Development of a European Building Inventory Database

H. Crowley, S. Özcebe
EUCENTRE, Pavia, Italy

R. Spence, R. Foulser-Piggott
Cambridge Architectural Research Ltd, UK

M. Erdik
KOERI, Istanbul, Turkey

K. Alten
AIT, Vienna, Austria

SUMMARY
The European FP7-funded project NERA (Network of European Research for Earthquake Risk Assessment and Mitigation) aims to develop a European building inventory database to feed into the Global Exposure Database initiative of the Global Earthquake Model (GEM). The main sources of building stock information being collected for each country are national building or dwelling censuses and national records on construction practices performed by statistical or financial services of the country. The main steps in the development of the European Building Inventory database include (1) identifying all the available data sources in the various European countries (2) in the absence of building data, developing methods to infer building counts from other data sources such as dwelling counts (3) producing preliminary algorithms to assess building structural typology characteristics from the available data (4) expert elicitation to check and further develop sub-national building typology distributions in each country.

Keywords: building stock, Europe, census, inventory, database

1. INTRODUCTION

The European FP7-funded project NERA (Network of European Research for Earthquake Risk Assessment and Mitigation) aims to develop a European building inventory database to feed into the Global Exposure Database initiative of the Global Earthquake Model (GEM) (www.globalquakemodel.org). This project will aim to build upon the work of ELER (Earthquake Loss Estimation Routine) within the context of the EU – FP6 NERIES project, wherein a first unified geo-gridded building inventory was developed for the Euro-Med region using proxy procedures that were based on Corine Land Cover and demographic information. As a first step to accomplishing this goal, a European Building Workshop was held in May 2011[1]. The purpose of this workshop was to understand the existing state-of-the-knowledge of buildings in Europe; in particular characteristics such as their location and structural typology, with a focus on the information needed for seismic risk assessment. At this workshop, experts from several European countries (Austria, Spain, Portugal, Italy, Switzerland, Turkey, France, Germany, Greece, Cyprus, Norway, Romania, Slovenia, Macedonia, Slovakia, UK) provided information on both country-wide building inventories and local building studies that have been used in both public and private seismic risk applications. Along with the experts, who were mainly academic researchers, the representatives from national mapping and cadastre agencies and the partners directly involved in the Global Earthquake Model were also brought together to share their available knowledge on building inventories.

---

[1] All presentations and minutes of this workshop are available at: www.globalquakemodel.org/NERA_GEM-workshop

Following the workshop, national building data of the represented countries were obtained and steps were also taken to identify data sources for the countries not represented at the workshop. The main sources of building stock information at a national level were found to be national building or population/dwelling censuses and national records on construction practices performed by statistical or financial services of the country. The available data from these sources were summarised and examined to obtain the building attributes as identified within the GEM Basic Building Taxonomy (Brzev *et al*., 2012), a new classification scheme for buildings.

The main steps being undertaken in the development of the European building inventory database include (1) identification all the available building data sources in the various European countries (2) in the absence of building data, development of methods to infer building counts from other data sources such as dwelling counts (3) creation of preliminary algorithms to assign building typology distributions from the available data (4) expert elicitation to check and further develop sub-national building typology distributions in each country.

The key objectives of this project will be to develop a database that describes the number and area of different European building typologies within each cell of a grid, with a resolution of at least 30 arc seconds (approximately 1km square at the equator) for use in the seismic risk assessment of European buildings. As will be described further in this paper, the statistical significance of the data within each grid cell will vary from administrative level 0 (i.e. country-based) down to administrative level 5 (the highest sub-national boundary level). A quality rating will also need to be assigned to the data, varying according to the resolution and source of the data. The focus in the first stage of development is on residential buildings, and then the inclusion of non-commercial buildings within the database will be considered.

2. EUROPEAN BUILDING DATA COLLECTION

2.1. Building/Dwelling Count Data

A number of data sources on building data in Europe have been investigated, and it has been found that national statistical services in each country (reporting population and housing censuses) provide the most useful source of data for what concerns the distribution of building/dwelling counts. Table 2.1 reports the building/dwelling count data available, the resolution at which this is publically available within the country, and the year(s) for which this data is currently published. Many countries carried out a national census in 2011 and it is expected that this data will gradually be made available for all countries over the next year. Figure 2.1 maps the spatial resolution of this information.

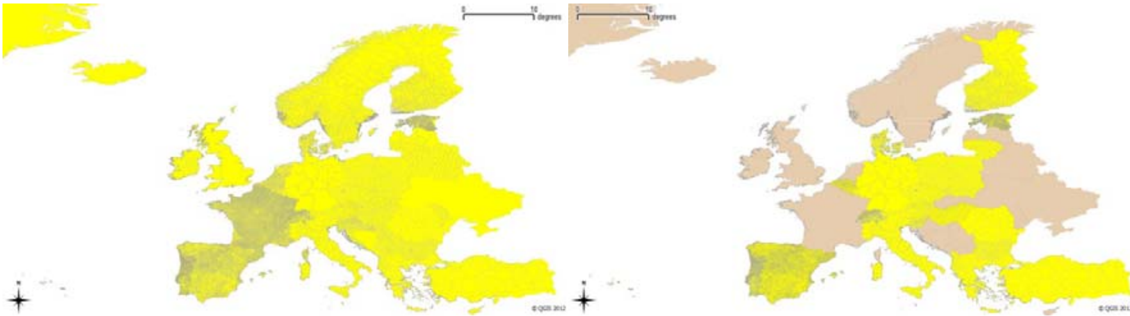
Table 2.1. Table on building/dwelling count data for each country in Europe

	Type	Resolution	Year
Albania**	Buildings*	Country, prefectures, municipalities/communes	2011
Austria**	Buildings*	Country, provinces, districts, statutory cities, municipalities	Municipality level from 2001 Province level form 2006
Belarus	Dwellings*	Country, regions, districts	2009
Belgium**	Buildings*	Country, regions, provinces, arrondissements, communes	2011
Bosnia	Dwellings*	Country, geographical area	2007
Bulgaria**	Buildings*	Country, districts, municipalities	Municipality level from 2009 District level from 2011
Croatia**	Dwellings	Country, counties, municipalities/towns, settlements	2011
Cyprus**	Dwellings*	Country, districts, municipality/communities, quarters	Quarter level from 2001 Municipality/Community level from 2011

Table 2.1. (cont.) Table on building/dwelling count data for each country in Europe

	Type	Resolution	Year
Czech Republic**	Buildings	Country, regions, districts, municipalities	2011
Denmark**	Buildings	Country, regions, provinces, municipalities	2011
Estonia	Buildings*	Country, counties, cities, rural municipalities	2000
Finland	Buildings, Dwellings	Country, provinces, regions, sub-regions, municipalities	2010
France**	Dwellings (Principal Residences	Country, regions, departments, districts, cantons, communes	2008
Germany**	Buildings	Country, states	2010
Greece**	Buildings*	Country, regions, prefectures, municipalities	2000
Greenland	Dwellings	Country, municipalities	2010
Hungary**	Buildings*	Country, regions, counties	2005
Iceland**	Dwellings	Country	2009
Ireland	Dwellings*	Country, province county or city	2011
Italy**	Buildings	Country, regions, provinces	2001
Latvia	Dwellings	Country, regions	2011
Lithuania	Buildings*	Country, counties, municipalities	2011
Luxembourg	Buildings	Country, districts	2009
Macedonia**	Buildings	Country, regions	2002
Malta	Dwellings	Country, districts	2005
Moldova**	Dwellings*	Country, districts	2010
Montenegro**	Dwellings*	Country, municipalities, settlements	2011
Netherlands	Dwellings	Country, regions, municipalities	2011
Norway	Buildings	Country, counties	2012
Poland	Buildings*	Country, provinces, counties	2011
Portugal**	Buildings	Country, districts, municipalities, parishes	2011
Romania**	Buildings*	Country, regions, counties	2011
Serbia**	Dwellings*	Country, counties, regions, municipalities/towns, settlements	2011
Slovakia**	Dwellings	Country, groups of regions, regions, districts, municipalities	2001
Slovenia**	Buildings*	Country, statistical regions, municipalities, settlements	2002
Spain**	Buildings*	Country, autonomous communities, provinces	2010
Sweden	Dwellings	Country, counties, municipalities	2011
Switzerland**	Buildings*	Country, cantons, communes	2010
Turkey**	Buildings	Country, provinces	2010
Ukraine	Dwellings	Country	2010
United Kingdom	Dwellings	Country, districts	2011

* A division of building/dwelling count between urban and rural areas is available.
** These countries will be given a higher priority in the first stage of database development, due to a higher seismic hazard



(a) (b)

Figure 2.1 Maps showing the countries and their sub-national resolution for which the following attributes are available (a) building/dwelling count, (b) building count

2.2. Building Attributes

In order to use a building inventory database for seismic risk assessment, the buildings needs to be classified according to attributes that influence their seismic performance. A number of building taxonomies have been proposed over the past 30 years (see e.g. Charleson, 2010), though many actually provide a list of building typologies rather than a scheme with which the main attributes of buildings can be classified. Hence, for the purposes of the European building inventory the decision has been made to use the recently proposed GEM Basic Building Taxonomy (Brzev *et al*., 2012), which will allow the raw data to be organized according to a common set of attributes. A distinct set of building typologies will later be extracted from this classification through the expert elicitation phase of this project, where structural engineers in each country will be called upon to identify the main building typologies in their country by grouping the attributes from the taxonomy.

Table 2.2 presents the main attributes of the GEM Basic Building Taxonomy. Each attribute can be described through one or more levels of detail, as illustrated in Figure 2.1. Table 2.3 shows the first and second levels of detail for the lateral load-resisting system attribute. Readers are referred to Brzev *et al*. (2012) for each of the tables referred to in Table 2.2.

Table 2.2. GEM Basic Building Taxonomy - attributes

#	Attribute	Reference	Attribute levels	Type	Example
1	Material of the Lateral Load-Resisting System	Table 1	Material type (Level 1) Material technology (Level 2) Material properties (Level 3)	Text	Steel
2	Lateral Load-Resisting System	Table 2	Type of lateral load-resisting system (Level 1) System ductility (Level 2)	Text	Braced frame
3	Roof	Table 3	Roof material (Level 1) Roof type (Level 2)	Text	Masonry
4	Floor	Table 4	Floor material (Level 1) Floor type (Level 2)	Text	Concrete
5	Height	Table 5	Number of stories	Integer	4
6	Date of Construction	Table 6	Construction completed (year)	Integer	1925
7	Structural Irregularity	Table 7	Type of irregularity (Level 1) Irregularity description (Level 2)	Text	Re-entrant corner
8	Occupancy	Table 8	Building occupancy class - general (Level 1) Building occupancy class - detail (Level 2)	Text	Residential

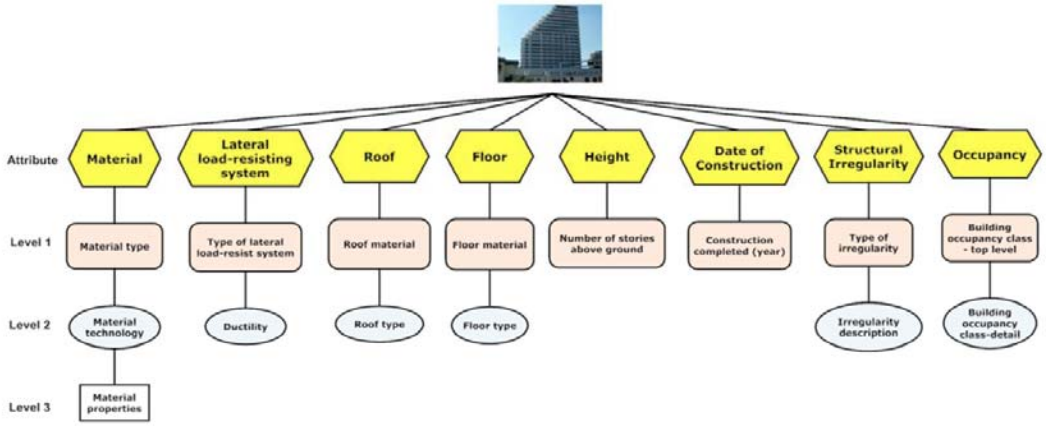


Figure 2.2 Illustration of the attributes and levels of details of the GEM Basic Building taxonomy

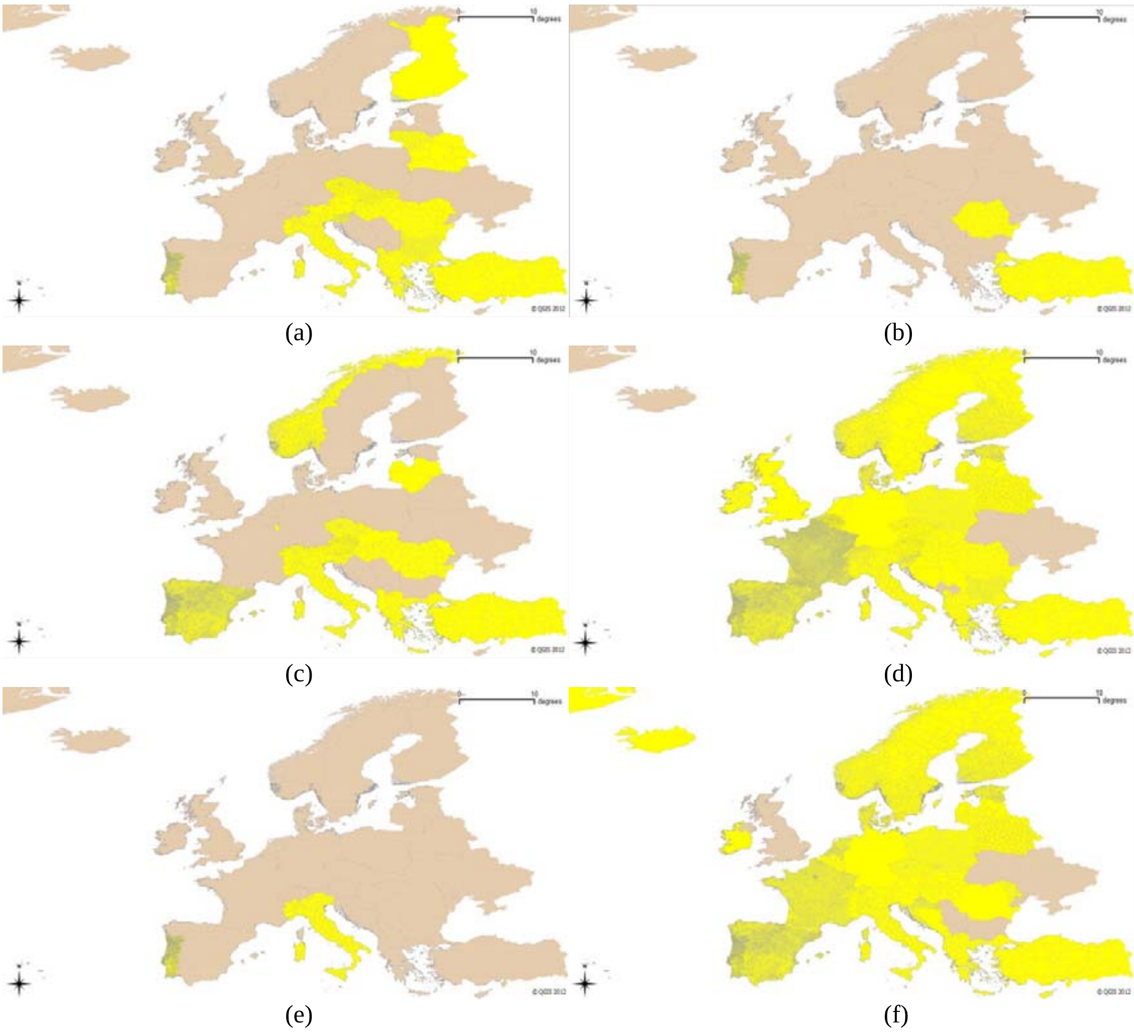
Table 2.3. GEM Basic Building Taxonomy – classification of lateral load-resisting systems

ID	Level 1 (L1)	ID	Level 2 (L2)
	Type of lateral load-resisting system		**System ductility**
L99	Unknown lateral load-resisting system	D99	Ductility unknown
LN	No lateral load-resisting system	DU	Ductile
LFM	Moment frame	ND	Non-ductile
LFINF	Infilled frame		
LFBR	Braced frame		
LPB	Post and beam		
LWAL	Wall		
LDUAL	Dual frame-wall system		
LFLS	Flat slab/plate or waffle slab		
LFLSINF	Infilled flat slab/plate or infilled waffle slab		
LO	Other lateral load-resisting system		

The information available on the attributes of buildings from the national statistics data sources referred to in Section 2.1 is reported in Table 2.4, and presented in maps in Figure 2.2. The column "material" in this table refers to both the material of the lateral load resisting system (where available), and the external wall material, which will need to be used to infer the lateral load resisting system. As can be seen from the table, the most common attribute available is the date of construction, followed by occupancy class, number of storeys, material, lateral load-resisting system and structural irregularity. Information on roof and floor type is not reported in any of the national building/housing census data.

Table 2.4. Building attributes (according to the GEM Basic Building Taxonomy) available from national census data

	Material	**Lateral Load Resisting System**	**Number of Storeys**	**Date of Construction**	**Structural Irregularity**	**Occupancy Class**	**Year of Data**
Albania	X		X	X		X	2001/2011
Austria	X		X	X		X	1991/2001/2010
Belarus	X			X			2009
Belgium			X	X		X	2011
Bosnia				X		X	2007
Bulgaria	X			X			2009
Croatia				X		X	2001
Cyprus				X		X	2001
Czech Republic	X		X	X		X	2001
Denmark				X		X	2011
Estonia				X		X	2000
Finland	X		X	X		X	2010
France				X		X	2008
Germany				X		X	2010
Greece	X		X	X		X	2000
Greenland						X	2010
Hungary	X		X	X		X	2001/2005
Iceland						X	2009
Ireland				X		X	2006
Italy	X		X	X	X	X	2001
Latvia				X		X	2011
Lithuania	X			X		X	2001
Luxembourg			X	X		X	2001/2009
Macedonia	X		X	X		X	2002
Malta				X		X	2005
Moldova	X		X			X	2010
Montenegro						X	2011
Netherlands				X		X	2001
Norway			X	X		X	2011/2012
Poland				X		X	2002
Portugal	X	X	X	X	X	X	2001/2011
Romania	X	X	X	X		X	2002
Serbia				X			2002
Slovakia	X		X	X		X	2001
Slovenia	X		X	X		X	2002
Spain			X	X		X	2001
Sweden				X		X	2011
Switzerland			X	X		X	2010
Turkey	X	X	X	X		X	2000
Ukraine							
United Kingdom				X			2009



(a) (b) (c) (d) (e) (f)

Figure 2.2 Maps showing the countries and sub-national resolution for which the following attributes are available: (a) Material (of external walls or lateral load resisting system), (b) Lateral load resisting system, (c) number of storeys, (d) date of construction, (e) structural irregularity, (f) occupancy

3. FILLING THE GAPS AND HARMONISING THE DATA

3.1. Population Data

An important dataset for ensuring that the goal of this project can be achieved (i.e. to be able to report the building count and area of each building typology within each cell of a grid with a resolution of at least 30 arc seconds) is the population density across Europe. The use of such datasets will be described further in the following sections, but the main objective is to allow the building count to be geographically distributed and for more buildings to be assigned to the cells where there are more people. Furthermore, this data will allow an estimation of the number of occupants within the buildings to be made.

Global datasets of gridded population with a resolution of up to 30 arc seconds (approximately 1km square at the equator) exist in both proprietary (e.g. LandScan^{TM}) and open (e.g. Gridded Population of the World, version 3) format. The GRUMP (Global Urban and Rural Mapping Project) dataset also identifies whether a given grid cell is urban or rural, which can be useful when the census data is also differentiated in such a manner (see Table 2.1). Datasets with 1km grids have also been produced focusing on European population density (e.g. Gallego, 2010), and recent developments are aiming to combine even higher resolution data on land use/land cover to increase even further the resolution of the grid. The developments in this field will be followed over the course of this project such that the European building inventory can make use of state-of-the-art population density and/or land use/cover data to realistically distribute the building counts/areas.

3.2. Building/Dwelling Count Data

As shown in Table 2.1, many countries already provide data on the number of buildings within a given geographical area which can vary from administrative level 0 (country) to administrative level 1, 2, 3, 4 or 5. This data can be distributed on a grid using information on the population density:

$$b(i,j) = \left\lfloor p(i,j) \Big/ \sum_Z p(i,j)_z \right\rfloor \times b_Z \qquad (3.1)$$

where $b(i,j)$ refers to the building count per grid cell, $p(i,j)$ refers to the population count per grid cell, $p(i,j)_z$ refers to the population count over an area z (which is the highest resolution at which the data is available e.g. municipality), and b_z refers to the aggregate building count over the area z. Once the building count in each cell has been computed, it will be multiplied by the distribution of building typologies (see Section 3.3) to get the building count of each building typology. This data can then be transformed from building count into built area through an average built area per building typology (which can be obtained from local building survey data, or expert opinion).

For those countries where the building count is not available, the dwelling count will need to be used, together with the average number of dwellings per building. As the average number of dwellings per building varies greatly as a function of the attributes of the building (in particular the material and the height), the data should first be reported in terms of the dwelling count for different building typologies. The means by which the latter will be done is described further in Section 3.3. The dwelling count for a given building typology is then converted into the building count for that typology by dividing by an average number of dwellings per building. The steps necessary to calculate the building count within a given grid cell, and the fraction of buildings of different building typologies in each grid cell $b^{(k)}(i,j)$ are thus as follows:

$$d^{(k)}(i,j) = \left[p(i,j) \Big/ \sum_Z p(i,j)_z \right] \times d_Z \times df^{(k)} \qquad (3.2)$$

$$b^{(k)}(i,j) = d^{(k)}(i,j) \Big/ \bar{d}_b^{(k)} \qquad (3.3)$$

$$b(i,j) = \sum_k b^{(k)}(i,j) \qquad (3.4)$$

where $d_f^{(k)}$ is the fraction of dwellings within a given building typology k, d_z is the aggregated dwelling count of an area z, $\bar{d}_b^{(k)}$ is the average number of dwellings per building for the building type k. The number of dwellings within a given building typology k within a given grid cell, $d^{(k)}(i,j)$, can be transformed into the built area for that building typology by using an average built area per dwelling, which is often available from the national census.

3.3 Distribution of Building Typologies

A number of attributes of buildings that are available at a European level have been presented in Section 2.2. It is apparent that there is a large heterogeneity across Europe, and different approaches will need to be taken in each country. Some countries (e.g. Italy, Portugal, Turkey) have sufficient attribute data for the distribution of typical building typologies at a sub-national level (e.g. administrative level 1, 2 or 3) to be directly derived. In other countries, it is apparent that the available attributes will need to be combined with inference algorithms to obtain the distribution of building typologies. These inference algorithms might make use of, for example, the height and date of construction to identify the most likely building typology.

A number of approaches will be investigated in order to develop these inference algorithms:

- The use of local, detailed building survey data from within the country (such as those presented during the NERA European Building Workshop);
- The use of data from other European projects such as Tabula (www.building-typology.eu) (where the focus is on identifying building typologies for energy assessment) such as the data in the table shown in Figure 3.1 which identify the common building types for different construction eras and occupancy types;
- The use of expert elicitation: structural engineers in each country within Europe will be indentified and invited to contribute to the project, by providing feedback on typical building typologies across the country and how these can be correlated with the attributes currently available.

	Region	Construction Year Class	Additional Classification	SFH Single-Family House	TH Terraced House	MFH Multi-Family House	AB Apartment Block
1	National (nicht regional spezifiziert)	... 1859	Generic (Basis-Typ)	DE.N.SFH.01.Gen		DE.N.MFH.01.Gen	
2	National (nicht regional spezifiziert)	1860 ... 1918	Generic (Basis-Typ)	DE.N.SFH.02.Gen	DE.N.TH.02.Gen	DE.N.MFH.02.Gen	DE.N.AB.02.Gen
3	National (nicht regional spezifiziert)	1919 ... 1948	Generic (Basis-Typ)	DE.N.SFH.03.Gen	DE.N.TH.03.Gen	DE.N.MFH.03.Gen	DE.N.AB.03.Gen
4	National (nicht regional spezifiziert)	1949 ... 1957	Generic (Basis-Typ)	DE.N.SFH.04.Gen	DE.N.TH.04.Gen	DE.N.MFH.04.Gen	DE.N.AB.04.Gen
5	National (nicht regional spezifiziert)	1958 ... 1968	Generic (Basis-Typ)	DE.N.SFH.05.Gen	DE.N.TH.05.Gen	DE.N.MFH.05.Gen	DE.N.AB.05.Gen

Figure 3.1 A table from the Tabula project which shows the typical building typologies per construction era, region and occupancy type.

4. NEXT STEPS

As described in this paper, there are a number of additional activities that will need to be carried out over the coming months to develop this European building inventory database. These include the further collection and updating of national census data on buildings and dwellings and their attributes; the estimation of building count and area for a gridded database based on the algorithms presented in Section 3.2; the identification of the distribution of building typologies using inference algorithms which will need to be tailored to each country. All of the above will involve expert elicitation through the network of European experts that was initially put together through the European Building

Workshop in 2011 and continues to grow. Further consideration will also need to be given to the assignment of a quality rating to the data in the database, which might be defined as a function of the use (or not) of algorithms for building count/area, the use (or not) of inference algorithms to identify the main building typologies, and the statistical significance of the data within each grid cell.

Despite the extensive research and development that still needs to take place, significant thought has already been given to how such a database might be tested against a series of validation datasets. These datasets have been collected through ground surveys previously conducted in different parts of Europe. A meeting was recently held with the owners of these datasets to discuss this issue further[2], and the main conclusions have been reported in an accompanying 15WCEE paper (Spence *et al*., 2012). Considering that the main objective of this European building inventory dataset is for the seismic risk assessment of buildings, it is currently thought that the most important metric for comparing the datasets should actually be a function of the damage/loss that is estimated with each of them. Further investigations into the optimal metrics for testing the database will be carried out over the coming months.

It is expected that once a first version of the European Building Inventory database has been compiled, quality rated, and tested, it will be open to a beta review involving the aforementioned network of European experts.

ACKNOWLEDGEMENTS
The authors would like to acknowledge all those that have attended meetings and workshops related to this initiative (see the list of participants on the following web links www.globalquakemodel.org/NERA_GEM-workshop and www.globalquakemodel.org/NERA_inventory_validation_meeting). The authors would also like to acknowledge the support provided by the European Commission through the financing of the FP7 research programme NERA (Network of European Research for Earthquake Risk Assessment and Mitigation), under the framework of which this work has been partially funded.

REFERENCES

Brzev S., Scawthorn C., Charleson A., and Jaiswal, K. (2012) GEM Basic Building Taxonomy, Version 1.0, GEM Ontology and Taxonomy Global Component project. Available from http://www.nexus.globalquakemodel.org/gem-ontology-taxonomy/posts/updated-gem-basic-building-taxonomy-v1.0

Charleson, A. (2011) "Review of existing structural taxonomies," Available from URL: http://www.nexus.globalquakemodel.org/gem-ontology-taxonomy/posts

Gallego, F.E. (2010) "A population density grid of the European Union," Population and Environment, 31, 460-473.

Spence, R., Foulser-Piggott, R., Guegen, P., Crowley, H., Pomonis, A., Masi, A., Chiauzzi, L., Zuccaro, G., Cacace, F., Zulfikar, C., Markus, M., Schaefer, D., Sousa, M.L., Kappos, A. (2012) "The European building stock inventory: creatng and validating a uniform database for earthquake risk modelling," *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Potugal.

[2] All presentations and minutes of this workshop are available at: www.globalquakemodel.org/NERA_inventory_validation_meeting