

### C. National Model Construction: Example for masonry houses

This example illustrates how the UESF and the 2002 Census data are used to estimate the masonry houses in a certain commune.

Consider the masonry houses in a fictitious *Commune Z*, divided in two census blocks. The 2002 Census houses information is shown in Table C.1. The houses prior to 2002 are separated in the census blocks and location (urban or rural). Masonry houses are identified in the 2002 Census for exterior wall material (Brick or Block).

Table C.1: Information of masonry houses in *Commune Z* from the 2002 Census

Location	Census blocks of Commune Z		Total
	1	2	
Urban	1,000	1,500	2,500
Rural	800	200	1,000
Total	1,800	1,700	3,500

The UESF provides the number of masonry houses built between 2002 and 2014 in the commune, identifying if they are located at the urban or rural area (Table C.2). Percentages of participation for houses of each type of masonry houses in the city are shown in Table C.2, separated by material unit, configuration condition (detached, semi-adjoining or adjoining) and location. The percentages of participation for houses per masonry unit and configuration condition for both locations (urban and rural) from the UESF data ( $P_{ijk}^{UESF}$ ) are calculated as follows:

$$P_{ijk}^{UESF} = \frac{N_{ijk}^{UESF}}{\sum_{j=1}^3 \sum_{k=1}^3 N_{ijk}^{UESF}} * 100, \quad \forall i, j, k \quad (\text{Equation C.1})$$

Note that:

$$\sum_{j=1}^3 \sum_{k=1}^3 P_{ijk}^{UESF} = 100, \quad \forall i$$

Where,

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

- $j$ : material unit =  $\begin{cases} 1, & \text{for handmade clay brick} \\ 2, & \text{for hollow clay brick} \\ 3, & \text{for concrete block} \end{cases}$
- $k$ : configuration condition =  $\begin{cases} 1, & \text{for detached houses} \\ 2, & \text{for semi-adjoining houses} \\ 3, & \text{for adjoining houses} \end{cases}$
- $N_{ijk}^{UESF}$ : Total number of houses according to configuration condition and material unit by location (urban or rural) obtained from UESF data for *Commune Z*.

Table C.2: Information of masonry houses in *Commune Z* from the UESF (2002-2014) separated by material unit, configuration condition and location

Location	Material unit	Configuration condition	$N_{ijk}^{UESF}$ : Number of houses	$P_{ijk}^{UESF}$ : Participation of houses according to material and configuration condition (%)
Urban	Handmade clay brick	Detached	50	15
		Semi-adjoining	20	6
		Adjoining	10	3
	Hollow clay brick	Detached	100	30
		Semi-adjoining	30	9
		Adjoining	20	6
	Concrete block	Detached	40	12
		Semi-adjoining	45	14
		Adjoining	15	5
<b>Subtotal</b>			<b>330</b>	<b>100</b>
Rural	Handmade clay brick	Detached	10	15
		Semi-adjoining	3	5
		Adjoining	1	2
	Hollow clay brick	Detached	30	46
		Semi-adjoining	5	8
		Adjoining	10	15
	Concrete block	Detached	5	8
		Semi-adjoining	0	0
		Adjoining	1	2
<b>Subtotal</b>			<b>65</b>	<b>100</b>
<b>Total</b>			<b>395</b>	<b>-</b>

Table C.3 shows masonry houses from the UESF separating the material unit by construction technique (confined, reinforced or unreinforced), according to the assumptions presented in Table 2.1. Participation of houses by location, material unit and construction technique from UESF data is calculated as follows:

$$P_{ijl}^{UESF} = \frac{N_{ijl}^{UESF}}{N_{ij}^{UESF}} * 100, \quad \forall i, j, l \text{ (Equation C.2)}$$

Note that:

$$N_{ijl}^{UESF} = 0, \quad \forall i, j = 1, l = 3$$

$$\sum_{l=1}^2 N_{ijl}^{UESF} = N_{ij}^{UESF}, \quad \forall i, j = 1$$

$$N_{ijl}^{UESF} = 0, \quad \forall i, j = 2, 3, l = 1$$

$$\sum_{l=2}^3 N_{ijl}^{UESF} = N_{ij}^{UESF}, \quad \forall i, j = 2, 3$$

$$\sum_{l=1}^2 P_{ijl}^{UESF} = 100, \quad \forall i, j = 1$$

$$\sum_{l=2}^3 P_{ijl}^{UESF} = 100, \quad \forall i, j = 2, 3$$

Where,

- $i$  : location =  $\begin{cases} 1, \text{ for urban} \\ 2, \text{ for rural} \end{cases}$
- $j$  : material unit =  $\begin{cases} 1, \text{ for handmade clay brick} \\ 2, \text{ for hollow clay brick} \\ 3, \text{ for concrete block} \end{cases}$
- $l$  : construction technique =  $\begin{cases} 1, \text{ for unreinforced masonry} \\ 2, \text{ for confined masonry} \\ 3, \text{ for reinforced masonry} \end{cases}$
- $N_{ijl}^{UESF}$  : Total number of houses according to construction technique by material unit and location (urban or rural) obtained from UESF data for *Commune Z*.
- $N_{ij}^{UESF}$  : Total number of houses according to material unit by location (urban or rural) obtained from UESF data for *Commune Z*.

Table C.3: Information of masonry houses in *Commune Z* from the UESF (2002-2014) with the relationship between material unit and construction technique

Location	Material unit	$N_{ij}^{UESF}$ : Number of houses	Masonry technique	$N_{ijl}^{UESF}$ : Number of houses	$P_{ijl}^{UESF}$ : Participation of houses by technique (%)
Urban	Handmade clay brick	80	Unreinforced	50	62.5
			Confined	30	37.5
			<b>Subtotal</b>	<b>80</b>	<b>100</b>
	Hollow clay brick	150	Reinforced	100	67
			Confined	50	33
			<b>Subtotal</b>	<b>150</b>	<b>100</b>
	Concrete block	100	Reinforced	70	70
			Confined	30	30
			<b>Subtotal</b>	<b>100</b>	<b>100</b>
	<b>Subtotal</b>	<b>330</b>	-	<b>330</b>	-
Rural	Handmade clay brick	14	Unreinforced	8	57
			Confined	6	43
			<b>Subtotal</b>	<b>14</b>	<b>100</b>
	Hollow clay brick	45	Reinforced	30	67
			Confined	15	33
			<b>Subtotal</b>	<b>45</b>	<b>100</b>
	Concrete block	6	Reinforced	3	50
			Confined	3	50
			<b>Subtotal</b>	<b>6</b>	<b>100</b>
	<b>Subtotal</b>	<b>65</b>	-	<b>65</b>	-
<b>Total</b>	<b>395</b>	-	<b>395</b>	-	

Using houses distribution of Table C.2 it is possible to obtain the number of houses by material unit in the commune for the residential stock built before 2002, obtained from the 2002 Census. The percentages of Table C.2 ( $P_{ijk}^{UESF}$ ) are multiplied by the total number of houses identifying the exterior wall material unit in the 2002 Census for the two census blocks in *Commune Z* (Table C.4). The following procedure explains how the number of houses prior to 2002 from Table C.1 are separated by material unit, configuration condition, census block and location:

$$P_{ijkm}^{Census} = P_{ijk}^{UESF}, \quad \forall i, j, k, m \quad (\text{Equation C.3})$$

$$N_{ijkm}^{Census} = \frac{P_{ijkm}^{Census}}{100} * N_{im}^{Census}, \quad \forall i, j, k, m \quad (\text{Equation C.4})$$

Where,

- $i$  : location =  $\begin{cases} 1, \text{ for urban} \\ 2, \text{ for rural} \end{cases}$
- $j$  : material unit =  $\begin{cases} 1, \text{ for handmade clay brick} \\ 2, \text{ for hollow clay brick} \\ 3, \text{ for concrete block} \end{cases}$
- $k$  : configuration condition =  $\begin{cases} 1, \text{ for detached houses} \\ 2, \text{ for semi-adjoining houses} \\ 3, \text{ for adjoining houses} \end{cases}$
- $m$  : census block in *Commune Z* =  $\begin{cases} 1, \text{ for Census block 1} \\ 2, \text{ for Census block 2} \end{cases}$
- $P_{ijkm}^{Census}$  : Percentage of participation of houses built prior to 2002 according to configuration condition and material unit by census block and location (urban or rural).
- $N_{im}^{Census}$  : Total number of houses according to census block by location (urban or rural) obtained from 2002 Census data for *Commune Z* (see Table C.1).

Table C.4: Estimation of the number of masonry houses per census block according to the material and configuration condition in *Commune Z*. This estimation covers the house stock built previous to 2002, and was calculated using the house distribution of the UESF.

Location	Census block	Material unit	Configuration condition	$P_{ijkm}^{Census}$ : Participation of houses according to material and configuration condition (%)	$N_{ijkm}^{Census}$ : Number of houses
Urban	1	Handmade clay brick	Detached	15	152
			Semi-adjoining	6	61
			Adjoining	3	30
		Hollow clay brick	Detached	30	303
			Semi-adjoining	9	91
			Adjoining	6	61
		Concrete block	Detached	12	121
			Semi-adjoining	14	136
			Adjoining	5	45
	<b>Subtotal</b>			<b>100</b>	<b>1,000</b>
	2	Handmade clay brick	Detached	15	227
			Semi-adjoining	6	91
			Adjoining	3	45
		Hollow clay brick	Detached	30	455
			Semi-adjoining	9	136
			Adjoining	6	91
		Concrete block	Detached	12	182
			Semi-adjoining	14	205
			Adjoining	5	68
	<b>Subtotal</b>			<b>100</b>	<b>1,500</b>
	<b>Subtotal</b>				
Rural	1	Handmade clay brick	Detached	15	123
			Semi-adjoining	5	37
			Adjoining	2	12
		Hollow clay brick	Detached	46	369
			Semi-adjoining	8	62
			Adjoining	15	123
		Concrete block	Detached	8	62
			Semi-adjoining	0	0
			Adjoining	2	12
	<b>Subtotal</b>			<b>100</b>	<b>800</b>
	2	Handmade clay brick	Detached	15	31
			Semi-adjoining	5	9
			Adjoining	2	3
		Hollow clay brick	Detached	46	92
			Semi-adjoining	8	15
			Adjoining	15	31
		Concrete block	Detached	8	15
			Semi-adjoining	0	0
Adjoining			2	3	
<b>Subtotal</b>			<b>100</b>	<b>200</b>	
<b>Subtotal</b>					<b>1,000</b>
<b>Total</b>					<b>3,500</b>

To obtain the estimated number of masonry houses per census block (Table C.5), the number of houses built before 2002 (Table C.4) are added with the number of houses from 2002 to 2014 (Table C.2), which are uniformly distributed in the total census blocks of *Commune Z*. The estimated number of masonry houses are estimated as follows:

$$N_{ijkm}^{Total} = \frac{N_{ijk}^{UESF}}{Cb} + N_{ijkm}^{Census}, \quad \forall i, j, k, m \text{ (Equation C.5)}$$

Where,

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

Table C.5: Total masonry houses in *Commune Z* by material unit

Location	Material unit	Configuration condition	$N_{ijkm}^{Census}$ : Number of houses prior to 2002		$N_{ijk}^{UESF}/Cb$ : Number of houses 2002-2014		$N_{ijkm}^{Total}$ : Total number of houses		Total
			Census block 1	Census block 2	Census block 1	Census block 2	Census block 1	Census block 2	
Urban	Handmade clay brick	Detached	152	227	25	25	177	252	429
		Semi-adjoining	61	91	10	10	71	101	172
		Adjoining	30	45	5	5	35	50	86
	Hollow clay brick	Detached	303	455	50	50	353	505	858
		Semi-adjoining	91	136	15	15	106	151	257
		Adjoining	61	91	10	10	71	101	172
	Concrete block	Detached	121	182	20	20	141	202	343
		Semi-adjoining	136	205	23	23	159	227	386
		Adjoining	45	68	8	8	53	76	129
Rural	Handmade clay brick	Detached	123	31	5	5	128	36	164
		Semi-adjoining	37	9	2	2	38	11	49
		Adjoining	12	3	1	1	13	4	16
	Hollow clay brick	Detached	369	92	15	15	384	107	492
		Semi-adjoining	62	15	3	3	64	18	82
		Adjoining	123	31	5	5	128	36	164
	Concrete block	Detached	62	15	3	3	64	18	82
		Semi-adjoining	0	0	0	0	0	0	0
		Adjoining	12	3	1	1	13	4	16
<b>Total</b>			<b>1,800</b>	<b>1,700</b>	<b>198</b>	<b>198</b>	<b>1,998</b>	<b>1,898</b>	<b>3,895</b>

Finally, using the percentages of Table C.3 it is possible to separate houses from Table C.5 by construction technique (Table C.6) and not only by material unit. It is important to note that the material unit concrete block is separated in reinforced and confined masonry techniques, but in the National Exposure Model these techniques are added according to the masonry typologies. The number of masonry houses by census block, location, material unit,

construction technique and configuration condition are estimated as follows for houses prior to 2002:

$$N_{ijklm}^{Census} = \frac{P_{ijl}^{UESF}}{100} * N_{ijkm}^{Census}, \quad \forall i, j, k, l, m \text{ (Equation C.6)}$$

For houses built between 2002 and 2014 per census block, the procedure is the following:

$$\frac{N_{ijkl}^{UESF}}{Cb} = \frac{P_{ijl}^{UESF}}{100} * \frac{N_{ijk}^{UESF}}{Cb}, \quad \forall i, j, k, l \text{ (Equation C.7)}$$

Then, the estimated total number of houses is calculated as:

$$N_{ijklm}^{Total} = N_{ijklm}^{Census} + \frac{N_{ijkl}^{UESF}}{Cb}, \quad \forall i, j, k, l, m \text{ (Equation C.8)}$$

It is important to note that

$$N_{ijklm}^{Total} = \frac{P_{ijl}^{UESF}}{100} * N_{ijkm}^{Total}, \quad \forall i, j, k, l, m \text{ (Equation C.9)}$$



Table C.6: Total masonry houses in *Commune Z* by material unit and technique

Location	Material unit	Configuration condition	Masonry technique	$N_{ijklm}^{Census}$ : Number of houses prior to 2002		$N_{ijkl}^{UESF/Cb}$ : Number of houses 2002-2014		$N_{ijklm}^{Total}$ : Total number of houses		Total
				Census block 1	Census block 2	Census block 1	Census block 2	Census block 1	Census block 2	
Urban	Handmade clay brick	Detached	Unreinforced	95	142	16	16	110	158	268
			Confined	57	85	9	9	66	95	161
		Semi- adjoining	Unreinforced	38	57	6	6	44	63	107
			Confined	23	34	4	4	26	38	64
		Adjoining	Unreinforced	19	28	3	3	22	32	54
			Confined	11	17	2	2	13	19	32
	Hollow clay brick	Detached	Reinforced	202	303	33	33	235	336	572
			Confined	101	152	17	17	118	168	286
		Semi- adjoining	Reinforced	61	91	10	10	71	101	172
			Confined	30	45	5	5	35	50	86
		Adjoining	Reinforced	40	61	7	7	47	67	114
			Confined	20	30	3	3	24	34	57
	Concrete block	Detached	Reinforced	85	127	14	14	99	141	240
			Confined	36	55	6	6	42	61	103
		Semi- adjoining	Reinforced	95	143	16	16	111	159	270
			Confined	41	61	7	7	48	68	116
		Adjoining	Reinforced	32	48	5	5	37	53	90
			Confined	14	20	2	2	16	23	39
Rural	Handmade clay brick	Detached	Unreinforced	70	18	3	3	73	20	94
			Confined	53	13	2	2	55	15	70
		Semi- adjoining	Unreinforced	21	5	1	1	22	6	28
			Confined	16	4	1	1	16	5	21
		Adjoining	Unreinforced	7	2	0	0	7	2	9
			Confined	5	1	0	0	5	2	7
	Hollow clay brick	Detached	Reinforced	246	62	10	10	256	72	328
			Confined	123	31	5	5	128	36	164
		Semi- adjoining	Reinforced	41	10	2	2	43	12	55
			Confined	21	5	1	1	21	6	27
		Adjoining	Reinforced	82	21	3	3	85	24	109
			Confined	41	10	2	2	43	12	55
	Concrete block	Detached	Reinforced	31	8	1	1	32	9	41
			Confined	31	8	1	1	32	9	41
		Semi- adjoining	Reinforced	0	0	0	0	0	0	0
			Confined	0	0	0	0	0	0	0
		Adjoining	Reinforced	6	2	0	0	6	2	8
			Confined	6	2	0	0	6	2	8
<b>Total</b>				<b>1,800</b>	<b>1,700</b>	<b>198</b>	<b>198</b>	<b>1,998</b>	<b>1,898</b>	<b>3,895</b>