

A. National Model Construction: Example for masonry buildings

This example illustrates how to use 2002 Census and 2002-2014 UESF data to calculate the number of masonry buildings, of each building typology defined, in a certain commune. This calculation is necessary because census data is referred to dwellings (for example, number of apartments in a building), while the classification by typologies is referred to the number of individual structures. To obtain the number of masonry buildings, census data is combined with two key data in the UESF at the communal level: distributions of stories in masonry buildings, and average number of apartments per story.

Consider masonry buildings in a fictitious *Commune X*, which is divided in two census blocks. The 2002 Census information is shown in Table A.1. The dwellings prior to 2002 are separated in census blocks and location (urban and rural). Apartments in masonry buildings are identified in 2002 Census from the material information of the exterior walls (brick or block).

Table A.1: Information of apartments in masonry buildings in *Commune X* from the 2002 Census

Location	Census blocks of Commune X		Total
	1	2	
Urban	1,200	900	2,100
Rural	800	600	1,400
Total	2,000	1,500	3,500

Table A.2 shows fictitious information from the UESF for *Commune X*, which provides the number of masonry buildings and the number of dwellings or apartments per masonry building built between 2002 and 2014 in the commune. The number of apartments and the number of buildings related are shown in Table A.2, separated by location (urban or rural), number of stories, and masonry material/technique. Percentages of participation for apartments and buildings of each type of masonry building in the commune are also shown in Table A.2.

Table A.2: Information of masonry apartments in *Commune X* from the UESF (2002-2014)

Location	Number of stories	N_{ij}^{UESF} : Total number of apartments	PN_{ij}^{UESF} : Participation of apartments per location (%)	B_{ij}^{UESF} : Number of buildings	Material-technique	N_{ijk}^{UESF} : Number of apartments according to technique and stories	PN_{ijk}^{UESF} : Participation of apartments according to technique and stories (%)	B_{ijk}^{UESF} : Number of buildings according to technique and stories	PB_{ijk}^{UESF} : Participation of buildings according to technique and stories (%)	A_{ijk}^{UESF} : Calculated average number of apartments per story according to technique and stories
Urban	3	180	21.0	10	Confined clay brick	84	46.7	4	40	7
					Reinforced hollow clay brick	60	33.3	4	40	5
					Concrete block	36	20.0	2	20	6
					Subtotal	180	100	10	100	-
	4	476	55.6	16	Confined clay brick	134	28.2	4	25	8.4
					Reinforced hollow clay brick	217	45.6	8	50	6.8
					Concrete block	125	26.3	4	25	7.8
					Subtotal	476	100	16	100	-
	5	200	23.4	5	Confined clay brick	40	20.0	1	20	8
					Reinforced hollow clay brick	70	35.0	2	40	7
					Concrete block	90	45.0	2	40	9
					Subtotal	200	100	5	100	-
	Subtotal	856	100	31	-	856	-	31	-	-
Rural	3	84	35.6	4	Confined clay brick	63	75.0	3	75	7
					Reinforced hollow clay brick	21	25.0	1	25	7
					Concrete block	0	0.0	0	0	0
					Subtotal	84	100	4	100	-
	4	72	30.5	3	Confined clay brick	48	66.7	2	67	6
					Reinforced hollow clay brick	24	33.3	1	33	6
					Concrete block	0	0.0	0	0	0
					Subtotal	72	100	3	100	-
	5	80	33.9	2	Confined clay brick	35	43.8	1	50	7
					Reinforced hollow clay brick	45	56.3	1	50	9
					Concrete block	0	0.0	0	0	0
					Subtotal	80	100	2	100	-
	Subtotal	236	100	9	-	236	-	9	-	-
Total	-	1,092	-	40	-	1,092	-	40	-	-

Participation (as percentages) of apartments according to the number of stories and location (urban and rural) from the UESF data (PN_{ij}^{UESF}), and the percentages of participation for apartments and buildings according to masonry material/technique by number of stories and location from the UESF data (PN_{ijk}^{UESF} , and PB_{ijk}^{UESF} , respectively) are calculated as follows:

$$PN_{ij}^{UESF} = \frac{N_{ij}^{UESF}}{\sum_{j=3}^5 N_{ij}^{UESF}} * 100 (\%), \quad \forall i, j \quad (\text{Equation A.1})$$

$$PN_{ijk}^{UESF} = \frac{N_{ijk}^{UESF}}{N_{ij}^{UESF}} * 100 (\%), \quad \forall i, j, k \quad (\text{Equation A.2})$$

$$PB_{ijk}^{UESF} = \frac{B_{ijk}^{UESF}}{B_{ij}^{UESF}} * 100 (\%), \quad \forall i, j, k \quad (\text{Equation A.3})$$

Note that:

$$N_{ij}^{UESF} = \sum_{k=1}^3 N_{ijk}^{UESF}, \quad \forall i, j$$

$$B_{ij}^{UESF} = \sum_{k=1}^3 B_{ijk}^{UESF}, \quad \forall i, j$$

$$\sum_{j=3}^5 PN_{ij}^{UESF} = 100 (\%), \quad \forall i$$

$$\sum_{k=1}^3 PN_{ijk}^{UESF} = 100 (\%), \quad \forall i, j$$

$$\sum_{k=1}^3 PB_{ijk}^{UESF} = 100 (\%), \quad \forall i, j$$

Where,

- i : location = $\begin{cases} 1, & \text{for urban} \\ 2, & \text{for rural} \end{cases}$

- j : number of stories = $\begin{cases} 3, & \text{for three-story building} \\ 4, & \text{for four-story building} \\ 5, & \text{for five-story building} \end{cases}$
- k : material/technique = $\begin{cases} 1, & \text{for confined clay brick} \\ 2, & \text{for reinforced hollow clay brick} \\ 3, & \text{for reinforced and confined concrete block} \end{cases}$
- N_{ij}^{UESF} : Total number of apartments according to building height by location (urban or rural) obtained from UESF data for *Commune X*.
- B_{ij}^{UESF} : Total number of buildings according to building height by location (urban or rural) obtained from UESF data for *Commune X*.
- N_{ijk}^{UESF} : Total number of apartments according to material/technique by building height and location (urban or rural) obtained from UESF data for *Commune X*.
- B_{ijk}^{UESF} : Total number of buildings according to material/technique by building height and location (urban or rural) obtained from UESF data for *Commune X*.

The number of apartments per story calculated from UESF data (A_{ijk}^{UESF}) is required to convert census number of apartments into number of buildings. This number is calculated per building height and location as shown by Equation A.4:

$$A_{ijk}^{UESF} = \frac{N_{ijk}^{UESF}}{B_{ijk}^{UESF} * j}, \quad \forall i, j, k \quad (\text{Equation A.4})$$

The masonry construction technique of the exposure model is not directly obtained from the UESF data, and the assumptions presented in Table 2.1 are considered. An example of this is presented in Table A.3. This table shows for the 14 three-story masonry buildings from Table A.2 (10 urban and 4 rural buildings), the percentage of wall material as per UESF, and the assigned building typology after the assumptions from Table 2.1 are considered.

Table A.3: Relationship between material data of buildings in UESF and building typology for all the three-story masonry buildings in *Commune X*

Building number	Material	Percentage wall (%)	Location	Typology
1	Handmade clay brick	80	Urban	Confined clay brick
2	Handmade clay brick	85	Urban	Confined clay brick
3	Handmade clay brick	90	Rural	Confined clay brick
4	Hollow clay brick	80	Urban	Confined clay brick
5	Hollow clay brick	70	Urban	Confined clay brick
6	Handmade clay brick	80	Rural	Confined clay brick
7	Hollow clay brick	85	Rural	Confined clay brick
8	Hollow clay brick	100	Urban	Reinforced hollow clay brick
9	Hollow clay brick	100	Urban	Reinforced hollow clay brick
10	Hollow clay brick	100	Urban	Reinforced hollow clay brick
11	Hollow clay brick	100	Rural	Reinforced hollow clay brick
12	Hollow clay brick	100	Urban	Reinforced hollow clay brick
13	Concrete block	80	Urban	Reinforced or confined concrete block
14	Concrete block	100	Urban	Reinforced or confined concrete block

Using the percentages of apartments (PN_{ij}^{UESF} , see Table A.2), it is possible to estimate the number of masonry apartments number of stories and location in the commune for the residential stock built before 2002 (Table A.4). Percentages of participation for apartments calculated for UESF data are used to separate the number of apartments obtained from the 2002 Census data from Table A.1 as follows:

$$PN_{ijl}^{Census} = PN_{ij}^{UESF}, \quad \forall i, j, l \text{ (Equation A.5)}$$

$$N_{ijl}^{Census} = \frac{PN_{ijl}^{Census}}{100} * N_{il}^{Census}, \quad \forall i, j, l \text{ (Equation A.6)}$$

Where,

- i : location = $\begin{cases} 1, \text{ for urban} \\ 2, \text{ for rural} \end{cases}$
- j : number of stories = $\begin{cases} 3, \text{ for three-story building} \\ 4, \text{ for four-story building} \\ 5, \text{ for five-story building} \end{cases}$
- l : census block in *Commune X* = $\begin{cases} 1, \text{ for Census block 1} \\ 2, \text{ for Census block 2} \end{cases}$

- PN_{ijl}^{Census} : Percentage of participation of apartments built prior to 2002 according to building height by census block and location (urban or rural).
- N_{il}^{Census} : Total number of apartments according to census block by location (urban or rural) obtained from 2002 Census data for *Commune X* (see Table A.1).
- N_{ijl}^{Census} : Total number of apartments built prior to 2002 calculated according to building height by census block and location (urban or rural).

With the estimated numbers of apartments built prior to 2002 separated by location, census block, and building height for *Commune X* (N_{ijl}^{Census}), and with the percentage of participation of apartments according to masonry material/technique by building height, census block and location (PN_{ijkl}^{Census}), the number of apartments by masonry material/technique (N_{ijkl}^{Census}) is estimated as follows:

$$PN_{ijkl}^{Census} = PN_{ijk}^{UESF}, \quad \forall i, j, k, l \quad (\text{Equation A.7})$$

$$N_{ijkl}^{Census} = \frac{PN_{ijkl}^{Census}}{100} * N_{ijl}^{Census}, \quad \forall i, j, k, l \quad (\text{Equation A.8})$$

Where,

$$k: \text{construction technique} = \begin{cases} 1, & \text{for confined clay brick} \\ 2, & \text{for reinforced hollow clay brick} \\ 3, & \text{for reinforced or confined concrete block} \end{cases}$$

To estimate the number of buildings (B_{ijkl}^{Census}) related to the estimated number of apartments built prior to 2002 according to masonry material/technique by building height, census block and location, the average number of apartments per story of each case was used using the following equations. See results in Table A.4.

$$A_{ijkl}^{Census} = A_{ijk}^{UESF}, \quad \forall i, j, k, l \quad (\text{Equation A.9})$$

$$B_{ijkl}^{Census} = \frac{N_{ijkl}^{Census}}{A_{ijkl}^{Census} * j}, \quad \forall i, j, k, l \quad (\text{Equation A.10})$$

Where,

A_{ijkl}^{Census} : Average number of apartments per story according to masonry material/technique by building height, census block and location (urban or rural).

Table A.4: Estimation of the number of masonry buildings per census block according to construction technique in *Commune X*. This estimation covers the building stock built previous to 2002, and was calculated using the building distribution of the UESF.

Location	Census block	Number of stories	P_{ijl}^{Census} : Participation of apartments (%)	N_{ijl}^{Census} : Total number of apartments	Material-technique	PN_{ijkl}^{Census} : Participation of apartments according to technique and stories (%)	N_{ijkl}^{Census} : Number of apartments according to technique and stories	A_{ijkl}^{Census} : Average number of apartments per story according to technique and stories	B_{ijkl}^{Census} : Number of buildings according to technique and stories	PB_{ijkl}^{Census} : Participation of buildings according to technique and stories (%)
Urban	1	3	21.0	252	Confined clay brick	46.7	117.8	7	5.6	40
					Reinforced hollow clay	33.3	84.1	5	5.6	40
					Concrete block	20.0	50.5	6	2.8	20
					Subtotal	100	252	-	14.0	100
		4	55.6	667	Confined clay brick	28.2	187.9	8.4	5.6	25
					Reinforced hollow clay	45.6	304.2	6.8	11.2	50
					Concrete block	26.3	175.2	7.8	5.6	25
					Subtotal	100	667	-	22.4	100
		5	23.4	280	Confined clay brick	20.0	56.1	8	1.4	20
					Reinforced hollow clay	35.0	98.1	7	2.8	40
					Concrete block	45.0	126.2	9	2.8	40
					Subtotal	100	280	-	7.0	100
	Subtotal	100	1,200	-	43.5	-				
	2	3	21.0	189	Confined clay brick	46.7	88.3	7	4.2	40
					Reinforced hollow clay	33.3	63.1	5	4.2	40
					Concrete block	20.0	37.9	6	2.1	20
					Subtotal	100	189	-	10.5	100
		4	55.6	500	Confined clay brick	28.2	140.9	8.4	4.2	25
					Reinforced hollow clay	45.6	228.2	6.8	8.4	50
					Concrete block	26.3	131.4	7.8	4.2	25
					Subtotal	100	500	-	16.8	100
		5	23.4	210	Confined clay brick	20.0	42.1	8	1.1	20
					Reinforced hollow clay	35.0	73.6	7	2.1	40
					Concrete block	45.0	94.6	9	2.1	40
Subtotal					100	210	-	5.3	100	
Subtotal	100	900	-	32.6	-					
Subtotal	-	-	2,100	-	76.0	-				
Rural	1	3	35.6	285	Confined clay brick	75.0	213.6	7	10.2	75
					Reinforced hollow clay	25.0	71.2	7	3.4	25
					Concrete block	0.0	0.0	0	0.0	0
					Subtotal	100	285	-	13.6	100
		4	30.5	244	Confined clay brick	66.7	162.7	6	6.8	67
					Reinforced hollow clay	33.3	81.4	6	3.4	33
					Concrete block	0.0	0.0	0	0.0	0
					Subtotal	100	244	-	10.2	100

	5	33.9	271	Confined clay brick	43.8	118.6	7	3.4	50	
				Reinforced hollow clay	56.3	152.5	9	3.4	50	
				Concrete block	0.0	0.0	0	0.0	0	
				Subtotal	100	271	-	6.8	100	
	Subtota	100	800	-	-	800	-	30.5	500	
	2	3	35.6	214	Confined clay brick	75.0	160.2	7	7.6	75
					Reinforced hollow clay	25.0	53.4	7	2.5	25
					Concrete block	0.0	0.0	0	0.0	0
					Subtotal	100	214	-	10.2	100
		4	30.5	183	Confined clay brick	66.7	122.0	6	5.1	67
					Reinforced hollow clay	33.3	61.0	6	2.5	33
					Concrete block	0.0	0.0	0	0.0	0
					Subtotal	100	183	-	7.6	100
		5	33.9	203	Confined clay brick	43.8	89.0	7	2.5	50
Reinforced hollow clay					56.3	114.4	9	2.5	50	
Concrete block					0.0	0.0	0	0.0	0	
Subtotal					100	203	-	5.1	100	
Subtota	100	600	-	-	600	-	22.9	-		
Subtota	-	-	1,400	-	-	1,400	-	53.4	-	
Total	-	-	3,500	-	-	3,500	-	129.4	-	

Finally, to estimate the total number of masonry buildings per census block (B_{ijkl}^{Total}) in the National Exposure Model (results in Table A.5), the buildings prior to 2002 (Table A.4) are added with the number of buildings from 2002 to 2014 (Table A.2), which are uniformly distributed in the total number of census blocks of *Commune X*, as shown in Equation A.11.

$$B_{ijkl}^{Total} = \frac{B_{ijk}^{UESF}}{Cb} + B_{ijkl}^{census}, \quad \forall i, j, k, l \text{ (Equation A.11)}$$

Where,

Cb : Total number of census blocks in *Commune X* = 2

Table A.5: Total number of masonry buildings in *Commune X*

			B_{ijkl}^{Census} : Number of buildings prior to 2002		$B_{ijkl}^{UESF/Cb}$: Number of buildings 2002-2014		B_{ijkl}^{Total} : Total number of buildings		
Location	Number of stories	Material-technique	Census block 1	Census block 2	Census block 1	Census block 2	Census block 1	Census block 2	Total
Urban	3	Confined clay brick	5.6	4.2	2.0	2.0	7.6	6.2	13.8
		Reinforced hollow clay brick	5.6	4.2	2.0	2.0	7.6	6.2	13.8
		Concrete block	2.8	2.1	1.0	1.0	3.8	3.1	6.9
	4	Confined clay brick	5.6	4.2	2.0	2.0	7.6	6.2	13.8
		Reinforced hollow clay brick	11.2	8.4	4.0	4.0	15.2	12.4	27.6
		Concrete block	5.6	4.2	2.0	2.0	7.6	6.2	13.8
	5	Confined clay brick	1.4	1.1	0.5	0.5	1.9	1.6	3.5
		Reinforced hollow clay brick	2.8	2.1	1.0	1.0	3.8	3.1	6.9
		Concrete block	2.8	2.1	1.0	1.0	3.8	3.1	6.9
Rural	3	Confined clay brick	10.2	7.6	1.5	1.5	11.7	9.1	20.8
		Reinforced hollow clay brick	3.4	2.5	0.5	0.5	3.9	3.0	6.9
		Concrete block	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	Confined clay brick	6.8	5.1	1.0	1.0	7.8	6.1	13.9
		Reinforced hollow clay brick	3.4	2.5	0.5	0.5	3.9	3.0	6.9
		Concrete block	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	Confined clay brick	3.4	2.5	0.5	0.5	3.9	3.0	6.9
		Reinforced hollow clay brick	3.4	2.5	0.5	0.5	3.9	3.0	6.9
		Concrete block	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total			74.0	55.5	20.0	20.0	94.0	75.5	169.4