Canadian Conference - Pacific Conference on Earthquake Engineering 2023
Vancouver, British Columbia
June 25th – June 30th, 2023

Measurement of Housing Recovery as a Disaster Resilience Outcome: A Case Study of the 2016 Kumamoto Earthquake

Yuto Shiozaki[1*], Fumio Yamazaki[2] and Wen Liu[3]

[1]Researcher, National Research Institute for Earth Science and Disaster Resilience (NIED), Tsukuba, Japan
[2]Research Fellow, National Research Institute for Earth Science and Disaster Resilience (NIED), Tsukuba, Japan
[3]Assistant Professor, Graduate School of Engineering, Chiba University, Chiba, Japan
[*]y.shiozaki@bosai.go.jp (Corresponding Author)

ABSTRACT

Recently the enhancement of urban resilience has come more important in disaster risk reduction. Although many studies have proposed various indicators for assessing the resilience of spatial units in a pre-disaster time, few studies have tested the validity of the resilience indicators. To examine which indicators are significant for resilience assessment, it is imperative to elucidate how the proposed indicators can explain the differences in resilience outcomes in affected areas by natural disasters. This study aims to measure housing recovery as one of the resilience outcomes for Mashiki Town, which was heavily affected by the 2016 Kumamoto, Japan, earthquake to the housing. Using building damage certificate data by the municipality and other GIS data, a dataset on the status of 9,179 houses regarding damage classification, demolition, and reconstruction was developed. An analysis of the developed data revealed that the housing reconstruction rate varied across the districts in Mashiki Town. Then the relationships between the housing reconstruction rate and nine resilience indicators were examined. As a result, five indicators, such as the ratio of senior citizens older than 65, showed a significant negative correlation with the reconstruction rate. However, two indicators, the homeowner household rate and the population rate of born-in-the-town and still-residing-there, indicated a significant negative correlation with the reconstruction rate.

Keywords: resilience outcome, recovery measurement, housing reconstruction, resilience indicator, the 2016 Kumamoto earthquake

INTRODUCTION

The concept of urban resilience has gained increasing attention in recent years following major disasters such as Hurricane Katrina in 2005, the 2009 Wenchuan, China, earthquake, and the 2011 Great East-Japan earthquake. Consequently, researchers and practitioners have proposed many indicators for resilience assessment [1-5]. Regions and communities assessed as highly resilient by these indicators should demonstrate better outcomes in a disaster event, such as less damage or faster recovery. However, a limited number of studies have conducted validation for these indicators [6-10]. One of the reasons for this is that the measurements of resilience outcomes have not been sufficiently accumulated. The validation of resilience indicators become more crucial due to the rising demand for enhancing urban resilience in response to climate change and rapid urbanization [11]. Measuring resilience outcomes gets more essential for conducting validation and identifying valid resilience indicators.

Several studies have validated resilience indicators with measured outcomes in the process of disasters [2, 6, 12, 13]. For example, Burton et al. [6] validated resilience indicators for municipalities in Mississippi State affected by Hurricane Katrina, using recovery scores of the built environment at the census block group as resilience outcomes. The recovery scores were obtained based on fixed-point observations in the field, which were carried out annually over five years. However, the observation points were sampled at intervals of 1.6 km. Song et al. [13] also validated resilience indicators in the affected districts after the 2015 Nepal earthquake using the relief score based on a five-point Likert scale survey on the subjective recovery status of the affected population as the outcome. The surveys were conducted monthly for six months after the earthquake, with more than 1,000 respondents for each survey. It requires great effort to comprehensively measure recovery over a long period and over an affected area. Thus the development of detailed outcome data on recovery is quite important and valuable.

This study measures housing recovery from the 2016 Kumamoto, Japan, earthquake towards validating resilience indicators. It develops the data on damage classification, demolition, and reconstruction for all houses in Mashiki Town, which was most severely affected by the 2016 Kumamoto earthquake. The data are then used to measure the progress of housing recovery in each district as resilience outcomes. Finally, the relationships between the measured resilience outcomes and indicators frequently used in literature are investigated.

MASHIKI TOWN AND THE 2016 KUMAMOTO EARTHQUAKE

Mashiki Town is one of the municipalities in Kumamoto Prefecture, located on Kyushu island, Japan. **Figure 1** shows the location of the town. According to the 2015 census [14] conducted before the 2016 Kumamoto earthquake, the town had 33,661 population and 11,477 households. Mashiki Town is adjacent to the east side of Kumamoto City, the capital of Kumamoto Prefecture, ranging from 8-20 km from the center of Kumamoto City. Hence, the town has been a residential area for people working or studying in Kumamoto City. The 2015 census [14] indicates that out of the 10,400 people living in Mashiki Town and commuting to other municipalities, 70.6% commuted to Kumamoto City. The town comprises 22 districts ("*Oaza"* in Japanese), corresponding to the smallest aggregation unit in the national census. Districts in the west, closer to Kumamoto City, were more populated, while those in the east were less populated, as shown in **Figure 2**.

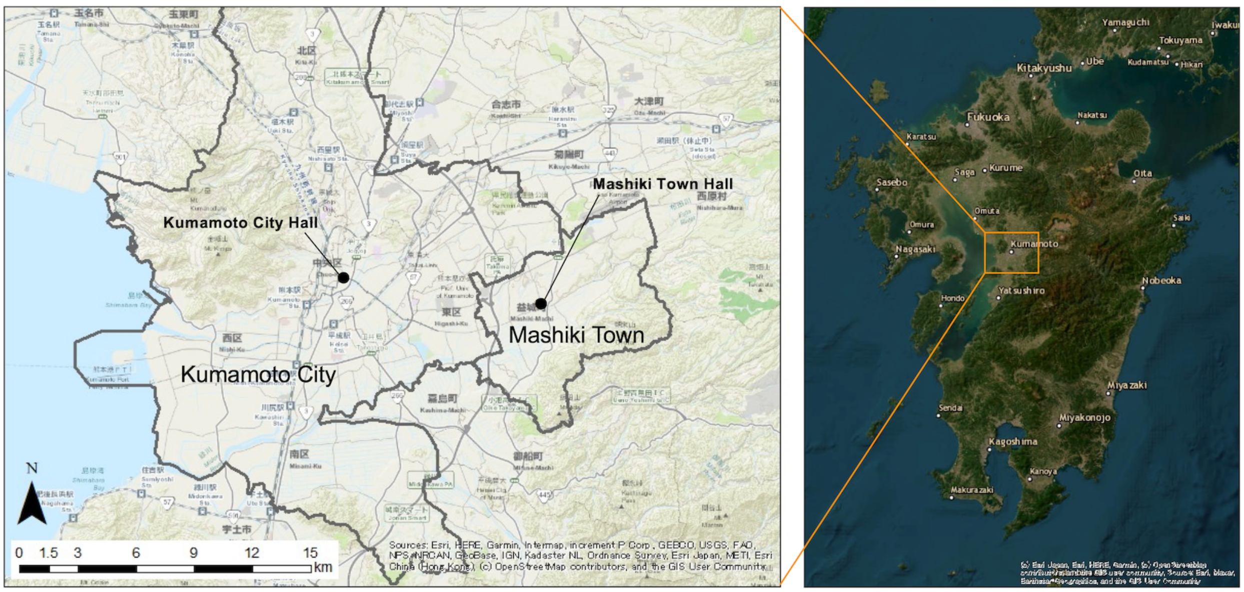


Figure 1. Location of Mashiki Town and Kumamoto City (left) and the extent of the left map in Kyushu Island (right).

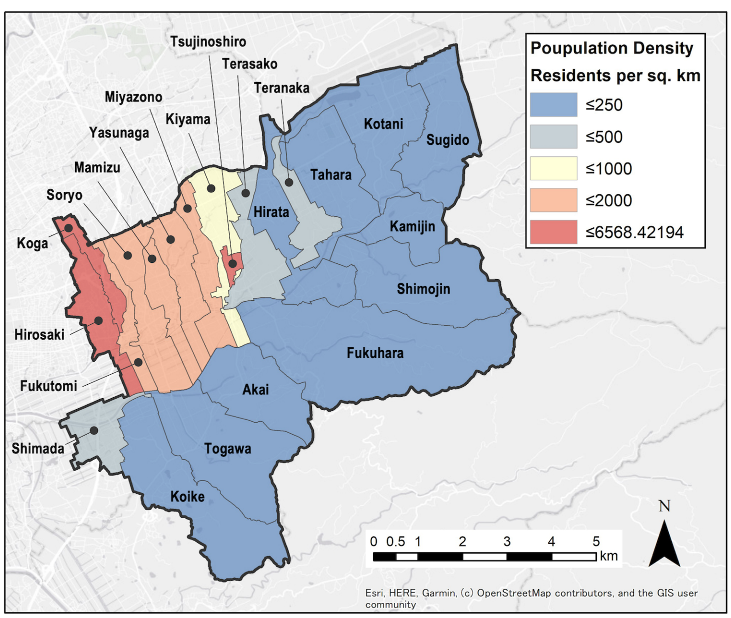


Figure 2. The population density in Mashiki Town by districts.

An Mw6.2 earthquake at 21:26 (JST) on April 14 and an Mw7.0 earthquake at 01:25 (JST) on April 16 hit the Kumamoto Prefecture. The two consecutive earthquakes caused 50 direct deaths in the prefecture [15]. In Mashiki Town, 20 people were killed mainly due to the collapse of wooden houses, and nearly all dwellings were damaged more or less [16]. Temporary housing was provided for people whose houses turned uninhabitable due to the earthquake damage and who could not secure housing by themselves. There are two types of temporary housing: construction-type and rented-type. In the former, the public sector builds and provides prefabricated houses; in the latter, rental housing is rented by the public sector and provided to refugees. In Mashiki town, 1,562 construction-type temporary housing units were built by November 2016, with a maximum of 1,515 units in use (as of January 2017). In addition, the rented type began to be supplied in April 2016, with a maximum of 1,453 units were provided as of May 2017 (Mashiki Town, 2018) [17]. All the temporary housing units in the town were closed by March 2023, following the construction of public housing for the affected people and the progress of individual housing reconstruction [18]. However, a number of sites in Mashiki Town remain vacant and unreconstructed after the houses were demolished due to earthquake damage. Housing reconstruction progress on these vacant sites appears to be heterogenous across the districts.

DATA DEVELOPMENT FOR MEASURING HOUSING RECONSTRUCTION RATE

This study attempts to determine what factors contribute to heterogeneity in housing recovery progress among the districts. We considered the housing reconstruction rate r_{hr}, defined by the following equation, as an indicator to measure the progress of housing recovery in each district:

$$r_{hr} = \frac{n_{rcstrt}}{n_{dmlsh}} \quad (1)$$

where n_{rcstrt} represents the number of houses built on sites where houses were demolished between 2014 and 2020, and n_{dmlsh} means the number of houses removed between 2014 and 2020. Note that the houses demolished between 2014 and 2020 were considered to become uninhabitable due to the earthquake. New dwellings constructed on the site of the demolished dwellings by 2020 were then counted as reconstructed buildings. Note that the above definition of the reconstruction rate does not consider buildings that were repaired to habitable condition without removal or abandoned buildings as vacant without repair. However, due to the limitation of the data, it was impossible to identify repaired dwellings or abandoned vacant buildings. Therefore, the above definition was used in this study as a proxy outcome variable for measuring the housing reconstruction progress in the districts. To obtain the housing reconstruction rate, the data presented in **Table 1** were used to construct data on the damage class and the status of removal and reconstruction of each building in Mashiki Town.

Table 1. Original data used in this study.

Data (year)	Explanation	Number of samples/records	Source
Building damage certificates (2016)	– Excel data – Data of buildings in Mashiki Town on damage class, structural type, postal addresses, GPS location data, etc.	13,718	Mashiki Town
Zmap Town II (2014, 2020)	– Building polygon data – Buildings of all uses included	26,466 (2014) 17,684 (2018)	Zenrin
Building Point Data (2014, 2018, 2020)	– Building point data created from the centroid of building polygons in Zmap Town II – Buildings except storage, warehouse, garage	10,973 (2014) 9,962 (2018) 10,751 (2020)	Zenrin

Building damage certificates

In case of disasters, the municipalities in Japan are obliged to conduct building damage surveys and issue damage certificates. The people affected by building property damage need this certificate to be eligible for various public aid. It should be noted that these building damage surveys only assess private properties and do not cover public facilities. Following this scheme in the 2016 Kumamoto earthquake, Mashiki town issued 13,718 damage certificate records. However, these data include records that are not suitable for the analysis of this study. As Yamazaki et al. [15] did, we used 10,159 certificate records obtained for our analysis by removing the following data: storage, warehouse, garage, etc. (2,945), those other than the final assessment (461), those with the area less than 20 m^2 (142), and those without a ground floor (11).

Each record of building damage certificates has information on damage class, structural type (material), postal address, GPS location data, and so on. **Figure 3(a)** shows the damage classifications for 10,159 buildings in Mashiki Town. Note that the damage classes of "minor" and "no" were merged since the buildings of "no" damage were only eight. For reference, **Table 2** shows the relationship of the damage class in Japan with other damage classification methods. **Figure 3(b)** shows the building certificate records plotted on GIS (Geographical Information System).

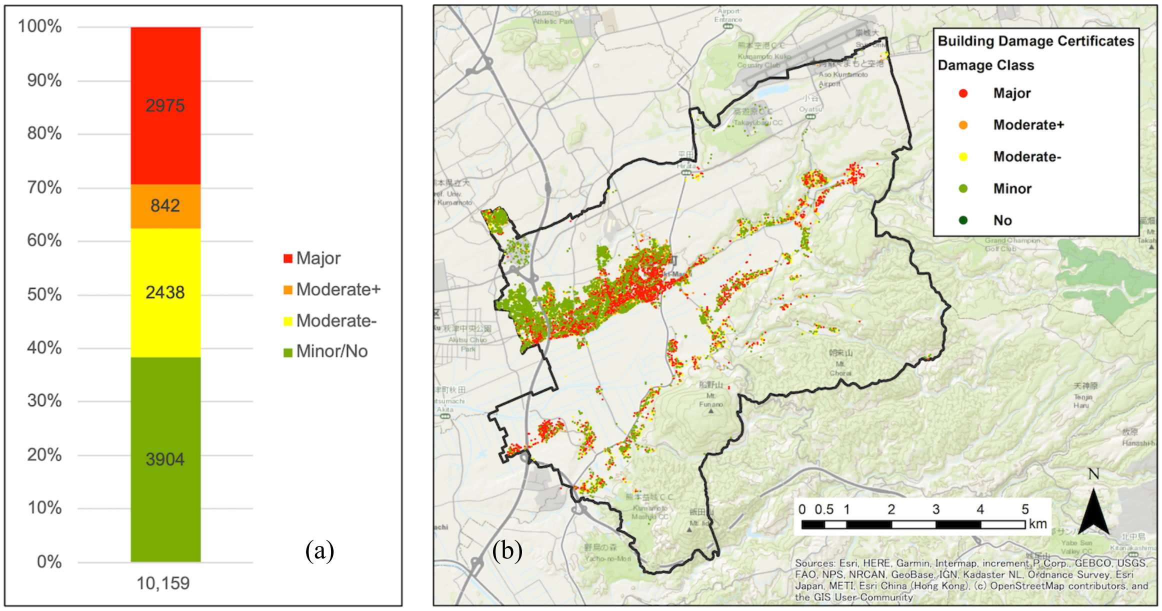
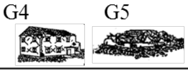


Figure 3. Building damage certificate data in Mashiki Town: (a) the number of buildings by damage class, (b) the spatial distribution of the building damage data.

Table 2. Earthquake damage class of buildings by local governments in Japan and schematic images of other damage classification methods (cited from Yamazaki et al. [15]).

Current Damage (Loss) Class	Former Damage (Loss) Class	Loss Ratio (r), Damage Index	EMS-98	Okada & Takai (2000)
Major	Major	$r \geq 60\%$	G4 G5 	D4 D5 
		$50\% \leq r < 60\%$	G3 	D3 
Moderate +	Moderate	$40\% \leq r < 50\%$		
Moderate –		$20\% \leq r < 40\%$	G2 	D2 
Minor	Minor	$0\% < r < 20\%$	G1 	D1 
No	No	$r = 0\%$	(G0)	D0

2014-2020 building data (for identifying the building status: remaining, demolition, and reconstruction)

We used two types of GIS building data: Zmap Town II (ZTII) (2014, 2020) and Building Point Data (BPD) (2014, 2018, and 2020). The former is polygon data, and the latter is point data created from the former's centroid. The other difference between them is that the former includes storage, warehouses, and garages, but the latter does not them. Therefore, only building polygon (ZTII) corresponding to point data (BPD) from the same year were extracted for our analysis. The number of extracted ZTII data in 2014 and 2020 was 10,973 and 10,751. The building polygon data (ZTII) with BDP has information such as occupant name, building use, and postal address.

Comparing building polygon data from 2014 and 2020 enabled us to identify whether each building in 2014 remained, was demolished, or reconstructed in 2020. For buildings that remained after the 2016 Kumamoto earthquake, the outlines of the 2014 and 2020 building polygons perfectly matched on GIS. Therefore, the 2014 buildings whose outlines did not match in 2020 were assumed to have been once demolished due to the earthquake's damage. Some buildings could have been demolished between 2014 and before the earthquake, but this number was considered very small compared to the number of buildings removed after the earthquake Additionally if a new building existed in 2020 on the site of the demolished building from 2014, it was assumed that the built environment of the place was reconstructed. Furthermore, comparing building point data from 2014, 2018, and 2020 allowed us to specify the timing of a building's demolition or reconstruction: 2014-2018 or 2018-2020.

Joining of damage certificates and 2014 building data

This study attempted to join 10,159 records of damage certificates into 10,973 building polygon data in 2014, which was the latest available building data before the earthquake. The joining of the two data made it possible to identify the building status of damage class, demolition, and reconstruction. We achieved the joining in the following procedure. First, the information on the postal address was used to join the combinations where the address information of the building polygons and the damage certificates matched perfectly. Although there were cases where multiple building polygons and damage certificate records existed at one postal address, only cases with a single building polygon and certificate record on a single address were combined. As a result, 7,005 pairs with the same address were combined. Secondly, regarding the data with multiple building polygons or damage certificate records on the same postal addresses, damage certificate records of which the GPS point was located within a building polygon on GIS were joined into the polygon. A record of the highest damage class was chosen to be joined if more than one GPS of damage certificate were located within a building polygon. If the damage classes of the records were the same, a certificate record of the smallest reference number was joined. In the second process, 587 certificate records were combined into building polygons. Thirdly, among the remaining data, pairs with the shortest distance between a building polygon and the certificate GPS point with the same postal address were chosen to be combined. The same procedure was repeated until all the pairs of building polygon and certificate records were joined with the same postal address. 283 certificate records were joined in the third process. Finally, for the building polygons and damage certificate records where the address information did not match exactly, the closest pair within a range of 10 meters was joined. The same procedure was repeated until all pairs of building polygons and certificate records within 10 meters were combined. Through this series of procedures, 9,474 building damage certificate records were joined into the 2014 building polygons. Consequently, 93.3% of the damage certificate data (10,159 records) and 86.3% of the 2014 building polygon data (10,973 buildings) were combined.

RESULTS OF HOUSING DAMAGE, DEMOLITION, AND RECOVERY IN MASHIKI TOWN

An overview of housing damage, demolition, and recovery in Mashiki Town is presented here using the developed data. **Figure 4(a)** shows the number and percentage of 2014 building polygons by damage class. As indicated in **Figure 4(b)**, 9,179 buildings are in residential use among 10,973 buildings in the 2014 building polygons. **Figure 4(c)** shows the number and percentage by damage class regarding the 2014 building polygons in residential use. As mentioned earlier, the building damage certificates only cover private buildings. Hence the damage class of all public facilities and housing is unknown. Additionally, **Figure 5** demonstrates the ratio of major damage by district in Mashiki Town.

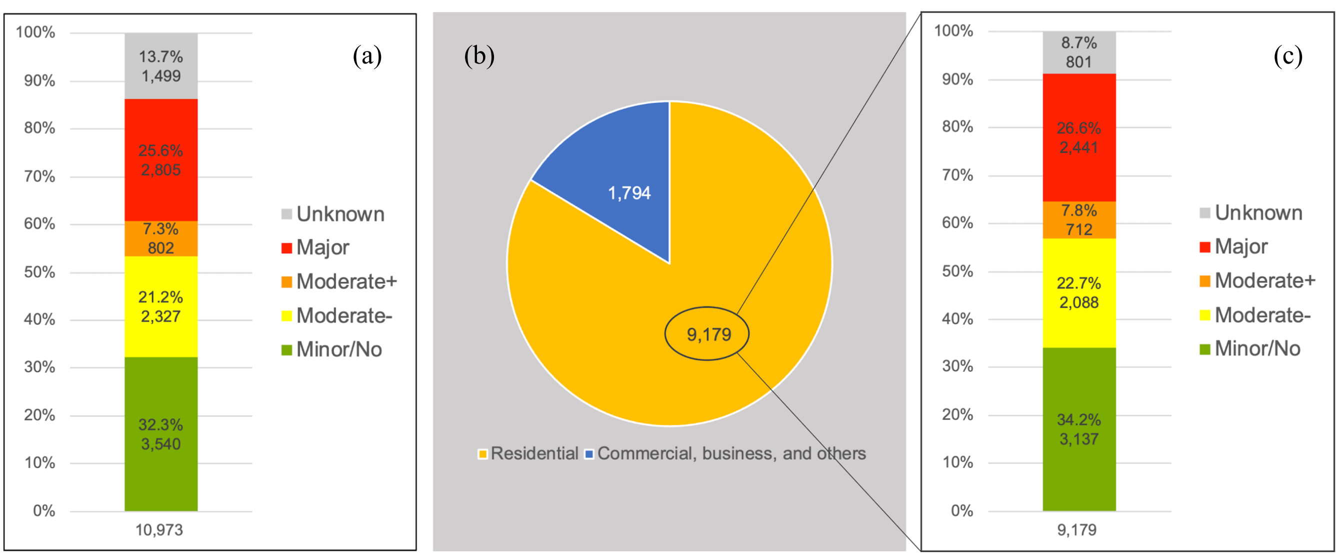


Figure 4. Data of 2014 building polygons in Mashiki Town: (a) the number of buildings by damage class, (b)the use of buildings, (c) the number of residential buildings by damage class.

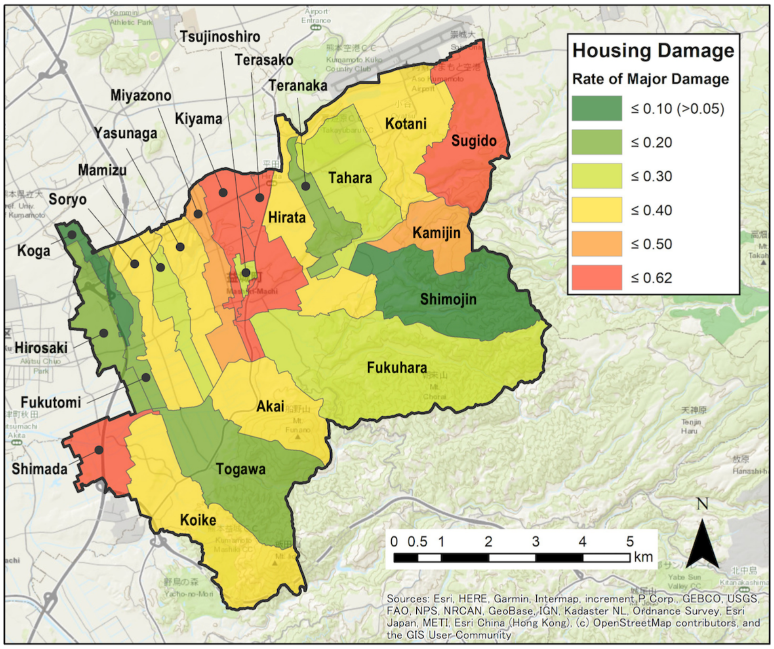


Figure 5. The rate of houses with major damage in Mashiki Town by district.

The percentage of residential buildings demolished out of the total number is shown in **Figure 6(a)**. First, 33.9% of all the buildings in residential use were demolished in Mashiki town. By damage class, 77.6% of residential buildings with major damage, 43.5% of ones with moderate+ damage, 19.3% of ones with moderate- damage, and 9.3% of ones with minor/no damage were cleared. The greater the damage to housing is, the higher the demolition rate is. Furthermore, **Figure 6(b)** indicates a very strong correlation between the rate of houses with major damage and the demolition rate of housing by district. Therefore, focusing on the spatial disparity in the demolition rate, the demolition rate is high in districts with a high rate of major damage (e.g. Terasako, Sugido, Shimada, and Kiyama), as **Figure 7** represents. On the other hand, the demolition rate is low in districts with a low rate of major damage (e.g. Hirosaki and Koga).

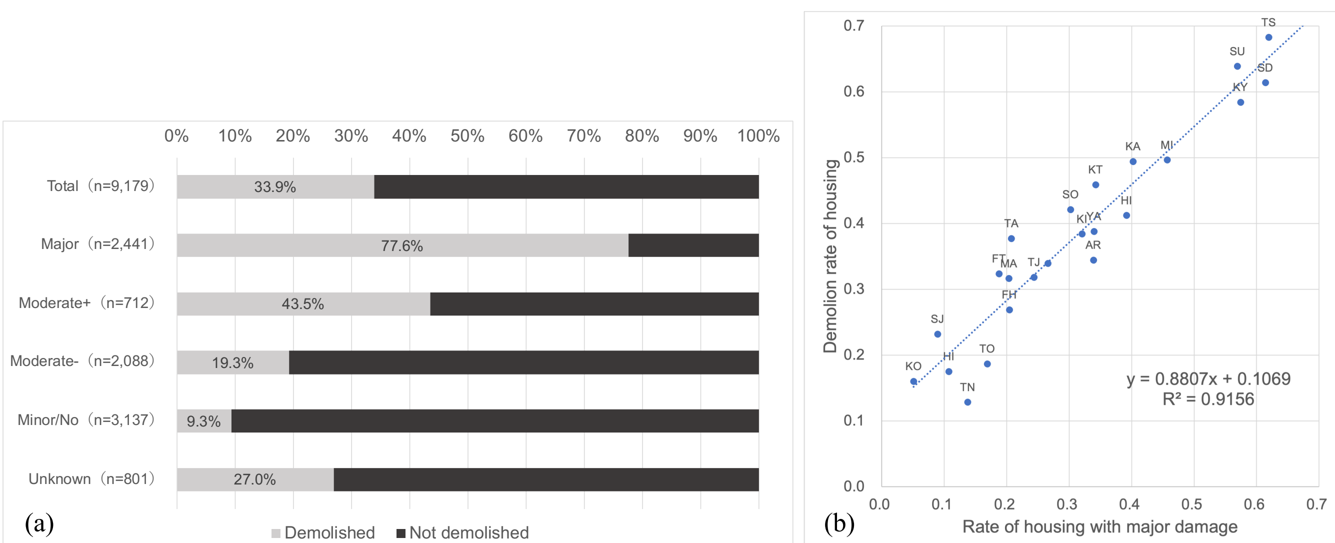


Figure 6. (a) The demolition rate by damage class, (b) the relationship between major damage rate and demolition rate for each district.

Figure 8(a) indicates the housing reconstruction rate, the percentage of sites with residential buildings reconstructed out of the sites where a dwelling was removed between 2014 and 2020. 60.3% of all the 3,116 houses demolished after 2014 were reconstructed as of May 2020. By damage class, in 54.3% of sites where dwellings were removed due to major damage, 59.0% due to moderate+ damage, 71.7% due to moderate- damage, and 86.0% due to minor/no damage, residential buildings were

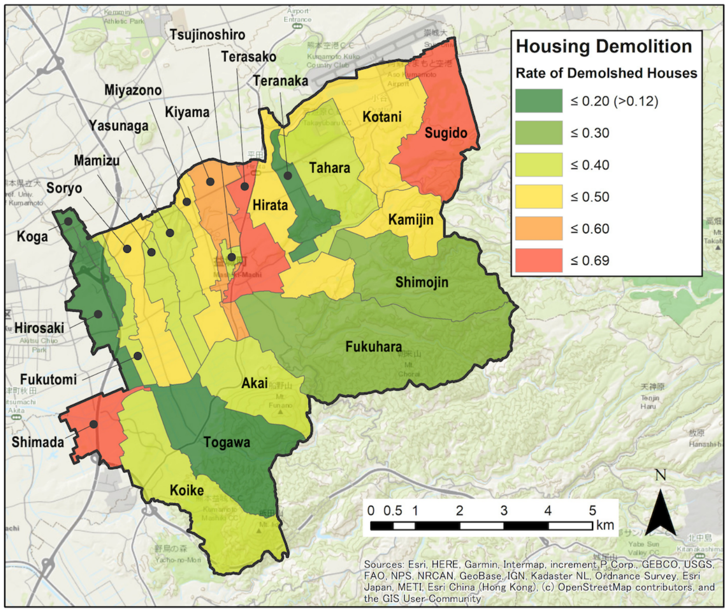


Figure 7. The demolition rate by district in Mashiki Town

reconstructed. Regarding the demolished dwellings, the lower the damage to buildings is, the higher the reconstruction rate is. The dwellings with moderate- and minor damage can often be repaired and need not be rebuilt in this case. Hence, the higher reconstruction rates of the housing with a lower damage class indicate the possibility that the renewal timing was brought forward due to the damage caused by the earthquake in many cases. Moreover, in the 2016 Kumamoto earthquake, buildings with greater than moderate- damage were allowed to be demolished at public expense, which also probably facilitated the clearance of buildings that did not need to be removed.

Figure 9 shows the housing reconstruction rates by district as of May 2020, indicating that the progress in housing recovery was spatially heterogeneous. The reconstruction rate in the western part of Mahiski town, which is close to Kumamoto city, was relatively high. Additionally, in the central and middle eastern parts, there were some districts with high reconstruction rates, such as Tsujinoshiro, Teranaka, Tahara, and Shimojin. On the other hand, the housing recovery rate is relatively low in the eastern and central districts, except for the above-mentioned four districts. In May 2020, the highest housing reconstruction rate was 76.7% in the Koga district, while the lowest was 40.2% in the Akai district. Furthermore, **Figure 8(b)** represents the districts' temporal change in the housing reconstruction rate. Note that in this figure, the reconstruction rate in April 2016, at the time of the earthquake, is set to zero for convenience. In July 2018, the districts with the highest and lowest rates were also Koga and Akai, with 58.6% and 17.7%. Comparing the recovery rates at the two-time points in 2018 and 2020 reveals a tendency towards recovery in all districts. However, the disparity in the recovery rates by district did not change substantially, although some ranking fluctuations occurred.

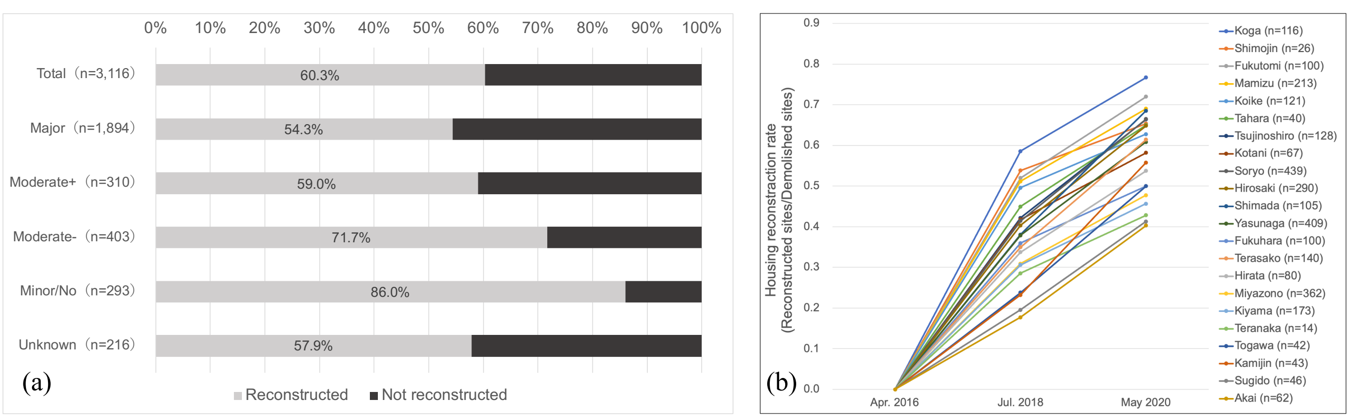


Figure 8. The relationship between damage class and housing reconstruction rate for demolished buildings: (a) the reconstruction rate by damage class, (b) the reconstruction rate of each district in July 2018 and May 2020.

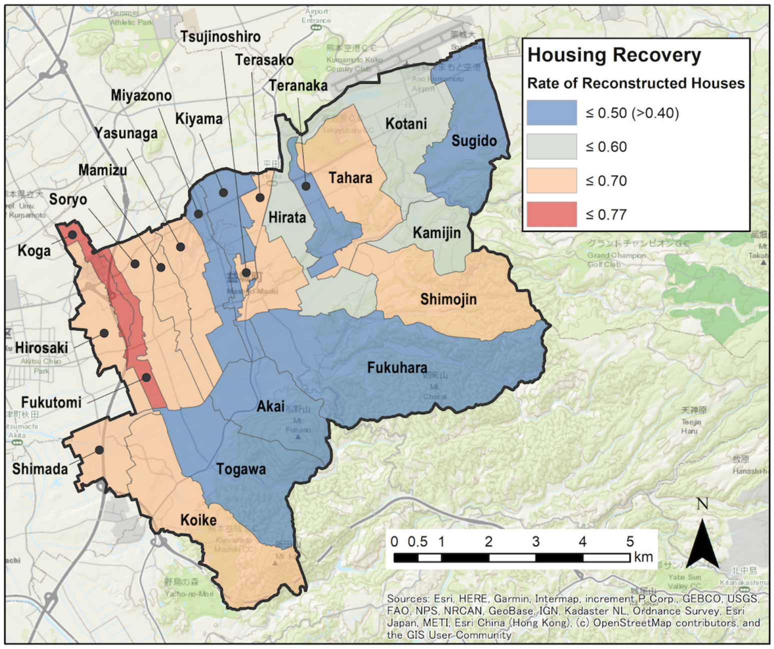


Figure 9. Housing reconstruction rate for demolished buildings by district in Mashiki Town

ANALYSIS OF RESILIENCE INDICATORS

This research focuses on determining what factors cause spatial heterogeneity in housing recovery progress. We tried to investigate whether the resilience indicators suggested in existing studies can explain the heterogeneity. Although multiple regression models incorporating several factors could be used for the analysis, this paper simply examines the correlation between reconstruction rates and potential resilience indicators by district as a preliminary study.

Potential resilience capacity variables

We collected representative resilience capacity variables that were previously discussed or utilized in the literature and also for data that are publicly accessible. The list of resilience capacity indicators selected in this study is shown in **Table 3**. Many previous studies assume that regional, urban, and community resilience comprises several subcomponents: social, economic, infrastructural, institutional, community, and environmental [6, 19, 20]. However, this study concentrates on resilience capacity variables related to social/economic resilience and community capital. It also excludes the other remaining subcomponents due to the limited geographical scope of the target area and data restrictions. Since this study focuses on a single municipality, it was assumed there would be no institutional resilience differences between districts. Additionally, we did not have access to data on infrastructure and environmental resilience variables to those used in previous studies.

Social resilience captures the social capacities of communities in addition to community health and well-being [6]. Districts with fewer elderly, fewer people with disabilities, and more people with at least a high school diploma are likely to exhibit greater resilience than districts without these characteristics [2]. Among those variables, the rate of the population over 65 years old was only available. To achieve community health and well-being, access to medical support, child care, adult education and training, social assistance, and recreational facilities is a key factor. Since higher population density is associated with more facilities providing a wider variety of services, population density was used here as a proxy for accessibility to services to support community health and well-being.

Economic resilience is the ability of communities related to economic and livelihood stability. Homeownership and employment status are key factors for economic and livelihood stability [6]. Therefore, districts with more homeowner households, female workforce participation, and employed working-age populations are more resilient. Moreover, connectedness to neighboring cities can enhance economic and livelihood stability [21]. The closer a district is to the neighboring major city, the greater its potential for housing development and the faster it is expected to reconstruct housing. Also, more people are likely to be employed in other cities, which can lead to a diversification of the economic resources in the district. In the case of Mashiki town, the neighboring major city is Kumamoto City. Hence, the distance to the center (the city hall) of Kumamoto city and the rate of the working-age population that works in other cities are proxy variables for the connectedness to neighboring cities.

Community capital is a subcomponent directly related to social capital. According to the literature, the crucial social capital factors are 1) social participation, 2) community bonds or a sense of place, and 3) innovation. The rate of the population born in a city and still living in that city was a proxy for the second factor. Also, the rate of employees for professional and technical services was a proxy for the third one. Unfortunately, the proxy variables for the first factor were not available.

Table 3. Potential resilience capacity variables (indicators).

Type	Variables	Justification
Social resilience	Population rate over 65 years old	Morrow (2008) [22]
	Population density	Ryu et al. (2011) [23]
Economic resilience	Homeowner household rate	Cutter, Burton, and Emrich (2010) [1]
	Female workforce participation rate	Cutter, Burton, and Emrich (2010) [1]
	Population rate over 15 years old with employment	Cutter, Burton, and Emrich (2010) [1]
	Population rate over 15 years working outside the town	Yabe et al. (2020) [21]
	Distance to the center (city hall) of Kumamoto city	Yabe et al. (2020) [21]
Community capital	Population rate born in the town and still residing	Cutter, Burton, and Emrich (2010) [1]
	Population rate over 15 years old working for professional and technical services	Cumming et al. (2005) [24]

Table 4. Correlation coefficients between the housing reconstruction rate and potential resilience capacity variables

	Recon. rate	Pop. rate over 65	Pop. density	HOP. HH. rate	FWP rate	Pop. Rate ≥15 Empl.	Pop. Rate ≥15 WOT	Dist. to CKC	Pop. Rate ≥15 BSRT
Pop. Rate over 65	**-0.633** **								
Pop. density	**0.451** *	-0.683 **							
HOP. HH. rate	**-0.442** *	0.825 **	-0.694 **						
FWP rate	**0.142**	-0.133	0.218	-0.387					
Pop. Rate ≥15 Empl.	**-0.174**	0.084	-0.147	0.373	0.652 *				
Pop. Rate ≥15 WOT	**0.558** **	-0.660 **	0.613 **	-0.734 **	0.165	-0.520 *			
Dist. to CKC	**-0.546** **	0.656 **	-0.536 *	0.716 **	-0.174	0.373	-0.844 **		
Pop. Rate ≥15 BSRT	**-0.468** *	0.789 **	-0.695 **	0.871 **	-0.161	0.460 *	-0.783 **	0.775 **	
Pop. Rate ≥15 WPTS	**0.531** **	-0.794 **	0.646 **	-0.882 **	0.595	-0.506	0.904 **	-0.767 **	-0.913 **

Note: Recon. rate = housing reconstruction rate, Pop. Rate over 65 = population rate over 65 years old, Pop. density = population density, HOP. HH. rate = homeowner household rate, FWP rate = female workforce participation rate, Pop. Rate ≥15 empl. = population rate over 15 years old with employment, Pop. Rate ≥15 WOT = population rate over 15 years old working outside the town, Dist. to KC = Distance to the center of Kumamoto city, Pop. Rate ≥ 15 BSRC = population rate born in the town and still residing, Pop. Rate ≥15 WPTS = population rate working for professional and technical services.
*$p \leq 0.05$, ** $p \leq 0.01$

Correlations between housing reconstruction rates and indicators (results and discussions)

Table 4 presents the correlations between the housing reconstruction rate and potential resilience capacity variables by district. For reference, **Table 5** shows the population, building status, and resilience variables for each district in Mashiki Town. In **Table 4**, the relationship patterns between the reconstruction rate and the variables are statistically significant ($p \leq 0.05$, twotailed), except for the rate of female workforce participation and the rate of the working-age population employed. For the rate of the population over 65 years old, population density, the rate of the population over 15 years old with employment, the rate of the population over 15 years old working outside the town, distance to the center of Kumamoto city, and the rate of the population over 15 years old working for professional and technical services, the correlations with the reconstruction rate were significant in the anticipated direction. The correlation coefficient showed a strong negative correlation for the rate of the population over 65 years old (R = -0.633), while for the other variables, the coefficients were moderate, with absolute values ranging from 0.442 to 0.558.

Next, for the rate of homeowner households and the rate of the population born in the town and still residing there, the results show strong negative correlations in the opposite direction to the original predictions. Previous studies (e.g., Cutter, Burton, and Emrich [1]) consider homeowner households more economically secure than rental households. Therefore, we assumed that districts with higher homeownership or lower rental household rates would demonstrate higher resilience. However, in Mashiki town, the need for rental housing might be higher in districts closer to Kumamoto city, where more employment opportunities are located. The proximity to Kumamoto city can enhance the resilience of a district while lowering the rate of homeowner households. This is supported by the strong positive correlation (R = 0.716) between the rate of homeowner households and the distance to the center of Kumamoto city. Also, the closer to Kumamoto, the greater the migration of residents is, which can lead to a relatively lower proportion of the people born and still residing in Mashiki town. For these two indicators, it is necessary to examine the effects of the indicators on the housing reconstruction rate in sample groups with an equivalent distance from Kumamoto City.

Table 5. Population, building status, and potential resilience capacity variables for each district in Mashiki Town.

District	Pop.	# Resi. Bdg.	Mjr. Dmg. Rate	Dmls. Rate	Recon. Rate	Pop. rate over 65	Pop. Dens.	HOP. HH. rate	FWP rate	Pop. rate ≥15 Empl.	Pop rate ≥15 WOT	Dist. to CKC	Pop. Rate ≥15 BSRT	Pop. Rate≥ 15 WPTS
Yasunaga	3707	1054	0.34	0.39	0.61	0.26	1885.8	0.81	0.47	0.45	0.63	11.01	0.11	0.15
Shimojin	354	112	0.09	0.23	0.65	0.40	68.5	0.97	0.43	0.45	0.43	17.08	0.37	0.08
Miyazono	2792	729	0.46	0.50	0.48	0.32	1638.3	0.65	0.47	0.46	0.57	11.37	0.11	0.17
Koga	2803	724	0.05	0.16	0.77	0.20	3276.3	0.63	0.44	0.47	0.70	8.52	0.12	0.18
Hirosaki	6342	1656	0.11	0.18	0.65	0.19	3291.1	0.65	0.45	0.48	0.68	8.57	0.09	0.19
Teranaka	381	109	0.14	0.13	0.43	0.42	258.8	0.99	0.42	0.43	0.40	14.10	0.29	0.09
Terasako	668	205	0.62	0.68	0.61	0.32	314.3	0.86	0.45	0.50	0.50	12.66	0.20	0.14
Kitani	659	146	0.34	0.46	0.58	0.28	148.9	0.96	0.33	0.62	0.20	15.52	0.29	0.04
Koike	1041	315	0.32	0.38	0.63	0.35	182.4	0.98	0.47	0.49	0.53	12.80	0.27	0.11
Kamijin	295	87	0.40	0.49	0.56	0.39	151.7	0.95	0.47	0.53	0.41	17.12	0.32	0.10
Sugido	261	72	0.57	0.64	0.41	0.40	64.1	0.98	0.44	0.54	0.29	17.68	0.41	0.05
Arai	563	180	0.34	0.34	0.40	0.46	168.6	0.98	0.42	0.47	0.38	13.63	0.31	0.05
Soryo	3892	1042	0.30	0.42	0.67	0.30	1511.0	0.67	0.46	0.42	0.60	9.69	0.11	0.16
Tsujino shiro	1515	402	0.24	0.32	0.66	0.22	6568.4	0.66	0.46	0.49	0.59	12.10	0.09	0.16
Tahara	377	106	0.21	0.38	0.65	0.33	102.7	0.86	0.44	0.41	0.40	14.56	0.18	0.13
Togawa	705	225	0.17	0.19	0.50	0.33	133.7	0.96	0.44	0.48	0.51	13.16	0.28	0.12
Shimada	513	171	0.61	0.61	0.69	0.39	299.6	1.00	0.47	0.50	0.54	9.81	0.29	0.09
Mamizu	2240	673	0.20	0.32	0.69	0.25	1675.0	0.77	0.48	0.45	0.62	10.37	0.12	0.17
Fukuhara	1269	372	0.20	0.27	0.50	0.32	125.2	0.94	0.44	0.49	0.50	15.91	0.24	0.12
Fukutomi	1437	309	0.19	0.32	0.72	0.17	1518.5	0.57	0.45	0.45	0.63	9.42	0.15	0.18
Hirata	609	194	0.39	0.41	0.54	0.37	204.5	0.99	0.45	0.53	0.42	13.90	0.34	0.09
Kiyama	1188	296	0.57	0.58	0.46	0.30	567.1	0.68	0.51	0.48	0.55	11.77	0.15	0.15

Note: Pop. = population, # Resi. Bdg. = the number of residential buildings, Mjr. Dmg. Rate = major damage rate, Dmls. Rate = demolition rate, Pop. Den. = population density (residents per square km), Dist. to CKC = Distance to the center of Kumamoto city (km), other abbreviations are the same in **Table 4**.

CONCLUSION

It is imperative to measure resilience outcomes for validating resilience indicators. This study developed a GIS dataset of 9,179 houses in Mashiki Town to measure housing recovery from the 2016 Kumamoto earthquake as a resilience outcome, using building damage certificate records and Geographic Information System (GIS) data. An analysis showed that the progress in housing recovery was spatially heterogeneous.

Moreover, a preliminary study was conducted to determine what factors caused the spatial disparity in housing recovery progress. In the first place, we chose nine representative resilience capacity variables previously discussed or utilized in the literature and also for data that were publicly accessible. Next, the correlation between the housing reconstruction rate and the resilience indicators was examined. The results showed that five indicators, including the rate of the population older than 65 years old and population density, showed significant correlations in the expected direction. On the other hand, two indicators, the rate of homeowner households and the rate of the population born in the town and still residing, demonstrated significant correlation, but the direction was contrary to the findings of previous studies. Regarding the latter two indicators, the effect of the connectedness to Kumamoto City should have been controlled. Additional validation is also needed, for example, using other methods such as multiple regression analysis or evaluations in different spatial units.

ACKNOWLEDGMENTS

This research was partially supported by JSPS KAKENHI Grant Number 19K15261 and 20H02270, Japan.

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