The GIRI global building exposure model (BEM)

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1. Introduction

Exposure models are an integral part of risk assessment and management. Exposure models help quantify and characterize the elements at risk in a given area by providing information about what is exposed to a particular hazard. This can include buildings and infrastructure (such as roads and bridges).

In the context of the GIRI project, two separate exposure models were produced and subsequently integrated for risk calculation.

One model deals specifically with the building stock, both for residential use and for all other activities (work, health, education): this is the Global Building Exposure Model, or simply BEM, which is the sole subject of this report.

The second model for calculating the economic value of infrastructure is the Infrastructure Exposure Model (IEM). Its original methodology was developed by Ingeniar, and later the data collection and all processing were done by UNEP/GRID-Geneva.

The BEM provides essential data for understanding the potential impact of hazards on the built environment. An exposure model that includes a global inventory of the building stock based on a purely bottom-up approach would require considerable human and economic effort and is beyond the scope of this project. In the absence of a bottom-up approach, a spatial disaggregation was used. This consists of a top-down or 'downscaling' approach, where information including socio-economic, building type and capital stock at national or sub-national level (statistical data) is transferred to a regular grid, using GIS data such as geographic population and Gross Domestic Product (GDP) distribution models as proxies.

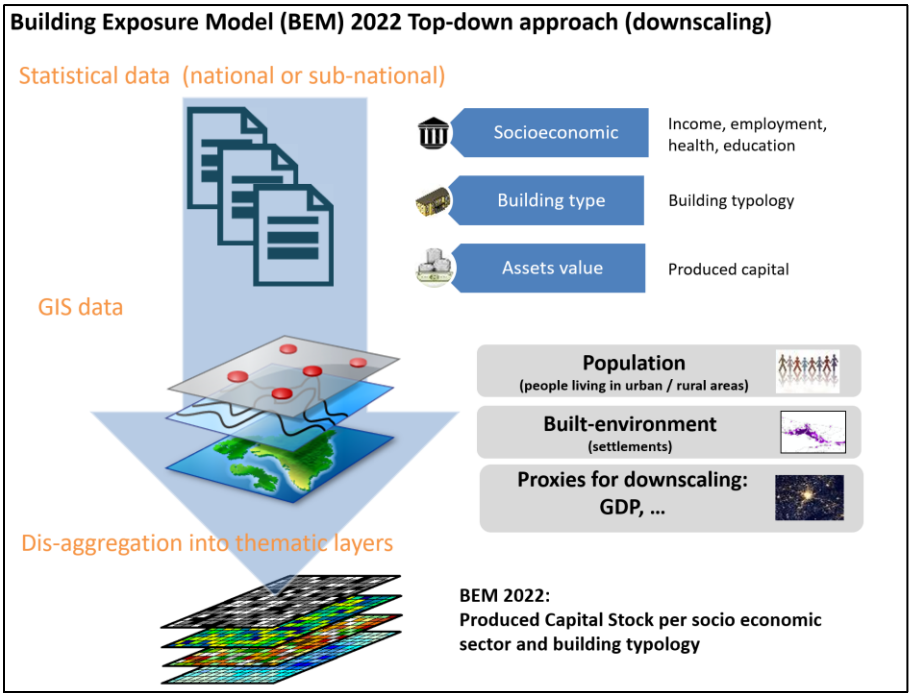

Figure 1: The BEM Top-down approach

2.1 Main components

This section outlines the main datasets (base data) and databases utilized in generating the BEM 2022.

2.1.1 Reference grids

During the disaggregation process, socio-economic indicators, building type and building stock are transferred onto uniform geographical units that are the reference grid at 2’30” (or approx. 5x5 km at equator). The choice of the resolution is justified by two significant reasons:

1. A 5x5 resolution is deemed sufficient for capturing the impacts of large-scale hazards like earthquakes and cyclones.
2. It ensures result consistency: while socio-economic indicators are available at a national scale, disaggregating to smaller cell sizes for certain larger, non-uniform countries could overly stretch the downscaling procedure.

Furthermore, this resolution optimizes analysis time required to obtain results from probabilistic risk calculations.

It's essential to emphasize that cell size represents only a single facet of dataset "resolution," which encompasses thematic aspects such as the amount and quality of information contained within each cell.

Additionally, the BEM 2022 incorporates a secondary grid at 30" resolution (around 1x1 km at the equator) designed to contain exposure data pertaining to coastal areas. This grid, built exclusively for a sector covering the initial 10 km of global coastlines, demands finer resolution to capture the magnitude of effects of small-scale hazards like storm surges and tsunamis. The data and methodologies employed to construct the 1x1 grid mirror those used for the 5x5 reference grid.

2.1.2 Population distribution

For population distribution, two global gridded datasets on population distribution were combined and then rescaled using the total population at country level provided in the UN Prospect 2019.

JRC’s Global Human Settlement Layer was selected as the most reliable source for population distribution data. While the accuracy of the latest available dataset during processing was considered, it was found lacking in several areas characterized by a patchy pattern, suggesting a uniform distribution of population within administrative units. A source with a more “granular” aspect, suggesting the population is distributed more accurately, and with higher resolution, was identified in the population distribution dataset provided by META and was also used in the process.

Recently, JRC has released an updated version of GHSL characterized by a more accurate population distribution. This dataset would have been selected as the only source for population distribution data if it was available at the time of the processing.

GHSL - Global Human Settlement Layer (JRC)

Layer: GHS-POP R2019A
Data time: 2015
Resolution: ~1km in WGS84
Unit: Number of people
Downloaded at: https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php
Source: Schiavina et al. (2019)

HRSL - High Resolution Settlement Layer (META)

Layer: hrslpop
Data time: 2016
Resolution: ~30m in WGS84
Unit: Number of people
Provided for Google Earth Engine by https://samapriya.github.io/awesome-gee-community-datasets/projects/hrsl/ and available at this asset: projects/sat-io/open-datasets/hrsl/hrslpop
Source: Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University (2016)

World Population Prospects 2019 (UN)

Data times: 2015, 2016, 2018 estimates
Resolution: Administrative units at level 0
Unit: Thousands of people
Downloaded at: https://population.un.org/wpp/Download/Standard/Population/
Source: United Nations, Department of Economic and Social Affairs, Population Division (2019)

2.1.3 Modelled urban settlements (WSF-3D)

In the process of modeling urban settlements, emphasis was placed on utilizing global gridded datasets that depict the extent of constructed surfaces per pixel, categorized by various building heights. Among the datasets meeting these criteria, the only one accessible during the processing stage was the pre-release edition of the World Settlement Footprint (WSF) 3D. However, this dataset exhibited certain drawbacks, including the absence of data for Australia and the presence of pixels where the total built area didn't align with the built-up area based on building heights. We have done everything possible to reduce the impact of these errors. It's worth noting that an updated and corrected version of this dataset has since been made available at:
https://gdk.gdi-de.org/geonetwork/srv/api/records/5d125fc9-7cf6-45a7-901a-3cdba013dad0

World Settlement Footprint 3D (DLR)

Resolution: ~1km in WGS84
Files received: Africa_stats_full.tif; AmericaTP_1_sum.tif; Asia_full_stats.tif; Europe_stats_full.tif; Oceania_stats_full.tif (excluding Australia)
Bands of each file:
- Band 1: Sum of area in [m2] for all pixels with height <=2m
- Band 2: Sum of area in [m2] for all pixels with height <=3m
- Band 3: Sum of area in [m2] for all pixels with height <=4m
- Band 4: Sum of area in [m2] for all pixels with height <=5m
- Band 5: Sum of area in [m2] for all pixels with height <=6m
- Band 6: Sum of area in [m2] for all pixels with height <=7m
- Band 7: Sum of area in [m2] for all pixels with height <=8m
- Band 8: Sum of area in [m2] for all pixels with height >8m
- Band 9: the Total Area [m2]
- Band 10: the Total Volume [m3]
Source: Received from WSF-3D Team directly by email

2.1.4 Gross Domestic Product (GDP) index

The global gridded GDP dataset developed by Chen et al. in 2022 was chosen to construct the GDP index, which portrays the extent of GDP fluctuations within each country at a spatial level. This GDP dataset, formulated from calibrated nighttime light information, is distinct from population data. This characteristic rendered the selected GDP layer the optimal candidate for assigning weight to the national-level building stock data as it is disseminated to the population distribution gridded layer.

> **Global 1km×1km gridded revised real gross domestic product and electricity consumption during 1992–2019 based on calibrated nighttime light data**
>
> Layer: GDP2019.tif
> Data time: 2019
> Resolution: 1km in Mollweide
> Unit: Millions of 2017 US dollars
> Source: Chen et al. (2022)

2.1.5 Building structure typology

For GAR 2015, the World Agency of Planetary Monitoring & Earthquake Risk Reduction (WAPMERR) provided all information regarding building structure typologies in each country for three settlement sizes or "complexity" expressed as percentage of individuals per building types (Wyss et al., 2013). Sub-national distribution of building types is available for 18 countries which include the largest heterogeneous ones (i.e., China, India, and Indonesia) representing approximately 3.83 billion people, i.e., about 50% of the world's total population. This data is used "as is" for the BEM 2022 as no update has been produced in the meantime.

WAPMERR obtained housing census data and occupancy rate statistics directly from the Statistics Office of each surveyed country. Whenever the collected data proved insufficient, supplementary information was sought primarily from research publications, reports, and photographs (Tolis et al., 2013). The level of detail and quality of information concerning the built environment considerably varies across different countries. Most of the collected data pertains to construction materials, while a few cases also encompass additional details like building age, floor count, or living quarters' attributes.

Subsequently, construction materials, along with other gathered parameters, were interpreted and transformed into PAGER building classifications.

The devised models for the building stock hinge on the size of settlements, given that villages and cities exhibit distinct building typologies. This led to the division of the building stock into three categories: large urban, small urban, and rural areas. This classification is based on the thresholds that define the distinction between rural and urban settlements, as proposed by Satterthwaite (2006).

WAPMERR also offers an estimation of building typologies for residential use (dwellings) and non-residential use. Regrettably, publicly available census data concerning the building stock is largely confined to residential housing, excluding commercial or institutional occupancy. As a result, in numerous cases, assumptions and decisions were necessary to estimate the typologies of non-residential building stock. These assumptions, along with the overall methodology and data sources, are elaborated in Tolis et al. (2013).

2.1.6 Socio-economic indicators (SEI)

Socio-economic indicators (SEI) are employed as proxies to gauge the sector-specific utilization of the building stock, corresponding to the urban size of each settlement area. These indicators consist of tabulated data at the national level.

A first set of indicators encompasses the resident population, categorized into four groups based on per capita income, following the classification established by the World Bank (WB)[1].

A secondary set of indicators, covering non-residents, is further divided based on economic activities (industry, services, government), health coverage (number of hospital beds in public/private facilities), and education within both private and public sectors (number of pupils).

The complete list of socio-economic indicators and their sources are available in the BEM 2022 technical documentation[2].

2.1.7 Building stock

The produced capital (World Bank, 2005) which includes the value of machinery, buildings, equipment, and residential and non-residential urban land tends to be the most readily understood form of capital due to its tangibility and the quality of data collected on investment levels. The World Bank (World Bank, 2021) published a dataset for 146 countries with values measured at market exchange rates in constant 2018 US dollars, using a country-specific GDP deflator.

The calculation of produced capital is derived from the Perpetual Inventory Method (PIM) and historical data on Gross Capital Formation (GCF) (World Bank, 2021). Additionally, the World Bank increased this estimation by 24% to incorporate the economic value associated with urban land.

As per PwC (PricewaterhouseCoopers, 2013), the World Bank's methodology stands out as the most coherent approach for assessing global produced and natural capital values. While there are other viable options like those proposed by the United Nations University (UNU, 2012) and the Organization for Economic Co-operation and Development (OECD, 2011), these alternatives are limited in terms of estimations, covering only a restricted set of countries.

The building stock is obtained by subtracting the infrastructure stock from the produced capital, as its exposure is assessed using a complementary model developed specifically for the Global Infrastructure Risk and Index (GIRI). The infrastructure stock has been calculated using a method developed by Ingeniar in 2022 which is described in the technical documentation[3].

2.2 Compilation and harmonization (missing data, assumptions)

Following an in-depth inventory of available data, 2018 has been selected as the “reference year” for all statistical and geospatial data as it is the most recent and most complete year. If no data was available for 2018, the most recent year available was used instead.

The UN administrative boundaries dataset comprises 291 countries/territories. Close to half of them had missing data, i.e., one or more socio-economic indicators, produced capital, and/or infrastructure

[1] https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2021-2022
[2] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/sei/sources.csv
[3] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/infrastructure_stock

stock. Substantial efforts were required to fill in the gaps to calculate the BEM for all inhabited countries/territories.

For socio-economic indicators, missing values were completed using different methods:

1. For territories/countries with an administering state, data was assumed to be equivalent to the latter.
2. For disputed territories, data was calculated from that of countries claiming sovereignty generally by averaging the values.
3. Data were searched for through national statistical offices e.g., the National Institute for Statistics (INSEE) for the French overseas departments and territories.
4. Data was retrieved from GAR 2015.
5. Data came from "global" unofficial databases such as the CIA Factbook or online reports.
6. Data were assumed to be equivalent to countries considered as "similar" in terms of geographic position, development, and economy.

For the produced capital, missing values were evaluated mostly following the approach outlined by PwC (PricewaterhouseCoopers, 2013):

1. For territories/countries with an administering state, the produced capital was assumed to be equal to that of the administering state scaled by the ratio of their GDP per capita.
2. To calculate the produced capital, the World Bank algorithms were applied using the World Bank Gross Capital Formation (GCF) data.
3. Otherwise, the World Bank algorithms were applied using GCF data derived from the GDP (fixed ratio between GDP and GCF). This method only applies to small territories and islands with low population.

For the infrastructure stock, missing values were completed using three methods already used for SEIs i.e., 1, 2, and 6.

The methods used and the assumptions made can be consulted in the technical documentation: https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/sei

2.3 Workflow: data preparation, downscaling and integration

Data on population, settlements and GDP are provided in a gridded format, which means they are already distributed across space. The workflow related to these data involved the resampling and the aggregation needed to match the resolution of the grids used in the BEM. The administrative units assigned to each pixel of the grid were taken into consideration during the process. This was essential to avoid data originally thought for one country to be resampled into the pixels of the grid that are assigned to another country close to the country borders.

Data on socio-economic indicators, building stock and building typologies are generally provided at the national scale by administrative units. In this section we will illustrate the methodology and assumptions to spatially disaggregate them onto the reference grids.

Essentially our distribution model will follow a multi-layered, asymmetric, spatial approach where data by administrative units are converted to a regular finer surface (reference grid) by means of ancillary data constituted by the rasters of population and GDP variation.

2.3.1. Preparation of reference grids[4]

The two reference grids used for the BEM 2022 are based on those built for GAR 2015. They were intersected with two datasets of administrative boundaries so that each cell of the grids is assigned the unique identifiers of the administrative entities (level 0 to 2) to which it belongs. These datasets are:

1. Official UN-recognized administrative boundaries (UNMap)[5]
2. WAPMERR sub-national boundaries for 18 countries

Once the intersections were made, only the cells covering land were kept in the grids to optimize file size and speed up calculations.

2.3.2 Preparation of the population distribution dataset [6]

The population layers from META and JRC were aggregated / snapped on to the resolution of the reference grid at ~1km scale and combined by giving higher priority to META [7,8].

- Countries with good coverage by META -> META
- Other countries -> JRC

The resulting layer was harmonized to the year 2018 by scaling the total population of each country based on the gridded layer to the total population per country in the UN Prospect 2019. Original population values were kept for countries that were not present in the UN Prospect 2019 dataset.

The generated population distribution layer at ~1km was also aggregated to the resolution of the ~5km grid using an unweighted sum process. As the initial process did not consider that a pixel in the ~1km grid can only be used in the aggregation process of a single country, a correction has been applied to pixels near the country borders of selected countries[9].

2.3.3 Preparation of the settlements model [10]

The WSF-3D dataset was snapped to the ~1km grid and then, for each pixel, additional attributes were calculated using the original bands and the surface area of the pixel.

- Surface occupied by buildings for each height interval (e.g., 2 to 3 m, 3 to 4 m, etc.);
- Percentage of surface occupied by buildings for each height interval;
- Percentage of surface occupied by buildings for each height interval over the total built area;
- Percentage of surface occupied by buildings with a given number of floors over the total built area.

[4] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/reference_grids
[5] https://www.un.org/geospatial/mapsgeo/webservices
[6] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/population
[7] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/population/HRSL%20iso3cd%20in%20pop_2018.csv
[8] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/population/GHSL%20iso3cd.%20in%20pop_2018.csv
[9] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/population/corrections
[10] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/wsf_3d/README.md

The definition of floors was based on the following assumption:

3 meters = 1 floor

Thus, buildings up to 3 meters were considered having 1 floor, buildings above 3 meters and below 6 meters were considered having 2 floors, while buildings above 6 meters were considered having 3 floors.

The validity of the calculated values was established through tests and only cells which values were considered valid were tagged to be used further in the BEM [11].

The WSF-3D layer was also used for the creation of an agglomeration dataset by only taking the pixels with at least 10% built-up surface. Each touching pixel of the agglomeration layer was considered a unique agglomeration and its total population was determined using the population distribution dataset generated previously. Each agglomeration was then classified into urban (cpx1), semi-urban (cpx2) and rural (cpx3) areas according to the classification of Satterthwaite (2006) and the derived class was assigned to all the pixels that fall in the agglomeration. This means that pixels with very little population falling into an agglomeration classified as urban were still classified as urban.

- **cpx1** = more than 20'000 people (**URBAN** population)
- **cpx2** = between 20'000 and 2'000 people (**SEMI-URBAN** population)
- **cpx3** = less than 2'000 people (**RURAL** population)

Satterthwaite (2006)

The remaining pixels (i.e., built-up coverage < 10% and population > 0.001) were also classified using the classification of Satterthwaite (2006). The only difference is that, in this case, the population of the pixel in the one to be evaluated.

The same parameters about built-up coverage by heights and floors were also calculated on the ~5km grid after the original layer was aggregated using the unweighted sum method.

The classification of the pixels in the ~5km grid was instead accomplished by resampling the classification values of the ~1km as input by always giving priority to urban classes.

- **Urban** = If at least one pixel of the ~1km grid classified as urban overlaps the ~5km pixel
- **Semi-urban** = If at least one pixel of the ~1km grid classified as semi-urban overlaps the ~5km pixel and no urban pixel overlaps it
- **Rural** = If at least one pixel of the ~1km grid classified as rural overlaps the ~5km pixel and no urban or semi-urban pixels overlap it
- **Null** = In all other cases

2.3.4. Calculate the GDP variation index [12]

The main aim of this process was to establish a GDP variation index within each country. This process involved calculating a ratio for each pixel by comparing its GDP to the average GDP of the corresponding country. The purpose of this index was to serve as a weighting factor for the spatial

[11] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/wsf_3d/wsf_3d_error_quantification.md
[12] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/gdp

distribution of the capital stock available at the country level, considering the population residing in each pixel.

Initially, the GDP layer was projected to the reference system EPSG:4326 and snapped to the ~1km grid using the nearest neighbor algorithm. This resampling method was selected as it avoided the spreading of GDP values beyond the country borders and because it respected the contrast of GDP values between cities and country sides.

The GDP layer was also aggregated to the ~5km grid using the unweighted sum method. The steps described in the following paragraphs were then performed on both resolution grids.

The GDP layer was initially cleaned to prevent the emergence of highly divergent GDP index values next to country borders that separate nations with significantly disparate average GDP values. This process was necessary due to the apparent correlation between GDP values and the country assignment of each pixel and because the country borders that could be inferred from the GDP layer did not match exactly with those of the reference grids. A solution had to be devised to meet the objective without substantially distorting GDP values far from country borders. This issue required a notable effort to meet the objective without substantially distorting GDP values far from country borders (see documentation for the detailed process [13]).

The pixels with population below 0.5 were then discarded from the GDP layer and the index was calculated on the remaining pixels as follows:

$$GDP\ Index_{x,y} = \frac{GDP_{x,y}}{average(GDP_{x,y})_{adm}}$$

Where:

- *GDP Index* $_{x,y}$ - The GDP index at x,y position (previously calculated)
- $GDP_{x,y}$ - The GDP at x,y position
- $average(GDP_{x,y})_{adm}$ - The average GDP at country/territory level associated to the x,y position

Due to the presence of outliers in cities next to the country borders that could not be targeted by the previous refining method, a manual correction was finally performed on these pixels to assign them the 99th percentile of the GDP of the country.

The intra-country variability of the GDP index, considered too large after testing, was reduced by summing the inverse of the variance of the GDP Index of a given country to the index of any given pixel. A slight variation on the formula exists between the two resolution grids.

$$New\ 1x1\ GDP\ Index_{x,y} = \frac{10000}{variance(GDP\ Index_{x,y})_{adm}} + GDP\ Index_{x,y}$$

$$New\ 5x5\ GDP\ Index_{x,y} = \frac{1}{variance(GDP\ Index_{x,y})_{adm}} + GDP\ Index_{x,y}$$

Where:

- *New GDP Index* $_{x,y}$: The refined GDP Index at x,y position
- *GDP Index* $_{x,y}$: The GDP index at x,y position (previously calculated)

[13] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/data/gdp/README.md#problems

- *variance(GDP Index$_{x,y}$)$_{adm}$*: The variance of the GDP within the country/territory level associated to the x,y position

Finally, the GDP Index was multiplied by the population residing in the pixel and was divided by the sum of the product at country level to ensure the average of the index is 1 at country level.

$$GDPvi\%_{x,y} = \frac{New\ GDP\ Index_{x,y} * Pop_{x,y}}{sum(New\ GDP\ Index_{x,y} *\ Pop_{x,y})_{adm}}$$

Where:

- *GDPvi%$_{x,y}$:* GDP variation index for the cell located at x,y position;
- *New GDP Index $_{x,y}$*: The refined GDP Index at x,y position
- *Pop$_{x,y}$*: The population at x,y position

2.3.5 Distribution of the population per socio-economic sectors[14]

The primary aim is to assess the building stocks pertaining to both residential and non-residential purposes using the socio-economic indicators described in §2.1.6.

First, all the required information were gathered in the reference grids, namely for each cell:

- the ISO 3166-1 alpha-3 (iso3) code of the country/territory
- the population
- the surface
- the cpx class

A filter was then applied to the reference grids to further reduce their size and thus optimize calculation times. Only the cells satisfying the following conditions were kept for further data processing:

- ~5km grid: population per cell ≥ 0.5
- ~1km grid: population per cell ≥ 0.1

Then, in line with the methodology previously developed for GAR 2015, the subsequent steps were outlined:

- Distribution of the population across income levels based on the World Bank's four established income classes.
- Assessment of the labor force categorized by occupation within industrial, governmental, and service sectors.
- Estimation of healthcare service capacity across both public and private sectors.
- Estimation of education service capacity within public and private sectors.

The population corresponding to a given socio-economic indicator for a given cell was mainly evaluated using the following equation:

$$SEI_{x,y} = \frac{SEI_{adm}}{\sum_{adm} Pop_{x,y}} * Pop_{x,y}$$

[14] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/model/01_distribution_population_per_sei

Where:

- $SEI_{x,y}$ - population per SEI per cell at *x,y* position;
- SEI_{adm} - population per SEI per administrative unit (i.e., country/territory);
- $Pop_{x,y}$ - population living in the cell.

Following these calculations, each cell represents the count of individuals exposed to selected socio-economic sectors (income, labor, education, and health) within a segment of an urban or rural area. The total residential population is the summation of all income classes. Non-residents encompass individuals employed in industrial, governmental, and service sectors, along with students and hospitalized individuals.

2.3.6 Distribution of the building stock per socio-economic sectors[15]

This downscaling process involves transferring the building stock from the administrative unit (country/territory) to the reference grid cells, with the estimated population per cell and sector serving as the primary proxy. To enhance the accuracy of the process and maintain a more realistic representation of the country's economic distribution, the results underwent further weighting using two distinct sets of variables:

1. The Gross Domestic Product (GDP) variability index as described in §2.3.4
2. The "unitary values" at national level and by socio-economic sector which was processed by CIMNE using data sourced from the Global Construction Cost and Reference Yearbook (Compass International Inc., 2012).

The unitary values act as weight factors and are seamlessly integrated into the process. Essentially, these values constitute assessments, specific to each country and socio-economic sector, of the building's surface area and its corresponding unit cost. It's crucial to emphasize that these surface and unitary cost values are comparative measures within the country. They are meant to be interpreted as factors used exclusively to distinguish the surface area and its cost between different socio-economic classes. In simpler terms, if, for a given country, there's a cost value of 2 for low-income buildings and 8 for high-income buildings, this merely signifies that the latter are priced at four times the cost of the former.

The building stock is downscaled to the level of individual cells utilizing population data, and subsequently, it's multiplied by the previously computed coefficient GDPvi. This process yields a database that shifts from a pure population distribution to a distribution based on the type of goods (population per building usage), as per the following equation:

$$BS_{SEI,x,y} = BS_{adm} * GDPvi\%_{x,y} * UV_{SEI}$$

Where:

- $BS_{SEI,x,y}$ - building stock per SEI for a given cell;
- BS_{adm} - building stock per administrative unit (i.e., country/territory);
- $GDPvi\%_{x,y}$ - GDP variation index for the cell located at x,y position;
- UV_{SEI} - coefficient related to unitary costs/surfaces per SEI.

[15] https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/model/02_distribution_building_stock_per_sei

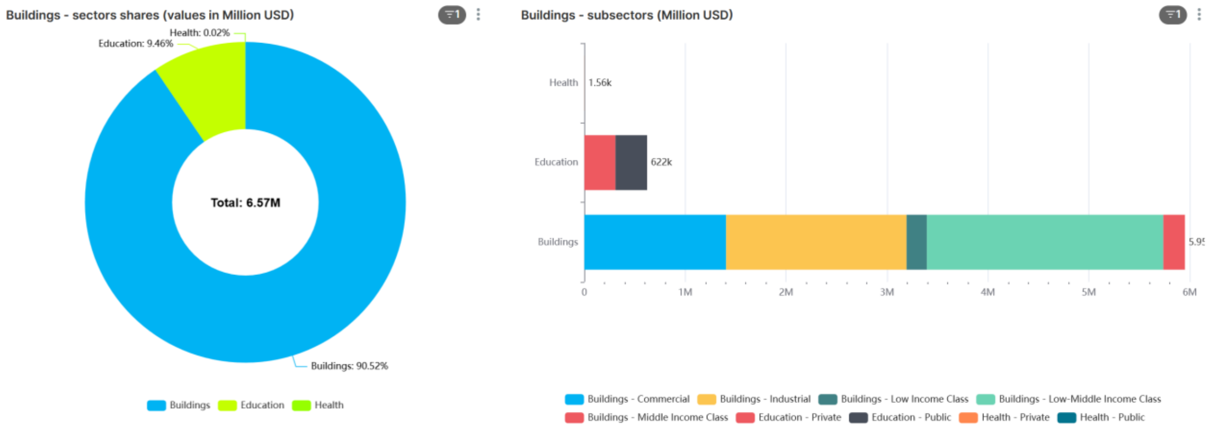

Figure 2: Example about the distribution of the building stock per socio-economic sectors. Charts refer to India. Data available at: https://giri.unepgrid.ch/facts-figures/building-infrastructures

2.3.7 Distribution of the building stock per socio-economic sectors and building types[16]

Once the population and capital stock estimates are established for both residential and non-residential usage, the next step involves allocating them across the various building typologies prevalent in the country. This integration of data is guided by information from WAPMERR, which provides insights into population distribution by complexity level and building type (or structural system). This allocation is carried out by simply multiplying the previously calculated sector-specific building stock ($BS_{SEI,x,y}$) per capita by the corresponding population residing in a given structural system.

Subsequently, after completing this final step, each record will correspond to a building type, based on the level of income/sector, specific to a grid cell of an urban area with an associated level of complexity (Figure).

16 https://git.unepgrid.ch/giri/exposure/src/branch/main/bem/model/03_distribution_building_stock_per_sei_and_building_types

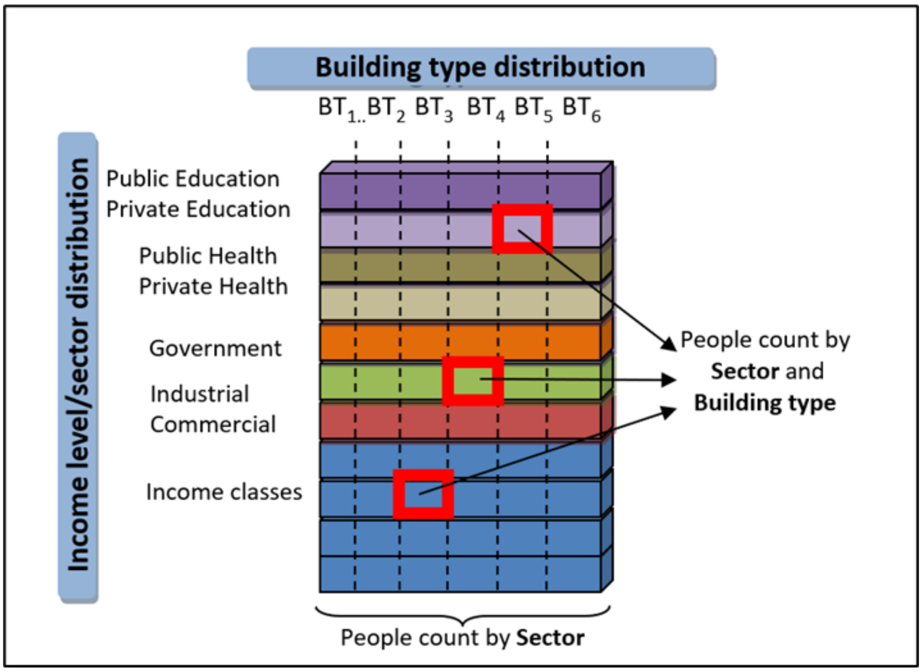

Figure 3: Multidimensional representation of the building exposure

2.4 Outputs

2.4.1 Datasets for probabilistic risk assessment

The BEM results were generated by country/territory based on the iso3 code assigned to each of the reference grid cells. These are tabular files in CSV format, one per reference grid, contain the information required for further probabilistic risk assessment:

- id_5x/id_1x: unique identifier of the cell
- iso3: ISO 3166-1 alpha-3 code of the country/territory
- cpx: complexity level
- sector: socio-economic sectors
- se_seismo: construction type for vulnerability classification
- bs_value_r: value per construction type and cpx class for residential use
- bs_value_nr: value per construction type and cpx class for non-residential use
- valhum: human occupation (people)
- valfis: exposed economic value (million US$)
- bd_1_floor: percentage of buildings with 1 floor
- bd_2_floor: percentage of buildings with 2 floors
- bd_3_floor: percentage of buildings with 3 or more floors

Cell geometry or centroids can be retrieved based on the unique cell identifier (i.e., id_5x/id_1x) that is transversal to all gridded datasets.

2.4.2 Datasets for cartographic representation

Three geospatial maps showing building stocks values (i.e., US$ per cell) were generated and published in the GIRI platform (Figure):

1. Building Exposure Model (BEM) – Total (Figure)
2. Building Exposure Model (BEM) - Residents
3. Building Exposure Model (BEM) - Non-residents (labor, education, and health)

These maps can be viewed from the following link: https://giri.unepgrid.ch/map?list=pinned&pin=MX-B7WR7-ZLQO2-J5OMQ&pin=MX-BWAS9-SV5W2-QZIZJ&pin=MX-28TMP-PCF4H-K00GB&view=MX-B7WR7-ZLQO2-J5OMQ

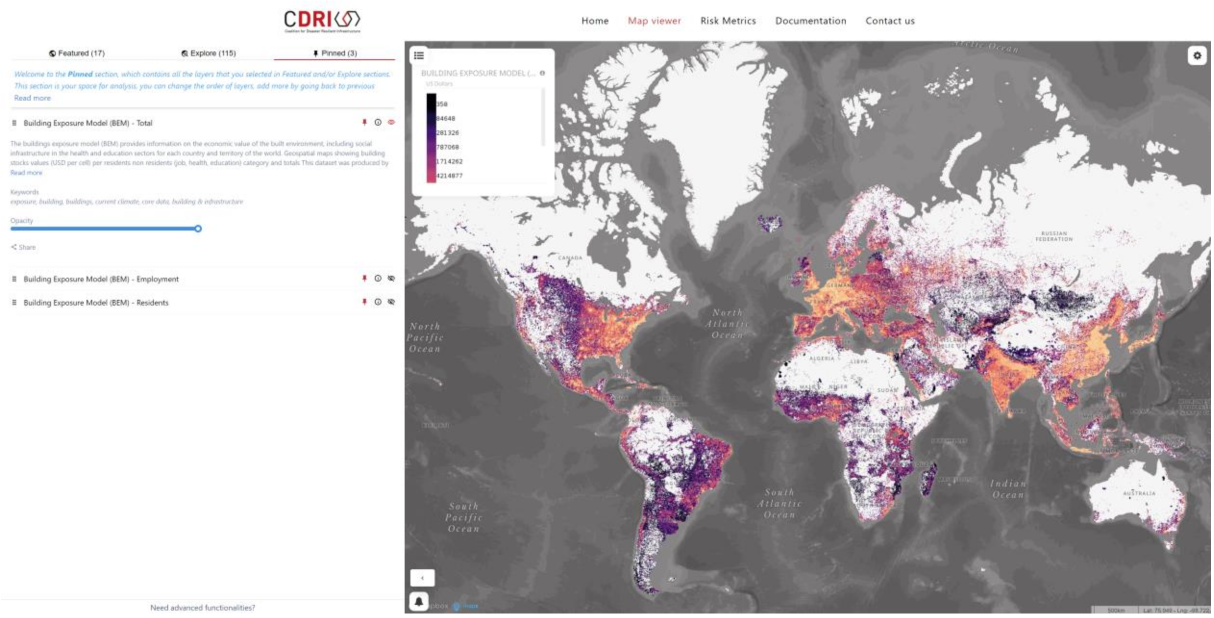

Figure 4: Overview of the cartographic section of the GIRI platform.

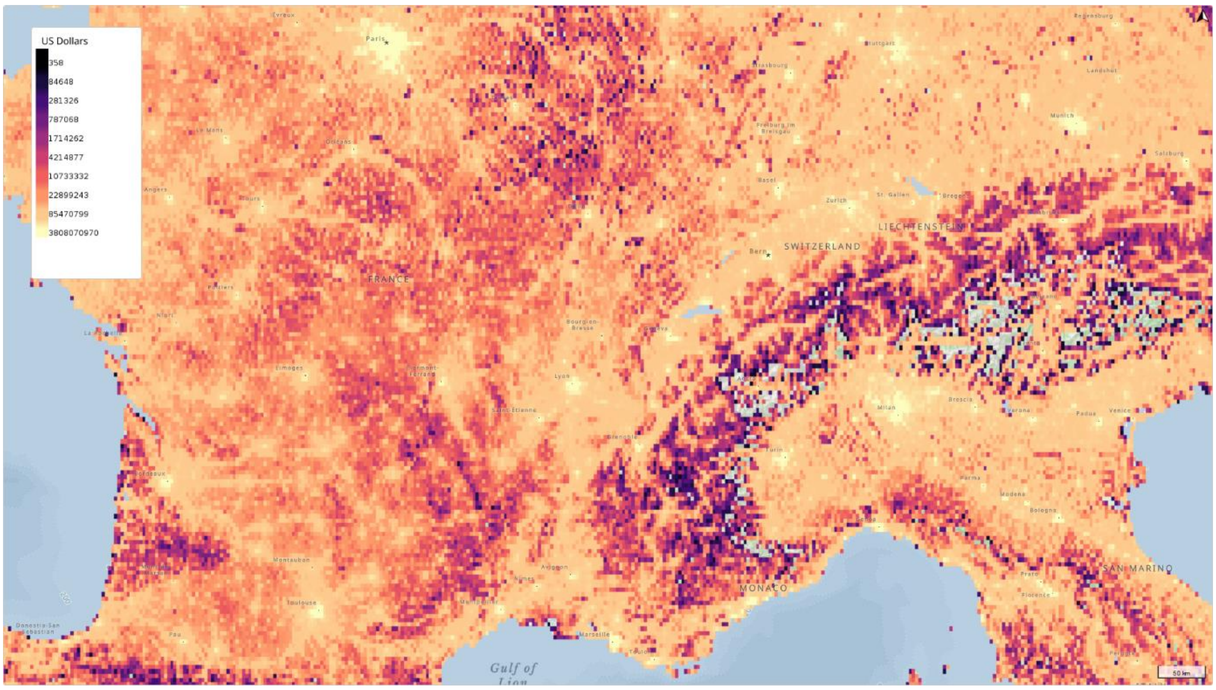

Figure 5: Building Exposure Model (BEM) – Total

3. Conclusion

Exposure is expressed as the value of a group of buildings in each 5x5 km cell. The four socio-economic sectors have been used to estimate the characteristics of the buildings at sub-national level according to the size of each urban/rural area. The distribution of building types is related to the population living in each typology and not to the number of buildings of each type. The produced capital (asset value) is distributed for each sector and type of building in each cell of the 5x5 km grid according to the relative number of people living in it, considering also two complementary elements: the occupation density and the unit cost per sector.

The objective of BEM is to provide a broad perspective on the potential economic value of exposed building stock when comparing countries. The robustness of the methodological approach employed in crafting BEM, coupled with the careful selection of the most up-to-date and relevant data for its application, has resulted in a product entirely aligned with the requirements of the global model for assessing probabilistic risk.

Nevertheless, several improvements are possible and desirable for the production of further models:

- use of the new data (GHSL) for population and 3D building stock (DLR and JRC) that were published during the creation of the BEM
- adoption of an approach that begins to integrate bottom-up data
- comparisons and calibration using existing exposure models such as GEM & Meteor (2022) and Paul et al. (2022).
- increase of resolution of the reference grid: it is now possible to start thinking about a global 1x1 model…

Supplementary material

The technical documentation and the scripts developed for the BEM have been published in an online code repository which is available here: https://git.unepgrid.ch/giri/exposure/src/branch/main/bem

The online platform developed for GIRI is available at: https://giri.unepgrid.ch/

The tabular data used later by Ingeniar for the probabilistic risk calculation (see section 2.4.1) can be provided on request.

References

Chen, J., Gao, M., Cheng, S. et al. Global 1 km × 1 km gridded revised real gross domestic product and electricity consumption during 1992–2019 based on calibrated nighttime light data. Sci Data 9, 202 (2022). https://doi.org/10.1038/s41597-022-01322-5

Compass International Inc., 2012. Global construction cost and reference yearbook (2012).

Facebook Connectivity Lab and Center for International Earth Science Information Network - CIESIN - Columbia University. 2016. High Resolution Settlement Layer (HRSL). Source imagery for HRSL Copyright 2016 DigitalGlobe. Accessed 01 06 2022. Data shared under: Creative Commons Attribution International.

Meteor (2022) Level 1 Exposure for Africa, Arabian Peninsula, continental Asia, Pacific region, available at METEOR Explorer

OECD, 2011. Land valuation in the National Accounts questionnaire (No.STD/CSTAT/WPNA(2011)7).

Paul et al., (2022): Development of a uniform exposure model for the African continent for use in disaster risk assessment. International Journal of Disaster Risk Reduction, Volume 71, 102823, ISSN 2212-4209

PwC (PricewaterhouseCoopers), 2013. UNISDR and PwC – Working together to reduce disaster risks. ISDR, Geneva, Switzerland.

Satterthwaite, David., 2006. Outside the Large Cities The demographic importance of small urban centres and large villages in Africa, Asia and Latin America. Human Settlements Working Paper. ISBN:9781843696230

Schiavina, Marcello; Freire, Sergio; MacManus, Kytt (2019): GHS population grid multitemporal (1975, 1990, 2000, 2015) R2019A. European Commission, Joint Research Centre (JRC) DOI: 10.2905/42E8BE89-54FF-464E-BE7B-BF9E64DA5218 PID: http://data.europa.eu/89h/0c6b9751-a71f-4062-830b-43c9f432370f

Tolis, Rosset, Wyss, 2013. Detailed building stock at regional scale in three size categories of settlements for 18 countries worldwide. Geneva, Switzerland.

United Nations University, 2012. Inclusive Wealth Report 2012: Measuring Progress Toward Sustainability. Cambridge University Press, Cambridge.

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition.

World Bank, 2005. Where is the Wealth of Nations? Measuring Capital for the 21st Century. Washington, DC: World Bank. doi:10.1596/978-0-8213-6354-6.

World Bank, 2021. The Changing Wealth of Nations 2021: Managing Assets for the Future. Washington, DC: World Bank. doi:10.1596/978-1-4648-1590-4.

Wyss, M., Tolis, S., Rosset, P., Pacchiani, F., 2013. Approximate Model for worldwide building stock in three size categories of settlements. Technical report prepared for GAR 2013. ISDR, Geneva, Switzerland.