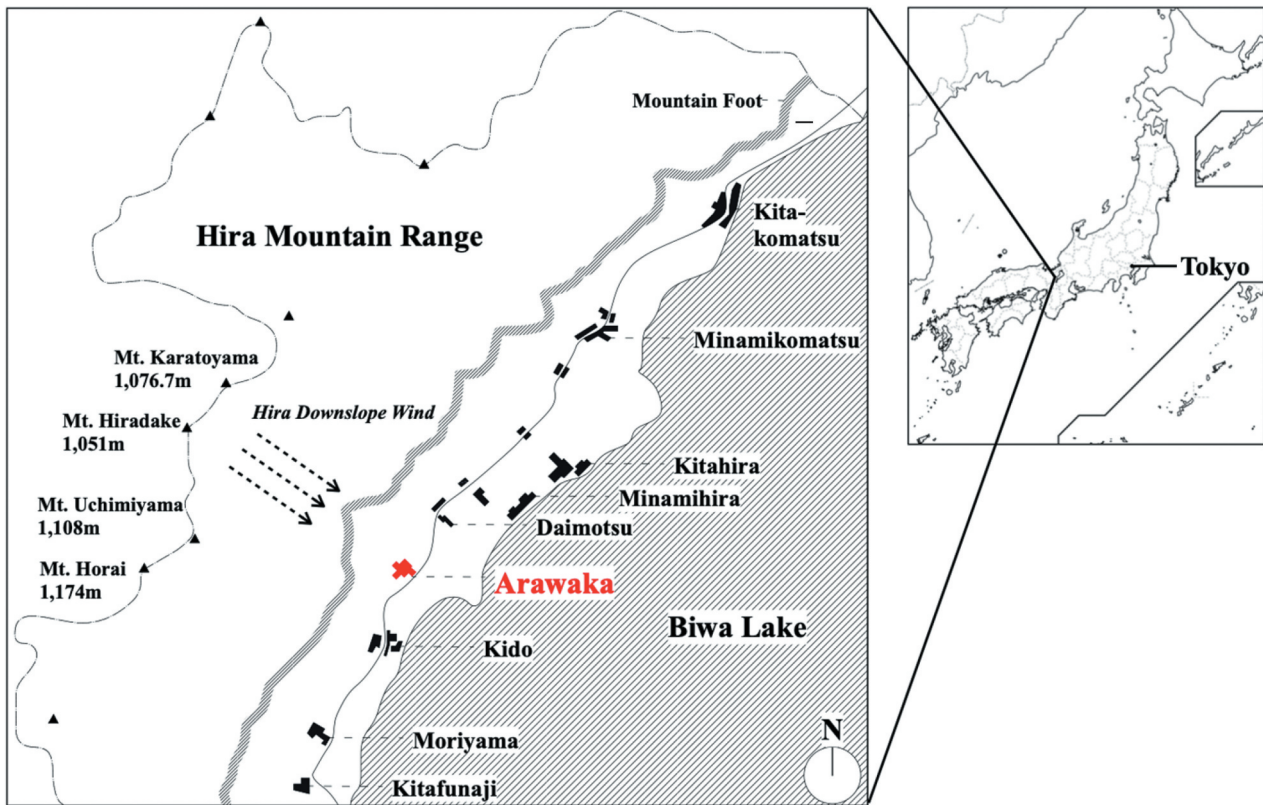


Figure 4. The map of Former Shiga Town in the Meiji Era.

Lake Biwa on the east, the region experiences a significant elevation difference of up to 1,100 m within the short east-west span. Therefore, it has historically suffered frequent natural disasters, such as landslides and floods between 1615 and 1935 (Village of Kido, History of Shiga Town, Shiga Prefecture Disaster Journal).<sup>6</sup> This has now been remarkably remedied by the construction of stone dikes and dams.

However, a strong mountain downslope windstorm called *Hira-oroshi* still occurs, posing a threat to the villagers throughout the year. A downslope windstorm usually requires a steep leeside slope and a mountain height of about 1 km or more (American Meteorological Society 2016). The Hira Mountain Range includes a series of steep mountains with a height of over 1,000 m, among which Mt. Horai towers at 1,174 m, followed by Mt. Uchimiya at 1,108 m, Mt. Karatoyama at 1,076.7 m, and Mt. Hiradake at 1,051 m. Heavy Hira windstorms from the Hira Mountains toward Lake Biwa were observed especially from March to May, and from September to November (Matsui and Takeda 2001), reaching a maximum speed of up to 50 km/s, or sometimes lasting through half of a day at 20 km/s (Oku and Iriyama 2020).

Consequently, Hira windstorms resulted in frequent damage to buildings, school closures, delays or suspension of railroad services, and even traffic accidents, such as truck overturns (Furumoto and Yamada 2014). Meanwhile, as a commuter town for city dwellers, Shiga Town has grown rapidly in accordance with the boom of urban migration, especially from the 1960s to the 1990s (Takahashi 2010). Natural hazards and a lack of understanding of the local climate have posed great challenges to the durability of its modern timber houses, causing ongoing worries, such as the violent shaking of houses in windy seasons, for the new inhabitants.

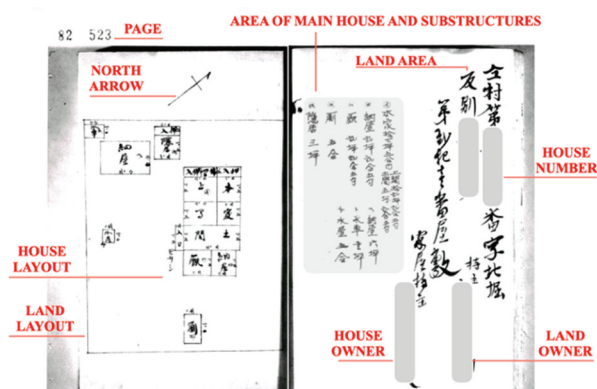
Arakawa Village is well known among the locals for facing more severe windstorms than the other eight villages; thus, it was targeted as the research site to study the features of traditional farmhouses and to examine vernacular building techniques that were developed to withstand the Hira downslope windstorms.

## 2.2. Interpretation of historical land register

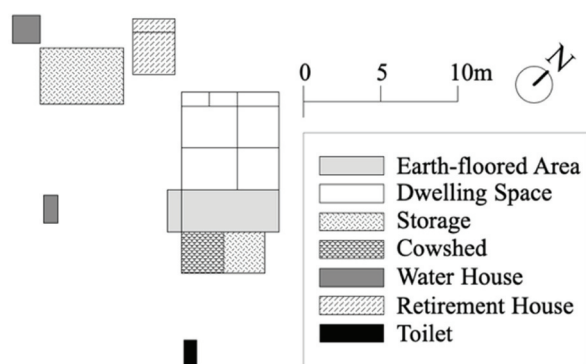
With assistance from professionals, the land register of Arakawa Village from 1899<sup>7</sup> was interpreted. The housing and land lot layouts for each household

<sup>6</sup>Titles of the three references are translated by the author. The original titles are *Kido-no-Sato*(Shiga Town Kido Elementary School 1874), *Shigachou-shi* (Editorial Board of the History of Shiga Town 2002) and *Shiga-ken-Saigai-shi* (Shiga Prefecture 2011) in Japanese.

<sup>7</sup>The original title of the land register is *Tatemono-Daicho* in Japanese. Copies are offered by the Otsu City Museum of History.



a. One- Page Sample of the Historical Land Register



b. Digital Interpretation of the Layout in the Sample

**Figure 5.** Study of the historical land register (a, b). (a) One-page sample of the historical land register. (b) Digital interpretation of the layout in the sample.

were carefully recorded, together with some administrative information regarding house number, land and house area, and the names of the house owners, and sometimes, the landowners as well (Figure 5). Mapping of the historical housing layouts was then completed based on the house numbers obtained. In total, it included 61 land lot layouts, which comprised 46 private households, one temple, one community house, 10 storages, one water house, and two retirement houses – the last 3 being substructures. Layouts of farmhouses were the main research targets for the layout study.

### 2.3. Analysis of housing layouts

Features of housing layouts were analyzed through a classification of housing layouts into eight typologies. Houses in Arakawa Village were observed to either have ridges extending along the wind direction (vertical house form) or perpendicularly to the wind direction (horizontal house form) (Figure 6(a)). Therefore, in combination with four directions of house entrance (namely from south, east, north, or west), eight types of house orientations were defined in total, where each type provided two entrance

possibilities, as they could be accessed either from the gable end, called *tsumairi*, or from the eave side, called *hirairi* (Figure 6(b)).

### 2.4. Analysis of land lot layouts

Features of land lot layouts were analyzed based on the positions of substructures in relation to a main house in eight different directions (Figure 7). Thus, tendency of substructure distribution in specific relative positions to a main house could be understood.

### 2.5. Field surveys

In total, field surveys of the study comprised an observation survey and six semi-structured interviews with three senior villagers (S, Y1, Y2) aged over 80, one villager (Y3) aged over 60, and three craftsmen (K, N, U), during the period from December 2019 to February 2021.

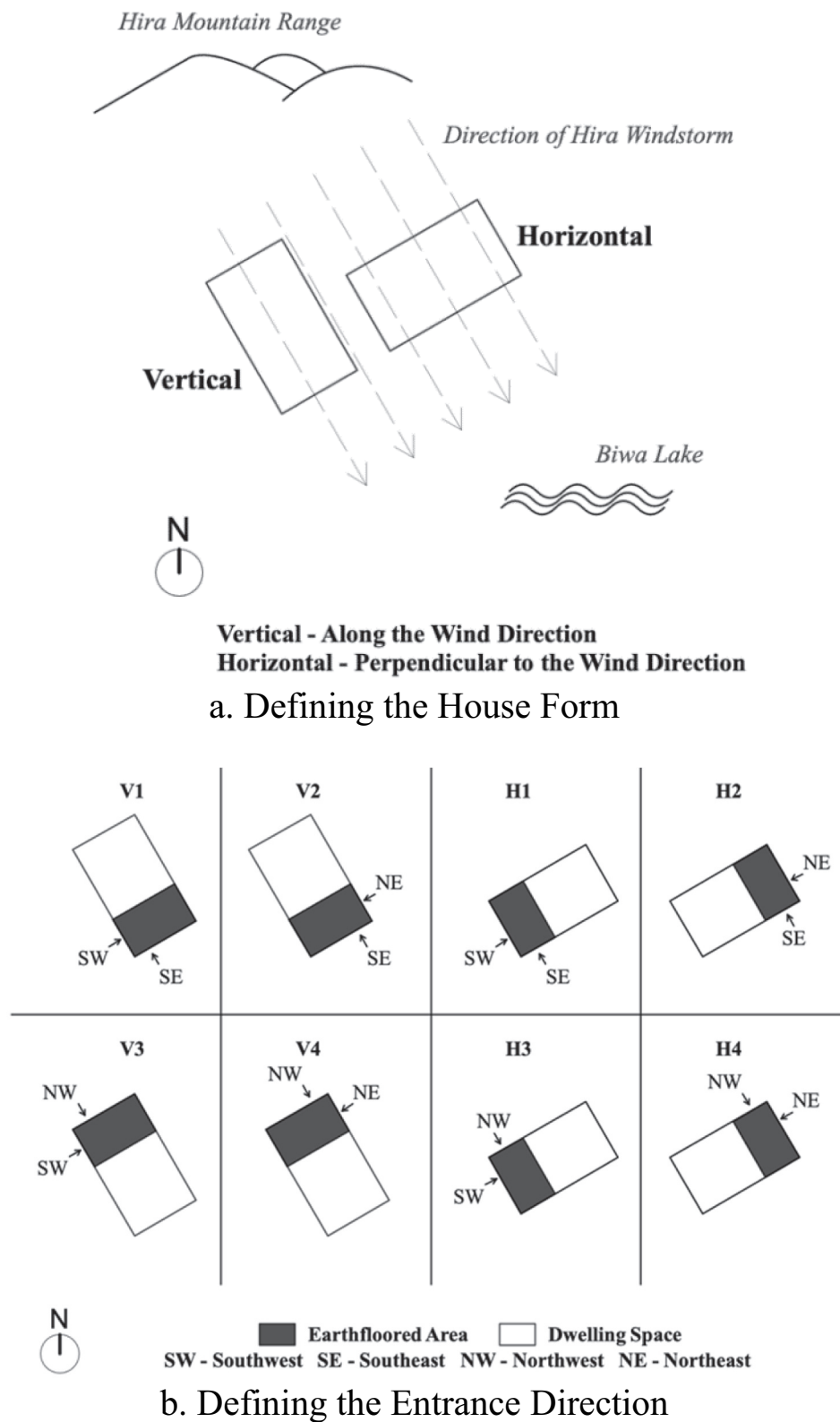
The observation survey assessed the current condition of targeted farmhouses and examined the consistency of house orientation with that in the Meiji era. Interviews with local villagers then helped evaluate the consistency between the past and the current housing layouts. As we could not find any craftsman in Arakawa, craftsmen from neighboring villages were interviewed. Interestingly, craftsmen from Shiga Town share similar building techniques to this day, regardless of their geographical origins within the town. The aim of these interviews was not only to gain a better understanding of the features observed from the historical housing and land lot layouts, but also to explore other wind-resistant building techniques.

## 3. Results

First, based on interpretation of the land register from the Meiji Era, features of the overall village form were explained. Second, by examining the distribution of housing layouts under the eight typologies, features of housing layouts, especially house orientation and housing layouts were understood. Third, based on the study of substructure distribution, features of land lot layouts were explained. Fourth, findings of housing and land lot layouts were further verified with underlying building techniques explained by local craftsmen, with some other wind-resistant techniques being explored as well.

### 3.1. Features of the historical settlement pattern

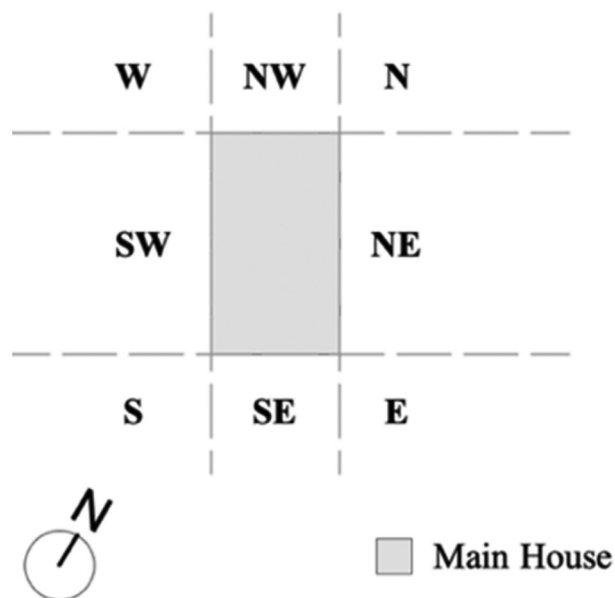
Based on the mapping analysis (Figure 8), it was found that Arakawa Village belonged to a typical clustered settlement pattern, with the temple and the community house sitting in the central village area. Initially, houses were built compactly near the temple and the



**Figure 6.** Eight typologies of housing layouts (a, b). (a) Defining the house form. (b) Defining the entrance direction.

village center, while some family members were given individual land properties some distance away. The border of the village was fenced with a stonewall called *shishigaki* to protect farm fields from wild boars and deer. Currently, tracks of stonewalls in other villages under Shiga Town barely remain and are difficult to locate. The stonewall in Arakawa Village, however, has

been well maintained, as it also served as protection against floods originating from the Otani River in the past. Thus, natural disasters exerted such impact on the village form that the housing layouts tended to be simplified from the four-squared type at the southwestern side to the one-, two-, or three-roomed types at the northeastern side of the village, which was closer to the



**Figure 7.** Eight possible relative positions of substructures to a main house.

Otani River and was more prone to floods during rainy seasons. Historically, the area was regarded as abandoned land and even agricultural activities were prohibited, as recorded in cadastral maps (Otsu City Museum of History).

### 3.2. Features of housing layouts

#### 3.2.1. Impact of the Hira downslope windstorm

Statistically, the majority of main houses in the Meiji Era belonged to the vertical house form (V1, V2, V3), making up a total percentage of 84.8%, while only seven houses were in the horizontal form (H1, H2, H3) (Figure 9). 71.7% of all houses were constructed in the Type V1 house form, while 10.9% of the houses followed Type V3 and Type H2 house forms, respectively. The distribution indicated that a significant majority of the houses were placed along the wind direction, with a south-facing house entrance.

The same feature of house orientation was observed in the modern era. Results of the observation survey revealed that 92.9% of the houses, rebuilt by local craftsmen and remaining in vernacular timber structures, were still oriented along the wind direction, which is even larger than the proportion of 84.8% in the Meiji Era. Additionally, all seven Meiji-Era houses under a horizontal house form (H1, H2, H3) had either been demolished or rebuilt in a vertical house form in the modern era (Table 1).

Thus, in both Meiji and modern eras, it was proved that houses were built along the northwest-southeast axis following the wind direction.

As for the housing layouts, it was observed that 76.1% of houses had been developed into the four-squared type in the Meiji Era (Figure 10), while 96.3% of four-squared houses attached with rooms that required no natural lighting— an alcove and an altar in the guest room, as well as a closet in the sleeping room (Figure 11).

Through interviews with local seniors, it was understood that the recessed alcove was called *tokonoma*, where calligraphic or pictorial scrolls were presented, and the delicate altar was called *butsudan*, used for paying respects to the Buddha and deceased family members. The closet in the sleeping room was used to store mattresses (Figure 12). To further validate that the room partitions near the front façade were a specific countermeasure against wind attacks rather than merely a cultural custom of the region, Type V3 with inverted housing layouts was studied as well. Interestingly, in these cases, only 20% of the households followed the custom of placing alcoves, altars, and closets simultaneously on the end of the dwelling space (Figure 13). Therefore, the adoption of a closed front façade was rather in consideration of the windstorm issues than merely a cultural obligation.

In conclusion, a majority of houses in Arakawa Village were oriented towards the wind direction and built based on the four-squared housing layout. Houses that were not built along the wind direction in the Meiji Era have now been reoriented, with the overall percentage of the vertical house form increasing from 84.8% to 92.9%. 96.3% of four-squared houses had a closed front façade to mitigate the effect of wind attacks. This was realized by arranging rooms that required no natural lighting at the end of the dwelling space, reflecting the impacts from local climate and cultural custom at the same time.

#### 3.2.2. Impact of sunlight and water accessibility

Another important factor influencing the housing layouts was sunlight. As mentioned earlier, most of the houses had their entrances toward the south to allow as much sunlight as possible into the earth-floored area, which was utilized as a working space. However, no house belonged to Type H4 or V4, indicating that an entrance toward the north, which had little sunlight, was not preferred.

Additionally, water accessibility played a significant role. Numerous watercourses flowing from the deep mountainous area into Lake Biwa basically overlap with the road network to this day. In the past, they served as important water sources for drinking, cooking, laundry, and field irrigation. As 80% of Type V3 houses had the watercourses to their northwest side, an inverted housing layout was preferred to ensure easy accessibility of the earth-floored area to a watercourse since it was significant for the functioning of the kitchen.



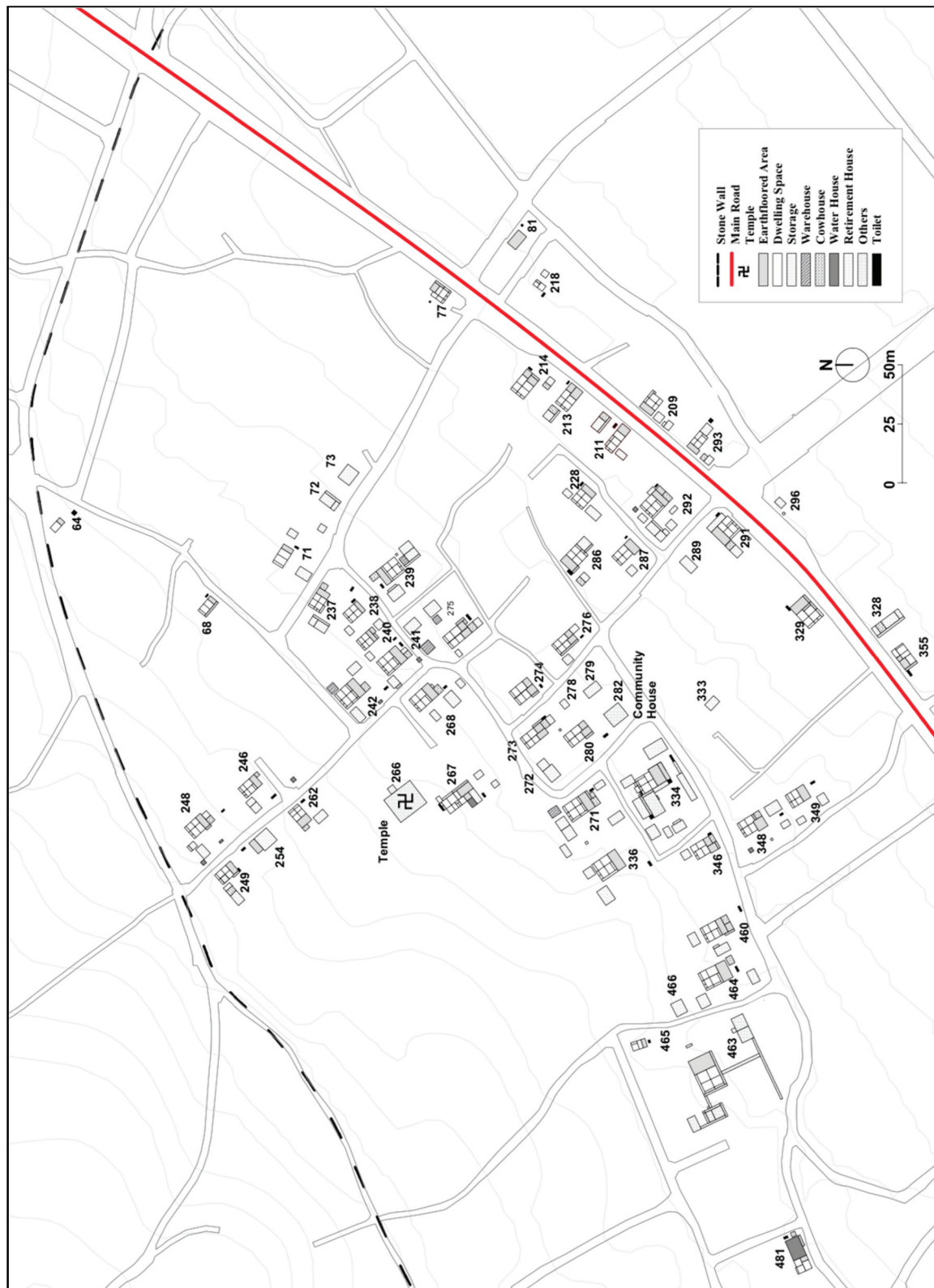


Figure 8. Mapping of Arakawa Village in the Meiji Era.

Therefore, it was understood that the amount of sunlight determined the entrance direction for farmhouses and ease of accessibility to a watercourse was prioritized over windstorm issues in housing layouts if necessary.

### 3.3. Features of land lot layouts

Land lot layouts in Arakawa Village corresponded to the land lot pattern with one open agricultural workspace, which was surrounded by a main house and several isolated substructures, as mentioned in section 1.2 (Figures 1 and 2).



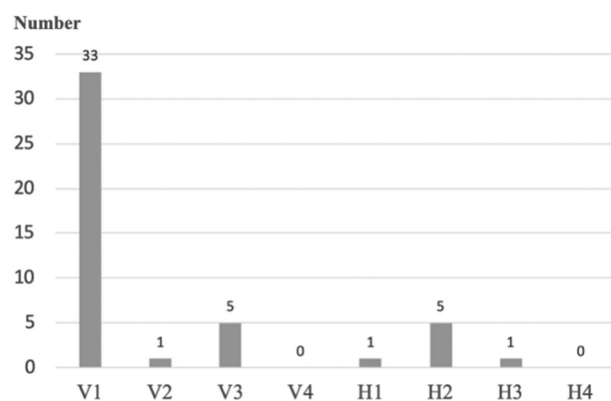


Figure 9. Distribution of types of house orientation.

The total number of substructures reached 179, among which Type V1 houses made up the greatest number of substructures at 139, followed by the V3 type at 23 substructures, H2 at 7, V2 with at 6, H1 at 3, and H3 with only one substructure. Therefore, we focused on Type V1 in order to determine the overall features of land lot layouts. Under Type V1, the number of individual substructures located at a relative position to a main house was calculated (Figure 14). The largest proportion of substructures, 31.7%, could be observed in the southeast direction, mainly comprising toilets (38.6%), cowsheds (31.8%), and storage buildings (20.5%). Meanwhile, 18.0% of buildings were in the south direction and mainly comprised toilets (32.0%) and storage buildings (28%). Similarly, 16.5% of substructures were in the westerly direction and comprised storage buildings (52.3%) and retirement houses (30.4%). The distribution of main substructures with respect to windstorm issues is explained in the following section below.

### 3.3.1. Impact of the Hira windstorms

The most dominant feature of land lot layouts under the impact of Hira windstorms was the distribution of storage buildings and retirement houses. Storage buildings were used for storing crops, farm tools, and daily necessities, whereas retirement houses were prepared as separate living and sleeping rooms for senior retired family members. Statistically, 45.8% of the

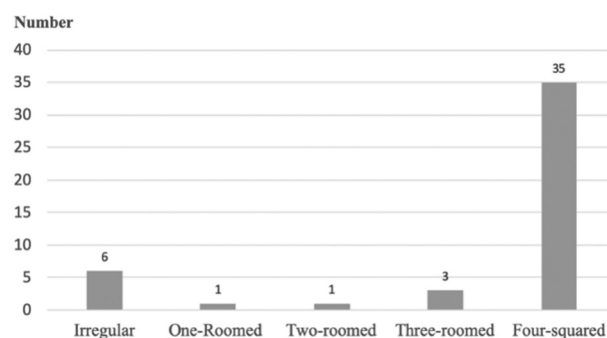


Figure 10. Distribution of types of housing layouts.

storage buildings under Type V1 tended to be located in the southwest and west directions (Figure 15). Among the 11 retirement houses, 63.6% were located in a westerly direction. Specifically, storage buildings and retirement houses in the southwest and west directions tended to be placed perpendicularly to a vertical main house, thus forming wind fences to protect the open space in front of the house entrance. The open space, together with the interior earth-floored area, served as agricultural workspaces for various activities, such as threshing rice and drying vegetables (Figure 16). In total, 58.9% of all housing layouts were found to follow this pattern in the Meiji Era.

Another feature related to windstorms was the direct attachment of substructures, such as storage buildings and cowsheds, to a main house in the southeast direction. In the pre-industrial era, cows were important labor forces for agricultural activities and regarded as an integral part of the households. Statistically, 18.8% of storage buildings were placed in a southeast direction, among which 55.6% were found to be directly attached to a main house. 82.4% of cowsheds were placed in a southeast direction, among which 76.5% were directly attached to a main house. Direct attachment of cowsheds not only increased the convenience of feeding the cows, but also helped to strengthen the timber framework of a main house, as explained in detail below (Section 3.4).

In short, it was found that most of the storage buildings and retirement houses were placed horizontally in the southwest and west directions to

Table 1. Current condition of horizontal housing layouts.

House Number	Demolished	Current Condition		Past V/H Category	Current V/H Category
		Vernacular Timber Construction	Modern Construction		
262		●		H1	V
77			●	H2	V
218		●		H2	V
329	●			H2	
481	●			H2	
463			●	H2	V
355	●			H3	

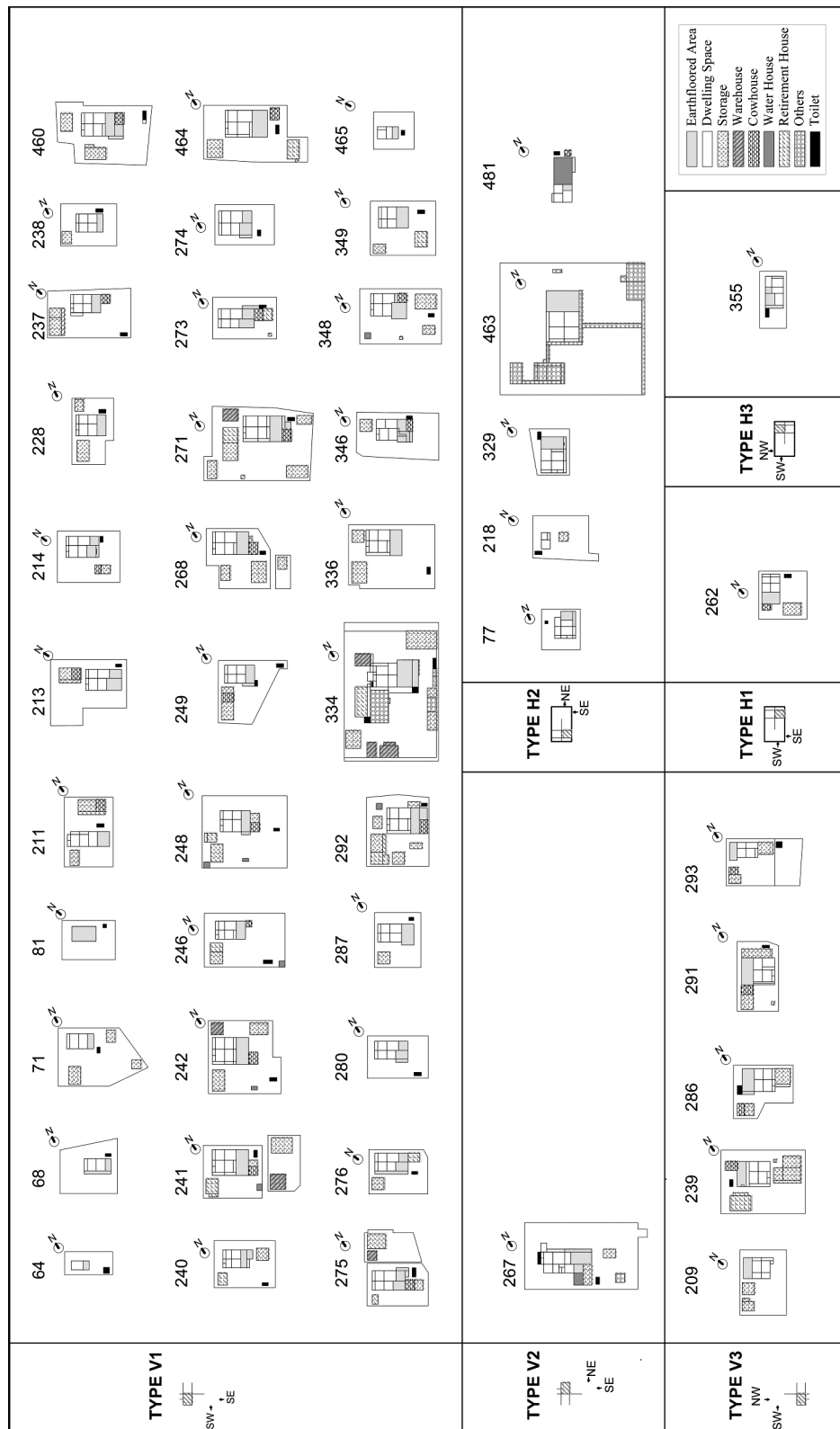


Figure 11. Layouts categorized into six types.

form long wind fences for the front yard as an agricultural workspace, while the storage buildings and cowsheds on the southeast side tended to be directly attached to a main house to strengthen the timber framework against wind attacks (Figure 17).

### 3.3.2. Impact of sunlight

Similar to the south-facing house entrance, the front yard also required sufficient sunlight and thus was located southwest of a main house. It eventually resulted in storage buildings and retirement houses being concentrated in the southwest and west, as mentioned above. In contrast, a Type V2 house,

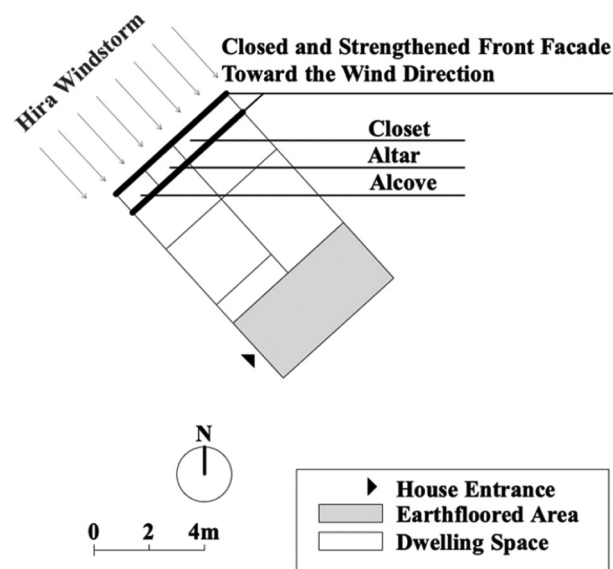


Figure 12. A typical four-squared housing layout under Type V1.

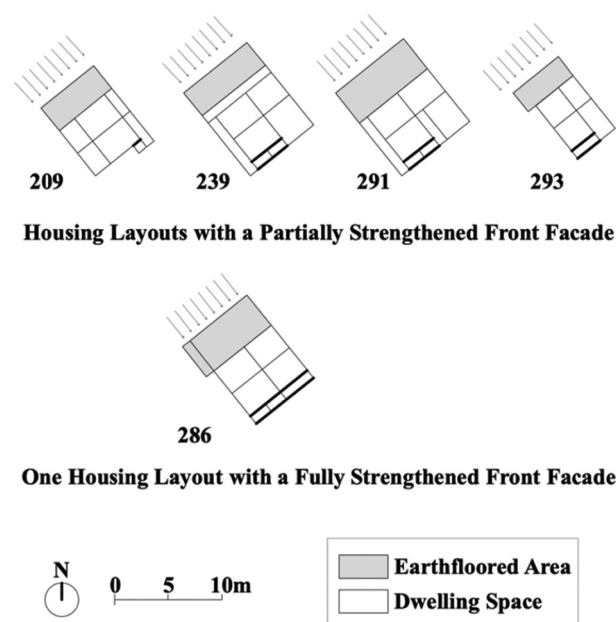


Figure 13. The five housing layouts under Type V3.

which was a part of the land property of a local temple, did not serve as a typical farmhouse and therefore, had its house entrance toward the east, without requiring a south-facing front yard. Additionally, toilets, as important sources of fertilizer for the paddy fields in the past (Brown 2013), tended to be located in south-east and south directions, with a total percentage at 72.7%, as a relatively warm temperature helped quick fermentation of excrements (Ikuko 2010). Therefore, it was understood that abundant sunlight also played a role in the distribution of substructures, resulting in the south-facing front yards and toilets.

### 3.4. Countermeasures explained by craftsmen

Through interviews with local craftsmen, findings based on the historical layouts were verified and various other local building techniques with regard to the windstorm issues were also explored.

Houses were oriented along the wind direction and had a closed front façade, not only to minimize the extent of wind attacks, but also based on the fact that a timber structure could bear more external forces directed along a length axis (Figure 18(a)). Further, the front façade could be structurally strengthened by an additional framework of room partitions of alcoves, altars and closets mentioned above (Figure 18(b)). Similarly, attaching some substructures (e.g. cowsheds, storage buildings) to a main house also strengthened the main timber structure against attacks along the wind direction (Figure 18(c)). Heavy lintels, called *sashikamoi*, with large depths of between 25 cm to 40 cm, were utilized to improve the overall structural performance as well (Figure 18(d)).

In particular, it was mentioned that the timber structure was built inclined into the wind direction to regulate deformation under the impact of Hira windstorms. The building process was explained in detail as follows (Figure 19):

- (1) Assemble the basic timber framework.
- (2) Define the columns in the center and at the corners of the structure as “main columns” and visually confirm the inclining direction, which should be “toward the mountains.”
- (3) Push or pull the main columns along the length axis from the border to the interior, e.g. from the columns at the axes  $x_1$  and  $x_3$  to those at the axis  $x_2$ . Use plumbs to confirm the deviation distance at about 3–5 cm, with an inclination of about  $1^\circ$  (degree).
- (4) Similarly, push or pull the main columns along the width axis, e.g. from the axes  $y_1$  and  $y_4$  to  $y_2$  and  $y_3$ .
- (5) Utilize diagonal struts to fix the deviation when reaching the expected inclination.
- (6) Assemble the roof structure and remove the diagonal struts after stabilizing the whole structure by knocking in the pins<sup>8</sup> to close the joinery of the timber framework.

This tacit technique inherited among craftsmen is still used today in construction projects in Shiga Town without any textual indications or verbal instructions from the architects

<sup>8</sup>A pin, or *sen* in Japanese, is made of hardwood, usually oak in the Shiga region. It would be added to angle joints *shiguchi* or end joints *tsugite* for purpose of tightening and strengthening the structure.

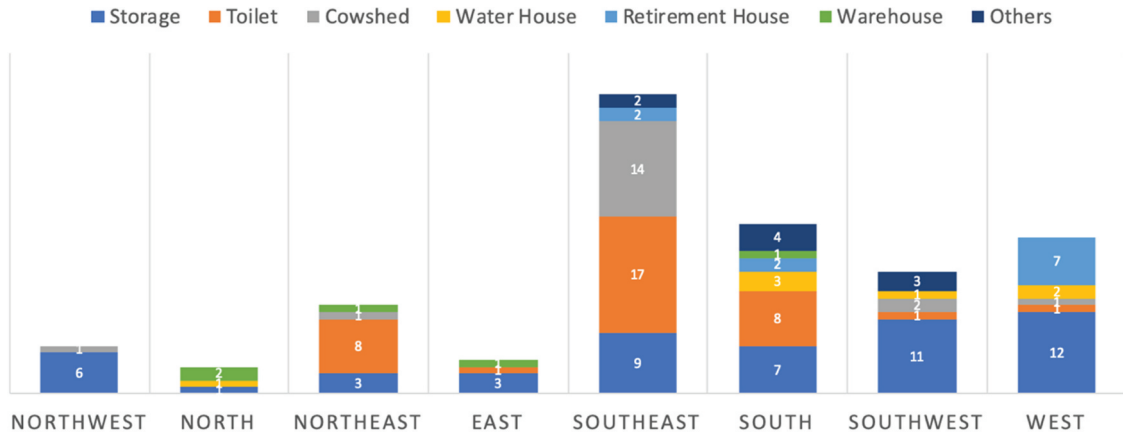


Figure 14. Number of individual substructures in each relative position to a main house under Type V1.

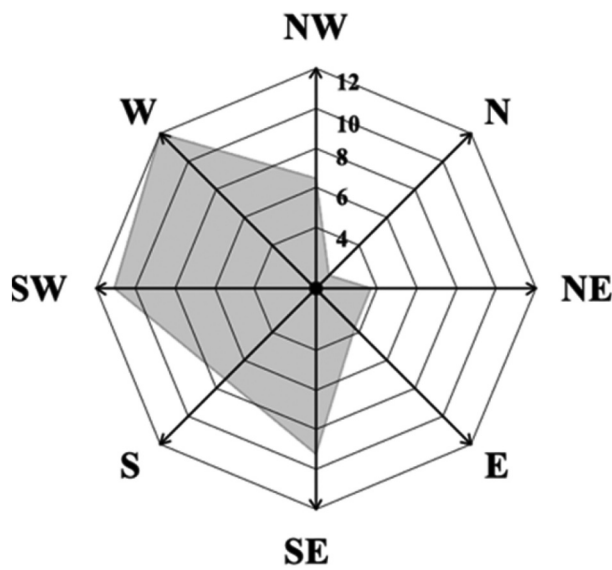


Figure 15. Distribution of storage buildings.

#### 4. Conclusion

Based on both quantitative analysis of layouts and qualitative interviews with villagers and craftsmen, this paper aims to enhance a comprehensive understanding of wind-resistant countermeasures adopted in local farmhouses, from spatial composition of layouts to building techniques. In the following, suggestions were made based on individual research findings accordingly.

In the Meiji Era, to withstand strong Hira windstorms, most of vernacular housings in Arakawa Village were built along the wind direction (the north-west–southeast axis) with a closed front façade. The houses that did not follow the wind direction were either demolished or reoriented by the wind axis in the modern era. This served to minimize the affected areas under wind attacks and to maximize the resistance of a timber structure against external forces

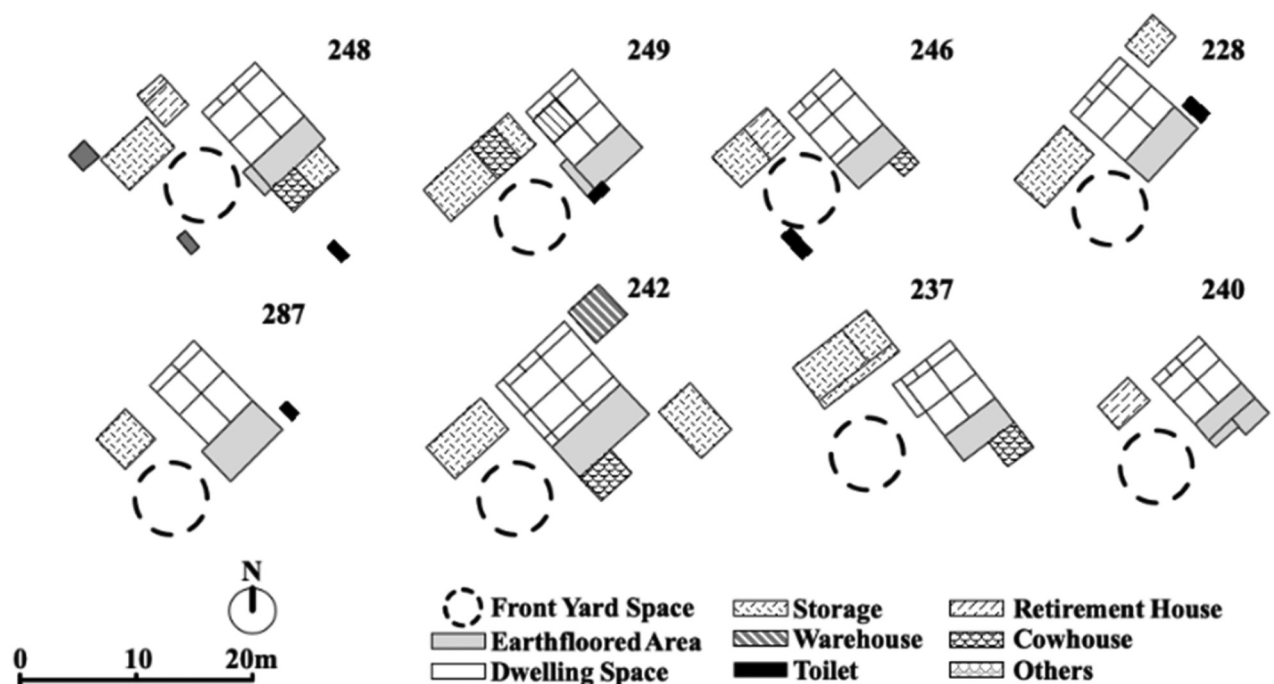
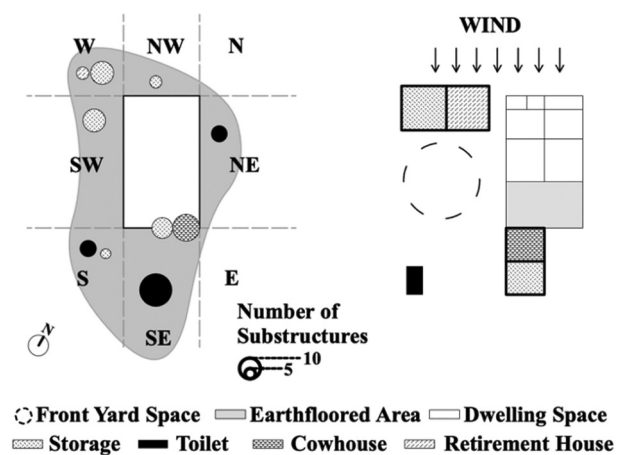


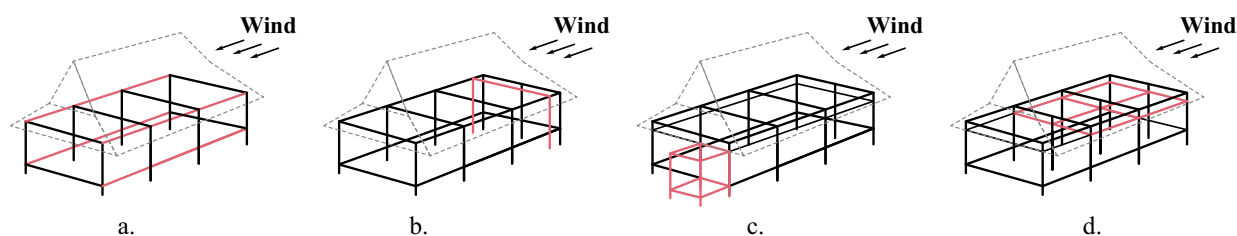
Figure 16. Examples of houses with a protected front yard.



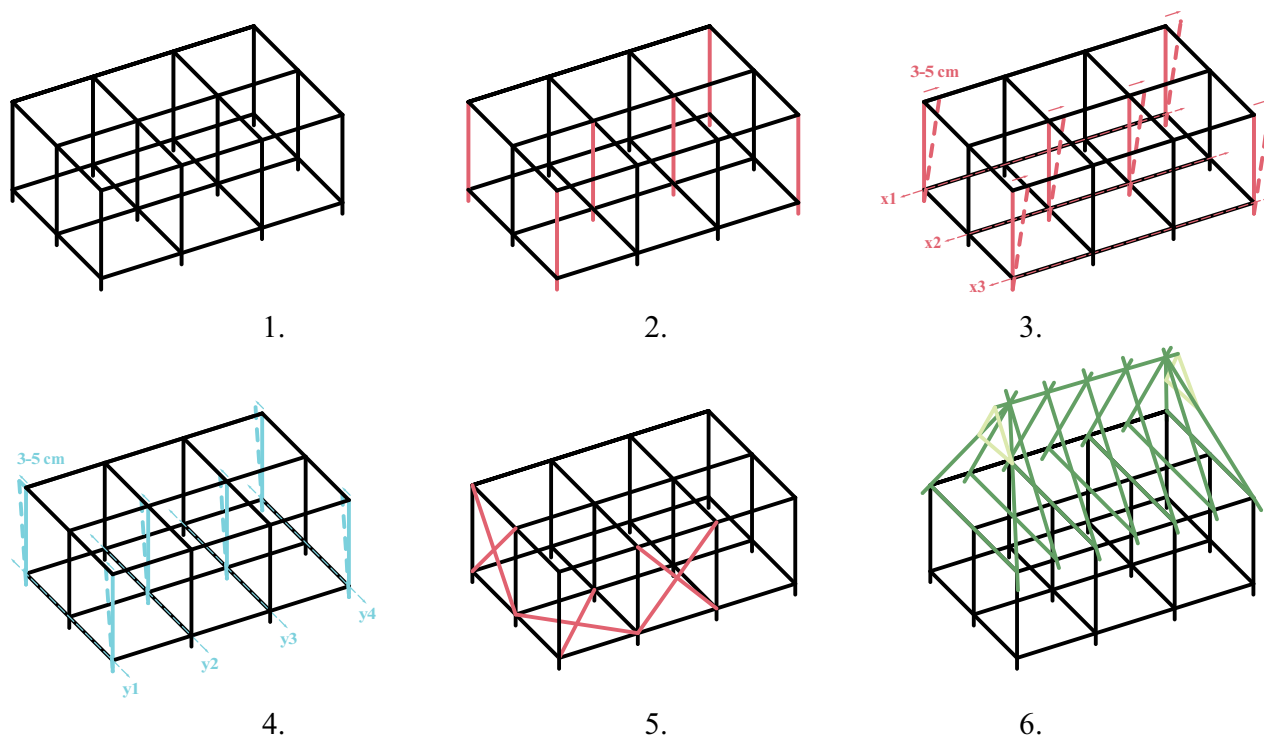
**Figure 17.** Distribution of main substructures (left) and a typical sample of land lot layouts (right).

along the wind direction. Therefore, it is suggested that, in regions prone to powerful prevailing winds, timber houses should be oriented toward the wind direction, possibly with a strengthened front façade. Based on the optimal building form in regard to wind direction, reasonable design of new residential plots during rural planning should be emphasized.

As for substructures, most storage buildings and retirement houses in Arakawa Village were found to be placed southwest and west of a main house, forming long wind fences to protect the front yard. Thus, for new houses that require an open area as a multifunctional workspace, it is recommended to have wind fences built in advance, either with wind-breaks, stonewalls, or subsidiary buildings. Besides, strategies to form wind fences could also be adopted



**Figure 18.** Countermeasures utilized to strengthen the structural performance.



**Figure 19.** Construction process of the timber framework inclined toward the wind direction.



in the stage of rural planning, such as utilization of a clustered settlement pattern, elevation differences or green belts of forests.

Still, it is noted that though the Hira downslope windstorms have been a prominent factor that shaped the historical housing and land lot layouts in Arakawa Village, spatial composition of vernacular farmhouses also represented local wisdom in comprehensive consideration of sunlight and water accessibility. Therefore, over-emphasis on one climatic issue should be avoided and integration of multiple climatic factors (e.g. wind, sunlight and water) is required for sustainable rural planning.

Limitations of the study, first of all, lie in the limited number of interviewees, including senior villagers and craftsmen, that possess relevant knowledge and willingness to cooperate. Difficulties of home visits increased especially after outbreak of the pandemic, so that a quantitative analysis of vernacular building techniques in current housing layouts could not be conducted. Second, findings of the study are only adoptable for regions with prevailing winds from one main direction. Third is the necessity of further structural assessment to verify the effects of an inclined timber structure. The construction process of houses with an inclination of about 3–5 cm into the wind direction, were explained by local craftsmen. This vernacular building technique has proposed a unique perspective of appreciating the elasticity of timber structure and creating buffer zones against natural hazards. Therefore, subsequent research is recommended for engineering scientists with similar interests.

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