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Post Earthquake Recovery in Suzu City: Evaluating Temporary Shelter Conditions, Policy-Driven Inequities, and 3D-Printed Reconstruction for Rural Communities

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Abstract The increasing severity of natural disasters, combined with aging and depopulation in rural Japan, has revealed critical shortcomings in current recovery frameworks. Focusing on the built environment and architectural dimensions of post-disaster recovery, this paper examines the structural, institutional, and social conditions affecting disaster recovery in Suzu City following the 2024 Noto Peninsula Earthquake. Drawing on ten days of qualitative field research conducted in March 2025, including site surveys, spatial observations, policy analysis, and semi-structured interviews with 30 residents and local stakeholders, this study investigates how temporary housing programs, geographic isolation, demographic decline, and administrative rigidity shape recovery trajectories in aging rural communities. While temporary shelter initiatives prioritize rapid deployment and uniformity, they often neglect the psychosocial needs, spatial habits, and autonomy of elderly residents. Many residents are facing layered challenges rooted in architectural deficiencies: inadequate thermal insulation, poor soundproofing, spatial inefficiencies, and a lack of secure, functional areas for daily tasks. These limitations disrupt routines, erode dignity, and delay emotional recovery, leading to prolonged displacement and deepened vulnerability. The findings reveal that administrative inflexibility, labour shortages, and logistical constraints further delayed reconstruction and reinforce patterns of social exclusion, particularly for elderly women and low-income households. In response, the study also examines grassroots recovery initiatives and assesses the viability of alternative architectural solutions, such as 3D-printed housing. Though not yet used as formal shelters, these customizable, cost-effective, and scalable models demonstrate potential for supporting localized reconstruction and economic revitalization. By centering the lived experiences of older individuals and the spatial realities of post-disaster shelter, this study redefines recovery as a socially embedded process and calls for site-sensitive, demographically responsive, and design-integrated recovery strategies.

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1. INTRODUCTION

On January 1st, 2024, at 16:10, a magnitude 7.5 (Mw) earthquake struck Japan's Noto Peninsula, triggering a tsunami that caused extensive coastal damage (Japan Meteorological Agency, 2024). Due to the proximity of the fault line to the mainland, the northern region of the peninsula experienced the tsunami's impact within minutes. The earthquake and subsequent tsunami devastated residential structures, disrupted essential infrastructure, and displaced thousands of residents (Suppasri et al., 2024). Over 15 months have passed, yet recovery remains slow and uneven, particularly in remote areas such as Suzu, where geographic isolation, aging infrastructure, and demographic vulnerabilities converge. The city's-built environment is dominated by traditional wooden houses with tiled roofs and deep eaves, designed to withstand heavy snow and strong coastal winds. However, many of these buildings are several decades old and lack the seismic resistance required under modern building codes. These structures, though culturally significant, are particularly vulnerable to earthquake damage and are costly to repair or replace. For elderly residents, many of whom live alone and on limited incomes, these conditions present substantial barriers to recovery and long-term housing security.

The Noto Peninsula, extending approximately 100 km into the Sea of Japan, Figure 1, is defined by rugged coastlines, mountainous terrain, and dispersed rural settlements. Suzu, situated at the north-eastern tip of the Noto Peninsula, is one of the most remote municipalities in Ishikawa Prefecture. Its steep topography, dense forests, and limited flat terrain have historically restricted large-scale development and now pose significant logistical challenges in post-disaster contexts.

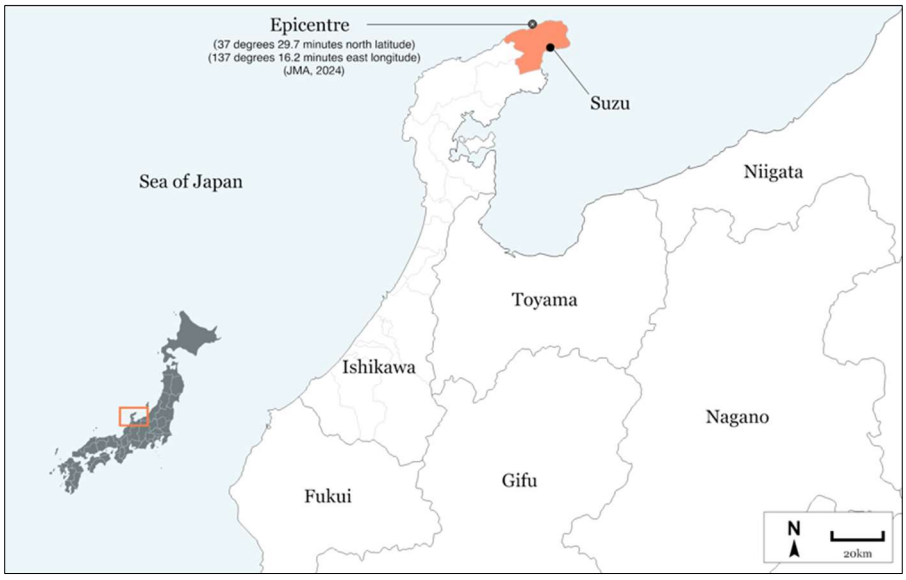


Figure 1. Location of Suzu in the Noto Peninsula, Ishikawa prefecture, Japan

Socio-demographic context and inequality in Suzu

After the 2024 Noto Peninsula Earthquake, this geographic constraint complicated the placement of shelters and temporary housing, resulting in the spatial separation of families. In some cases, younger family members relocated, leaving behind elderly relatives in isolation. While Suzu's remoteness has contributed to the preservation of cultural landscapes and traditional practices, it has also delayed the delivery of emergency services, supplies, and reconstruction resources, further exacerbating disaster impacts.

2. LITERATURE REVIEW

2.1 Disaster Recovery for Elderly Populations

The global demographic shift toward an aging population presents growing challenges for disaster management and recovery. According to the World Health Organization (2025), by 2030, one in six people will be aged 60 or older, rising to 2.1 billion by 2050. The population aged 80 and above is projected to triple to 426 million. These trends demand urgent adaptation of disaster recovery frameworks to address the intersecting vulnerabilities faced by older adults in disaster-prone regions.

Disaster recovery involves restoring or improving the health, livelihoods, and social systems of affected communities while promoting sustainability and reducing future risks (UNDRR, 2017). However, traditional recovery models often fail to account for the specific needs of aging populations. Older adults face complex risks that include not only physical and cognitive limitations but also social isolation, economic insecurity, and reduced access to services. These factors combine to intensify disaster impacts and slow recovery, especially in remote or rural communities.

A key limitation in disaster policy and practice is the tendency to treat older adults as a homogenous vulnerable group whereas, in reality, aging populations are highly diverse. Widiastuti (2025) highlights that while some older adults remain active and independent, others face mobility challenges, chronic illnesses, and cognitive decline. Vulnerability is further influenced by disaster experience, access to information, social networks, and community engagement (Sri-on et al., 2019). Despite these variations, older adults are frequently marginalized in disaster planning, reinforcing stereotypes that position them solely as passive recipients of aid.

Recent studies challenge this narrative by recognizing the resilience and contributions of older adults in disaster contexts. While earlier research often portrayed older individuals as fragile and dependent (Andrade et al., 2021), emerging evidence emphasizes their psychological resilience. Drawing on the UNDRR's definition of resilience, which includes the capacity to absorb and recover from disaster impacts while maintaining essential functions, Navarrete-Valladares et al. (2023) argue that older adults often demonstrate greater emotional stability and coping abilities than younger populations. Life experience and adaptive strategies can strengthen mental resilience, helping older adults manage disaster-related stress.

Older adults also play active roles in supporting community recovery. Skinner et al. (2014) describe how older residents in rural Canada have strengthened local services through volunteering, contributing to social cohesion and economic activity. Madsen et al. (2019) similarly argue that resilience is built through everyday social participation. Their review identifies positive reframing, personal purpose, and social belonging as key to fostering both personal and community resilience. Studies from Chimanimani, Zimbabwe following Cyclone Idai carried out by the author also highlight the role community participation plays in aiding disaster recovery. These findings call for a shift in recovery frameworks to move beyond age-based vulnerability and recognize the social and economic contributions of older adults.

However, not all older adults have equal access to supportive networks. Drolet and Choudhury (2024) emphasize that social isolation, especially among those living alone or in rural areas, is a major barrier to disaster preparedness and recovery.

Their research highlights the importance of promoting community engagement and providing accessible services to reduce isolation and support recovery. Informal networks, such as family and neighbour support, play a critical role alongside formal services. Fletcher et al. (2021) reinforce this view in their study of Hurricane Michael, showing that community-based support, provided by faith-based groups, non-profits, and local organizations was essential for older adults navigating recovery. These studies illustrate that effective recovery depends not only on formal assistance based on policies but also on the strength of local social infrastructure. However, access to such support varies widely across communities, raising concerns about equity in recovery outcomes.

While the literature highlights the potential of an inclusive, community-centred recovery approach, it also reveals significant limitations. Not all communities have the same capacity to mobilize local support, and poorly designed policies can exacerbate social inequalities. Older adults who lack social connections or live in resource-scarce areas are at higher risk of being left behind. This risk is particularly acute in rural and super-aged communities, where service gaps and demographic decline reduce recovery capacity.

These disparities point to the broader issue of post-disaster inequality, where recovery benefits are unevenly distributed, creating divides between those who recover quickly and those who face prolonged hardship. While some individuals leverage strong social networks to build back better, others struggle with fragmented support systems and limited resources. This study addresses gaps in understanding how recovery policies influence post-disaster inequality in remote, aging communities. Examining the lived experiences of elderly survivors in Suzu City offers new insights for designing more inclusive and equitable recovery frameworks.

2.2 Structural Disparities and Polarization in Recovery Outcomes

While research on disaster recovery has grown in recent years, there remains a gap in fully understanding the extent of social and spatial inequalities that emerge in the recovery process, particularly in remote and super-aged communities. Existing studies consistently show that disasters have uneven impacts across different population groups, leading to post-disaster

polarization, the widening of disparities between those who recover quickly and those who experience prolonged hardship (Cappelli et al., 2021; Sakai et al., 2017). This situation is especially pronounced in rural areas with aging populations, where older adults face compounded challenges due to physical, economic, and social vulnerabilities (Rafiey et al., 2016).

UNESCWA (2020) defines polarization as the social division that results from factors such as income inequality, housing market shifts, and economic displacement. Joseph et al. (2021) note that marginalized groups, including older adults, face limited access to recovery resources due to discrimination, reduced mobility, and exclusion from decision-making. Yodsuban and Nuntaboot (2021) further report that older adults in southern Thailand were often overlooked and received little support during flood response efforts, demonstrating how systemic neglect contributes to unequal recovery outcomes for vulnerable populations.

In this study, the term '*disparity* 'is used to describe unequal recovery conditions, while '*post-disaster polarization*' refers to the progressive divergence of recovery trajectories as outlined by Capelli et al., 2021; Sakai et al., 2017. Whereby existing disparities intensify into contrasting recovery trajectories over time.

Beyond the immediate aftermath, recovery processes often reproduce or deepen pre-existing inequalities. Kammerbauer and Wamsler (2017) examine post-disaster housing reconstruction and argue that complex bureaucratic procedures and market dynamics, such as rent increases and limited insurance payouts, disproportionately exclude low-income and elderly homeowners from accessing rebuilding assistance. These processes not only slow recovery but also entrench long-term marginalization. In contrast, civil society actors such as volunteers have demonstrated the potential to reduce inequalities by helping vulnerable groups navigate formal recovery systems and access needed support.

Despite these challenges, a more optimistic perspective is offered by Kino et al. (2023). Noting that after the 2011 disaster in Japan, inclusive recovery policies, such as equitable access to housing, financial aid, and community health programs, helped prevent a widening of socioeconomic gaps. Proactive local engagement and the presence of social infrastructure like community centres and volunteer-led activities contributed to maintaining social cohesion. However, the study also acknowledges the risk of biased outcomes due to selective migration where the most vulnerable may have left the area or were not captured in the data. Nonetheless, it demonstrates that equitable recovery is possible when policies are designed to be inclusive and accessible. This perspective aligns with earlier research by HelpAge International (2000), which emphasizes that reducing the vulnerability of older individuals is not about creating separate services but ensuring equal access to mainstream support systems. In rural areas, older adults hold valuable knowledge and skills that could accelerate community recovery if properly mobilized. However, when older populations are neglected or excluded, their potential contributions remain untapped, further widening recovery gaps.

Ding et al. (2024) underscore that socioeconomic factors such as income, occupation, and age significantly influence resilience. In Suzu, many older residents lost boats, farmland, and

tools essential for their livelihoods, resulting in disproportionate financial losses and reduced recovery capacity. These findings are consistent with research by Coleman et al. (2024), which shows that areas with higher median incomes tend to recover faster, even when exposed to severe hazard impacts, while low-income and minority communities experience prolonged recovery even with less severe damage.

This divergence in recovery outcomes is commonly referred to in Japan as the scissor gap (Hasami-jo-kakusa), where some residents rebuild quickly while others remain in extended precarity. Fieldwork in Suzu revealed that this divide is not only material but also emotional. Elderly women reported feelings of shame and hopelessness when comparing their situations to those of neighbours with newly rebuilt homes. These emotional impacts reflect broader patterns identified in resource and exposure theories, which argue that elderly individuals often have lower economic resilience and face greater physical and informational barriers, limiting their ability to recover effectively (Rafiey et al., 2016).

Collectively, these studies underscore the urgent need for context-sensitive, inclusive recovery frameworks that address both structural inequalities and psychosocial well-being. Recovery policies must go beyond material reconstruction to ensure that elderly and marginalized populations are fully included in recovery planning and support systems. Without such efforts, post-disaster disparities will likely persist, leaving the most vulnerable further behind.

3. METHOD

3.1 Research Design

This study critically examines the complexities of disaster recovery in remote communities, with a focused case study on Suzu City in Japan, following the 2024 Noto Peninsula Earthquake. It explores how aging demographics, geographic isolation, and institutional limitations intersect to shape the lived recovery experiences of elderly survivors. Particular attention is given to temporary shelter environments, prolonged delays in reconstruction, and the resulting post-disaster polarization within affected communities. Uniquely, the study investigates policy-induced disparities in access to aid and housing, an area largely overlooked in existing literature, and evaluates the potential of alternative, human-centred solutions such as 3D-printed housing to address the limitations of current shelter provision. Grounded in field interviews, site surveys, and policy analysis, this research offers new insights into disaster recovery within contexts marked by demographic decline and infrastructural fragility.

To examine these recovery conditions in depth and analyse the factors shaping these outcomes, the study employed a qualitative ethnographic case study design. Fieldwork was conducted in Suzu over a continuous 10-day period in March 2025, approximately one year after the disaster, to assess the challenges of recovery. The research was conducted in collaboration with an NPO based in Fukuoka City, which had been continuously involved in

supporting the recovery of the Noto Peninsula since the earthquake (M5.5) that occurred on March 13, 2020. Through this collaboration, trust-based relationships were established with participants in Suzu City, enabling the investigation.

A purposive sampling strategy guided the selection of two key participant groups: elderly survivors of the earthquake and local recovery stakeholders, including community leaders and non-profit staff. This approach enabled both individual and institutional perspectives to be examined. Immersion in the community also allowed for observational data, informal dialogue, and a deeper understanding of the layered processes shaping post-disaster housing recovery in a remote, rural, and aging society.

3.2 Research Objectives

The following objectives have been established to guide the direction and scope of this study. They reflect the core aims of the research and are intended to address the key questions emerging from the post-disaster recovery context in Suzu City.

1. To examine the challenges linked to delays in infrastructure and housing reconstruction and their impact on disaster recovery in Suzu. (Chapter 4, Section 1)
2. To analyse how policy frameworks shape the pace, equity, and disparities in post-disaster recovery for elderly survivors, and to identify key gaps in rural recovery systems related to communication, housing, and support infrastructure (Chapter 4, Section 2).
3. To analyse the challenges related to the planning, design, and living conditions of temporary housing settlements in Suzu, with a focus on how these issues impact the recovery and well-being of the elderly population (Chapter 4, Section 3)
4. to explore alternative architectural solutions such as 3D-printed housing prototypes that can enhance safety, dignity, and comfort in future disaster recovery efforts (Chapter 4, Section 4).

3.3 Data Collection

Data were collected through a combination of interviews and field observations, ensuring triangulation of perspectives on housing recovery:

- **Interviews with Elderly Survivors** (n = 20): Semi-structured interviews were conducted with twenty elderly earthquake survivors, with an average age of 77.1 years, who had experienced damage to their homes. An interview guide with structured questions was used to focus on topics of housing and shelter recovery, but the format was flexibly adapted to each participant's needs. Researchers took care to accommodate the pace and comfort of older interviewees, allowing them to narrate their experiences in their own words. These interviews typically lasted about 10-15 minutes and were carried out outside

of the survivors' residences or temporary housing units, providing additional contextual insight into their living conditions.

- **Interviews with Local Stakeholders** (n = 10): Informal conversational interviews were held with ten key stakeholders involved in the recovery process, including staff from local non-profit organizations (NPOs), volunteer coordinators, and municipal officials. These discussions were unstructured, allowing stakeholders to freely discuss their roles, observations of community recovery, and challenges specific to aiding an elderly population. By engaging in open-ended conversations (often at NPO offices or community meeting places), the researchers gathered insights into institutional efforts, coordination among agencies, and broader socio-economic issues (such as depopulation) affecting recovery.

- **Site Surveys and Observation**: The fieldwork also involved direct observation of living conditions in the affected areas. The researchers conducted site surveys of temporary housing clusters and damaged neighbourhoods to record physical conditions and infrastructure status. Detailed field notes were kept on the state of temporary shelters, the availability of basic services (water, power, accessibility), and any modifications or coping strategies residents had adopted. This ethnographic observation helped contextualize interview findings by providing firsthand evidence of the environment in which survivors were navigating their recovery.

- **Photographic Documentation**: Complementing the interviews and observations, photographic documentation was used to capture visual evidence of housing and shelter conditions. With participants' permission, the researchers photographed temporary housing units, repair works in progress, and communal facilities for the displaced elderly. These images served as an additional data source to verify and illustrate reported conditions (for instance, showing the size and condition of temporary units, or the persistence of debris and structural damage in certain areas). Photographs were carefully managed to avoid capturing identifiable individuals, focusing instead on physical structures and settings.

This multi-pronged data collection approach provided a rich, triangulated dataset. The use of multiple sources and personal narratives of elderly survivors, perspectives of those aiding recovery, and on-site observations enhances the credibility and depth of the findings. For example, stakeholders' descriptions of challenges in repairing homes for the elderly could be cross-validated with survivors' personal accounts and visual observation of their living conditions. Such triangulation strengthens the study's methodological rigor, allowing a comprehensive understanding of the housing recovery process in Suzu.

3.4 Data Analysis

In this study, thematic analysis and triangulation were applied to analyse qualitative data collected from semi-structured interviews, site surveys, photographs, and secondary sources. These methods were chosen to ensure a systematic, context-sensitive approach to

understanding the disaster recovery challenges in Suzu following the 2024 Noto Peninsula Earthquake. Thematic analysis followed the six-phase framework proposed by Braun and Clarke (2006), enabling structured interpretation of patterns and themes in the data:

1. Familiarization with Data - Interview transcripts (Originally in Japanese and translated where necessary), observational notes, and site visit records were reviewed repeatedly to build a comprehensive understanding of the content.

2. Generating Initial Themes - The data was coded into meaningful units, with recurring issues such as emotional strain, delayed reconstruction, spatial discomfort, and information inaccessibility being highlighted.

3. Searching for Themes - Codes were organized into broader thematic categories representing physical, institutional, and psychosocial challenges associated with disaster recovery in aging, remote areas.

4. Reviewing Themes - Emerging themes were refined to ensure internal consistency, relevance to the study objectives, and support from multiple data points.

5. Defining and Naming Themes - Each theme was clearly labelled and described to reflect its contribution to understanding shelter living conditions and recovery dynamics.

6. Producing the Report - Themes were synthesized into a structured narrative, incorporating direct quotes and photo evidence to show lived experiences and support critical discussion.

This approach enabled the identification of challenges through purposive interviews with 30 individuals, 20 elderly survivors and 10 NPO staff and local actors. It also accommodated the flexibility needed in post-disaster contexts, especially with elderly participants. Triangulation was employed to cross-validate data from three key sources: field interviews, site observations, and policy or NGO documentation. Key aspects of its application included: (1) Cross-Referencing Data Sources; Survivor interviews were cross-checked with observations and institutional reports to confirm findings and reduce bias; (2) Highlighting Stakeholder Divergences; Triangulation revealed mismatches between governmental provisions and actual survivor needs, especially among elderly residents; (3) Strengthening Contextual Validity. The integration of visual data and narrative accounts ensured that findings reflected real-world conditions of prolonged shelter living. (Hammerton and Munafo, 2021).

The results of the thematic coding are presented explicitly in the Findings and Discussion section, where analytically derived themes are used to systematically structure the presentation of interview findings. Each theme is supported by representative interview excerpts presented in direct, colloquial form to preserve participants' voices and lived experiences. Authorial interpretation is provided separately following each excerpt to clearly distinguish participant perspectives from analytical discussion. This structured presentation enables transparent tracing between coded data, thematic interpretation, and broader analytical claims, thereby strengthening the rigor and interpretability of the qualitative findings.

3.5 Ethical Considerations

This study adhered to the ethical guidelines of Kyushu University and international research standards to ensure the protection, dignity, and autonomy of all participants, particularly elderly individuals. Informed consent was obtained after explaining the study's aims and procedures, and participants were assured of their right to withdraw at any time. Interviews were conducted with care and sensitivity, scheduled at convenient locations and times to reduce burden, and designed to accommodate the health and comfort of elderly respondents. Confidentiality was maintained through anonymization of data and secure handling of all materials. Visual documentation was used responsibly, avoiding identifiable imagery without explicit consent. No participants experienced undue distress, and many expressed appreciation for the opportunity to share their experiences.

4. SOCIO-DEMOGRAPHIC CONTEXT AND INEQUALITY IN SUZU - BEFORE AND AFTER THE EARTHQUAKE

Suzu faces one of Japan's most extreme demographic challenges. As of 2021, 52% of its 12,929 residents were aged 65 or older (Statistics Bureau of Japan, 2021), with 29% aged 75 or above, and 11% exceeding 85 years of age. Many households consist of elderly-only residents, positioning Suzu as a "super-aged" society. This demographic structure of Suzu substantially heightened vulnerability prior to the 2024 Noto peninsula Earthquake, particularly in relation to mobility, health, access to information and recovery capacity. This section examines Suzu's socio-demographic conditions before and after the earthquake to clarify whether inequalities observed in the reconstruction process, further discussed in subsequent sections, were produced by the disaster, or rooted in pre-existing structural conditions. Establishing this distinction aims to provide a baseline for interpreting the recovery outcomes and housing conditions examined in this study.

4.1 Demographic Structure and Pre-Existing Vulnerability

Figure 2 illustrates the population composition and age distribution by age group of Suzu before the earthquake. The dominance of older age groups reflects long-term rural depopulation and the outmigration of younger generations to urban centres. A large share of the residents experience reduced physical mobility, chronic health conditions, cognitive decline, or sensory impairments, all of which affect the ability to evacuate, access services, and engage with post-disaster processes. These vulnerabilities were structurally embedded in the region prior to the earthquake.

Elderly only households are particularly prevalent in Suzu, limiting access to informal support networks during emergencies and recovery periods, reducing their recovery capacity. The scarcity of alternative housing options and limited rental stock further restricts relocation following housing damage. As a result, demographic vulnerability in Suzu should be

understood as a product of long-term socio-spatial processes rather than as a direct consequence of the disaster itself.

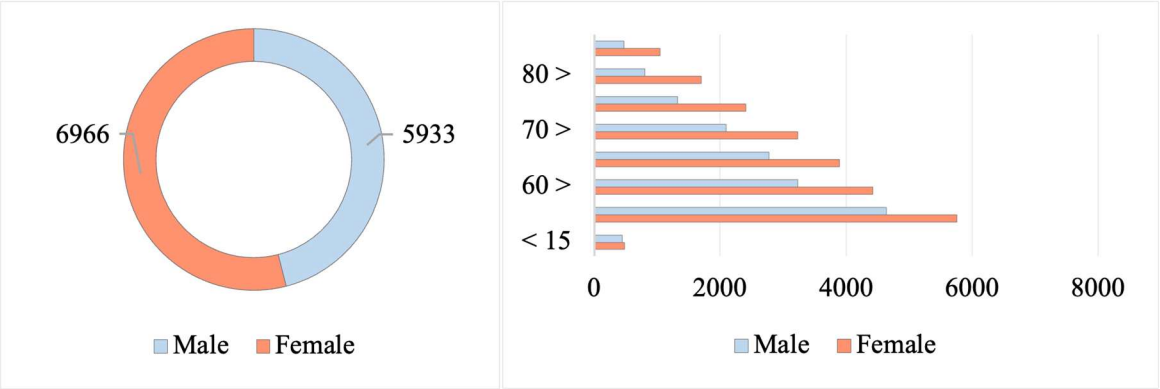


Figure 2. Suzu population and distribution by age group
Source: Statistics Bureau of Japan 2021

Figure 3 shows a steady and substantial population decline in Suzu, with a total population projected to decrease from approximately 11,273 in 2025 to 5083 by 2050. This presents a reduction of more than 50% over 25 years, reflecting the ongoing outmigration, low birth rates, and advanced population aging. Such demographic contraction is expected to constrain local labour availability, service provision, and institutional capacity, thereby intensifying existing structural vulnerabilities in post-disaster recovery.

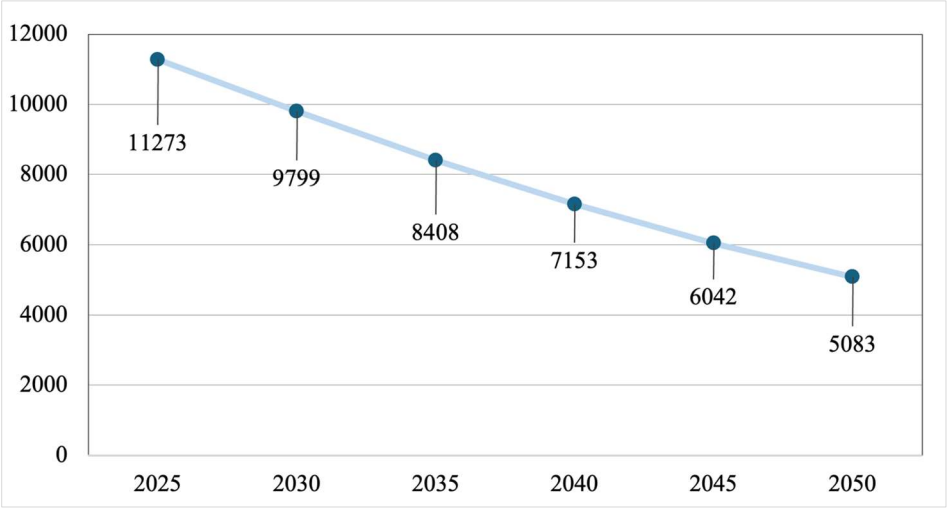


Figure 3. Population projection for Suzu (2025-2050)
Source: Statistics Bureau of Japan 2025

4.2 Gendered Dimensions of Demographic Inequality

Gender disparities further compound this vulnerability as residents aged 65 and above, 58% are women. This imbalance becomes more pronounced among those aged 85 and older, where women constitute roughly 71% (1,042 women to 472 men). As a result, post-disaster community resilience increasingly relies on elderly women, a group often facing both physical frailty and economic disadvantage, including lower pension benefits. For many, recovery is

hindered by the absence of familial support, difficulty accessing and interpreting disaster-related information, and challenges navigating insurance and rebuilding processes.

Post-disaster community resilience in Suzu increasingly depends on elderly women, many of whom face overlapping forms of disadvantage, including physical frailty, social isolation, and economic vulnerability linked to lower pension benefits. Recovery is often hindered by the absence of familial support, difficulties accessing and interpreting disaster-related information, and challenges navigating insurance claims and rebuilding procedures. These gendered inequalities were present prior to the earthquake but became more visible and consequential in its aftermath.

4.3 Demographic Constraints on Recovery Capacity

Suzu's recovery capacity is. Further constrained by the interaction between demographic imbalance and geographic isolation. A rapidly aging population paired with a declining workforce, limiting the availability of skilled labour, healthcare professionals, caregivers, and administrative workers (Kanbara et al., 2025). These shortages weaken both emergency response and long-term reconstruction capacity, slowing infrastructure repair, increasing service backlogs, and placing additional strain on already limited municipal institutions. Labour shortages delayed demolition and rebuilding cycles, while understaffed local governments struggled to coordinate relief efforts, share information, and manage complex logistical demands. Together, geographic isolation, demographic decline, and infrastructural fragility render Suzu structurally disadvantaged in post disaster recovery. The findings that follow demonstrate that recovery inequalities were not produced by the earthquake itself, but rather emerged from pre-existing socio-structural conditions.

5. FINDINGS AND DISCUSSION

Building on the infrastructural and institutional constraints outlined above, this section examines how prolonged recovery conditions are experienced at the household and community level. Drawing on thematic analysis of qualitative data, five analytical themes emerged: Policy-induced administrative barriers, spatial and design constraints in temporary housing, mobility and safety limitations, loss of privacy, autonomy, and social interaction, and attachment to land and self-directed recovery preferences. The following discussion presents interview and site survey findings under these themes using direct excerpts, followed by analytical interpretation, to illustrate how structural recovery delays translate into uneven lived experiences in Suzu City.

The prolonged disrepair of public infrastructure in Suzu City stands as a visible testament to the fragmented and protracted nature of its post-disaster recovery. More than 15 months after the 2024 Noto Peninsula Earthquake, core systems such as roads, electrical networks, and drainage remain severely compromised. These infrastructural failures not only disrupted everyday life but also directly impeded the progress of private housing reconstruction, which

has been further delayed by the slow pace of demolition. A lack of available contractors, coupled with blocked or unstable access routes, has resulted in prolonged waiting periods for affected households. This cascading effect where the inability to repair infrastructure obstructs demolition, which in turn prevents rebuilding has trapped many residents, particularly the elderly, in a state of prolonged displacement.

Critically, the persistent dysfunction of public systems illustrates more than just logistical delay; it reflects the structural limitations of rural disaster governance, where aging populations, shrinking municipal budgets, and limited administrative capacity converge to hinder comprehensive recovery. In such contexts, recovery is not merely slow; it is structurally uneven, often privileging areas with stronger political or economic leverage. Suzu's situation reveals how disaster recovery in peripheral regions can become a drawn-out negotiation between state capacity and infrastructural inertia, leaving vulnerable populations suspended between destruction and reconstruction with no clear resolution in sight.

5.1 Delays in Reconstruction and Damage to Infrastructure

These images in Figure 4 show the exposed and displaced components of the municipal drainage system, with manholes extruded from the ground and surrounding pavement fractured. The extent of the damage reflects the severity of the ground movement during the earthquake and highlights the slow pace of public infrastructure repair. As of the time of this study, critical systems such as water and sewage remain visibly unrepaired, posing not only functional disruption but also safety hazards to residents. The persistence of such damage more than a year after the disaster underscores the strain on recovery resources and the infrastructural vulnerabilities.

(Photography by Author, 2025)

Figure 4. Damage to underground water infrastructure in Suzu City, after the 2024 Noto Peninsula Earthquake (March 2025).

Figure 5 illustrates the ongoing disruption to basic mobility infrastructure in Suzu. The left image shows a public parking area along the waterfront that remains visibly fractured and unusable, while the right image captures a cracked roadside footpath at night, highlighting persistent hazards and accessibility issues for pedestrians, particularly the elderly. Damage of

this kind not only restricts daily movement but also impedes demolition and reconstruction efforts by limiting vehicular and machinery access. The prolonged state of disrepair reflects both the logistical challenges and the limited municipal capacity that characterize recovery in rural, aging communities. Residents have expressed frustration that such visible infrastructural failure remains unaddressed over a year after the disaster, reinforcing a sense of abandonment and delaying meaningful return to normalcy.

(Photography by Author, 2025)

Figure 5. Earthquake damage to mobility and public use infrastructure in Suzu City. (March,2025)

Figure 6 illustrates a common reconstruction challenge in Suzu City, whereby rebuilding is often delayed when adjacent lots remain uncleared, creating legal and logistical barriers to full demolition. Survivors expressed concern that undemolished buildings pose physical risks, as they may collapse onto newly constructed homes, deterring rebuilding efforts. Beyond the safety implications, the prolonged presence of debris has contributed to psychological strain, particularly among elderly residents, reinforcing both visible and emotional disparities between those who have begun to recover and those still waiting. This chain of dependencies between road clearance, demolition, and reconstruction has left many residents, especially elderly women, in prolonged displacement. Emotionally exhausted and with limited agency over their recovery trajectories, they remain confined to temporary shelters, uncertain when or how they will return to stable, permanent housing.

(Photography by Author, 2025)

Figure 6. Collapsed home adjacent to cleared land in Suzu City. (March 2025)

The photographic evidence highlights that rebuilding efforts over the past year have progressed slowly. Although debris removal has advanced in parts of Suzu, recovery remains slow and difficult in many other areas. The cost of recovery is much higher than initially

anticipated, primarily due to labour shortages in the Noto Peninsula and the skyrocketing of construction materials (Peace Winds America, 2024). The situation is further exacerbated, as even though some houses were not completely destroyed, they may not have running water, and residents build homes with loans from the bank and still carry debt from their homes that were destroyed.

The images shown in Figure 7, taken during fieldwork in March 2025, over a year after the 2024 Noto Peninsula Earthquake, illustrate the extent of housing destruction and the slow pace of recovery in Suzu. Entire homes remain collapsed, with visibly warped roofs, dislocated foundations, and uninhabitable interiors. In some cases, buildings have entirely shifted off their original sites, or the ground of public infrastructure has sunken, rendering it unusable and dangerous, highlighting the scale of structural damage and the ongoing danger these sites pose to residents.

The prolonged presence of such destruction underscores critical delays in demolition and reconstruction, exacerbated by limited labour capacity and logistical constraints in this remote municipality. The fact that many properties remain untouched this long after the disaster reflects deeper systemic issues beyond physical damage pointing to administrative bottlenecks, funding limitations, and demographic challenges. These conditions set the stage for understanding how Suzu's population, especially its disproportionately elderly residents, experience post-disaster recovery.

(Photography by Author, 2025)

Figure 7. Visible delays in post-earthquake housing recovery, Suzu

5.2 Policy-Induced Post-Disaster Disparities

The findings from fieldwork conducted in Suzu City highlight how official policy frameworks may inadvertently contribute to post-disaster recovery disparities by reinforcing existing social and spatial inequalities. A primary source of discontent among affected residents stemmed from the government's standardized housing damage classification system, which is

directly linked to financial compensation and eligibility for reconstruction support. The official framework for post-earthquake building assessment in Japan follows a standardized flow as outlined by Nakano et al. (2004), as illustrated in Figure 8.

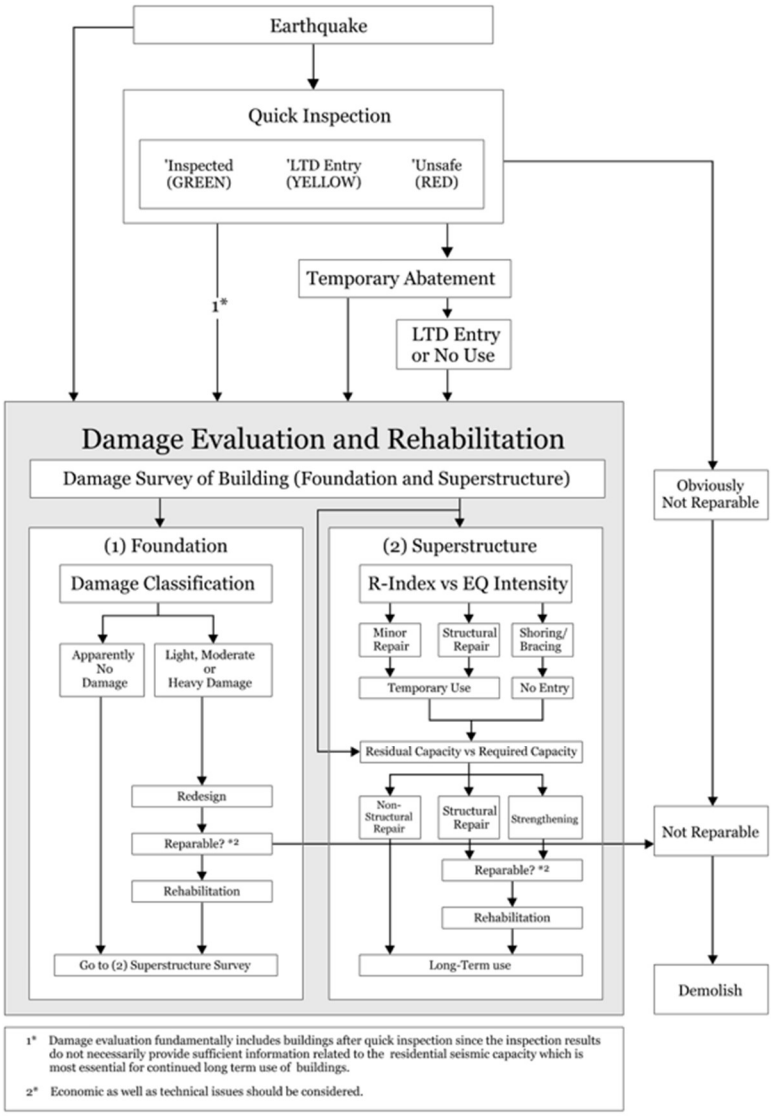


Figure 8. General flow of Damage Evaluation and Rehabilitation Guidelines (Nakano et al., 2004)

Japan's post-earthquake building assessment begins with a rapid visual inspection categorizing structures into three safety levels: 'Inspected (Green)', 'Limited Entry (Yellow)', and 'Unsafe (Red)', aimed at immediate risk management. While useful for quick decision-making, this stage has limitations. As the Cabinet Office (2024) notes, such inspections are conducted under time pressure and may not accurately reflect a building's residual seismic capacity. A more detailed evaluation follows, assessing the superstructure and the foundation. Structural damage is quantified using engineering indices, such as the R-Index against earthquake intensity, to determine appropriate rehabilitation options, including repair, strengthening, or demolition. Additionally, the Cabinet Office defines a classification system based on visual assessments and component-specific weightings to calculate an overall damage ratio.

Buildings are then assigned one of six damage levels, as outlined in Table 1, determined by the extent of floor area affected or the economic value of structural loss (Cabinet Office, Government of Japan, 2024). This multi-step approach provides a standardized framework for guiding post-disaster recovery and resource allocation.

Table 1. Structural damage assessment criteria for residential buildings in Japan

	Total Damage Ratio	Damage Classification	Japanese Term
1	50% or more	Complete destruction of residence	Zenkai
2	40% - Less than 50%	Partial destruction (Large Scale)	Daikibo Hankai
3	30% - Less than 40%	Partial destruction (Medium Scale)	Chukibo Hankai
4	20% - Less than 30%	Partial destruction (Small Scale)	Shokibo Hankai
5	10% - Less than 20%	Half damage of residence	Hankai
6	Less than 10%	Quasi partial damage	Jun-Hankai

In practice, a house classified as *Quasi-Partial damage* may be entirely uninhabitable due to compromised foundations or surrounding land instability, yet such cases typically receive significantly less financial support. This disconnect between technical classification and functional usability has led to unequal recovery outcomes, particularly for elderly individuals residing in traditional wooden homes that, due to outdated construction standards, are structurally undervalued in assessments. These findings suggest that while the current system provides administrative clarity and facilitates resource distribution, it lacks the flexibility to respond to diverse housing conditions and social vulnerabilities, thereby reinforcing disparities in post-disaster recovery.

This technical evaluation process closely parallels the broader engineering framework presented in national guidelines, which include a key decision point concerning reparability. Notably, reparability is assessed not only in terms of structural integrity but also economic feasibility, introducing a pragmatic dimension to post-disaster resource allocation. However, this logic also reveals a fundamental tension between objective engineering judgments and residents' subjective lived realities. Buildings categorized as "not reparable" may still hold deep social, emotional, and cultural value for their occupants, complicating decisions around demolition and displacement. Consequently, while the framework provides a structured and technically sound protocol for guiding post-earthquake recovery, its limitations in addressing socio-spatial vulnerability and non-material losses highlight the need for more inclusive and context-sensitive recovery strategies.

Many elderly residents described significant difficulties understanding government procedures related to housing recovery. Interviewees repeatedly referred to official documentation as confusing, overly technical, and physically difficult to read. As one woman in her late 80s explained,

"The papers they hand out to us are full of complicated terminology, and the letters were so small, I can't understand it." She added, *"I don't know who to ask for help. My children are so far away and if I went to a lawyer, it would cost me so much".*

From an analytical perspective these accounts indicate that administrative systems were experienced as largely inaccessible to older residents, particularly with declining vision, cognitive fatigue, or limited social support. Rather than enabling recovery, policy procedures in practice appear to shift the burden of navigating post disaster recovery to the individuals least equipped to manage it.

The emotional consequences of these barriers were also described in interviews, particularly by elderly women. A 92-year-old woman explained her housing decision as follows.

"My daughter said I could stay with her in the city. But after a while I felt like I was causing so much strain in her household, so I applied to be in a shelter and came back here to Suzu. But now I am in a place I don't really know with little support."

While she did not explicitly describe her emotional state as 'isolation', her prolonged stay in accommodation resulted in reduced daily social interaction and increased separation from family support networks. Similarly, a 76-year-old woman whose home was severely damaged in the earthquake stated,

"I can't rebuild the house, and I can't sell the land. I am completely stuck, and I am not sure what to do next."

Taken together, these statements indicate how policy design and administrative complexity may unintentionally deepen post-disaster disparities by limiting elderly residents' capacity to make informed recovery decisions. Rather than reflecting individual vulnerability alone, the difficulties described here point to policy-induced constraints that shape unequal recovery trajectories, particularly for older women living alone in rural contexts.

The proposed rent structure of Suzu City's public housing, as highlighted in Figure 9 reveals a steep and uneven escalation in rent based on unit size, with the most substantial percentage increases affecting the smallest units. Specifically, rent for a 45m² unit increases an expected by 243%, followed by a 214% increase for 55m², 206% for 65m², and 205% for 75m². This trend indicates that households occupying smaller units, often elderly individuals and elderly women living alone, face the greatest relative financial burden.

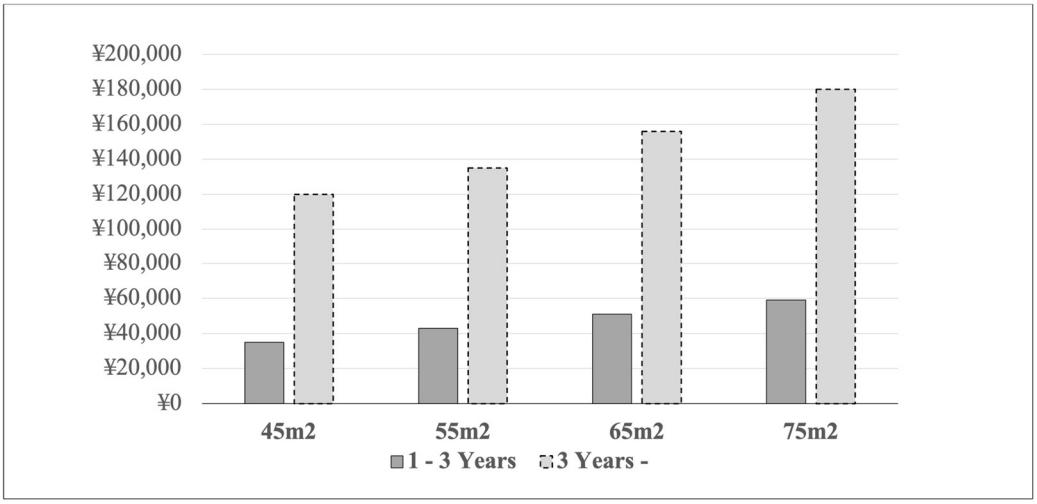


Figure 9. Proposed rent structure of public housing in Suzu (Suzu City, 2024)

While all unit sizes experience more than a doubling in rent, the sharper rise for smaller spaces exposes a regressive structure that fails to account for gendered and age-based vulnerabilities. Elderly women, who are statistically more likely to live alone, have lower lifetime earnings and rely on limited pensions, are placed at heightened risk of secondary displacement or prolonged recovery stagnation. Rather than prioritizing those with the fewest resources, the policy applies a uniform standard that disproportionately penalizes socially and economically marginalized groups. This approach reinforces structural inequality and undermines the principles of equitable recovery in super-aged, rural disaster-affected communities.

Findings from Suzu City demonstrate how rigid post-disaster recovery policies can inadvertently reinforce social inequality, particularly among elderly residents and women living alone. Although Japan's damage assessment system is robust, it often fails to account for functional loss, resulting in underestimation of housing damage and inadequate aid allocation. Many elderly survivors reported difficulty navigating complex bureaucratic procedures with limited digital access or institutional support, effectively excluding them from key recovery mechanisms. These challenges are compounded by a steep rent structure in public reconstruction housing, where rates are expected to rise by over 200% after three years, disproportionately affecting occupants of smaller units: often those with the fewest financial and social resources. By relying on standardized criteria that overlook intersecting vulnerabilities related to age, gender, isolation, and income precarity, the system perpetuates long-term recovery disparities.

5.3 Recovery Challenges in Temporary Housing Communities

Suzu City's temporary shelter communities, comprising 1,718 units across 52 locations as illustrated in Figure 10, reveal significant spatial and infrastructural variation (Suzu City, 2025).

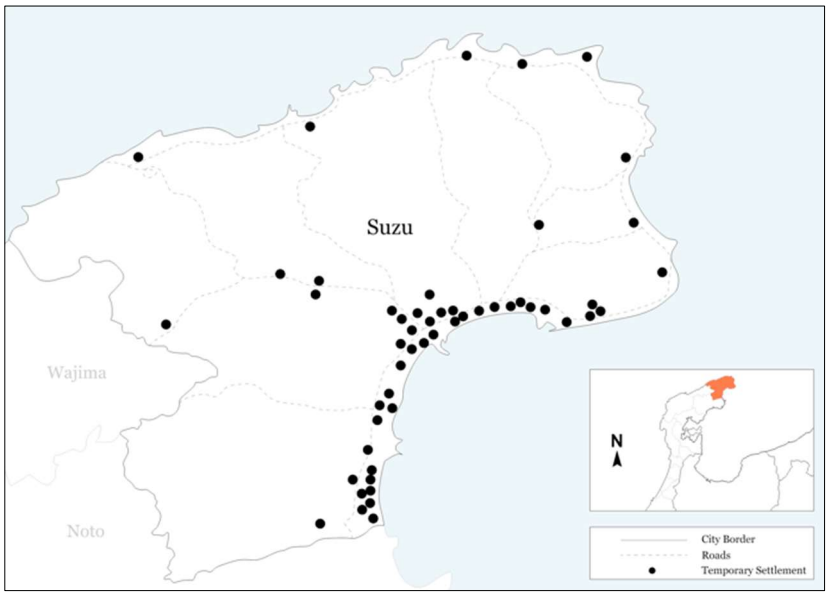


Figure 10. Temporary housing settlement Map in Suzu, adapted by Author based on data from Suzu City, (March 2025)

The largest site, located at the Horyu Elementary and Middle School grounds, accommodates 153 households, while the smallest, at Karakasacho ranch site, consists of just a single unit. These shelters are spread across various locations, including school grounds, parking lots, parks, golf courses, tennis courts, and dockyards. Site observations and interviews revealed that living conditions differ not only by the number of units but also by site type, with notable contrasts between larger communities and isolated units, as well as between settings such as parking lots and parks. Despite these differences, residents commonly reported challenges related to privacy, accessibility, and limited communal spaces.

Many temporary housing settlements in Suzu are concentrated along the coastline, where flat terrain and existing infrastructure make construction easier than inland. While this spatial arrangement supports rapid deployment, several residents described how daily life in these settlements felt socially constraining. An 81-year-old woman now living in a container house who had previously lived in a detached home which was destroyed in the tsunami reflected on her change in her living environment, stating,

"There is no one around during the day. It very quiet and there is no one to talk to." She contrasted this with her pre-disaster life, explaining, *"I used to live in a big house with lots of space. Friends or my children and grandchildren would come over for new years and holidays."*

These statements underscore the contrast between pre- and post-disaster living conditions in the temporary settlements. Although they were physically crowded, daytime recovery activities meant that residents with limited means, particularly older residents with reduced mobility, remained behind, resulting in reduced social interaction and increased isolation.

Several residents described tensions within temporary housing environments, which they associated with overcrowding and the need to share confined space. One elderly resident explained,

"We are living too close together here. Even small things can turn into arguments. I can hear people arguing at night."

Interviewees frequently contrasted these conditions with their pre-disaster living environments, noting that traditional homes in Suzu are typically detached, with multiple rooms and spacious plots of land. An 83-year-old woman expressed a strong preference to return to her original property rather than remain in the shelter. She explained,

"I want to remove the damaged house and build a small shed, just with a kitchen, a toilet, and a shower." She added, *"If I'm there, I can at least feel like I'm at home again, and I can grow vegetables in my garden."* She also described concerns related to security, stating, *"Sometimes people steal things from the drying racks or the balconies."*

These accounts suggest that the transition from spacious, private homes to compact temporary shelters introduced not only physical discomfort, but also emotional strain linked to loss of privacy, insecurity, and disruption of everyday practices. Recovery preferences among elderly residents were shaped not only by housing quality, but by attachment to land, autonomy, and familiar routines such as agriculture.

Several temporary housing sites in Suzu are in remote mountain areas, far from the coastal and agricultural livelihoods that many residents once depended on. This relocation has disrupted daily routines, social ties, and caused stress, particularly for those engaged in fishing or farming. Such displacement contradicts the UNDRR's (2017) definition of recovery, which emphasizes restoring livelihoods and well-being. Transport barriers further isolate these communities, as individuals lost their vehicles when homes collapsed, leaving them without personal transport.

At Takojima Temporary Shelter Community 6, residents live in densely packed metal container units (Figure 11), increasing discomfort and limiting daily activities. These temporary units offer quick installation and lower costs, but interviews reveal that living conditions remain difficult even after 15 months. While ramps improve accessibility, cramped interiors, poor insulation, and lack of privacy continue to make daily life uncomfortable, especially for elderly residents who rely on routine, stability, and comfort. A 44-year-old woman described how the layout of the container unit affected daily routines. She explained,

"The kitchen is so small I can't really cook properly for my family, so we end up buying food from the convenience store most of the time." She also noted, *"There's nowhere to hang clothes outside, so we have to dry everything inside the house."*

These statements suggest that design limitations within container units constrained everyday household practices, increasing living costs, reducing dietary autonomy, and contributing to moisture and discomfort indoors. Such conditions illustrate how temporary housing designed for short-term use can impose additional burdens when occupation becomes prolonged, particularly for families.

(Photography by Author, 2025)

Figure 11. Temporary housing units in Takojima Community 6, Suzu (March 2025)

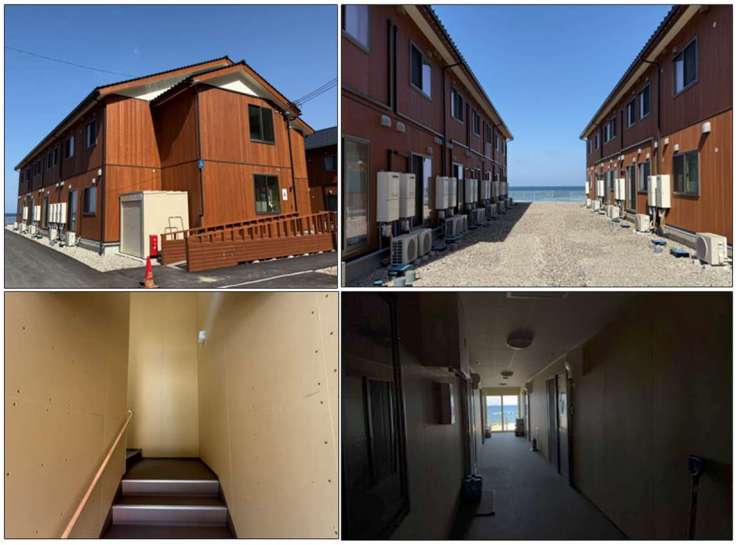
Figure 12 illustrates the current reality in Takojima Temporary Housing Community 4, where residents were forced to make modifications to their units to have a more comfortable space with additional room. Reflecting the lack of space when temporary solutions extend into long term habitation.

Figure 13 shows a large-scale temporary housing site in Suzu, constructed using timber on a former middle school ground. The site accommodates 72 households, making it one of the most densely populated temporary housing communities in the city. Unlike quickly deployable

container or trailer units, these timber structures offer better insulation and a more home-like environment. However, this benefit came at the cost of longer construction times, as the units had to be assembled on-site. While ground-level units are equipped with ramps for wheelchair access, the buildings lack elevators. This poses challenges for elderly residents or those with mobility difficulties who must climb stairs to access upper floors.

(Photography by Author, 2025)

Figure 12. Temporary housing community in Takojima 4, Suzu (March 2025)



(Photography by Author, 2025)

Figure 13. Temporary housing community in Otani 1, Suzu (March 2025)

As the majority of residents are elderly, this design limits their movement and may discourage social interaction or access to community support services. The units also lack outdoor balconies or drying areas, forcing residents to dry laundry inside their already small living spaces. This not only reduces living comfort but also raises moisture-related health concerns, particularly for older adults with respiratory issues. An 86-year-old man described difficulties using shared circulation spaces, stating,

"The corridor and stairs are very dark, even during the day. I'm scared I might trip, so I hardly go outside." He also noted, *"There's no elevator, so going up and down is not easy."*

These conditions suggest that inadequate lighting and vertical circulation barriers limited mobility and reduced opportunities for social interaction among elderly residents.

Prolonged exposure to the challenges of temporary housing communities undermines the recovery of aging populations. While designed to meet immediate shelter needs, these environments often introduce new stressors, including overcrowding, lack of privacy, poor accessibility, and limited opportunities for maintaining daily routines. Such conditions have pushed some residents, particularly older adults, to abandon temporary shelters in favour of returning to their damaged homes, despite the risks.

One such example is shown in Figure 14, which documents the precarious living conditions of a resident who chose to return to his severely damaged home after leaving temporary housing. The only habitable space remaining is the former dining room (Left), now repurposed as a combined bedroom, living room, and kitchen. The surrounding rooms (Right) remain cluttered with debris, broken glass, and torn partitions, creating an unsafe yet familiar environment. Without access to running water or electricity, the resident relies on solar panels for basic energy needs and collects water from external sources.

(Photography by Author, 2025)

Figure 14. Reoccupied earthquake-damaged house (March 2025)

Similarly, Figure 15 shows a residence damaged by both the earthquake and the tsunami. Despite the visible damage, the occupant chose to return and independently manage the reconstruction process. A small cabin was built next to the damaged house, where the household now resides while gradually repairing the main structure. During interviews, the occupant explained that although this approach requires time and sustained effort, it was experienced as more comfortable and less stressful than remaining in temporary shelter settlements. Returning to their own land enabled the household to retain a sense of autonomy and familiarity, allowing recovery to proceed at a self-determined pace.

(Photography by Author, 2025)

Figure 15. Reoccupied earthquake-damaged house (March 2025)

These cases highlight the limitations of standardized temporary shelter strategies in Suzu, which have failed to meet the psychosocial and practical needs of elderly survivors. While such housing schemes provide basic necessities, they often compromise well-being, autonomy, and quality of life, ultimately delaying post-disaster recovery. However, consistent with existing literature, the resilience demonstrated by older adults underscores the importance of recovery policies that prioritize dignity, routine, and long-term well-being (Navarrete-Valladares et al., 2023; UNDRR, 2017).

5.4 Comparative Assessment of Post-Disaster Housing Options

Post-disaster housing recovery is increasingly understood as a process shaped by not only the physical damage, but the pre-existing structural conditions that influence access to resources, institutional support, and recovery capacity. This study examines and highlights the inequalities embedded in social, economic, and demographic systems that often translate to disparities and uneven recovery trajectories. This trend is particularly noted in marginalized and aging communities (Kammerbauer & Wamsler, 2017).

In Japan, post-disaster housing provision is often limited to a set of established approaches, prefabricated housing, container housing, timber-based temporary housing, and owner-driven reconstruction. While these options remain central to national recovery frameworks, their effectiveness varies depending on local contexts. Findings from this study suggest that these approaches face distinct limitations in super-aged and geographically isolated regions, necessitating a comparative evaluation of alternative housing options adopted in Suzu.

Prefabricated container housing is commonly adopted in the aftermath of disasters due to its rapid deployability and standardized logistics. In Suzu, container units played an important role in providing emergency shelter. However, field observations and interviews indicate that prolonged reliance on these units posed significant challenges, particularly for elderly residents. Limited interior space, insufficient thermal insulation, and a lack of adaptability to individual needs reduced their suitability for extended use. Aligning with findings from studies by Kammerbauer and Wamsler (2017), showing that these conditions contribute to social and economic isolation among older occupants, illustrating how standardized solutions can unintentionally reinforce recovery disparities when displacement becomes long-term.

Timber temporary housing represents a higher quality alternative within Japan's disaster recovery system, offering improved spatial comfort, insulation, and a more familiar domestic environment. In Suzu, residents who relocated into timber housing units reported better living conditions compared to container shelters. Timber construction requires sustained availability of skilled labour, longer construction timelines and stable and affordable material supply chains. In Suzu, demographic aging and the workforce decline significantly constrained these requirements, delaying delivery and limiting the number of units that could be provided.

Owner driven reconstruction is often framed as the most favourable long-term recovery solution, allowing affected residents to return to permanent housing on their original land. In practice, however, this option was inaccessible for many elderly households in Suzu. Fixed

incomes, limited savings, rising construction costs, and the administrative complexity of insurance and rebuilding procedures posed substantial barriers to recovery. Studies have shown that structural inequalities frequently lead to diverging recovery trajectories, whereby households with greater financial, social, or institutional access recover more quickly than those without (Cappelli et al., 2021).

Within this constrained recovery landscape, 3D printed temporary housing is examined in this study as a context-specific and complementary approach to existing recovery housing typologies. Its relevance lies in its potential alignment with these structural conditions observed in Suzu.

Automated or semi-automated production processes may reduce dependence on scarce skilled labour, a critical consideration is super aged communities. Construction timelines may be shorter than timber alternatives, and unit layouts can be customized to accommodate accessibility requirements, thermal comfort standards, and household configurations to address several shortcomings this study identifies in the existing temporary housing solutions.

Figure 16 presents a completed 3D printed housing prototype currently used as accommodation for recovery personnel. Although not yet deployed for displaced residents, its current use provided empirical insight into spatial configuration, construction logistics, and material performance. The 50m^2 1LDK layout and thick double walls suggest improved suitability for prolonged habitation compared to container shelters, particularly in climates characterized by cold winters and hot summers. From a comparative perspective, these attributes indicate potential advantages in Suzu where recovery timelines have extended beyond the short term.

(Photography by Author, 2025)

Figure 16. 3D Printed Housing Prototype (March 2025)

This study acknowledges the important limitations associated with 3D printed housing. Transporting prefabricated components may introduce logistical challenges, while in situ printing requires substantial upfront investment in equipment, regulatory approval, and operator training. Uncertainties also remain regarding long term seismic performance, which is a crucial consideration in Suzu. In addition, social acceptance in rural contexts is a major factor for consideration. Taken together, these constraints indicate that 3D printed housing cannot yet be regarded as a standalone solution. Rather, this study considers its potential relevance through a comparative assessment alongside existing post-disaster housing solutions. Compared with container, timber, and owner-driven housing, 3D printed housing is examined for its potential to address constraints related to labour shortages, prolonged recovery timelines, and accessibility needs in super-aged and rural communities. These comparisons suggest that in the context of Suzu, 3D printed housing could be explored as one component within a diversified recovery strategy, with the aim of addressing structural disparities.

6. CONCLUSION

Suzu City's recovery following the 2024 Noto Peninsula Earthquake highlights the complex and layered barriers faced by super-aged, rural communities in disaster contexts. While physical damage was severe, this study demonstrates that demographic decline, labour shortages, and rising reconstruction costs have had a more enduring impact on the pace and equity of recovery. With over half of Suzu's population aged 65 or older, elderly residents face distinct mobility, economic, and social challenges that limit their ability to navigate complex recovery processes, particularly when support systems are poorly coordinated or inaccessible.

This study identifies critical gaps in existing recovery frameworks, particularly the inadequacy of standardized damage assessments and uniform temporary housing models. These approaches often fail to account for the psychosocial, physical, and practical needs of aging populations. While temporary shelters provide basic safety, they frequently compromise residents' autonomy, privacy, and quality of life, leading some to abandon shelter communities and return to unsafe, damaged homes. This study also highlights how rigid policy structures, rising public housing rents, and bureaucratic procedures reinforce post-disaster disparities, disproportionately impacting elderly women, single-person households, and those with limited financial resources. In response to these challenges, the study explored the potential of 3D-printed housing as a scalable and adaptable alternative. Offering customizable, cost-effective, and quickly deployable shelter, these units present an opportunity for survivors to remain on their land, preserve social ties, and restore daily routines. However, logistical challenges, material performance uncertainties, and the need for skilled operators must be addressed through further research and local capacity building. Ultimately, this study calls for more inclusive, context-sensitive recovery policies that address structural inequalities and prioritize the dignity, agency, and long-term well-being of vulnerable populations. Suzu's experience provides important lessons for strengthening resilience in other aging, resource-constrained communities globally.

7. STUDY LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

While this study provides valuable insights into disaster recovery challenges in aging and rural communities such as Suzu, several limitations must be acknowledged. Fieldwork was conducted over a short period of 10 days in March 2025, allowing for meaningful engagement but limiting the depth of data collection. Disaster recovery is a long-term process, and this study captures only a snapshot of Suzu City's situation one year after the 2024 Noto Peninsula Earthquake. A longer engagement would allow tracking of changing recovery conditions and evolving community needs over time. Although the study achieved a reasonable sample of 20 residents and 10 local stakeholders, participation was limited. Some residents were unavailable, while others declined due to personal reasons or interview fatigue. Consequently, the findings may not fully reflect the experiences of more isolated or severely affected individuals, highlighting the need for broader, long-term research to capture these overlooked perspectives.

A key limitation of the study lies in the speculative nature of the comparison between conventional temporary housing and the proposed 3D-printed housing solution. The 3D-printed prototype examined in this study was not in use as a temporary shelter but as volunteer accommodation. Consequently, comparisons were based on theoretical benefits and manufacturer claims rather than empirical evidence of user experience. This restricts the strength of conclusions drawn regarding the suitability, comfort, and long-term performance of 3D-printed housing in real-world post-disaster contexts.

Pilot testing and user-based evaluations of such alternative housing models are necessary to validate their role in future recovery strategies. Nevertheless, given that existing literature offers few reports of 3D-printed housing being implemented in disaster recovery settings in this context, this study's report holds significance even as an early contribution to the field.

Future research should adopt a design which captures the evolving nature of recovery over time. Expanded participant recruitment, including more diverse and harder-to-reach groups, would provide a more representative understanding of community-wide experiences. Detailed interior assessments of temporary housing and empirical testing of alternative housing solutions, including 3D printed units, are also essential to provide evidence-based evaluations of their effectiveness. Comparative case studies involving other disaster-affected communities in Japan and beyond would offer valuable insights into shared challenges and potential policy solutions. Addressing these limitations through future research will build a more comprehensive knowledge base for improving disaster recovery strategies, particularly for aging and marginalized populations in rural and remote regions.

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