ESTIMATES OF BUILDING STOCKS AS A BASIS FOR DETERMINING RISK[1]

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In the event of earthquakes and other natural disasters, it is extremely useful to have as rapidly as possible approximate estimates of the total number of buildings at risk. Strong regularities and relationships characterize social systems which should make it possible to arrive at satisfactory estimates even with minimal information about the social system which has been affected. These regularities can be derived deductively from a knowledge of the nature of social systems, and a model of the relationships between the number and types of buildings and other characteristics of the system can be created. Empirical investigations can then calibrate the parameters of the model to determine within narrow ranges what the numerical relationships are likely to be. Then with minimal information about a social system subject to a disastrous event, rapid estimates can be made concerning the number of buildings at risk.

The most important concern in earthquakes and other disasters is loss of human life and physical injury. Consequently, various tabulations of major earthquakes frequently use as a threshhold criterion some stated number of deaths or some magnitude of shock. Frequently, events of high magnitude are excluded from the list, if they did not result in any loss of life. The second most important concern is with human deprivation and suffering as a consequence of the loss of buildings, structures, and artifacts. Earthquakes and other disasters are usually reported in terms of the number of individuals or households who were made homeless or who were left without shelter. In this regard homelessness or loss of shelter is used as a surrogate for the destruction of buildings and their contents. In addition to dwellings themselves, this implies clothing, furniture, utensils, stores of food, linkages to vital services such as water supply, waste water disposal, electricity, telephone, gas and other fuels. Not only are survivors without shelter from the elements, they are without heat, light, food, means of cooking, water for drinking and personal hygiene, bedding, and clothing. Homelessness also is used to imply the loss of other kinds of buildings although these are sometimes stated explicitly. The most important are places of work, and again the loss is not merely that of the structures themselves, but of the tools, machinery, equipment and inventories that were associated with these buildings. Having estimates of the number of buildings at risk can assist pre-event disaster preparedness planning and planning for disaster relief and reconstruction efforts. In the emergency period immediately after an event, such estimates can be useful in assessing the extent of the damage and determining the severity of the event. Rapidly developed estimates can aid relief efforts by determining rough quantities of material that need to be provided. In the reconstruction phase after an event, such estimates can give a first indication of what will be necessary to restore the social system to its previous state.

Estimates of building stocks even if they were quite rough would be extremely useful in a variety of ways in pre-event planning. Measures taken to reduce vulnerability often involve the adoption of seismic building codes or other similar ordinances. These frequently take cognizance of the existing building stock at the time the ordinance was passed and specify that these structures must be brought into conformity with the code within some stipulated period of time. There is almost never any indication of the number of buildings involved nor of the construction effort that would be necessary to accomplish this objective. Disaster preparedness planning could use estimates of building stocks by determining in advance rough numbers of buildings by small geographical areas subject to various kinds of natural disasters. This would aid in planning evacuation procedures and determining the number of alternate and temporary shelters and facilities that would be needed.

In the case of a disastrous event, damage assessment is usually undertaken at an early stage. Criteria for external assistance is often based on some proportion of the pre-existing stock that was lost. Such measures are used to express economic value of losses as a ratio of gross regional product. This relationship is frequently the basis for determining whether or not a stricken area is entitled to external assistance or could be expected to cope with the situation with internal resources. In the weeks that follow, careful counts of structures suffering various degrees of damage are carried out. However, there is almost always no information regarding the total number of structures that existed before the event. Damage assessment procedures could be facilitated by estimates of existing building stocks. In the emergency following a disaster, relief efforts must be mounted with great speed. To be efficient, they require rapid estimates of the magnitude of destruction. The degree of mobilization of external resources and the logistics necessary to deliver them to the stricken region must be determined very quickly. Estimates of existing building stocks that could be made rapidly and easily would greatly assist this process. The earthquake which struck Campania-Basilicata in 1980 blocked roads with rubble because all the highways went from town to town and through each settlement rather than around them. Consequently, it was several days before it was possible to penetrate into the center of the region and determine how great the magnitude of the destruction really was. With rapid estimates of the number of buildings, the type of construction, and the magnitude of the shock, it should have been possible to make a first estimate within a matter of hours.

For example, UNDRO uses three categories of buildings in the MSK-64 scale and six grades of damage. Relationships have been established between intensity of shock and percent of structures of different categories suffering various degrees of damage. Percent loss of value of structure is related to degree of damage also [United Nations, 1980]. In a short period after an earthquake, the intensity of the shock and the area impacted at various degrees would be known. Estimates could rapidly be made of the building stock in the impacted area and assumptions based on familiarity with the region could be used to develop a distribution of buildings by category. Degrees of damage could then be calculated. A rough estimate of economic loss could be determined as a first approximation. As reports come from the field providing further information, the estimates could be successively revised and refined.

Reconstruction efforts must always await detailed damage estimates made by experts over a period of weeks. However, initial reconstruction planning can proceed immediately based on information derived from building stock estimates that would serve as a first approximation.

Since the stock of buildings in an area has tremendous economic and social importance, and since information about stocks and their characteristics is so useful in disaster situations, it is extraordinary that so little information about them is readily available. Most countries in the world make no attempt to enumerate buildings, let alone gather information about their characteristics. In the United States, no federal agencies gather systematic and complete information about buildings. Some countries with highly centralized governments make serious efforts, but often the quality of the data is variable. Information about housing is normally gathered in most countries. However, relationships between housing units and residential buildings and residential structures and total building stocks are not available.[2] At the state, provincial, or regional level in most countries the situation is usually worse. Frequently, most information exists at the local level. However, the completeness and quality of data vary extremely from one locality to another. The data are usually gathered for a specific purpose such as the assessment of taxes and other levies so that there are strong incentives for avoidance resulting in underenumeration. Further, the quality of the data will not vary randomly but systematically with certain types of structures disproportionately undercounted compared with others. Categories of buildings not relevant to the purpose of the count, such as untaxed properties, may be omitted entirely. Moreover, these data are usually stored locally and may have been destroyed or made inaccessible by the disaster. In any event, attempting to seek out the data and assemble them from a large number of localities would consume so much time and effort as to obviate the purpose of making the estimates.

What is necessary is a means of making rapid estimates with tolerable degrees of accuracy that would justify the effort and cost of making them for pre-disaster, emergency, and post-disaster purposes. Fortunately, social systems are characterized by many regularities which persist with fairly stable rates of change over long periods of time.[3] Since this is the case, it is possible to make estimates about unknown characteristics of human societies on the basis of other characteristics for which data are readily available. Once the relationships have been determined either through several instances of enumeration or sampling procedures, models can be developed which permit making estimates about current or past phenomena in situations in which the desired information is not known for one reason or another. Forecasting and predicting which is so essential to decision-making both in public and private sectors are based upon these procedures. Economic forecasts generally involve establishing stable relationships between individuals and artifacts and use projections of numbers of individuals and various demographic and social characteristics that they have. The dependent variable in economic forecasts is usually some product, good or service, and often a physical artifact. The independent variables often include population and demographic characteristics. Forecasts for services, such as telephone usage, are the basis for decisions about capital equipment, such as coaxial cables and switching equipment. Housing market analysis which is concerned with forecasting the demand for additional housing units in future periods is one of the techniques that comes as close to making estimates of building stocks from other characteristics of social systems as anything currently in practice.

The problem is to devise a rapid, simple means of arriving at plausible estimates of the magnitude and characteristics of the building stock in a given place at a given point in time using some sort of information about the social system that is readily available. Perhaps the single piece of information that exists for most places at most points in time is the size of the resident population. If a relationship between the population and the building stock can be established, this would serve the present need. The purpose of buildings is to shelter the activities of people. However, the relationship between population and buildings will be different in different social systems. We can expect the relationship to vary with the demographic structure of the population, the level of social organization, the level of technology, the age of the social system, the types of activities that are carried on, and the level of income the population receives. Whether or not the system is developing or declining will be important. The size of the population, the degree of concentration or dispersion, the density of settlement will all cause variation. However, it is reasonable to start with a basic model which posits fundamental relationships and permit later refinements to elaborate upon it. Univariate models are convenient starting places and are often all that is necessary. Multi-variate models can develop as other modifying relationships are explored and factors found to be relevant. Additional variables often make models more specific to particular times and places. Forecast accuracy is gained by the sacrifice of generality.

A very simple model can be developed. Because of its high level of aggregation and lack of complexity, it may yield better estimates than more elaborate ones. The model states as a fundamental precept that buildings are some function of population.

$$B = f\,(P) \tag{1}$$

The building stock will have accrued through an accretionary process and will reflect relationships that prevailed at various periods in the community's history. The building stock is recognized as an aggregate of survivals of increments to the stock from previous periods.

The relationship between buildings and population will vary with population size, density, and the magnitude of the agglomerations or centers of concentration. Larger buildings tend to be found in places that have larger populations. This is a sufficiently important modification of the initial premise that it should be stated as a corollary that the population-building ratio is some function of the population.

$$\frac{P}{B} = g(P) \tag{2}$$

As the population grows, increments to the building stock will reflect the population-building ratios characteristic of the new scales of population. The relationship at any point in time will again be an aggregate of structures surviving from previous periods characterized by different ratios. The change in the population-building ratio will probably vary with population size. It will probably be low for small populations then rise and subsequently fall as population continues to grow as shown schematically in Figure 1. For very small populations, buildings represent inordinately large per capita capital expenditures and require very high levels of saving and investment. Consequently, the buildings are modest and very intensively used. As the society becomes larger, more complex, and more productive, buildings and other constructions become relatively cheaper and more plentiful. As populations continue to grow in size and social complexity, larger agglomerations of population are assembled, larger buildings are constructed, and the population-building ratio probably rises.

The way in which building stocks vary with population is not direct and simple but reflects extremely complex relationships. They are shown schematically in Figure 2. The changing slope of the curve as population grows reflects changes in building technology and changes in transport technology. When population delines in a city or a region, the building stock does not normally contract as rapidly. The building stock in many communities which suffered in the Montenegran earthquake of 1979 had been erected to shelter the activities of much larger populations than remained at that time. A classic example is the picturesque village of Perast near Kotor. This village had substantially larger populations in the 17th and 18th century than it has at present. It contains a number of large and imposing structures, the maintenance and repair of which have been beyond the capacity of the population for many years.

Buildings are not of uniform size measured either in floor area, height, or volume. A building stock will be characterized by some sort of size distribution. It is implicit in the relationships already stated that the distribution of buildings by size class intervals will be a function of the population. The relative frequency distribution of the number of buildings by area can be stated as some function of the number of buildings.

$$(A_1, A_2, \ldots A_n) = h(B) \tag{3}$$

Changes in the number of buildings necessarily imply a change in the shape of the frequency distribution. As the number of buildings increases (as a function of population), buildings with larger areas can be expected to be built, and the distribution should move to the right. Once again, the stock of buildings at any point in time is an aggregate of the distributions characterizing survivors from previous periods.

The distribution is bounded on the left by zero and has no effective bound on the right. Therefore, a frequency distribution can be expected which is skewed to the right as shown in Figure 3. For simplicity, it is assumed the distribution conforms reasonably to the log normal.[4] Changes over time can be described easily. The mean of the distribution will increase with increasing size of population. The size of the largest building will increase and the variance of the distribution will increase also reflecting greater skewness. Such a change is shown on log normal probability graph paper in Figure 4. The lower curve t_1 represents the

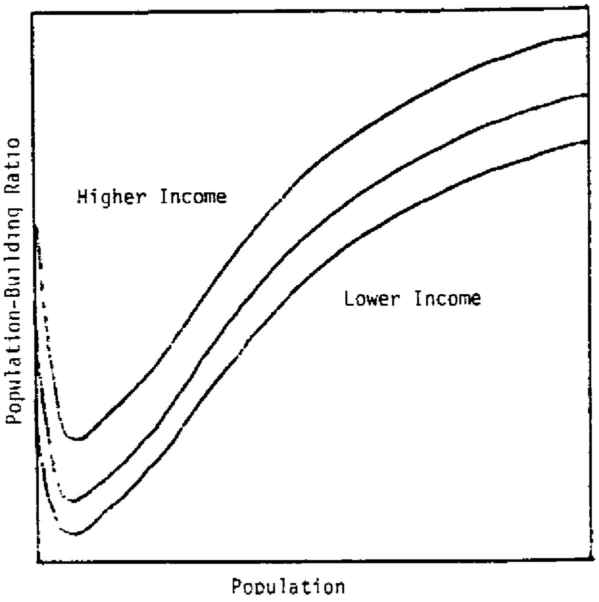


Figure 1

Schematic Relationship of Population-Building Ratio With Population for Different Levels of Real Per Capita Income

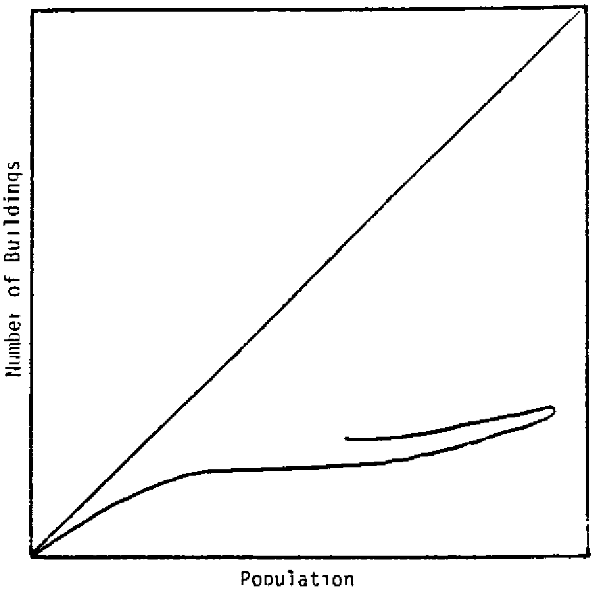


Figure 2

Schematic Relationship of Building to Population first point in time and the upper curve t_2 represents the second. The upper curve has a larger mean, a greater variance, a larger intercept, and therefore a bigger largest building, and the building stock contained by it has a greater total floor area.

Similar conditions prevail with respect to the height distribution of buildings. The relative frequency distribution of the number of buildings by height will also be some function of the number of buildings.

$$(H_1, H_2, \ldots H_n) = i(B) \quad (4)$$

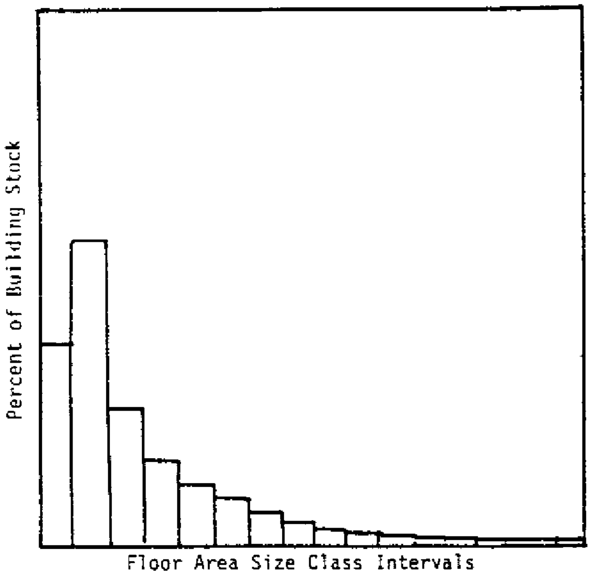
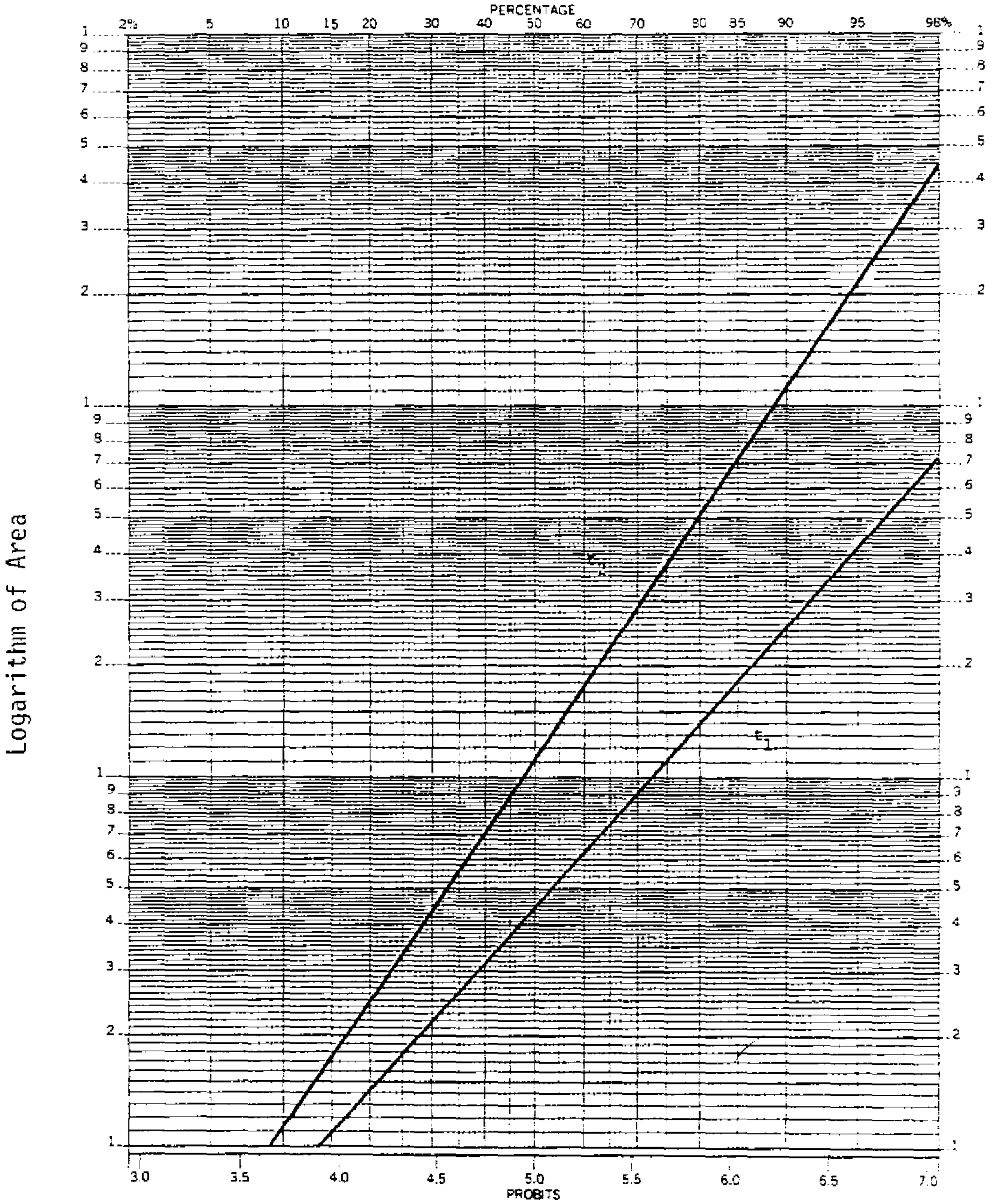


Figure 3

Schematic Distribution of Buildings by
Floor Area Size Class Intervals

If buildings are classed by the number of stories, a similar distribution skewed to the right can be anticipated. Constraints of technology and cost will affect this distribution more than the one for floor area. A similar log normal distribution as for area will exist but with somewhat different parameters. Floor area and height are not independent of each other. Class intervals for floor area and height can be cross-tabulated in matrix form. Given the skewed distributions assumed above, the means of height, and the means of area will vary systematically in some such fashion as that shown in Figure 5. The resulting distribution with these assumptions is a bi-variate log normal distribution similar to the one shown schematically in Figure 6 [Yule and Kendall, 1950].

The accretionary process by which building stock accumulates that has been referred to repeatedly is portrayed schematically in Figure 7. In Period 1, N_1 buildings are built, D_1 of which are destroyed through fire, flood, demolition, and other causes, and S_1 survive to the next period.



Cumulative Probability

Figure 4

Schematic Distribution of Building Areas

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 14.

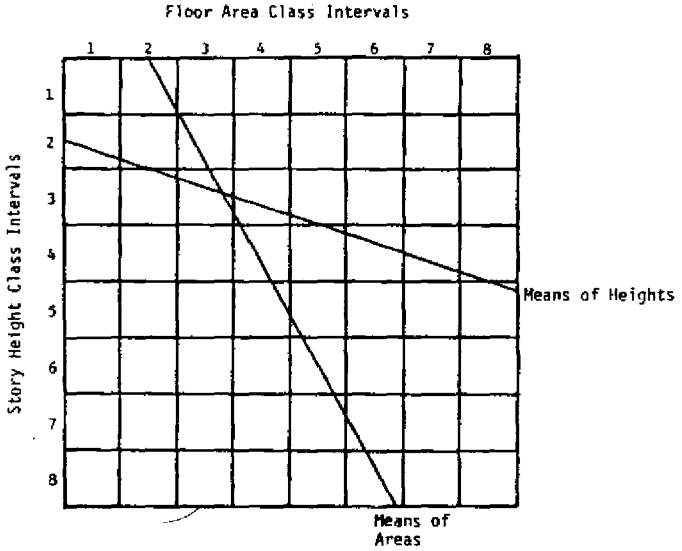


Figure 5

Schematic Cross Classification of Buildings
by Area and Height

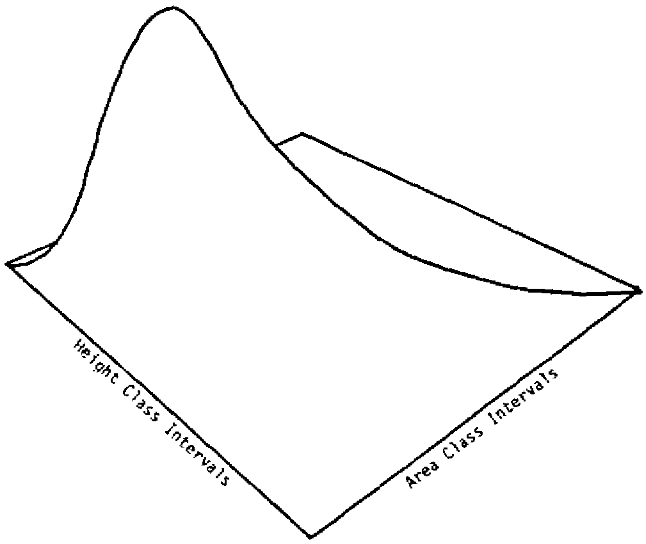


Figure 6

Schematic Joint Distribution of Buildings
by Areas and Heights

In Period 2, there is a great deal of construction activity, N_2, but also much destruction, D_2, which falls proportionately on buildings from both Periods 1 and 2. In Period 3, there is moderate building activity and considerable destruction. The way the diagram is drawn the building stock actually contracts in Period 3 as more buildings are demolished than constructed. Periods in which there is little demonstration of capability for growth of the building stock or actual contraction of it may also be characterized by little capability for maintenance. Buildings in poor repair are more vulnerable to earthquakes and other kinds of disasters, other things being equal. This experience was clearly demonstrated in both the Friuli and Montenegran earthquakes. Not only did destruction vary from urban center to urban center depending upon economic growth or decline, but also from center city to fringes in relation to levels of income and capacity for new building activity. The bottom diagram represents the situation at the end of Period 5. The surviving building stock, $S_1 + S_2 + S_3 + S_4 + S_5$, is constituted of strata of buildings from each of the periods of the community's history. The dotted lines and shaded area depict buildings that have been built at various points over time and the periods in which they were destroyed. The building accretion process is portrayed as a cohort survival model and can be expressed in terms of a matrix algebra formulation [Copur, 1976], [Rogers, 1971].

A very simple deductive model has been developed which specifies a number of characteristics of building stocks as plausible relations of social systems. The model is descriptive and macro-behavioral. Such models provide little in the way of explanation or understanding of phenomena and make few contributions to the body of theory. However, these kinds of models are often extremely useful for making estimates and forecasts with reasonable degrees of accuracy.[5] Obviously, the model can be elaborated to include buildings of different types by use and occupancy as well as other features. However, at this stage of development, such disaggregation is inappropriate.

An empirical test of the model was carried out to determine whether or not the relationships that were posited could be observed.[6] Existing sets of data had to be used, and information was found for populations and buildings for a number of cities at different points in time. Simple regression analysis of five sets of city building stocks as a function of population was carried out, and the results are shown in Table 1 and the scatter diagrams displayed in Figures 8 and 9. The estimated and actual buildings using the equations are compared in Appendix Tables A.1 through A.5. The difference is expressed as a percent of the estimate which accentuates the estimating errors. For the most part the estimated buildings are relatively close to the actual number.

Regression analysis was also carried out on the population-building ratio as a function of population using the logarithm of population. The results shown in Table 2 have, as expected, much lower coefficients of determination. The scatter diagrams ~~show~~ strong relationships but considerable variation from one city to another. The equations derived from this anlaysis were used to make estimates of population-building ratios for hypothetical city sizes as shown in Table 3. While there is a considerable range in the ratios depending on the equation used, there is greater convergence for the large samples of cities and the more recent years. The ratios in Table 3 can be used to make rough estimates of building stocks for analytical purposes. They were the basis for

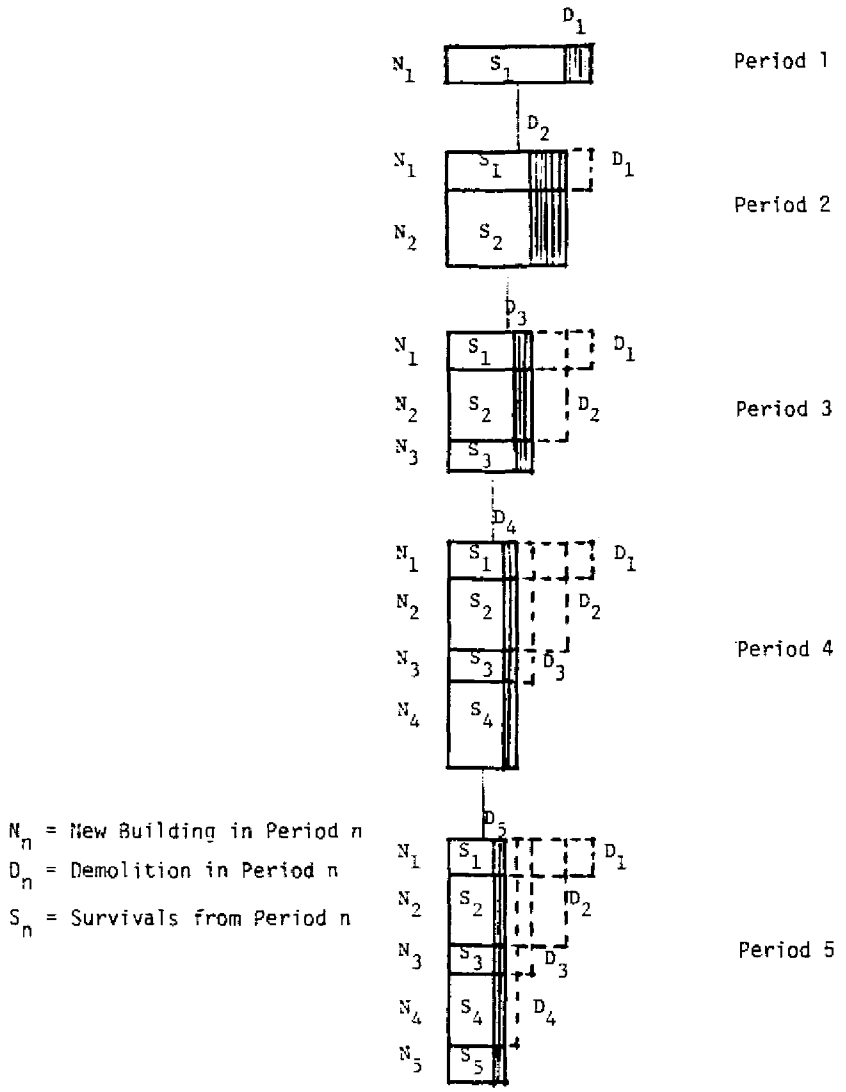


Figure 7

Schematic Representation of Different Patterns of Survival, Construction, and Demolition of Building Stock Over Several Time Periods

Source: Adapted from Ülker Copur. "Survival Through Change: A Developmental Perspective" (unpublished doctoral thesis). Ithaca, New York: Cornell University, 1976. Page 163.

Table 1

Buildings as a Function of Population: Regression Analysis, Various Cities, Various Years

City Set	a	b	Standard Error of b	R^2	F	Standard Error
Columbia (19 Cities)						
1951	1323	.12586	.00321	.98906	1536.288	2161.29
1964	3594	.11946	.00309	.98876	1495.468	4939.62
Turkey (48 Cities)						
1970	5124	.10571	.00268	.97133	1558.640	6350.15
Turkey (14 Cities)						
1927	3964	.16787	.00537	.98788	977.854	3613.39
1970	7058	.10345	.00506	.97211	418.304	10845.84

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, *The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities*. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 46.

Table 2

Population-Building Ratio as a Function of Logarithm of Population: Regression Analysis Various Cities, Various Years

City Set	a	b	Standard Error of b	R^2	F	Standard Error
Columbia (19 Cities)						
1951	7.0111	.6805	.2073	.3880	10.7775	1.0720
1964	6.4418	.9695	.1593	.6855	37.0550	.8961
Turkey (48 Cities)						
1940	6.4322	.9447	.1791	.3770	27.8370	1.2401
Turkey (14 Cities)						
1927	4.3610	.3051	.1971	.1665	2.3971	.8823
1970	6.6452	.8551	.2968	.4089	8.2996	1.4234

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, *The Estimation of Building Stocks and Their Characteristics in Urban Areas An Investigation of Empirical Regularities*. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 65.

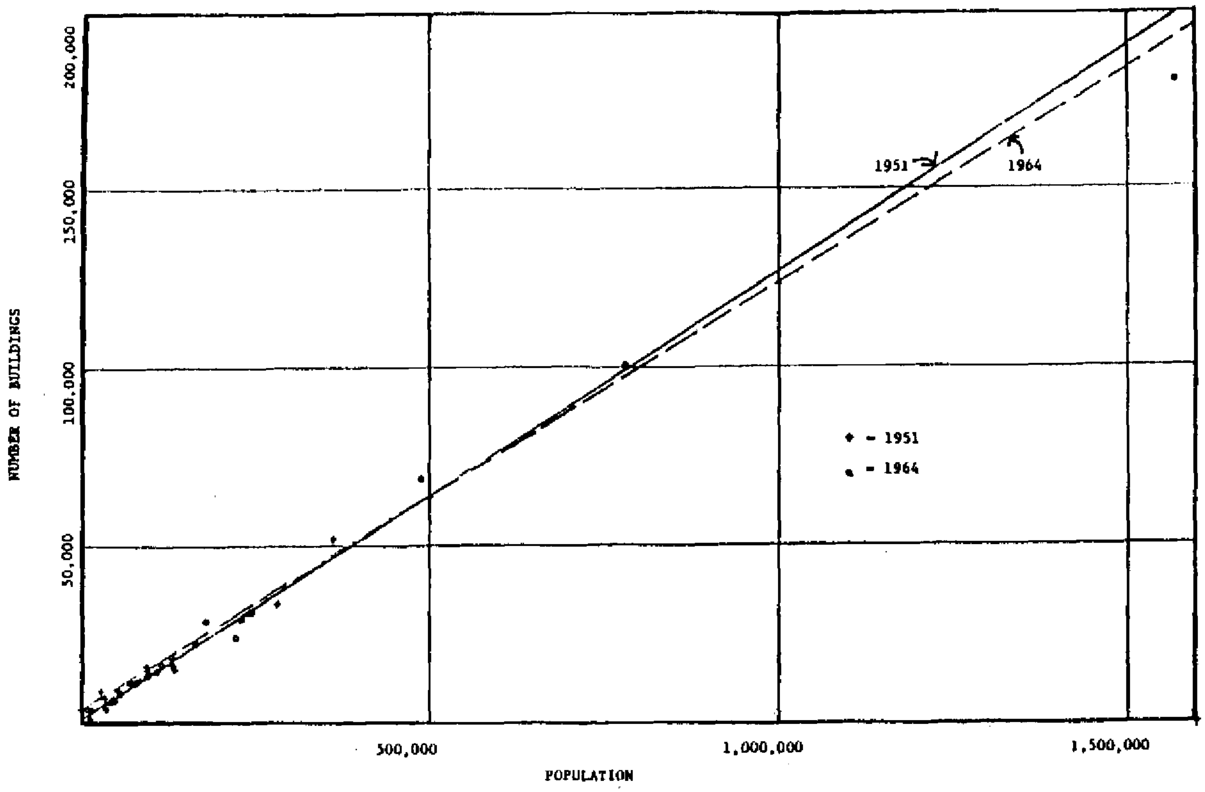


Figure 8

Scatter Diagram with Regression Lines Number of Buildings and Population Columbia (19 Cities), 1951, 1964

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 48.

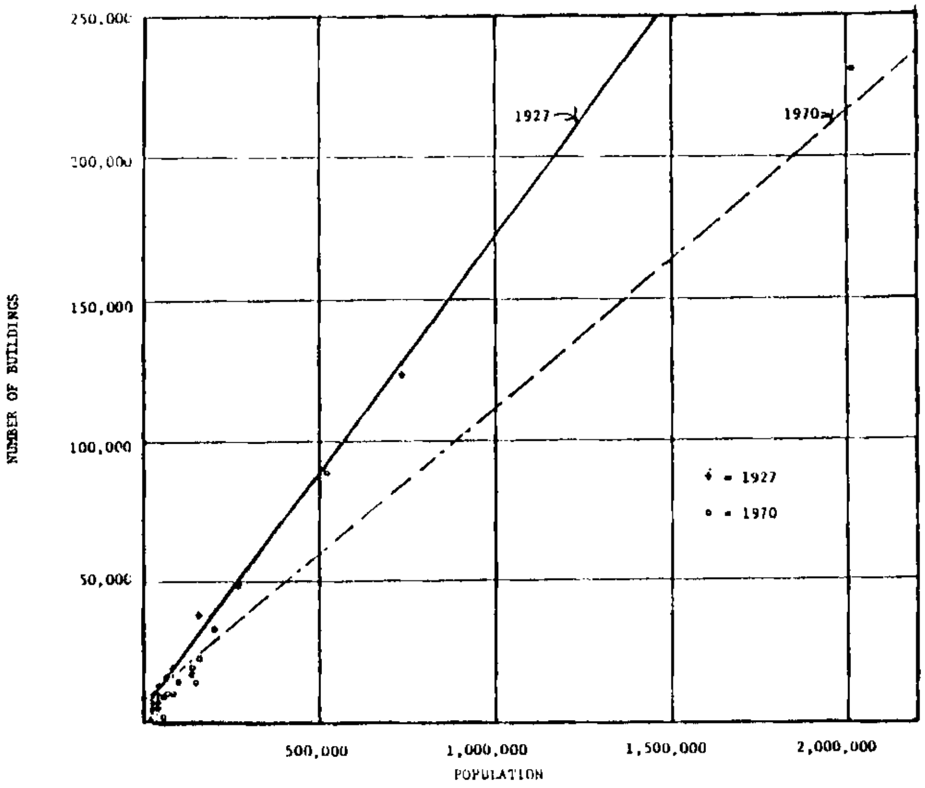


Figure 9

Scatter Diagram with Regression Lines Number of Buildings and Population
Turkey (14 Cities), 1927, 1970

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, *The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities*. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 49.

Table 3

Population-Building Ratio Estimated from Various Functions of Population Hypothetical Sizes, Various Years

	1951		1964		1970		1927		1970	
	A	B	A	B	A	B	A	B	A	B
10,000	3.87	5.44	2.09	4.21	1.62	4.26	1.77	3.66	1.24	4.68
50,000	6.57	6.54	5.23	5.77	4.80	5.78	4.05	4.15	4.09	6.05
100,000	7.19	7.01	6.44	6.44	6.37	6.43	4.82	4.36	5.75	6.65
250,000	7.62	7.63	7.47	7.33	7.92	7.30	5.44	4.64	7.59	7.43
500,000	7.78	8.11	7.90	8.00	8.62	7.95	5.69	4.85	8.51	8.02
1,000,000	7.86	8.58	8.13	8.67	9.02	8.61	5.82	5.06	9.05	8.61
1,500,000	7.89	8.85	8.21	9.07	9.16	8.99	5.86	5.19	9.25	8.96
2,000,000	7.90	9.05	8.25	9.35	9.24	9.26	5.89	5.27	9.35	9.21

Sources: A - Equation (24), parameters from Table I
B - Equation (26), parameters from Table II

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 70.

estimating the percent of the building stock in Bucharest destroyed in the Romanian earthquake of 1977.[7]

Size data for buildings by area and height that can be tabulated separately and cross-tabulated are very difficult to find. A good data set that had been subjected to a great deal of refinement and elimination of errors was obtained for a large percentage of the total building stock of the five boroughs that comprise New York City totalling about 800,000 buildings.[8] Distribution by class interval for areas is shown in Table 4, and the obvious skewness of the distribution was anticipated by the model. The distributions for total buildings are more regular than those for residential buildings and non-residential structures.

Similar results were obtained from an analysis of the height distribution of buildings shown in Table 5. The tabulation conforms to expectations. Log normal probability plots were made for residential and non-residential structures for both area and height separately. These are shown in Figures 10 and 11. Analyzed in this fashion residential structures show less conformity to expectations both for area and for height. It seems apparent that residential structures are a heterogeneous set that combine two separate populations: single family, duplex, and garden apartment units and large apartments and condominiums.

Floor area and height were cross-tabulated and the resulting distribution was much as anticipated by the model. The results are shown in numbers of structures in Table 6 and by relative frequency distribution in Table 7. The distributions were more skewed than was anticipated. One of the surprising findings was that 77% of the buildings in the five boroughs were less than three stories tall and contained 4,000 square feet or less. This is not the usual image that one has of New York City.

Empirical regularities and persisting relationships between populations and building stocks were assumed and a deductive model was constructed. Empirical tests carried out on the few sets of data that were readily available explored these regularities and estimated the parameters of the relationships. The basic tenets of the model were confirmed. Obviously, substantial additional research is necessary to refine the model and produce equations that would provide reliable estimates in a number of different kinds of situations.

It is clearly possible to develop techniques for making rapid, inexpensive estimates of building stocks in areas subject to earthquakes and other natural disasters. Such estimates would be extremely useful in pre-event situations by determining the magnitude of the task of reducing vulnerability and retrofitting and in planning to mitigate the effects of earthquakes. Using the United Nations method described earlier with more accurate information on the percent distribution of buildings by category, it would be possible to use the building stock estimates to make fairly refined forecasts of the probable economic loss from earthquakes of various magnitudes for any region. In emergency situations, such estimates would be useful to arrive at first approximations of the magnitude of the situation with which one is confronted. In post-event recovery periods, the estimates could be compared to damage assessments to obtain some concept of the relative effect of the disaster on the impacted region. The estimates would also serve to permit beginning recovery planning sooner after the event and

Table 4

Residential, Non-Residential and Total Buildings by Floor Area Class Intervals: New York City-All Boroughs, 1972

Floor Area in thousands of square feet	Functional Use		
Size Class	Residential	Non-Residential	Total
0 - 1 K	117062	13186	130248
1 - 2	350782	9898	360680
2 - 4	164180	12733	176913
4 - 6	24301	7685	31986
6 - 10	15161	8510	23671
10 - 15	10762	4786	15548
15 - 25	7592	4434	12026
25 - 50	6469	3749	10218
50 - 100	4480	2211	6691
100 - 500	2430	1774	4204
500 -1000	105	168	273
1,000,000+	36	93	129
TOTAL	703360	69227	772587

Table 5

Residential, Non-Residential and Total Buildings by Height Class Intervals in Stories: New York City - All Boroughs, 1972

Height (in stories)	Residential	Non-Residential	Total
0	24	10	34
1	101174	38914	140088
2	457089	12798	469887
3	84609	5873	90482
4	25042	3749	28791
5	19983	3052	23035
6	11503	1575	13078
7	676	630	1306
8	273	369	642
9	312	233	545
10	144	253	397
11-15	1490	983	2473
16-20	783	377	1160
21-40	247	339	586
41-60	10	64	74
60+	1	8	9
TOTAL	703360	69227	772587

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies. Cornell University, 1976. p 90.

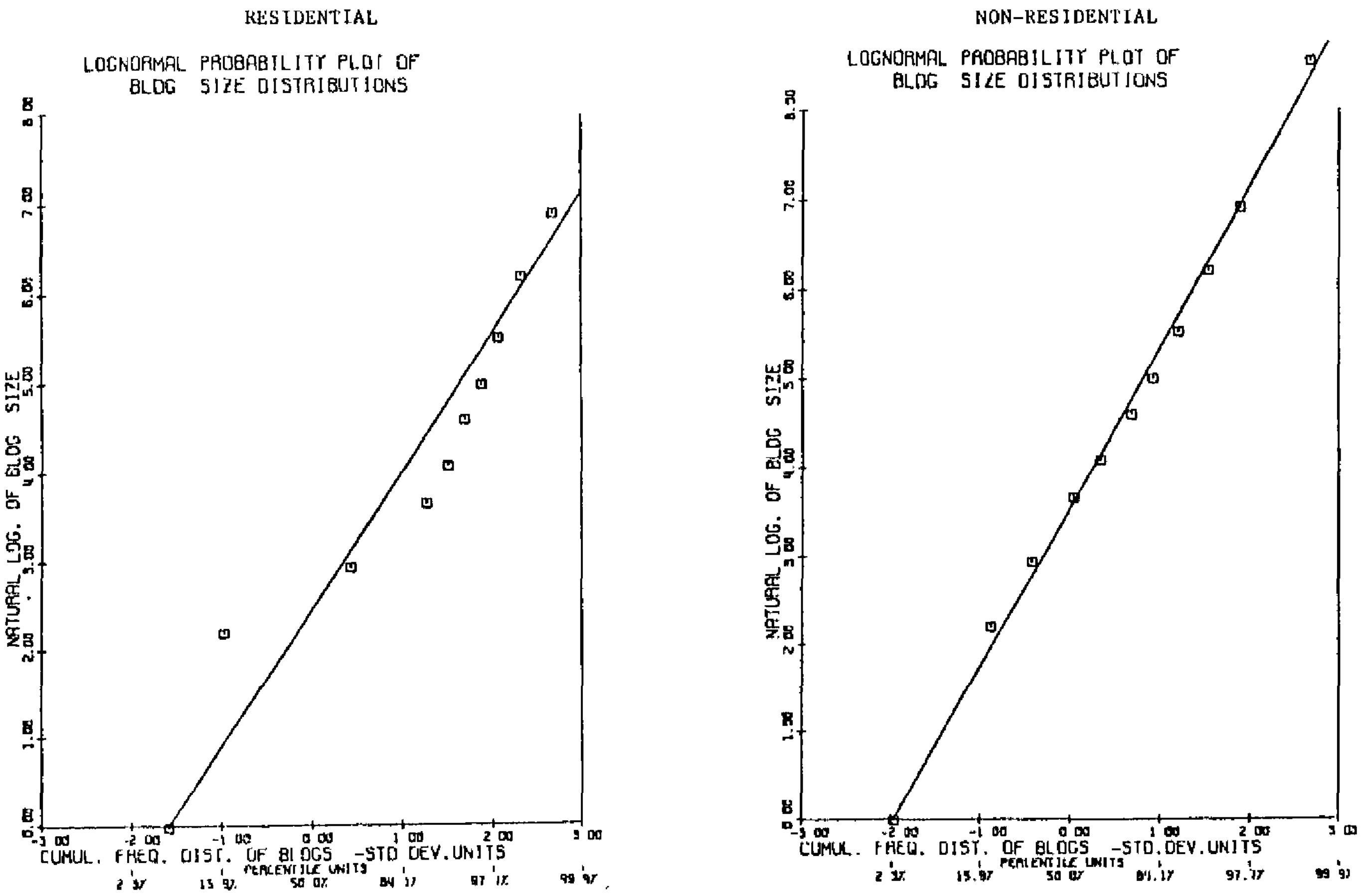


Figure 10

Floor Area Class Intervals: Lognormal Probability Plot of Cumulative Frequency Distributions
New York City - All Boroughs, 1972

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 80.

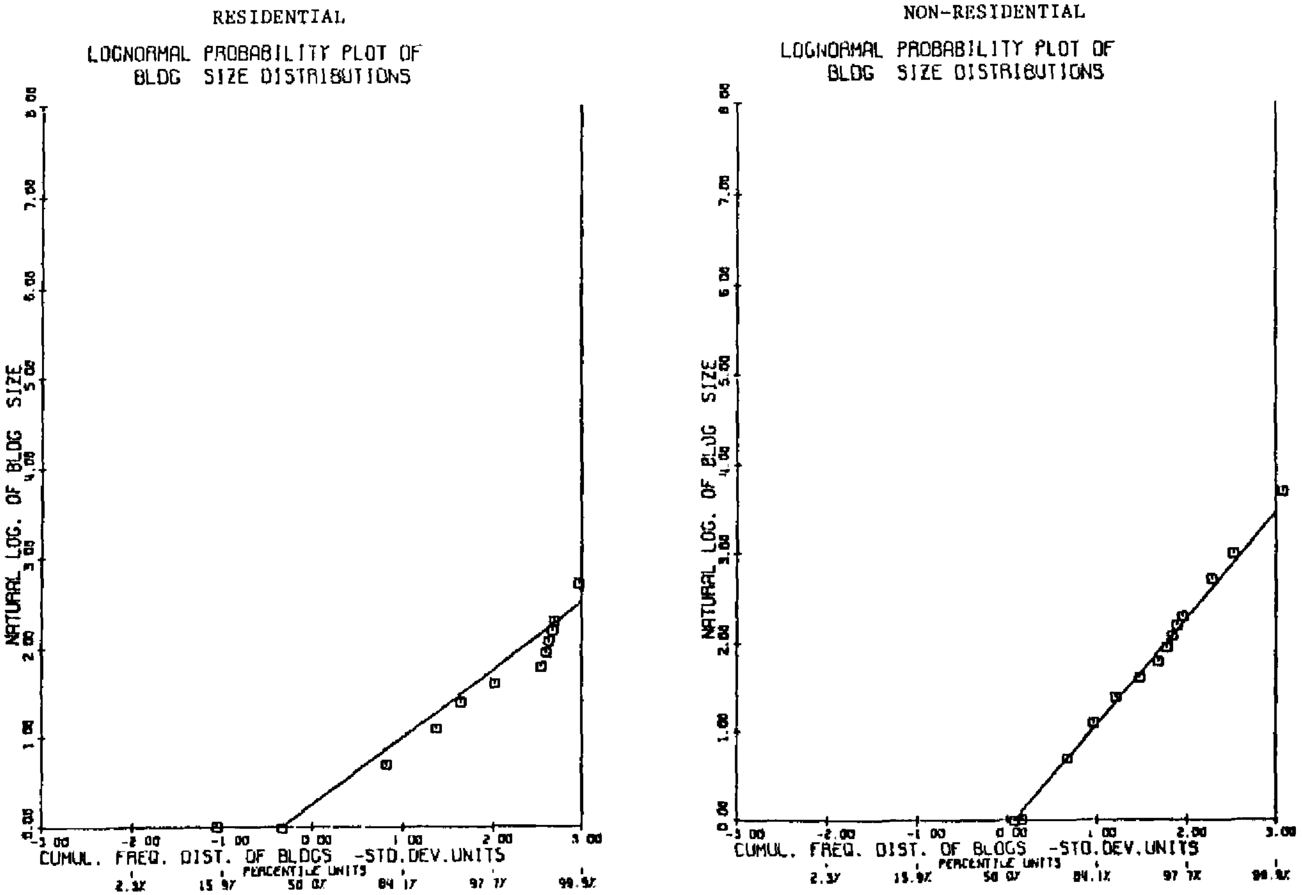


Figure 11

Height Class Intervals by Stories: Lognormal Probability Plot of Cumulative Frequency Distributions, New York City - All Boroughs, 1972

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 98.

Table 6

Cross Tabulation by Area and Height Class Intervals: Residential and Non-Residential Buildings, New York City - All Boroughs, 1972

Floor Area in Thousands of Square Feet

Height in Stories

	0-1K	1-2K	2-4K	4-6K	6-10K	10-15K	15-25K	25-50K	50-100K	100-500K	500-1M	1M+	TOTAL
0	17265	17042	3549	837	1133	397	217	83	46	37	9	8	40623
1	81683	38192	8384	4144	3996	1728	1126	574	192	87	6	4	140116
2	48324	308465	104020	2905	2489	1347	1263	677	268	155	9	14	469936
3	223	13873	57693	13836	2052	882	819	592	312	210	9	5	90506
4	9	137	6337	8117	7297	3184	1921	1278	336	184	11	3	28814
5	1	6	383	2906	7263	6268	3646	1931	487	155	5	2	23053
6	0	2	68	73	508	1885	2773	3728	3140	899	15	3	13114
7	1	0	3	5	50	199	287	423	211	129	7	0	1315
8	0	0	1	1	5	39	61	242	174	107	10	5	645
9	0	0	0	0	2	4	46	228	186	80	8	2	556
10	0	0	1	0	4	4	27	106	148	123	7	2	422
11-15	0	1	0	0	1	4	43	395	973	1117	86	22	2642
16-20	0	0	0	0	1	4	11	41	258	881	60	14	1270
21-40	0	0	0	0	0	0	1	0	1	4	10	2	18
41-60	0	0	0	0	0	0	2	1	3	61	30	42	139
60+	0	0	0	0	0	0	0	0	1	6	0	6	13
TOTAL	147506	377718	180459	32824	24801	15945	12243	10299	8736	4235	282	134	813182

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 107.

Table 7

Relative Frequency Distribution of Cross Tabulation by Area and Height Class Intervals: Residential and Non-Residential Buildings, New York City - All Boroughs, 1972

Floor Area in Thousands of Square Feet

Height in Stories	0-1K	1-2K	2-4K	4-6K	6-10K	10-15K	15-25K	25-50K	50-100K	100-500K	500-1M	1M+	TOTAL
0	0.02123	0.02096	0.00436	0.00103	0.00139	0.00049	0.00027	0.00010	0.00006	0.00005	0.00001	0.00001	0.04996
1	0.10045	0.04697	0.01031	0.00510	0.00491	0.00212	0.00138	0.00071	0.00024	0.00011	0.00001	0.00000	0.17231
2	0.05943	0.37933	0.12792	0.00357	0.00306	0.00166	0.00155	0.00083	0.00033	0.00019	0.00001	0.00002	0.57790
3	0.00027	0.01706	0.07095	0.01701	0.00252	0.00108	0.00101	0.00073	0.00038	0.00026	0.00001	0.00001	0.11130
4	0.00001	0.00017	0.00779	0.00990	0.00897	0.00392	0.00236	0.00157	0.00041	0.00023	0.00001	0.00000	0.03543
5	0.00000	0.00001	0.00047	0.00357	0.00893	0.00771	0.00448	0.00237	0.00060	0.00019	0.00001	0.00000	0.02835
6	0.00000	0.00000	0.00011	0.00009	0.00062	0.00232	0.00341	0.00458	0.00386	0.00111	0.00002	0.00000	0.01613
7	0.00000	0.00000	0.00000	0.00001	0.00006	0.00074	0.00035	0.00052	0.00076	0.00016	0.00001	0.00000	0.00262
8	0.00000	0.00000	0.00000	0.00000	0.00001	0.00005	0.00008	0.00030	0.00021	0.00013	0.00001	0.00001	0.00079
9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00006	0.00028	0.00023	0.00010	0.00001	0.00000	0.00068
10	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00003	0.00013	0.00018	0.00015	0.00001	0.00000	0.00052
11-15	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00005	0.00049	0.00120	0.00137	0.00011	0.00003	0.00325
16-20	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00001	0.00005	0.00032	0.00108	0.00007	0.00002	0.00156
21-40	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00002
41-60	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00008	0.00004	0.00005	0.00017
60+	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.00000	0.00001	0.00002
TOTAL	0.18139	0.46449	0.22192	0.04056	0.03050	0.01961	0.01506	0.01267	0.00878	0.00521	0.00035	0.00016	1.00000

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 108.

hopefully shorten the period of deprivation and suffering of the populations subjected to the disaster. Such techniques are not conceived as a replacement or a substitute for existing processes and procedures dealing with disaster preparedness, emergency relief, damage assessment, or reconstruction planning. Instead they are offered as a means of assisting and facilitating these processes and in so doing, mitigating the effects of earthquakes and other disasters on social and economic systems.

FOOTNOTES

1. Some of the research reported in this paper was supported by the National Science Fondation through Grant Number GI-43867.

2. For a detailed description of difficulties which limit the usefulness of the U.S. Census of Housing for estimating residential structures let alone total buildings, see Hibbs [1978].

3. One of the first works to call explicit attention to the subject in spatial analysis is the section entitled "Some Empirical Regularities" in Isard [1956]. An early compilation of techniques for describing these regularities is Isard [1960].

4. The observation that various skewed distributions can be usefully applied to different kinds of urban phenomena goes back more than 50 years. There are a number of historical reviews of this literature. A classic article in the urban literature which has had much influence is that by Simon [1957]. A basic work on the log normal distribution is by Aitchison and Brown [1957].

5. The usefulness of models of this kind is argued and a comparison with micro-behavioral models is made in Jones [1977].

6. The research results reported here were first presented and described in greater detail in Jones, Manson, Mulford, and Chain [1976].

7. With apparently reliable reports on the number of buildings damaged and destroyed and census information on the population, it was possible to use the technique described here to estimate that only two to three percent of the buildings in Bucharest had been destroyed or severely damaged in the earthquake of March 4, 1970 [Jones and Avgar, 1977].

8. The original source of the data was the Real Property Assessment File of the Real Property Assessment Department of the City of New York Finance Administration. This file and the Multi-Structure Parcel Records File were acquired through the Tri-State Regional Planning Commission which had spent a considerable amount of time updating and refining the basic data. The data were unpublished and are available only on tape.

APPENDIX A

Table 1

Estimated Buildings Compared with Actual: Columbia (19 Cities), 1951

City	Population	Number of Buildings		Difference Between Actual and Estimated	Per Cent Difference is of Estimate
		Actual	Estimated		
Bogotá D.E.	648324	82044	82921	877	1.06
Medellin	358189	52456	46405	-6051	-13.04
Cali	284186	34398	37091	2693	7.26
Barranauilla	279627	34444	36517	2073	5.68
Cartagêna	128877	15222	17543	2321	13.23
Manizales	126201	16206	17207	1001	5.82
Bucaramanga	112252	14632	15451	819	5.30
Ibagué	98695	13285	13745	460	3.34
Cúcuta	95150	15742	13299	-2443	-18.37
Pasto	81103	11678	11531	-147	-1.28
Monteria	77057	11152	11021	-131	-1.19
Neiva	50494	7910	7678	-232	-3.02
Santa Marta	47354	7179	7283	104	1.43
Popayán	44808	6234	6963	729	10.46
Quibdó	36558	6484	5924	-560	-9.45
Villavicencio	33342	4487	5519	1032	18.71
Tunja	27402	8486	4772	-3714	-77.84
Riohacha	13068	3004	2968	-36	-1.22
Leticia	3493	570	1763	1193	67.66
Total	2546180	345613	345599	-14	

Table 2

Estimated Buildings Compared with Actual: Columbia (19 Cities), 1964

City	Population	Number of Buildings		Difference Between Actual and Estimated	Per Cent Difference is of Estimate
		Actual	Estimated		
Bogotá D. E.	1568101	181166	190919	9753	5.11
Medellin	772887	106941	95923	-11018	-11.49
Cali	637929	89426	79801	-9625	-12.06
Barranauilla	498301	68659	63121	-5538	-8.77
Cartagêna	242085	31307	32513	1206	3.71
Bucaramanga	229748	29238	31040	1802	5.80
Manizales	221916	24206	30104	5898	19.59
Cúcuta	175336	28760	24540	-4220	-17.20
Ibagué	163661	22334	23145	811	3.50
Monteria	126329	18709	18685	-24	-0.13
Pasto	112876	15876	17078	1202	7.04
Santa Marta	104471	14346	16074	1728	10.75
Neiva	89790	13531	14320	789	5.51
Popayán	76568	11305	12741	1436	11.27
Tunja	68905	11621	11825	204	1.73
Villavicencio	58430	8595	10574	1979	18.72
Quibdó	42926	7370	8722	1352	15.50
Riohacha	31897	7180	7404	224	3.03
Leticia	4013	2060	4073	2013	49.43
Totals	5226169	692630	692604	-26	

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 51 and 52.

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Table 3

Estimated Buildings Compared with Actual: Turkey (48 Cities), 1970

City	Population	Number of Buildings		Difference Between Actual and Estimated	Per Cent Difference is of Estimate
		Actual	Estimated		
Istanbul	2132407	230244	230541	297	0.13
Ankara	1236152	117464	135798	18334	13.50
Izmir	520832	87986	60181	-27805	-46.20
Adana	347454	52208	41853	-10355	-24.74
Bursa	275953	49409	34295	-15114	-44.07
Gaziantep	227652	34051	29189	-4862	-16.66
Eskisehir	216373	36387	27997	-8390	-29.97
Konya	200464	33110	26315	-6795	-25.82
Kayseri	160985	23772	22142	-1630	-7.36
Diyarbakir	149566	14953	20935	5982	28.57
Samsun	134061	18227	19296	1069	5.54
Sivas	133979	17324	19287	1963	10.18
Erzurum	133444	18845	19230	385	2.00
Malatya	128841	14924	18744	3820	20.38
Kocaeli	120694	18288	17883	-405	-2.27
Icel	112982	14852	17067	2215	12.98
Elazig	107364	13944	16473	2529	15.35
Sakarya	101283	16475	15831	-644	-4.07
Urfa	100654	14023	15764	1741	11.04
Antalya	95616	20232	15232	-5000	-32.83
Kirikkale	91658	12297	14813	2516	16.99
Balikesir	85004	15863	14110	-1753	-12.43
Denizli	82372	15656	13832	-1824	-13.19
Trabzon	80795	11594	13665	2071	15.15
Zonguldak	77135	9833	13278	3445	25.94
Tarsus	74510	12079	13000	921	7.09
Manisa	72276	13888	12764	-1124	-8.80
Hatay	66520	10959	12156	1197	9.85
Karabuk	64999	8933	11995	3062	25.53
Edirne	53806	10675	10812	137	1.27
Akhisar	48796	13459	10282	-3177	-30.90
Van	46751	7265	10066	2801	27.83
Nazilli	45159	10601	9898	-703	-7.11
Kilis	43438	9677	9716	39	0.40
Salihli	34478	7818	8769	951	10.84
Kirsehir	33173	6022	8631	2609	30.23
Adiyaman	31263	5392	8429	3037	36.03
Aksaray	30138	5704	8310	2606	31.36
Kastamonu	29338	6560	8225	1665	20.25
Ereğli	28904	3817	8179	4362	53.33
Kadirli	28109	4796	8095	3299	40.76
Tire	28018	8913	8086	-827	-10.23
Lüleburgaz	27808	4771	8064	3293	40.83
Bolu	26944	4269	7972	3703	46.45
Kozan	26097	5816	7883	2067	26.22
Nevsehir	25685	5511	7839	2328	29.70
Edremit	24115	5757	7673	1916	24.97
Bitlis	20824	3279	7325	4046	55.24
Total	7964869	1087922	1087918	-4	

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, <u>The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities</u>. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 53.

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Table 4

Estimated Buildings Compared with Actual: Turkey (14 Cities), 1927

City	Population	Number of Buildings Actual	Number of Buildings Estimated	Difference Between Actual and Estimated	Per Cent Difference is of Estimate
Istanbul	729457	124374	126418	2044	1.62
Izmir	153845	38165	29790	-8375	-28.11
Ankara	74784	19525	16518	-3007	-18.20
Bursa	61451	17639	14280	-3359	-23.52
Kunya	47496	12919	11937	-982	-8.23
Edirne	34669	9524	9784	260	2.66
Erzurum	31457	11984	9245	-2739	-29.63
Diyarbakır	30709	5760	9119	3359	36.84
Kayseri	30134	10098	9023	-1075	-11.92
Urfa	29918	5594	8986	3392	37.75
Sivas	28498	6467	8748	2272	25.97
Trabzon	24634	6348	8099	1751	21.62
Antakya	23550	5146	7917	2771	35.00
Iznik	2260	650	4343	3693	85.03
Total	1302862	274202	274207	5	

Table 5

Estimated Buildings Compared with Actual: Turkey (14 Cities), 1970

City	Population	Number of Buildings Actual	Number of Buildings Estimated	Difference Between Actual and Estimated	Per Cent Difference is of Estimate
Istanbul	2132407	230244	227656	-2588	-1.14
Ankara	1236152	117464	134938	17474	12.95
Izmir	520832	87986	60938	-27048	-44.39
Bursa	275953	49409	35605	-13804	-38.77
Kunya	200464	33110	27796	-5314	-19.12
Kayseri	160985	23772	23712	-60	-0.25
Diyarbakir	149566	14953	22531	7578	33.63
Sivas	133979	17324	20918	3594	17.18
Erzurum	133444	18845	20863	2018	9.67
Urfa	100654	14023	17471	3448	19.73
Trabzon	80795	11594	15416	3822	24.79
Antakya	66520	10959	13939	2980	21.38
Edirne	53806	10675	12624	1949	15.44
Iznik	10038	2131	8096	5965	73.68
Total	5255595	642489	642503	14	

Source: Barclay G. Jones, Donald M. Manson, John E. Mulford, and Mark A. Chain, The Estimation of Building Stocks and Their Characteristics in Urban Areas: An Investigation of Empirical Regularities. Ithaca, New York: Program in Urban and Regional Studies, Cornell University, 1976. p. 54.

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