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A Country-by-Country Building Inventory and Vulnerability Index for Earthquakes in comparison to historical CATDAT Damaging Earthquakes Database losses

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Abstract

In this study, a country-by-country global building inventory and vulnerability index has been produced for 244 nations using individual country studies in order to make rapid loss estimation without regionalised assumptions.

Over 1500 individual census forms and statistical yearbooks, in addition to demographic and health surveys, WHE-PAGER reports, United Nations data, individual government reports, energy building stock reports and other sources, were used on a country-by-country basis to create an urban and rural building inventory. Parameters in the residential building database include building type (houses, apartments etc.), wall and roof type (in terms of HAZUS classes), age of the building (8 classes of year ranges), number of floors, number of rooms, building quality, number of buildings, building cost data and household size (occupancy).

A general building practice factor has been created using a combination of socio-economic indices like corruption, relative income and other parameters. A review of the various seismic resistant codes around the world was undertaken and subjectively rated. 151+ out of 244 countries have some form of seismic resistant code (enforced or otherwise). Building related losses (damage, deaths and economic) from the historical CATDAT Damaging Earthquakes Database are compared.

Keywords: EQLIPSE, CATDAT, earthquake loss estimation, collapse, global vulnerability estimation, index, risk.

Introduction

There is a need for a worldwide building inventory for analysis of rapid loss from any earthquake worldwide. A significant first step was made by PAGER (Prompt Assessment of Global Earthquakes for Response) in producing a global building inventory encompassing WHE (World Housing Encyclopaedia), research, some census data and other components in 87 HAZUS classes. PAGER uses 35 different countries building typologies to define the world in terms of building stock, using wall data as the descriptor of the residential and non-residential stock. However, the need for an accurate building inventory based on country-by-country conditions, and not an inventory with regionalized assumptions, was acknowledged in the creation of the global damaging earthquakes database component of CATDAT to accurately portray a socio-economic loss estimate (Daniell, 2010b, Daniell et al., 2011b). A building inventory requires many components for a reasonable determination of earthquake damage given a scenario event. A building inventory is primarily of residential buildings. In addition, commercial and industrial buildings also play a role. Each country, depending on economic and social situations, will have different percentages of commercial, industrial and residential buildings.

The building inventory created in CATDAT provides a review of the available census data, energy system reports, demographic and health surveys, WHE-PAGER data, United Nations data and other government data for building typologies. The goal was to create a virtual earth of first-order building typologies for each country. In addition, a seismic code index was created in order to look at the effects of seismic codes on the building types. It can be seen that borders between countries influence the difference of corruption in building practice, seismic code implementation and cultural differences. In many countries, data exists for building typologies that have not been previously shown in a worldwide setting (Daniell, 2010a, Daniell, 2010c, Daniell, 2010d, Daniell, 2011a, Daniell et al., 2011a).

The Building Inventory

The starting point for the global building inventory was the list of countries in CATDAT and the population data determined for these countries from a combination of CIA Factbook, UN Census Round information and other population estimation sources (worldgazetteer and urbaninfo). In addition, the labour force statistics produced in CATDAT from a combination of World Bank and UN information were incorporated.

Thus, the population in urban and rural settings was set. In addition, within CATDAT a number of different global socio-economic indices were produced, including corruption, building practice factor, HDI (Human Development Index), exchange rate, urbanity index, unskilled wage, GDP (PPP) (Gross Domestic Product (Purchasing Power Parity) and other factors.

A review of PAGER was then undertaken in the form of the database v1.4 available online. It was seen that the PAGER database utilised WHE data for certain countries. This data is provided as a HAZUS class based building type but only on expert opinion, rather than relying on exact statistics in many cases. In nearly every country, there will be different building practices and materials used, due to different cultural, mineral, wealth and environmental governance factors. On a level 1 system, these differences are generally not determined.

The following main sources of information have been reviewed and collected for the worldwide dataset. In the same way that PAGER defines a range of ratings (low, medium and high) for their preferred sources, the author has also defined preferred ratings.

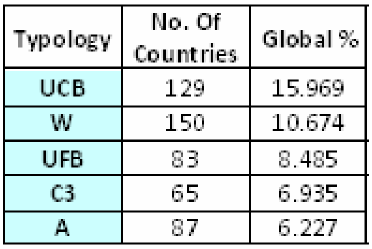
Table 1: Various worldwide rapid earthquake loss estimation software packages.

Source	Rating	Status
1. Census data from 208 countries	Medium-High	Added
2. Housing Surveys	Medium-High	Added
3. UN-HABITAT Data	Medium	Added
4. WHE	Medium	Added
5. WHE-PAGER	Medium-High	Added
6. Energy Building typology papers and projects including TABULA, EnperEXIST and other similar worldwide	High-Medium	Added
7. UN (1993) survey	Low-Medium	Added
8. UN correspondence by PAGER (2007)	Medium	Added
9. Technical Papers from Journals.	High	Added
10. Architecture reports.	Medium	Added
11. ReliefWeb damage and infrastructure reports	Medium	Added
12. Government infrastructure report cards	High	Added
13. Demographic and Health Surveys (DHS), Household Income Expenditure Surveys (HIES)	Medium	Added
14. UNESCO Data reports including Petrovski (1983)	Low-Medium	Added
15. PAGER Research Studies	High	Added
16. EQLIPSE Research Studies (Daniell (2010) and others)	High	Continuing
17. Personal Contacts in countries	Medium	Continuing
18. Combinations of surrounding influence countries (15 out of 244)	Low	Continuing

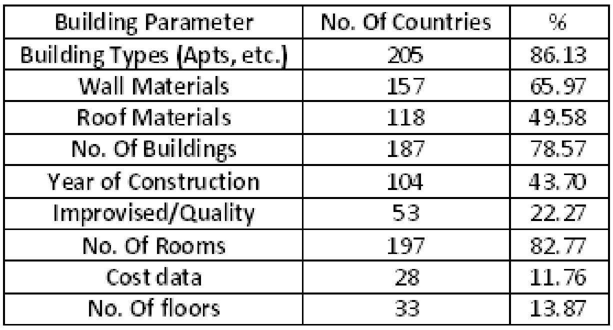
Using these sources, the following information has been extracted for residential urban and rural environments and also for non-residential environments on an urban setting. In some countries, a discretized system based on urban population is also implemented using a P3 (large town), P4 (small city) and P5 (large city) and for rural population (P1 (small village/rural) and P2 (small town)).

1. Walling types (87 HAZUS classes + Inferior and Unknown)
2. Roofing types (4 classes – Tiles, hard, medium, soft with associated information)
3. Flooring types (4 classes)
4. Household Size (no. of people)
5. Labour Force Participation Rate (%)
6. Storey heights (no., distribution)
7. Age of building stock (year range, distribution – 8 classes of year ranges)
8. No. of floors, rooms and buildings
9. Building quality and building cost data.

Over 1500 census round forms worldwide from 1900-2011 have been reviewed as part of the building inventory production. Of 238 countries, the following census values were found for building parameters, among others. From the census dataset survey alone, 157 countries contain wall type information and 118 countries contain roof type information.



Typology	No. Of Countries	Global %
UCB	129	15.969
W	150	10.674
UFB	83	8.485
C3	65	6.935
A	87	6.227

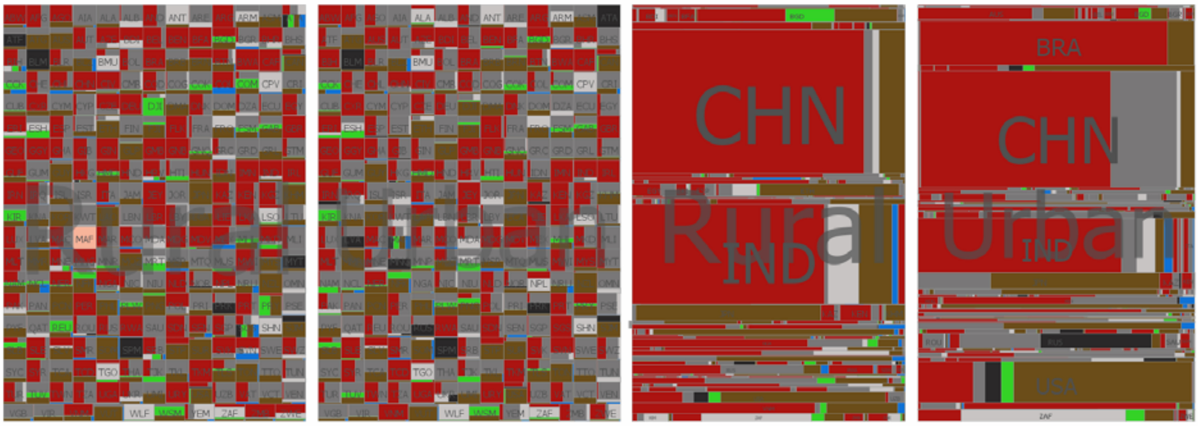


Building Parameter	No. Of Countries	%
Building Types (Apts, etc.)	205	86.13
Wall Materials	157	65.97
Roof Materials	118	49.58
No. Of Buildings	187	78.57
Year of Construction	104	43.70
Improvised/Quality	53	22.27
No. Of Rooms	197	82.77
Cost data	28	11.76
No. Of floors	33	13.87

**Expanded in the Appendices **UCB=Unreinforced Concrete Block Masonry, W=Wood/Timber, UFB=Unreinforced Fired Brick Masonry, C3= Nonductile Reinforced Concrete Frame with Masonry Infill Walls, A = Adobe Buildings*

Figure 1: Average Storey heights of the urban and rural building stock for 244 countries (left); The top 5 most used building typologies in the world (upper right); The no. of separate countries with census details of building parameters over 7 census rounds (lower right)

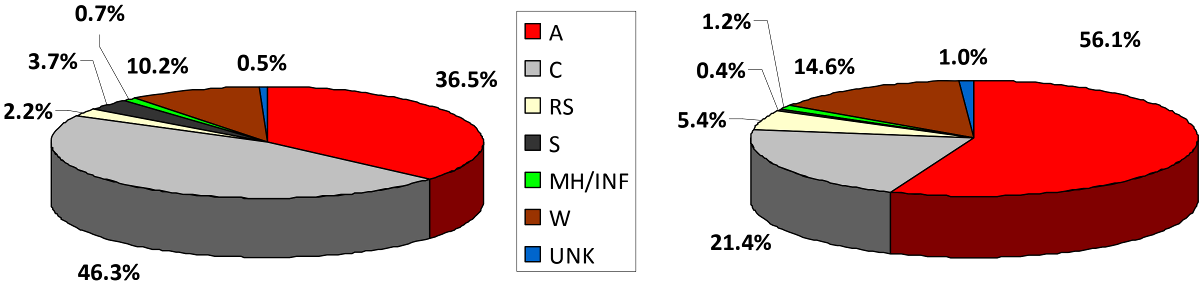
A large number of wall types exist worldwide. Conveniently, the HAZUS methodology used by PAGER allows for 87 distinct classes of wall types to define the building stock of any country. This has been undertaken for each separate country in the world, providing a significantly improved building stock for each country. In addition, nearly every housing census dataset from UN (1993) used in PAGER has been updated to the 2000 or 2010 Round of Census data. The most common building types in the world are unreinforced concrete blocks with about 16% of the global urban residential building stock. In addition, common wood building types have 10.67% of the global urban stock. Each country is shown in terms of building types aggregated from the 87 classes to 7 classes to make viewing easier. It can be seen that the population living in Adobe/Brick/Masonry buildings predominates worldwide.



**Typologies as per Figure 3 and expanded in Appendices.*

Figure 2: Urban and Rural Building Types in each ISO country (left); Population living in various urban and rural building types (right) (Daniell et al., 2011, Slingsby et al., 2011)

The relative share of each aggregated set of building classes is shown in the following diagram for the urban stock for each country in the world. The aggregation is as follows for the relative HAZUS building types. This is the same aggregation for the rural building stock, also shown below.



**A=Adobe/Masonry, C=Concrete, RS=Rubble Stone, S=Steel, MH/INF=Mobile Homes/Inferior building stock, W=Wood/Timber/Bamboo, Unk=Unknown typologies.*

Figure 3: Urban (left) and Rural (right) population living in aggregated building classes.

A general building practice factor has been created using a combination of socio-economic indices such as corruption, relative income and other parameters. For earthquakes, a review of the various seismic resistant codes around the world has been undertaken and these have been subjectively ranked in comparison to the relative hazard of a particular country.

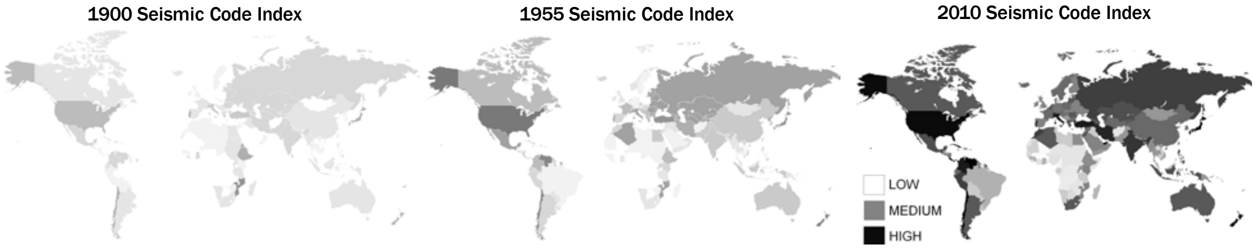


Figure 4: The evolution of the quality of seismic codes around the world.

Vulnerability Indices and Comparison

If countries are assumed to build equally to the hazard within the country across zones i.e. high-risk earthquake zones built to a higher standard, low-risk earthquake zones built to lower standard, then the following view can be made of the world in terms of relative vulnerability using building practice, building fragility function and seismic codes. The seismic code index ranks the quality of seismic codes since 1900 in each nation. The building practice factor ranks the quality in terms of corruption indices and building practice, engineering etc.

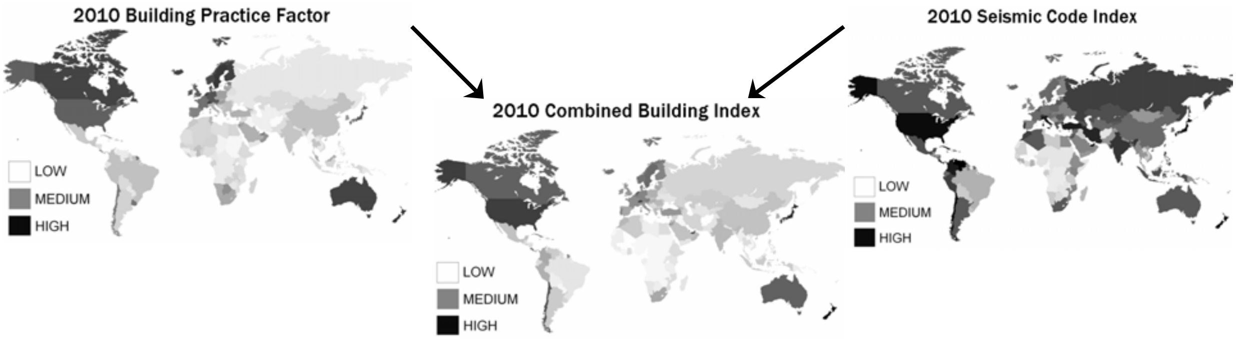


Figure 5: The evolution of the combined building index from the seismic code index and building practice factor.

The fragility function comes from the 87 HAZUS classes described above for 244 nations. These have been adapted from PAGER to the building inventory created in this study.

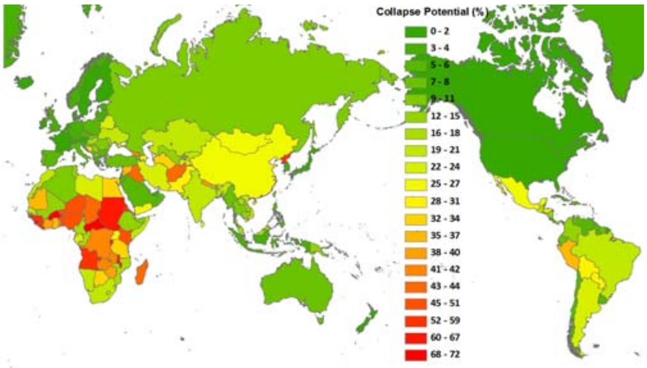


Figure 6: The collapse potential of building stock.

This can be compared to other vulnerability models around the world. A reminder is that vulnerability may be influenced by hazard, but does not represent risk. The relative risk in each of the GSHAP (Global Seismic Hazard Assessment Program) Hazard zones is shown below.

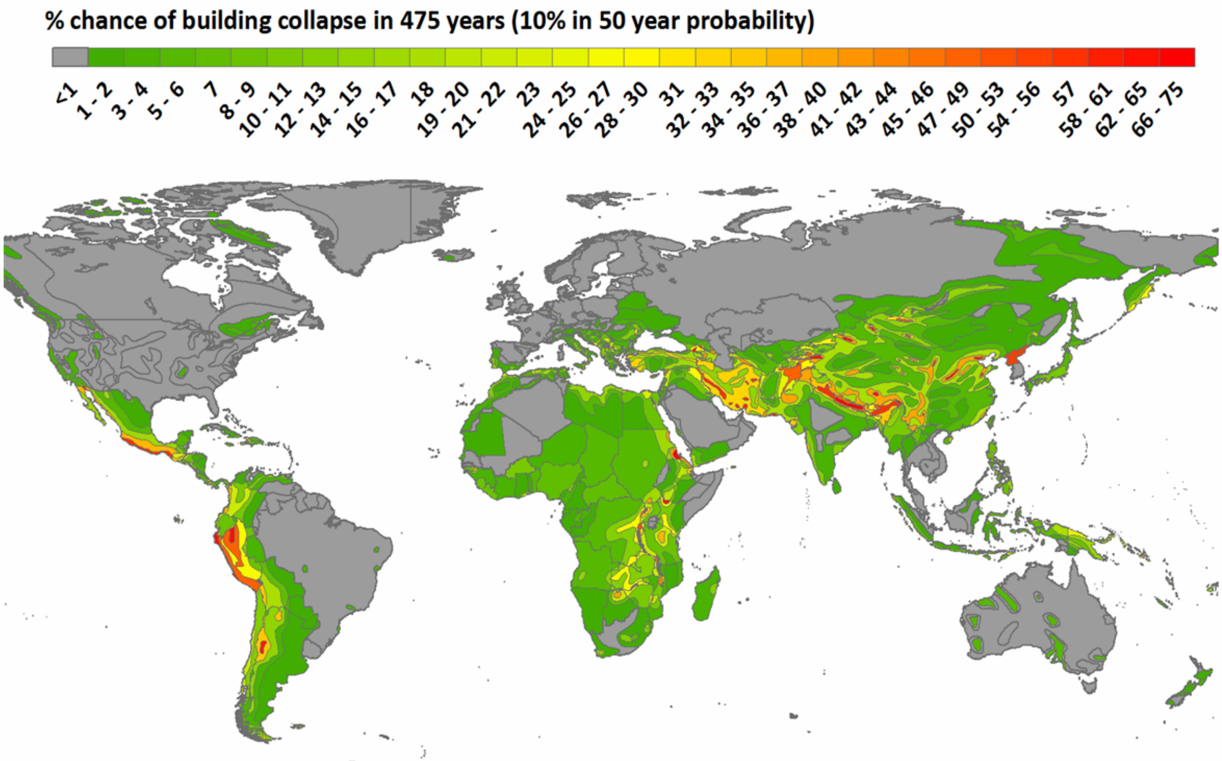


Figure 7: Chance of building collapse in 475 years using GSHAP as the hazard input

The following diagram shows the relationship of about 1500 historic earthquakes with destroyed or heavily damaged building data in the CATDAT Damaging Earthquakes Database, indicating a general envelope of shaking-related fatalities vs. building damage. In the right diagram, the ratio of fatalities to homeless is a tighter fit, meaning that there are many other factors, and not just damage to buildings, which affect the number of shaking related fatalities. Foreshocks, earthquake knowledge, and many fatalities occurring in other damage classes are just some reasons why there is such a range.

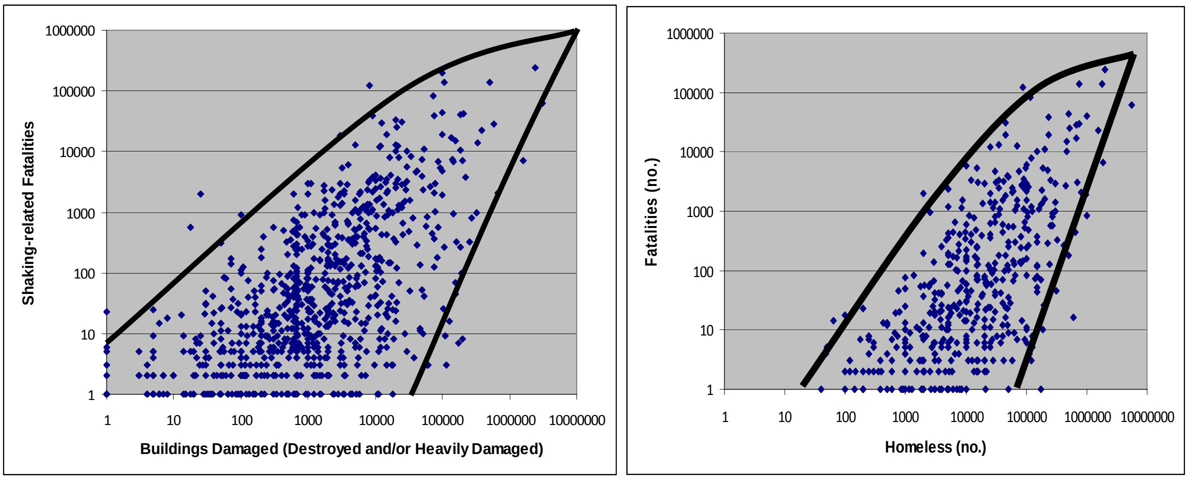


Figure 8: Shaking Fatalities vs. Buildings (Destroyed and/or Heavily Damaged) (Left); Shaking Fatalities vs. Homeless (no.) (Right)

The ratio of fatalities to homeless has reduced significantly through time. This is due to two reasons: 1) better building practices reduce the fatality ratio from buildings, and 2) higher population in the shaking area means that more people will be in red-tagged buildings.

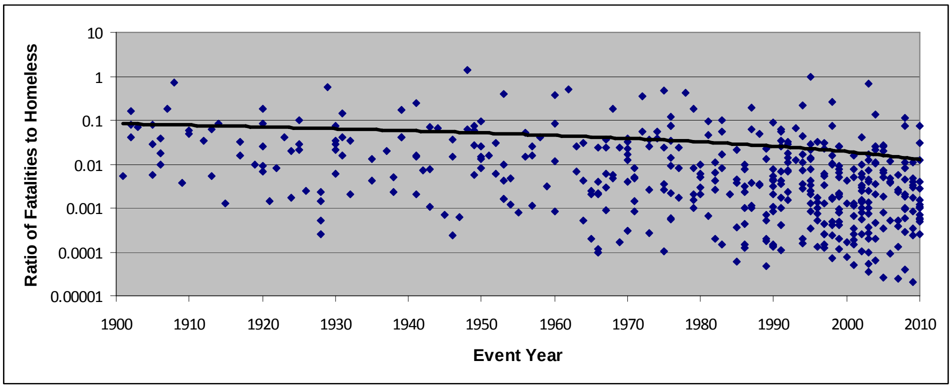


Figure 9: Ratio of Fatalities to Homeless from 1900 onwards (using larger events as the basis)

Conclusion

The country-by-country building inventory is assembled frommany sources around the world and aims to create an accurate inventory for worldwide rapid loss estimation. In addition, it has been integrated into the CATDAT Damaging Earthquakes Database to provide useful empirical trends for analysis.

This database provides a lot of extra information for vulnerability functions as well as socio-economic loss ratios via code information, building type information and many additional parameters.

In combination with work created on an Asia-Pacific physical and community risk index for earthquakes and volcanoes in 2010 (Daniell et al., 2010), and additional work on recreating historic earthquakes, further combinations of CATDAT with the building inventory will be created and presented in the author's PhD.

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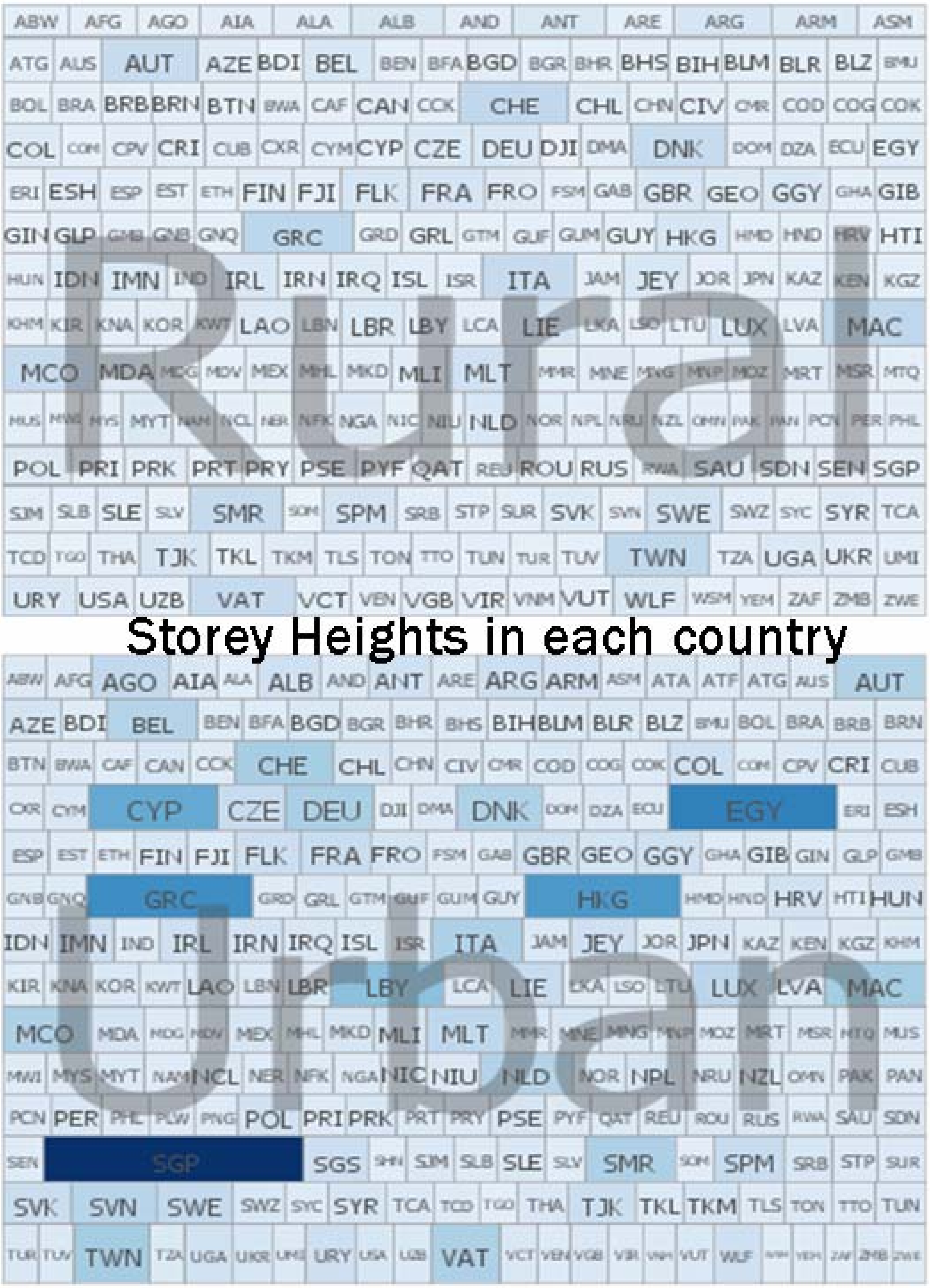
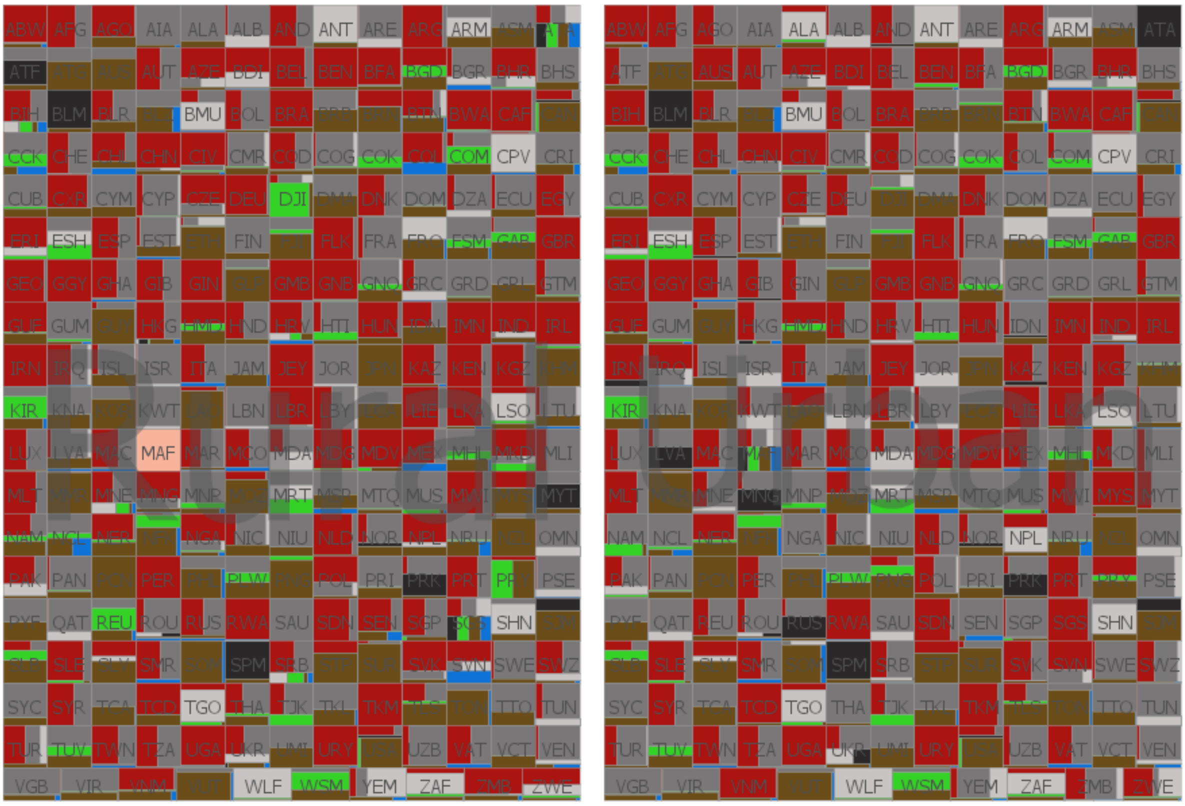
Appendices to the Paper (Expansion of Figure 1 (Left) and Figure 2 (Left and Right).

Size shows the average storey height where color also emphasises those countries (ISO3166-1 codes) with the highest average storey height for rural and urban settings. It can be seen that Singapore has the highest average storey height, closely followed by Hong Kong.



Rural (left) vs. Urban (right) building typologies by % of buildings for alphabetical ISO3166-1 country code using raw typologies as per Figure 3.



Rural (left) vs. Urban (right) building typologies by population living in buildings by alphabetical ISO3166-1 country code using raw typologies as per Figure 3.