Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

DISASTER RESILIENCE AND THE SOCIAL FABRIC OF SPACE

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Abstract

Resilience is the ability of a system to rebound after a major disaster. The concept of resilience has been increasingly applied in urban planning and other fields in the context of emergency management, an area formerly driven by risk mitigation and other top-down approaches. Fostering resilient communities at a grassroots level is now known to be important for increasing adaptive capacity and other qualities that make communities more resilient. Therefore, many studies have examined the precise factors that promote a more resilient community that is able to withstand and quickly recover after a debilitating disaster such as a hurricane or earthquake. Many contributing factors that relate to resilience have been associated with integration, reach, and other syntax measures. These include social interactions that foster social capital, urban poverty, economic activity, and the distribution of land uses, among others.

This paper examines the role of syntactical and other built environment measures in relation to community resilience after Hurricane Katrina in 2005. Communities in Mississippi that were hardest hit by storm surge and wind damage are analyzed. The recovery along this roughly 130-kilometer coast has been uneven, with some communities experiencing a vibrant renaissance while others have been depopulated. This paper analyzes the built environment factors related to these differences in recovery patterns, using data from before and after Hurricane Katrina. Along with syntax measures of metric and angular reach, types of organizations known to support social networks (recreational and community gathering places), parks, historic sites, and housing patterns are analyzed. Results show that integrated and varied urban environments are more conducive to resilience, particularly greater street accessibility, and the accessibility of community gathering places.

Keywords: *disaster, resilience, social networks, social infrastructure, recovery*

Theme: *Urban Space and Social, Economic and Cultural Phenomena*

Introduction

Disasters have the power to disturb every aspect of a community, with the built environment and social fabric among the most affected segments. Housing, businesses, institutions and other structures may be damaged and social disruptions caused by evacuations and displacement complicate the recovery process. Social networks are particularly important in forging a strong recovery after a disaster. Resilient communities, or those that are able to rebound quickly and effectively after a disaster, have been shown to be associated strong formal and informal social networks. Given the effects of space on social structures, to what extent does the social fabric of space impact a community's ability to recover? This paper examines space syntax and other built environment factors known to impact social networking and, controlling for sociodemographics, damage, and disaster aid received, measures the impact of a more socially varied and integrated built environment on disaster resilience by analyzing communities in coastal Mississippi, U.S.A. that were impacted by Hurricane Katrina in 2005.

Background:

Social networks have been shown to be important for increasing resilience and reducing disaster vulnerability in preparing for and responding to a disaster (Cutter, Boruff, and Shirley 2003), for facilitating response and mitigation tactics such as evacuations from the bottom-up (Aguirre 2006), and for improving household-level disaster preparedness by increasing the perception of the availability of resources (Paton 2003). In terms of associational membership, research has demonstrated the positive impacts of community groups in recovery efforts (Patterson, Weil, and Patel 2010).

In addition, the relationship between space and social networks has been well-studied across many disciplines. For example, urban planning research has shown that walkable, mixed-use neighborhoods encourage the development of social capital and place attachment through an increase in interactions and a higher density of neighborhood amenities, including characteristics of the built environment that influence social networks, such as varied land uses and pedestrian-oriented design (Leyden 2003). New Urbanism claims that factors that influence social capital include density, street connectivity, design, and land uses. However, some argue that this is only because physical design actually increases the probability of community building through interaction and not necessarily through manufacturing a sense of community (Talen 1999).

Space syntax further informs how space and social functions interact and the implications for resilience. Previous studies have shown that the spatial configuration of spaces affects social behavior. For example, retail and other movement-seeking land uses gravitate toward higher movement locations, which are statistically more likely to be well integrated with the urban grid (Hillier 1999a). Additionally, it has been shown that the level of development of a neighborhood is contingent upon its embeddedness in the circulation system of a city, either preventing or encouraging economic activity and social capital (Hillier 1999b). Finally, many factors that relate to resilience have been associated with integration, reach, and other syntax measures. These include urban poverty, economic activity, social interactions, and the distribution of land uses, among others.

The relationship between space and poverty (which is highly correlated with greater disaster vulnerability) has been investigated and defined by recent space syntax research (Vaughan 2007, Vaughan et al. 2005, Carpenter and Peponis 2010). Generally, access to economic and social opportunities through well-integrated spaces has been associated with a higher incidence of wealth at the smallest levels of analysis (parcels and block faces). Vaughan shows that poverty at least partially explains the causes and persistence of poverty (Vaughan et al. 2005). The concentration of poverty in urban areas and increased isolation from the wealthy has been well documented (Massey 1996). Since the formation of the earliest settlements, the density of impoverished households has been increasing in cities, with the greatest extremes seen in the current post-industrial era. Spatial and social isolation is yet another indicator of disaster vulnerability, as demonstrated in a deadly 1995 Chicago heat wave (Klinenberg 2002).

Given these established threads linking social networks and the built environment and social networks and resilience, this research sought to determine empirically whether a link could be established between a more integrated and varied built environment (using space syntax and other measures) and resilience.

Method:

To test the theory that a built environment supportive of social interactions and social networks will result in a more resilient community, a cross-sectional Ordinary Least Squares (OLS) multivariate linear regression model was employed in order to establish causality and to isolate the effects of individual variables.

The study area for this research was limited to Mississippi, although Hurricane Katrina impacted Louisiana and Alabama as well. The type of damage and response was very different in each state, with Mississippi sustaining wind and storm surge damage typical of a strong hurricane, while New Orleans (Louisiana) struggled with levee failures and prolonged flooding. Investigation of the Mississippi Gulf Coast also allowed comparison of a wide variety of urban forms impacted by a catastrophic event at a common point in time. A variety of development patterns exist in Mississippi, including high- to medium-density urban, pre-war single family neighborhoods, post-war suburbs, traditional small towns, waterfront resort communities, rural areas, and many others. Therefore, comparison among and across several of these typologies was possible.

The cities along the coast of the Gulf of Mexico have a long history of hurricane strikes, however, 2005's Hurricane Katrina proved to be the most costly and among the most deadly hurricanes on record, with more than 1,800 dead, one million people displaced, $80 billion in property damage, and 233,000 square kilometers of land impacted (Cutter et al. 2006). At its peak strength in the Gulf of Mexico, Katrina was a Category 5 hurricane, with winds of 274 kilometers per hour and a 322 kilometer radius (Cutter et al. 2006). Katrina made landfall a second time, its eye crossing at the border of Mississippi and Louisiana, at 9:45 a.m. on August 29, 2005. At this point, the storm was a Category 3 hurricane with wind speeds of 225 kilometers per hour and a radius of 225 kilometers and took nearly two hours to reel through the area. Storm surges of up to 9.1 meters inundated the coast of Mississippi; in Mississippi alone, there were 230 deaths, more than 100,000 left homeless, and more than 200,000 homes that received some damage (Governor's Report on Recovery 2010).

Since Katrina, communities in coastal Mississippi have recovered at unequal rates. The return of occupied households, for example, has ranged greatly, with pockets of healthy restored housing near nearly abandoned neighborhoods, as illustrated by the change in occupied housing units (normalized by area) from five years before to five years after Katrina (Figure 1).

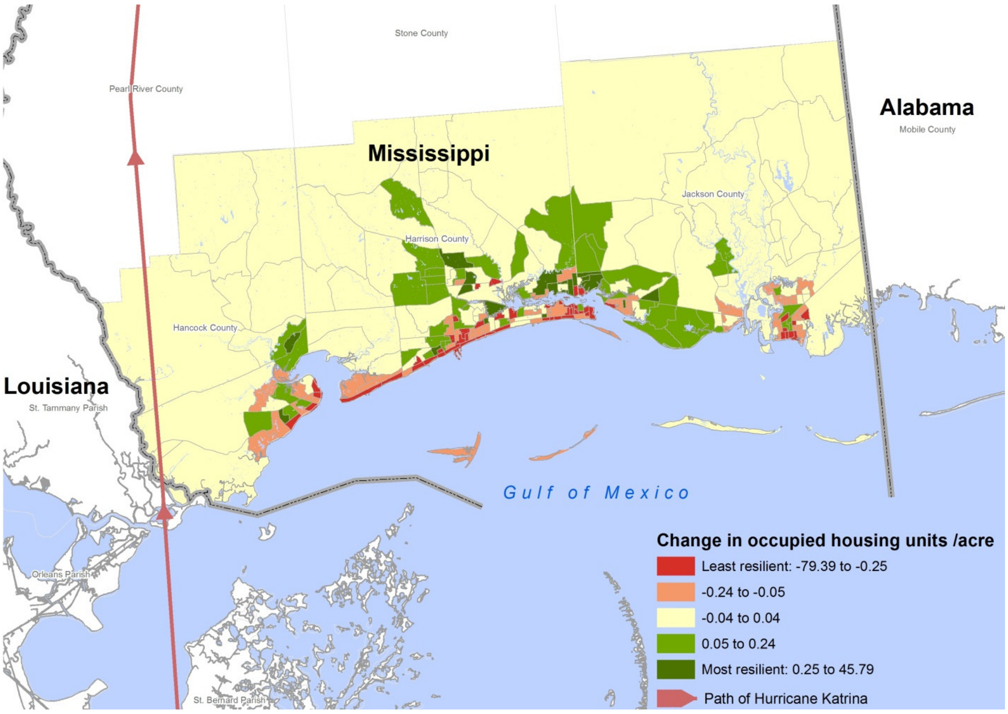

Figure 1 Change in occupied housing units 2000-2010 normalized by area for Census block groups in coastal Mississippi

Variables chosen for the OLS model were collected at the unit of analysis of U.S. Census blocks, which are equivalent to city blocks. There are approximately 14,000 Census blocks in the three-county study area of coastal Mississippi. However, blocks that were not in the storm inundation area, were less than a half-acre (2,023 square meters), or had fewer than five occupied housing units were excluded, reducing the sample size to 3,222 blocks. Blocks outside the storm inundation limit were excluded to control for level of storm exposure and very small or nearly unpopulated blocks were excluded due to reliability issues, as population counts are less accurate at such small increments.

The dependent variable was a proxy measure of resilience, calculated by the change in occupied housing units from 2000 to 2010 (five years before to five years after Katrina), and normalized by area. Based on field visits and interviews, in some cases, structures have been rebuilt but remain vacant. The number of occupied housing units is uniquely able to measure the actual rebound of the people. The return of households was chosen as the dependent variable representing resilience for several reasons. Most notably, it has been shown that housing comprises the greatest amount of damage in disasters (Comerio 1997) and that commercial recovery is strongly tied to housing recovery (Olshansky, Johnson, and Topping 2006), therefore housing is an aspect of resilience that underpins all other sectors and therefore serves as a proxy for overall resilience. Although an area's capacity to rebound is also captured in the return of businesses and generally of structures and infrastructures, the return of a resident population is even more fundamental and essential for the recovery of other sectors. As housing is only one aspect of resilience, this is only a partial metric of resilience. However, because this research focused on household social networks, it is also most appropriate to examine the return of households.

Several independent variables were chosen to measure the potential of the built environment to support social networks. Many properties of the built environment contribute to greater social capital in a community. All built environment variables were measured using pre-Katrina conditions, in order to capture the qualities of the built environment that impacted resilience rather than the resultant conditions from the storm. Metrics of the built environment included a set of variables and indices of the relative social vibrancy or isolation a community. Included were space syntax measures, land use mix, net residential density, the density of social gathering places, and the presence of parks and open space. These measures capture access to spaces in which people are likely to gather. Finally, historical site density was used as a proxy for place attachment, as monuments and heritage sites promote a sense of local continuity and pride. In order to capture the community or neighborhood scale, these measures were taken for a larger geometry, a one-kilometer buffer around each block. The block in which a household lives is influenced by a wider swath of the built environment, rather than the block itself in isolation. Buffers were created for a walkable distance of one kilometer to capture the greater sphere of influence of the built environment on the block. A distance of one kilometer is often cited as a distance easily walkable in 10 minutes. It is also the area in which residents are likely to encounter neighbors in their social networks.

Several intervening variables were introduced in the model as well. These included pre-Katrina sociodemographic variables that have been shown to be significant for resilience and vulnerability as well as external factors related to damage and ability or feasibility to rebuild. Growth normalized by area from the previous Census period of 1990-2000 was used to control for endogenous growth or contraction in the population. The number of occupied housing units per acre in 2000 was also included as an intervening variable to control for the large variance in block populations, as population density can vary greatly throughout the region.

For this paper, space syntax measures included metric and angular reach, which quantify the connectivity of streets by identifying the length of street network accessible within a given distance or number of direction changes (Peponis, Bafna, and Zhang 2008). Metric and angular reach were chosen over other measures such as integration in order to assign syntactical measures to the block face and to build upon previous work on poverty and space (Carpenter and Peponis 2010). Metric reach in particular is better suited for analysis of local rather than global network trends. A range of distance values were tested to determine which variables were best suited for the model. These included metric (distance-based) reach at a quarter, half, one, and two kilometer network distances and angular (based on direction changes) reach at zero, one, two, and three direction changes. Metric reach measures the length of street network accessible from the center of a street segment. Angular reach measures the length of street network accessible given a specified number of direction changes. As shown in Figure 2, metric reach is not impacted by a more distorted grid, while angular reach values decrease with more complexity in the grid. Angular reach captures the topological properties of street networks, which is shown to impact the cognitive load of humans attempting to wayfind in a grid.

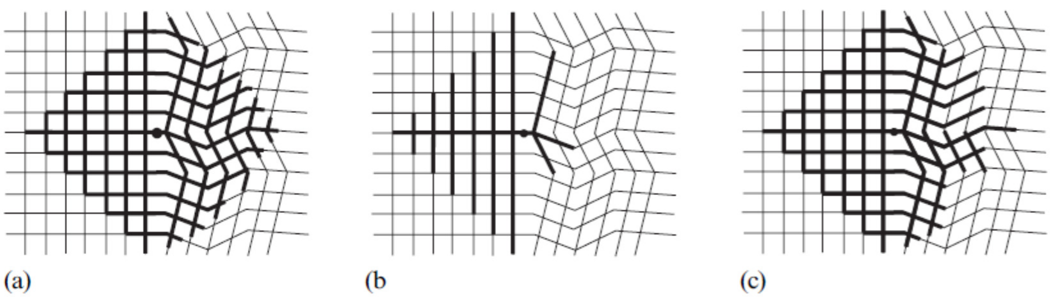

Figure 2 Metric reach (a), angular reach of one direction change (b), and angular reach of three direction changes (c)
Source: (Peponis, Bafna, and Zhang 2008)

To determine which metric distance of number of direction changes was most appropriate to capture local networks and resilience, correlations were calculated with the dependent variable

(Table 1). The most significant correlations were calculated for metric reach at a smaller scale of one-quarter or one-half kilometer, consistent with other findings examining neighborhood-scale dynamics and space syntax (Carpenter and Peponis 2010). Angular reach resulted in lower, sometimes insignificant correlations. This is not surprising, as angular reach, based on the number of direction changes, tends to be less influential at a smaller neighborhood scale. This could be because of the deeper knowledge of one's immediate surroundings (versus a larger scale network, where cognitive maps are less ingrained). For this reason, having direct access to a longer, unbroken thoroughfare does not increase social interaction among residents. The calculations were taken for the block itself, for a buffer around the block, and for the block centroid. Of these, it was decided that the centroid was most appropriate, as the measure is already designed to capture the length of street network accessible for a certain area. The block and block buffer measures were calculated by averaging the reach of all street segments in the area, weighted by street length. This dilutes the measure significantly, as the area can be quite large and the streets captured in the edges of the buffer in particular may by taking into account streets well outside the intended area of influence. The centroid captures the total accessible area within the designated distance from a point approximating a household in that block.

Unexpectedly, all correlations between space syntax measures and resilience were negative. The reasons for this are largely due to the widespread damage and high density of housing lost in the most integrated portions of the street grid. In particular, several high-density multi-family towers were badly damaged and either converted to hotels or demolished. These areas skewed the bivariate correlations; however, the effect of metric reach on resilience in the model was indeed positive with the introduction of additional contributing variables.

Table 1 Space syntax variable correlations (metric and angular reach)

	Change in occupied housing units (2010-2000) normalized by area	
	Pearson Correlation	Sig. (2-tailed)
Metric reach 0.25km (block)	-.219**	.000
Metric reach 0.5km (block)	-.186**	.000
Metric reach 1km (block)	-.152**	.000
Metric reach 2km (block)	-.143**	.000
Angular reach 0direction changes (block)	-.044*	.012
Angular reach 1direction changes (block)	-.059**	.001
Angular reach 2direction changes (block)	-.079**	.000
Angular reach 3direction changes (block)	-.103**	.000
Metric reach 0.25km (buffer)	-.214**	.000
Metric reach 0.5km (buffer)	-.205**	.000
Metric reach 1km (buffer)	-.194**	.000
Metric reach 2km (buffer)	-.171**	.000
Angular reach 0 direction changes (buffer)	.043*	.016
Angular reach 1 direction changes (buffer)	-.011	.549
Angular reach 2 direction changes (buffer)	-.039*	.026
Angular reach 3 direction changes (buffer)	-.079**	.000
Metric reach 0.25km (centroid)	-.195**	.000
Metric reach 0.5km (centroid)	-.194**	.000
Metric reach 1km (centroid)	-.162**	.000
Metric reach 2km (centroid)	-.153**	.000
Angular reach 0 direction changes (centroid)	-.033	.060
Angular reach 1 direction changes (centroid)	-.063**	.000
Angular reach 2 direction changes (centroid)	-.087**	.000
Angular reach 3 direction changes (centroid)	-.117**	.000

Although correlations were more significant at the smaller metric reach distances, metric reach of one kilometer was selected to be more consistent with the other built environment factors, which were measured for a one-kilometer buffer around each block (a map with sample street network metric reach values can be seen in Figure 3.

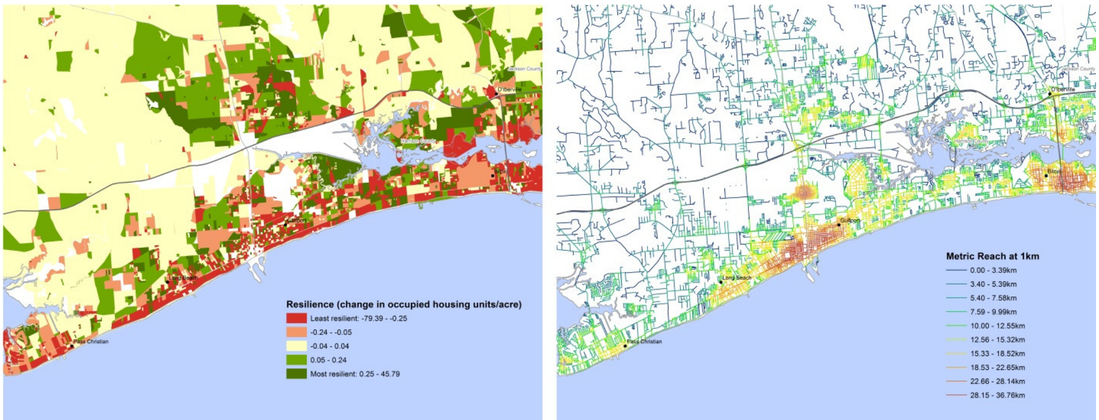

Figure 3 Detailed view of change in occupied housing units 2000-2010 normalized by area for Census blocks (left) and metric reach at one kilometer (right) in Gulfport area

Other built environment variables in the OLS regression model included land use mix, net residential density, social networking organization density, the presence of parks, and historic site density. Land use mix was calculated using pre-Katrina parcel level land use data. A housing analysis database for coastal Mississippi was created in November 2008 by FEMA for the Mississippi Governor's Office of Recovery and Renewal in order to assess land use change and property value change at the parcel level. Using the FEMA land use data, a land use mix index was calculated. This was an entropy measure reflecting the evenness of distribution of several land use types in each block buffer that has been used in previous work (Frank et al. 2008). Net residential density was calculated using the total number of housing units in the buffer divided by the total residential area of the buffer, using Census data for housing counts and the aforementioned FEMA land use data for residential acreage.

The density of organizations that support social networking was calculated using August 2004 business directory data for 3,228 businesses from a commercial vendor. Organizations were chosen based on an oft-cited study examining social capital and associational activity (Rupasingha, Goetz, and Freshwater 2000), which pointed to bowling alleys, public golf courses, membership sports and recreation clubs, civic and social associations, religious organizations, labor organizations, business associations, professional organizations, or political associations. Added to this were gathering places such as eating and drinking places, book stores, beauty and barber shops, cultural centers, and recreational establishments not mentioned above. Organizations and gathering places are of interest as a greater density of these locations provides opportunities for interactions and is associated with richer social networks and greater social capital (Isserman, Feser, and Warren 2007).

The locations of parks were found using several parks databases (the website OpenStreetMap, state data, and the FEMA land use databases described above). Non-residential historical site density was used as a proxy for place attachment, as monuments and historically significant sites promote a sense of local continuity. For historic sites, data were taken from the National Register of Historic Places (NRHP) and from a state historic preservation database provided by the Mississippi Department of Archives and History (MDAH). All properties extant at the time Katrina struck were included (many of these were subsequently destroyed by the storm), a total of 505 sites.

Several intervening variables were included in the model as well. These included sociodemographic variables that have been shown to be significant for resilience as well as external factors related to storm damage and ability or feasibility to rebuild. Sociodemographic variables included percent African American, median income, percent of housing that is renter-occupied and multifamily, and percent of the population in poverty. All variables were derived from the Census. Additional housing variables included median housing value and median age of structure. The median housing value was calculated from the housing values found in the FEMA database. The median age of housing was taken from 2000 Census data.

Damage and aid were also included as intervening variables. Several sources captured damage caused by Katrina. These included remote sensing data taken by FEMA on August 30, 2005 and the assessments found in the FEMA parcel database described above. Aid amount was taken from the Public Assistance Funded Projects Summary FEMA database. The database includes money distributed under the Presidentially Declared Disasters Public Assistance Program. According to FEMA, the grants are used for “debris removal, emergency protective measures, and the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain Private Non-Profit (PNP) organizations” (2012). The total amount of aid distributed to coastal Mississippi and detailed in this database was $1,974,633,280. Although this database does not include the large outpouring of support from small nongovernmental sources, it is difficult to obtain meaningful and consistent data for all aid distributed.

The percent of the population living in the area in 1995 was included as a measure of housing stability. The percent living in the same three-county Gulfport-Biloxi Census Primary Metropolitan Statistical Area in 1995 was taken from 2000 Census data. Growth from the previous Census period of 1990-2000, normalized by block area, was used to control for endogenous growth or contraction in the population. This is the same measure used for resilience, but for the previous decade. The number of occupied housing units in 2000, normalized by area, was also included as an intervening variable to control for the large variance in block populations, as population density can vary greatly throughout the region.

Finally, local fixed effects were incorporated by creating a dummy variable for the local government area each block was located in, which included 27 municipal and unincorporated county areas. Therefore, 26 dummy variables were included in the model, with one of the 27 areas excluded. This was meant to capture the effects of local government efficacy and the political will of local leadership. For example, levels of infrastructure restoration and other public built environment improvements funded by local governments varied across localities. Furthermore, some leaders were more aggressive about locating funding and ensuring residents’ needs were met after Katrina.

Because of a skewed distribution, a logarithmic transformation was used for two variables: social organization density and historic site density. The establishments that foster social networking tended to be highly concentrated in a relatively small number of blocks near the coast, skewing the results. Similarly, historic patterns of development occurred in a similar pattern near the waterfront, resulting in most historic site density occurring in a relatively small area.

The final model in equation format is shown below (variable names are described in Table 2), descriptive statistics are shown in Table 3.

Resilience = Built environment factors + intervening factors + control factors

$$(occ10\text{-}occ00)/area = \beta + \beta_{mr\_1km} + \beta_{lu\_mix} + \beta_{net\_res\_dens} + \beta_{ln\_soc\_orgs\_dens} + \beta_{park\_dummy} + \beta_{ln\_nrhp\_dens} + \beta_{pc\_af\_amer} + \beta_{med\_inc} + \beta_{pc\_mf\_rent} + \beta_{pc\_pov} + \beta_{hsg\_val\_med} + \beta_{hsg\_age\_med} + \beta_{pc\_damage} + \beta_{aid\_amount} + \beta_{pc\_same\_pmsa} + \beta_{(occ00\text{-}occ90)/area} + \beta_{occ00/area} + \text{local fixed effects} + \varepsilon$$

Table 2 Equation variables

Variable Short Name	Variable Full Name
resilience ((occ10-occ00)/area)	Resilience (change in occupied dwelling units in block from 2000 to 2010 divided by area of Census block in acres)
mr_1km	Space syntax variable, metric reach at 1km
lu_mix	Land use mix
net_res_dens	Net residential density (housing units per residential acre, 2000 U.S. Census)
ln_soc_orgs_dens	Social gathering place density (natural log)
park_dummy	Parks and open space density
ln_nrhp_dens	Historic sites density (natural log)
pc_af_amer	percent African American
med_inc	Median income, (2000 U.S. Census)
pc_mf_rent	Tenure (percent multifamily rental housing, 2000 U.S. Census)
pc_pov	Poverty status
hsg_val_med	Housing values
hsg_age_med	Age of housing stock
pc_damage	Level of storm damage
aid_amount	Federal, state, and nonprofit aid received
pc_same_pmsa	Population living in same region in 1995
(occ00-occ90)/area	Change in occupied housing units per acre, 1990-2000
occ00/area	Initial occupied housing units per acre, 2000

Table 3 Descriptive statistics

	Minimum	Maximum	Median	Mean	Std. Deviation
resilience	-45.12	45.79	-0.14	-0.47	1.99
mr_1km	0.00	36.76	10.95	12.10	6.92
lu_mix	0.07	1.00	0.70	0.68	0.14
net_res_dens	0.04	28.97	2.29	2.72	1.89
ln_soc_orgs_dens	-9.04	-1.59	-4.02	-4.2	1.47
park_dummy	0	1	0	0.29	0.45
ln_nrhp_dens	-9.4	-2.94	-5.65	-5.59	1.03
pc_af_amer	0.00	0.96	0.17	0.21	0.19
med_inc	$17,209	$78,986	$35,503	$36,823	$9,175
pc_mf_rent	0.00	0.51	0.08	0.10	0.09
pc_pov	0.01	0.40	0.12	0.13	0.07
hsg_val_med	$19,576	$163,536	$50,319	$54,940	$19,018
hsg_age_med	5.75	59.12	28.82	29.68	12.29
pc_damage	0.00	0.98	0.17	0.25	0.24
aid_amount	$0	$15,277,504	$56,858	$258,803	$886,812
pc_same_pmsa	0.07	0.99	0.74	0.71	0.16
d90_00_area	-28.07	40.82	0.08	0.30	1.74
occ00_area	0.00	45.12	1.39	1.88	2.07

Results

The results of the Ordinary Least Squares (OLS) linear regression model are shown in Table 4.

Table 4 OLS Model results

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-2.564	0.422		-6.069	0.000***
Built environment variables:					
mr_1km	0.014	0.006	0.047	2.313	0.021**
lu_mix	0.267	0.254	0.018	1.051	0.293
net_res_dens	0.068	0.029	0.065	2.366	0.018**
ln_soc_orgs_dens	0.035	0.016	0.032	2.172	0.030**
park_dummy	-0.161	0.077	-0.037	-2.098	0.036**
ln_nrhp_dens	0.023	0.013	0.030	1.806	0.071*
Intervening variables:					
pc_af_amer	0.324	0.282	0.031	1.147	0.251
med_inc	2.57E-05	6.29E-06	0.119	4.097	0.000***
pc_mf_rent	1.690	0.465	0.074	3.636	0.000***
pc_pov	0.049	0.792	0.002	0.062	0.951
hsg_val_med	3.76E-06	2.51E-06	0.036	1.498	0.134
hsg_age_med	0.001	0.005	0.009	0.287	0.774
pc_damage	-0.345	0.135	-0.041	-2.551	0.011**
aid_amount	-8.95E-08	3.24E-08	-0.040	-2.765	0.006***
pc_same_pmsa	1.800	0.272	0.143	6.614	0.000***
Control variables:					
d90_00_occ_area	-0.221	0.018	-0.194	-12.064	0.000***
occ00_area	-0.550	0.018	-0.573	-31.155	0.000***

Spatial fixed effect coefficients for 26 local dummies not shown here

*** significant at 1%, ** significant at 5%, * significant at 10% confidence interval

R^2 = 0.488
N = 3,222

Dependent variable = resilience

The built environment effects demonstrated the overwhelmingly positive influence of space syntax and other physical characteristics (with the exception of parks) that are associated with greater social networking activity on the return of households, the measure of resilience in the model. Overall, the model displayed good explanatory power (R-squared of 0.488).

The selected space syntax measure of metric reach at one kilometer had an influential (and a positive) effect on resilience, as measured by standardized coefficients. A one standard deviation increase in metric reach at one kilometer (an increase of 1.99 kilometers of accessible street network) is associated with 4.7 percent of a standard deviation increase in resilience. This, in turn, is equivalent to an increase of 0.09 occupied housing units per acre (23.3 units per square kilometer) from 2000 to 2010. Given the mean resilience of -0.47 units per acre (116.1 units per square kilometer), this is a moderate but not inconsequential effect. As noted previously, the bivariate correlation between metric reach at one kilometer and resilience was actually negative, indicating that the addition of variables such as housing type and amount of damage sufficient to isolate what is, in actuality, a positive effect of movement-seeking space on resilience. In reverse order of magnitude, net residential density, metric reach at one kilometer, the density of social networking organizations, historic site density, and land use mix all had a positive effect. The presence of parks actually had a negative impact on resilience (it is believed that the uneven spatial distribution of parks and the higher incidence of parks in undevelopable coastal areas that sustained great storm damage skewed the results).

Of the intervening variables, percent of the population living in the area in 1995, median income, and percent multifamily rental housing had the most influential positive effects on resilience, which were greater than the effects of the built environment variables as measured by the standardized coefficients. Percent damage and amount of aid each had a relatively strong negative impact on resilience. The other intervening variables (percent African American, median housing value, housing age, and percent of population living in poverty) had a weaker positive influence than metric reach at one kilometer. Many sociodemographic variables had a surprising effect on resilience, as ethnic and racial minority populations have been shown to exhibit greater social vulnerability to disasters. However, the weak and statistically insignificant positive effect may be a product of the demographics and spatial distribution of ethnic and racial groups in the area. African American (and relatively poor) neighborhoods tended to be located further inland in coastal Mississippi where real estate was less expensive and therefore were likely to experience lower levels of damage from Katrina.

Control values of change in occupied housing units from 1990 to 2000 normalized by area and occupied housing units normalized by area each had a significant, relatively large negative impact on resilience. This can be explained by the high rate of growth in the time period of 1990 to 2000, when casinos were legalized and the local population was rapidly growing. During this time, many blocks reached carrying capacity for housing units and therefore could only lose and not gain housing units from 2000 to 2010. Previously built-out areas that could only lose housing units, as well as a few low-density areas that have been converted to condominium or higher-density housing, were responsible for the unexpected control variable effects.

Local fixed effects on resilience were mixed as expected. Only six localities exerted a statistically significant effect on resilience, and all of these six had a positive effect, demonstrating that these areas were more resilient, controlling for other variables, than the omitted place category. The high-resilience areas with the largest unstandardized coefficients included Ocean Springs, which had the greatest positive impact on resilience, Gulf Park Estates, St Martin, Diamondhead, D'Iberville, and unincorporated Hancock County.

Implications

In summary, metric reach, which is associated with physical connectedness, accessibility for all modes of transport, and particularly with walkability was a significant factor contributing to resilience, as measured by the return of occupied housing units, in the OLS model. With the inclusion of other known contributing factors to vulnerability and resilience such as demographics, damage, and other significant variables, metric reach had a positive influence on the return of occupied households, despite a negative bivariate correlation between the two variables.

The observed influence of metric reach is consistent with the literature. Better connected areas are more visible and centrally located due to street patterns in the Mississippi Coast area, where higher reach tends to occur near the well-traveled waterfront and central business districts. Walking is more likely in areas with greater local connections, based on previous findings (Ozbil, Peponis, and Stone 2011). Therefore, residents are likely to have more social encounters to support their social networks. Furthermore, such spaces are likely to be more intelligible to residents and tourists alike (Bafna 2003). Higher reach values may also be associated with a positive psychological effect on residents and former residents, as returning to a relatively well-connected area rather than a remote area (where fewer homes have been rebuilt) would seem to be undesirable. Similarly, net residential density, which also had a positive effect on resilience, increases the probability of social encounters and local social networks through increasing the number of social network connections within the neighborhood. Therefore it was not surprising, of the built environment factors chosen, metric reach and net residential density had the strongest positive influence on resilience.

Although it would be difficult to redesign the street layout of the mostly built-out Mississippi Coast region, a redevelopment approach incorporating greater metric reach, or local connectivity, would likely improve resilience to future natural disasters. Historic communities in Mississippi situated on the Gulf of Mexico are laid out, more or less, on an orthogonal grid; however, more recently established communities that have recovered at a slower rate are laid out along dendritic suburban street patterns, such as the St Andrews neighborhood in Ocean Springs. Given the difficulty of retrofitting city streets, the creation of trails and paths could improve the connectivity without altering the underlying street pattern. Planners should be aware of the limitations of disconnected subdivisions for resilience.

We are an increasingly mobile and technologically linked society, but our desire to make our homes in “livable” communities has intensified in recent decades. Creating the kinds of spaces that support triangulation, or the phenomenon in which activity and social interaction prompt one another (Whyte 1980), has many economic and social benefits and is associated with safer, more resilient communities. Disasters can place a significant strain on social networks; however, stronger networks are able to endure the strain more readily and actually increase the effectiveness and rate of recovery efforts. This research shows that the effect of the built environment, including metric reach, on social networks and resilience should not be discounted.

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