



STATISTICAL INDICATORS OF DEMOLITION DEBRIS
VOLUME

Bilen Gebremichael

Bachelor's thesis
May 2013
Environmental Engineering

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ABSTRACT

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BILEN GEBREMICHAEL:
Statistical Indicators of Demolition Debris Volume

Bachelor's Thesis. 44 pages
May 20113

In dealing with C&DW management the best solution up-to-date following the waste management hierarchy is recycling or material recovery. Starting from the beginning of 1980's the production of material from recycled C&DW has been the major input for major construction projects like road construction replacing primary aggregates. The demand for few of the recycled materials has been growing and so the need to find new application for the use of recycling materials and products. Though the recycling and production of new material has been the preferable choice in solving the problem facing C&DW to decide on selective demolition, the recycling industry is experiencing problems like lack of reliable statistical data and figures . Information on the different sources, type and amount of waste in comparison with the type ,size and age of structures to be built or demolished has a great advantage on giving the industry a clue what kind of situation they are dealing with.

This study provides an overall information on determining the volume and type of demolition waste produced using simple parameters of a structure that are available and easy to access. A general overview of the volumetric and design composition of a possible demolition waste generated from various typologies of buildings was done in advance to the study. Moreover, the attached residential buildings that are mostly common in the city of Oostende were chosen as sample building. The study mainly focused on pointing out indicators that are useful for comparing different components of a building. These indicators are used to estimate and define volume of other building components .The results that were achieved from this study, can later be used in similar studies of other typologies.

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ACKNOWLEDGEMENTS

As an Environmental Engineer, my interest has always been on making a change on the construction sector. I would like to thank Dr. Eeva-Liisa Visskari the head of department of environmental engineering in Tampere University of Applied sciences for making all the possible contacts in arranging the possibility of working my final thesis on the subject of my interest. I would also like to praise the effortless help and assistance I have been getting from all the member of the department of construction in KHBO- Katholieke Hogeschool Brugge-Oostende.

Chapter 1 Introduction

In the recent day's movement of reducing the carbon footprint of different industrial sectors which are responsible for the highest rate of emission. Series of actions taken on construction sector will have a significant role in creating some positive impact on the environment.

Each year millions of tons of construction materials are produced for constructing and renovating projects and millions are discarded from the demolition of such structures .In the production of such new materials an enormous amount of energy, resource and labor is used. On the other hand starting from the early 1980s the production of available construction materials recycled from demolition or construction debris is also increasing providing choice of materials and options in the market.

The use of recycled products from construction and demolition debris has many advantages: Reducing carbon print of the original material, increasing the life cycle of a product, creation of a link between past present and future in terms of material use, cost reduction ,providing another work sector for recycling companies. However, the use of such materials has been limited on few applications .Availability and competency on the market, quality, and acceptance by the industry and society can be mentioned as a reason for their limited use. In widening the use of this materials and promoting recycling of construction material many actions are being taken: The provision of nationwide policies in few countries by the government is seen as one of the first steps on making positive impacts on the construction sector. Nevertheless, as most specialists believe the change of our contractors' perception and ours about recycled materials in general will even have a bigger impact than government policies. In order to do this, different kind of studies either from the side of contractors or recycling industries is required on identifying material characteristics, possible new application of recovering and even further materials.

Furthermore recent demolition demonstration projects show that a high diversion rate of materials can be generated. (Giroux, 1997): However, an advanced estimation of the quantity and type of waste produced can help manage the whole process.

The quantity of materials can be estimated using several different approaches. It is not certain, however, that the predicted amount of materials will be the total amount that can be recycled. Factors such as the methods of demolition, separation, and collection will greatly influence the

amount of material that can be recycled. This study focuses on providing very important information in advance to a demolition project. This study can be used in general estimation of the quantity of materials produced from the different components of a building using simple and easily accessible parameters.

According to their use and age, buildings have different design arrangement, size, structural components and construction techniques. These characteristics of any building have an impact on the nature of materials generated on their demolition. Finding the common ground or a statistical indicator for the different typology of buildings in estimating the demolition volume is the major target of the project. Buildings of different typology in the city of Oostende, Belgium have being surveyed in identifying and selecting the most common typology as a sample for the study.

The attached low-rise buildings are the most common type of buildings that are commonly used as a residential blocks in most part of Belgium. Taking the fact that they are the dominant buildings in most cities, the attached residential blocks take a significant role in the production of demolition waste after the end of their life cycle. The study was done in identifying special parameters that a demolition contractor or a recycling industry can use in advance to a demolition of the sample building. The parameters are helpful in estimating the quantity and type of materials used.

The major problem the demolition sector including the recycling industry facing is contamination. Some build materials unless handled very carefully while demolition is hazardous. Selective demolition has been the major solutions for such problems. In addition, results from such a study are handy in identifying hazardous materials and their quantity.

1.1 Problem

In determining and categorizing different streams of demolition debris from each sample buildings, the variety of construction materials used was one of the challenges. Throughout the advancement of the construction technology, Buildings have used multiple materials and engineering skills. The physical and chemical characteristics of this materials used is also varying as the technology varies. Infact this creates a problem on the nature of today's

demolition waste. Mostly wall and floor finishes, insulation, roofing and partitioning walls are components of the buildings that the variation of materials is common.

Next to the variation of construction material used, the difference in design layout was the other challenge. The attached residential sample buildings mostly have a similar interior design layout. However some adjustments that are made on the design of individual blocks: facade design, interior openings, roof designs has a significant change on the volume of each component. Finding a way to identify the quantity of these components using simple indicators was another big task in the project.

1.2 Background

The major components of demolition waste are: Concrete, brick work, tiles, asphalt, metal, wood, etc. Concrete and masonry works, the major components of demolition are recycled in to aggregates. These aggregates are used as a primary input for road constructions and few building projects. (Dolan Patrick, June 1999)

The amount and type of demolition waste generated differs on the characteristics of the demolition project. This implies that the quantification of waste in each project also varies.

Demolition plans have been mainly used as quantifying documents for demolition waste. These documents are mainly prepared from the already existing plans of the buildings or by making an as built drawing for buildings with no available document. This process requires an additional work and labor according to the size of the project. In addition each building requires the same effort in order to achieve an accurate amount of demolition debris.

1.3 Scope and Objectives

- Provide a reliable data that can provide the appropriate indicators to determine the type, quality, measurability and quantity of demolition items with reclamation and recycling potential. The information can also be handy in Identifying removal methods, staff, time and storage area required.

- Through a thorough study of different typology of buildings this study will help provide a significant useful data for determining a quantity of demolition waste in advance to any demolition or renovation of residential attached buildings in the city of Oostende, Belgium.
- Create multiply construction models that can be used for determining volumes of demolition waste from different possible sources in the residential attached blocks.
- The quantification of demolition waste will have an adequate information on the construction and demolition waste management, and will provide data related with the choice of resource material, which is one of the early stages of project management in the in both construction and recycling industry, contributing to a sustainable development in the construction activity .
- Providing a statistical data that is useful in estimation of annual waste in production of waste assessment documents
- Provide information in determining demolition cost.
- Creating a mathematical index to determine and compare demolition waste volumes in different structures.
- Promote selective demolition and the recycling of demolition waste: The reuse of buildings and structures or part of the structure not only provides environmental benefits, but an opportunity to take advantage of the legacy that such reuse offers : maintaining heritage and connections between past, present and future generations.

Chapter 2 Methodology

2.1 Methodology

This research proposes a simple strategy to approach a demolition project by using readily available information of the building. This information regarding the professional involved is handy and simply accessible for any agent involved in construction or demolition process. Using this strategy we will not only be able to quantify and classify demolition wastes generated from the residential attached buildings but also will have a hint on how to manage the same problems for other typology buildings. In order to achieve the objectives of the study a structural that has three main steps was developed (Figure.1).

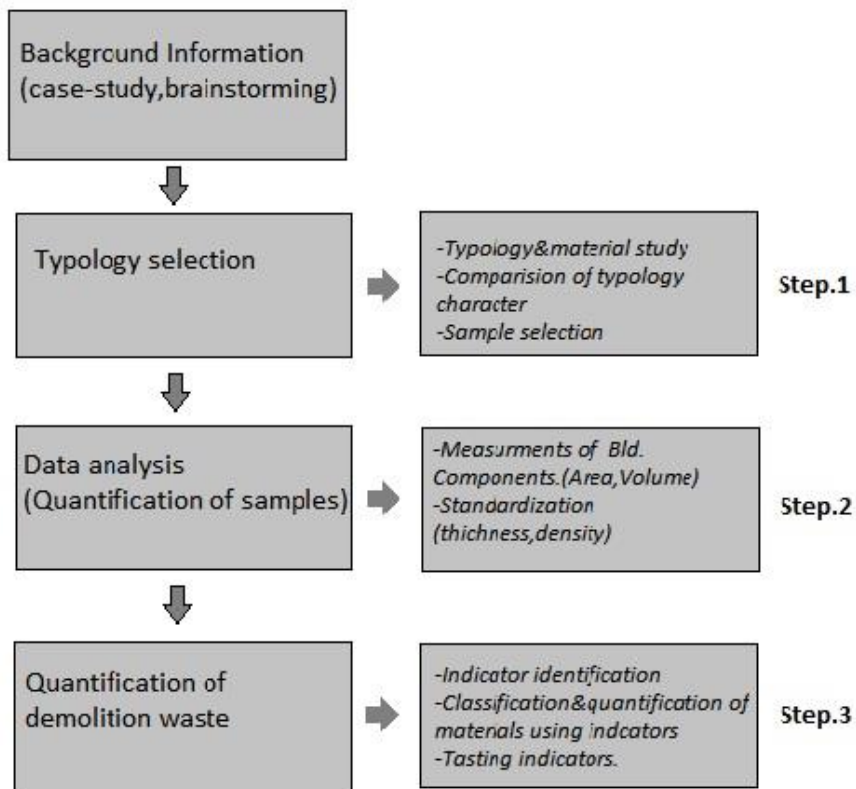


Figure 1 Methodological scheme

The first step of the study was gathering background information on similar studies and general information about demolition and demolition waste management. This was the process where most of the materials used for the whole study were collected. Once there was the general information, the next step was to identify the different local building materials and construction waste streams of each building component. The materials were then classified according to their application in each building component.

Table 1 Typical components of demolition and construction debris

<i>Material</i>	<i>Components Content Examples</i>
Wood	Forming and framing lumber, stumps, plywood, laminates
Wall finish	Drywall Sheetrock, gypsum, plaster
Metals	Pipes, rebar, flashing, steel, aluminum, copper, brass, stainless steel
Plastics	Vinyl siding, doors, windows, floor tile, pipes
Roofing	Asphalt & wood shingles, slate, tile, roofing felt
Brick	Bricks and decorative blocks
Glass	Windows, mirrors, lights
Rubble	Asphalt, concrete, cinder blocks, rock, earth
Miscellaneous	Carpeting, fixtures, insulation, ceramic tile

Source: U.S. EPA, Characterization of Building-Related Construction and Demolition Debris in the United States, 1999, Available at <http://www.epa.gov/epaoswer/osw/pub-c.htm> (accessed April,2012)

Furthermore, the typical demolition materials with recyclable capacity were classified according to their location in each building part. The classification was done by taking in the common construction materials and techniques used to accounts.

Table 2 Sources of recycle waste in building parts

<i>Building components</i>	<i>Recyclable materials</i>
Structure(Column, Beam, Structural wall)	Concrete ,Steel
Wall(Interior ,Exterior)	Brick ,concrete ,gypsum board, insulation
Floor	Concrete, wood, Floor finish, swage and electrical installations
Roof	Concrete, clay tiles, wood, Insulation
Openings	Wood, aluminum, glass, p.v.c

The next step in the study was a visual observation and study of different typology. The sample typologies were chosen randomly from different location of the city of Oostende, Belgium. Images taken from Google street view and personal site survey were used as a method to collect the samples. The study on each typology helped identify the nature of possible demolition debris that will be generated at the end of their life cycle. The observation directly relates the characteristic of the buildings with the type and quantity of demolition waste with a recyclable potential. The characteristic of the buildings includes the design layout, material usage, construction technique used, volumetric composition of components and age of construction. Here is the list of typologies covered under the study:

1. Attached residential blocks
2. Stand-alone residential blocks
3. Apartment Blocks
4. Public buildings

1. Attached residential blocks

The attached buildings are the most common type of buildings used as residential block in city areas. These buildings are mostly located in congested parts of the city facing the streets. Most of these building have 2-3 floors each with some having mezzanine floor for storing few items according to the necessity. According to the location of the blocks few of the blocks has garage at the ground floor.



Block.1



Block.2



Block.3



Block.4

Figure 2 Residential attached blocks: available at, <http://maps.google.de/maps> (accessed April, 2012)

The common observed features of the typology are:

- Similar facade design layout
- Similar use of construction materials
- Identical opening size and window to dead wall proportion
- Depending on the age of the blocks, the use of construction technique is different in few blocks.

2. Stand-alone residential blocks

The standalone residential buildings are the second most common blocks that are used for residential purpose. As the attached residential buildings most of the blocks has two floors and some a single floor with a bigger usable floor area and larger plot. In addition these blocks are widely located on the peripheries and suburb part of most cities.



Figure 3 Standalone residential block: available at, <http://maps.google.de/maps> (accessed March, 2012)

The common observed features of the typology are:

- Various design layout according to the needs of the owners and plot size
- Similar use of construction materials (Brickwork, concrete, clay tiles, wood, etc.)
- The use of similar roof design (pitch roofing)
- Common and similar use of openings

3. Apartment blocks

Due to the compact settlement of Belgian cities, apartments are widely used as residential block. According to their location, the plot size and number of floors of each block varies .Apartments that are close to the city centers and are located along the main roads mostly have commercial facilities on their ground floor.

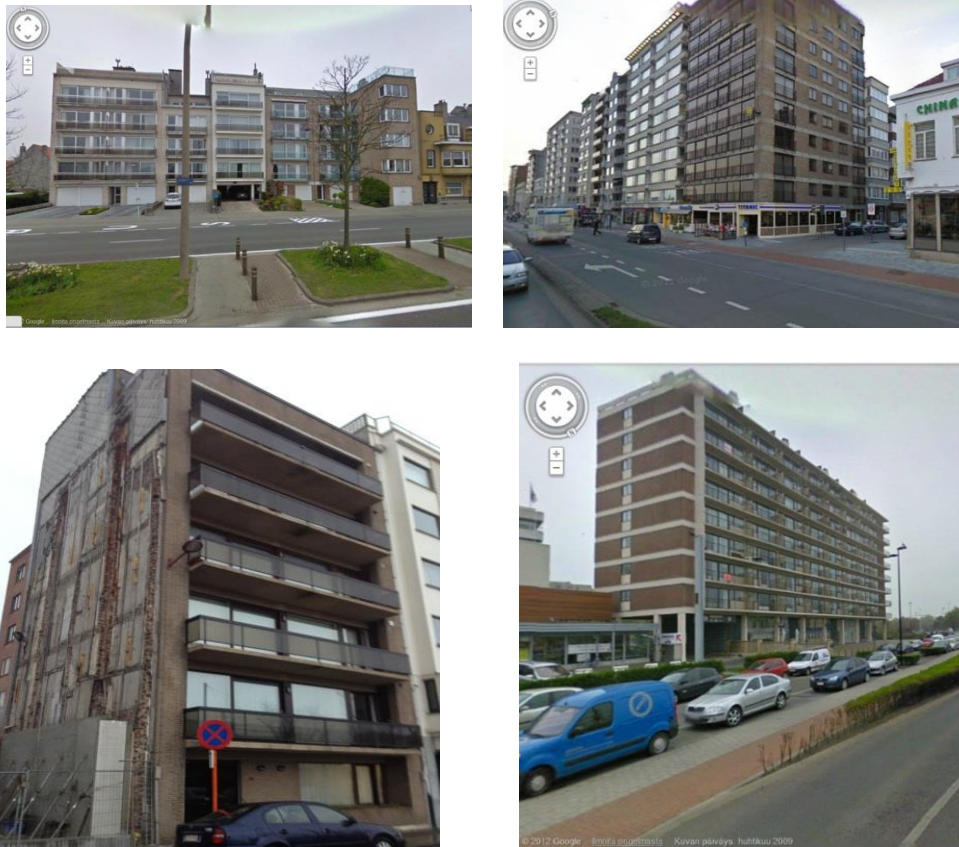


Figure 4 Apartment Blocks: available at, <http://maps.google.de/maps> (accessed April, 2012)

The common observed features of the typology are:

- More number of floors
- Wider and bigger floor areas depending on number of occupants
- Orthogonal design layout
- More interior partitioning walls
- Similar construction material usage (Brick work, Concrete, steel, glass, etc.)

4. Public building blocks

The public building blocks are mainly used as service buildings: schools, hospitals, recreational centers, libraries, etc. They are located in different parts of the city. According to their function this blocks have different design and size. In relation to the other typologies on the survey, the service buildings have wider usable floor areas. The use of various construction materials can also be seen vary in each blocks.

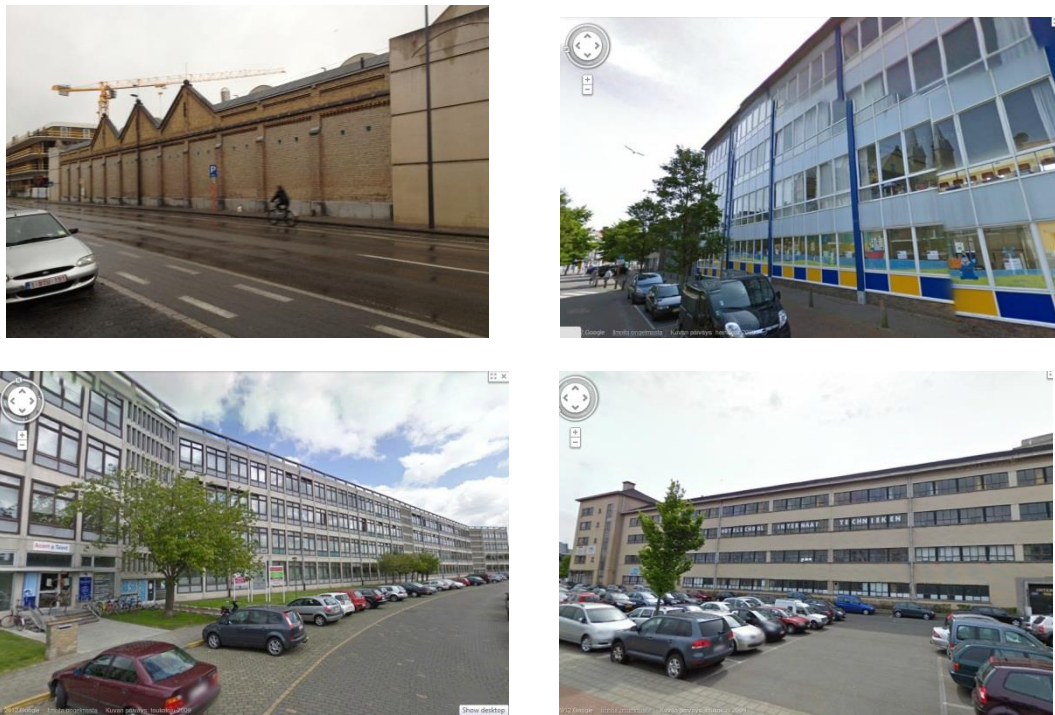


Figure 5 Public building blocks: available at ,<http://maps.google.de/maps> (accessed april,2012)

Common observed features on public building typology

- Bigger and wide total floor area
- Lesser interior partitions
- Wider openings and glazing
- Similar use of construction materials and techniques
- Orthogonal design layout

Finally, after a thorough study on four typologies, nine buildings were chosen from the residential attached blocks as sample buildings. Due to the difficulty of accessing construction drawings for the old buildings, the sample buildings are newly built models with similar characteristics with the typical residential blocks that are common in the city. Dimensions from the construction drawings were used in estimating areal and volumetric values of the different structure.

The next step on the project was to take a single sample in order to see the overall compositional feature of the different component and materials. The sample building was taken apart in to the following components.(Fig.6)

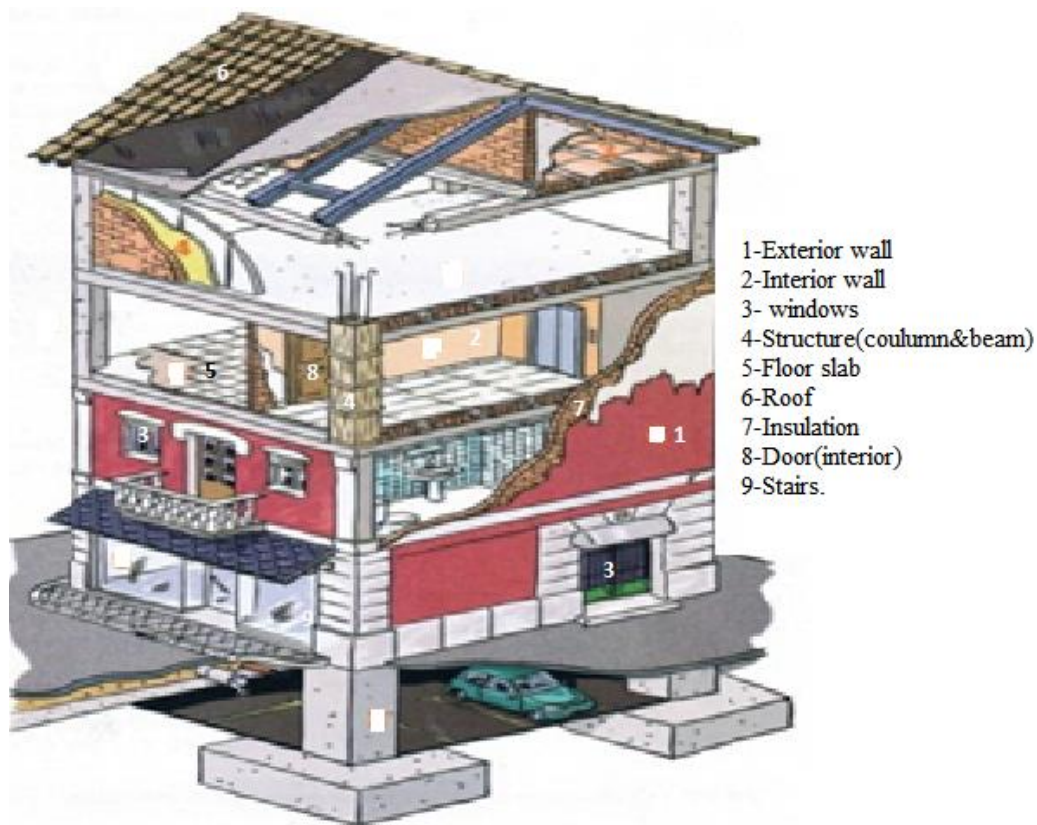


Figure 6 Building components: available at ,<http://www.shutterstock.com/pic->(accessed april,2012)

The volume of each component was calculated using dimensions from the construction drawings. The result was later used to compare the distribution of different components and construction material on the rest sample buildings.

Chapter 3 Results

3.1 Statistical Analysis of demolition volumes of buildings

Depending on their structural and functional use, different components of buildings have different volumetric composition. Studying an overall relation of volumes of the these components in the sample buildings is essential in identifying possible indicators that can be later used in estimation of demolition debris .In the beginning the volumetric analysis was done only on one sample and later on it was compared with result of the rest eight samples.

The first sample was used to relate the total volumetric composition of each component to the total volume of the block .The measurements were taken in a way that a possible accurate amount of demolition product can be estimated finally. However, an accurate measurement of the individual building component was also problematic. Some materials were not readily available for measurement or are included in the measurement of other material

Comparing the main components of the first sample (Table.1), the floor slab (38%) and Exterior wall (33%) takes the bigger part out of the total volume. Roofing (9%), Insulation (9%), and interior wall (6%) takes the rest consecutively.

Table 3 *Building components volumetric comparison (sample.1)*

<i>Bld. Component</i>	<i>Thickness/m</i>	<i>T. area/m²</i>	<i>T. volume/m³</i>	<i>Ratio /T. volume (%)</i>
Exterior Wall	0.15	324.6	57.15	33
Interior Wall	0.1	108.3	9.66	6
Insul.Wall	0.15	108.6	16.29	9
Slab	0.35	185.5	64.925	38
Staircase	0.35	5.2	1.82	1
Colum & Beam	0.4	11.7	4.68	3
Roof	0.25	63.5	15.875	9
Window/door	0.05	26.1	1.305	1
Door(Interior)	0.1	11.7	1.17	1
		Total .volume	173	

Using the result of the first sample the same comparison of possible demolition debris volume was done on the rest eight sample buildings (Figure.2). This taste was done in order to figure out the similarity of volume distribution of components throughout the sample buildings and the factors affecting it.

In defining volumes of each sample the thickness of material was a significant factor .The values for most building parts were taken straight from the construction drawings. However, for some of the components standard values were used.

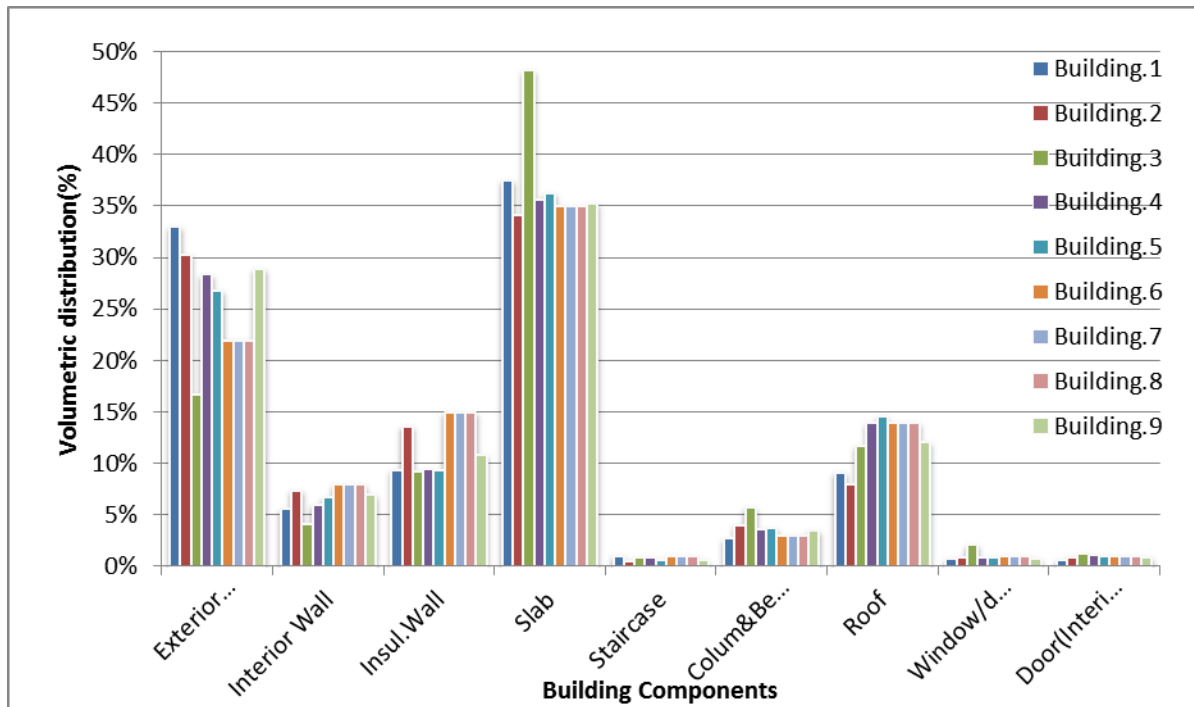


Figure.2 Volumetric Composition of Demolition debris components (Sample.1-5)

The observed factors from the comparison of volumes of building parts on the nine sample buildings are as follows:

- On eight sample buildings out of nine, the volume distribution of building parts was similar.
- The total usable slab volume takes the biggest part of the possible demolition debris with walls exterior and interior, roofing, insulation, structure following consecutively.

- The volume of interior walls, staircase, window, doors and structure is similar on each sample with negligence difference.
- Specific design characters of each sample building like; an open down from the first floor slab of sample.3, has significant effect on the volume distribution.

3.2 Building component analysis

In this section the measured value of each component is recorded. The measured values were converted in to possible parameters in identifying the possible relation of dimensions between building components. These measured values were converted in to possible parameters to formulate indicators. For materials which did not have correct measurements, standard values were considered according to the local construction practice.

3.2.1 Exterior wall, Interior wall , Insulation .Windows and Door analysis

3.2.1.1 The Exterior wall

Includes double layer freestanding wall (0.30m) with insulation (0.15m) and single layer Sidewalls (0.15m). Since the sample is a low energy building the thickness of insulation is higher than the normal old buildings. Brick work is the main construction material on most of the attached residential block with some having an extra wall finish. Wall surface is used as a parameter in determining the volume of possible demolition debris.

Exterior wall/ window ratio is used in comparing the maximum amount of solid wall produced and the total area of opening on the surface. Out of the nine sample buildings tested the possible percentage of solid wall produced while demolition was in a close range for the eight buildings. The result shows that an average of 89% is a sold wall and 11% of opening (Figure.7). The opening includes window and doors all located on the exterior wall. The distribution of exterior wall to window ratio is with the range of standard deviation 1% for each sample samples.

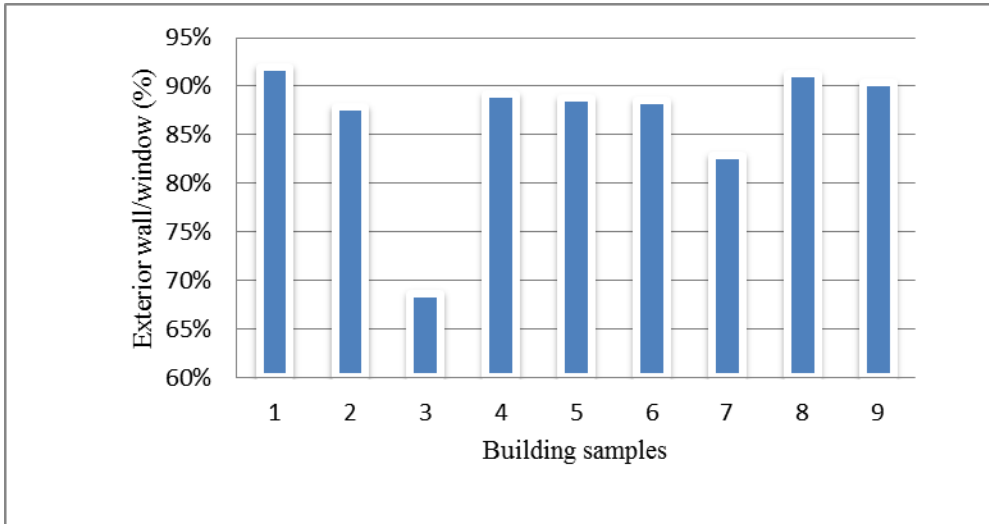


Figure 7 Exterior wall /window ratio

In most old attached blocks the side walls normally serve as a common wall for two blocks .In such particular case the use of a general exterior wall/window ratio does not give an accurate information in estimation of solid wall volume debris. Instead *Free wall/ window ratio* is more appropriate and can also be used in estimating volume of wall finishing materials and insulations. With the exception of sample 3 & 7 the free wall/window ratio shows an average of 76% is sold wall and the rest 24% opening on the free wall.

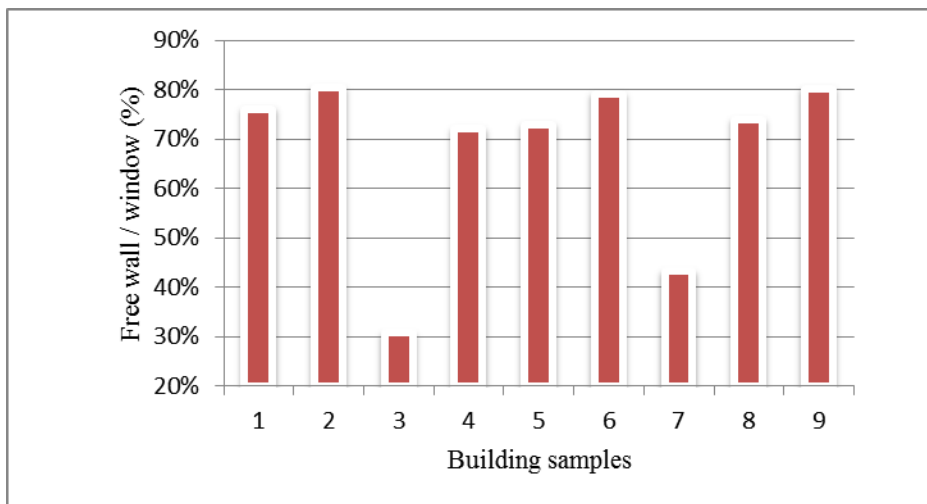


Figure 8 *Free wall / window ratio*

Table 4 Analysis of surface area of exterior wall to window and free wall to window

Bld. sample	Surface area (m ²)			Surface area/ window ratio (%)	
	Ext. Wall	Free wall	Window	Ext. wall/windows	Free wall/Window
1	298.6	82.6	26	92	76
2	203.4	115.2	28.2	88	80
3	103	20.8	47	69	31
4	173	54	21	89	72
5	206	70	26	89	73
6	209.8	102.8	27.2	89	79
7	132.2	20.7	27.3	83	43
8	213.6	57.6	20.4	91	74
9	200.6	86.6	21.4	90	80
			Average	87	76
			MIN	69	31
			MAX	92	80
			STDEV.S	7	18

The result on Sample 3 & 7 are considered exceptional in identifying the exterior wall volumes. In sample 3 the introduction of courtyard inside the block has extended an aerial coverage of the exterior wall. More over the introduction of floor to floor extending openings on the walls has made the *exterior wall/ window and free wall/ window ratio* quite less than the ratios observed on the rest samples. In sample 7 the free walls on the second floor are missing instead the roof serves as a wall. The total surface area and the ratios were only taken using the surface area of first floor exterior wall and the side walls of the second floor resulting on lesser values.(Table.4)

3.2.1.2 Interior walls:

Interior walls are the partitioning walls that are mainly used in dividing different spaces of a house hold. The nine sample buildings used brick partitioning wall with a thickness of 0.1m. In most residential attached blocks part of the brick interior walls serve as structural walls. However according to the functional use of the space and their structural purpose the use of gypsum boards and fiber board with higher sound insulation is also common in most residential blocks. In order to compare and estimate the amount of solid wall work produced from interior walls, *surface area/door area* ratio is used. The distribution of solid wall to opening was similar on all

sample buildings. The total solid wall work takes an average of 86% from the total wall area while the rest 14% is covered by doors. (Figure 8)

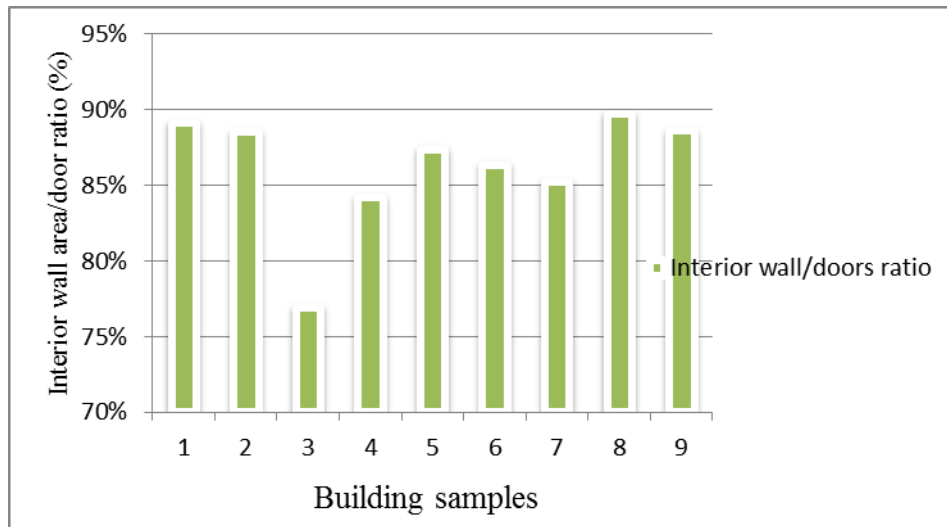


Figure 9 Interior wall area / door ratio

The specific difference of design features that was observed on sample 3 & 7 did not have a significant effect on the interior wall to opening distribution. Instead the number of rooms and the spatial arrangements of rooms are considered as factors affecting the distribution. Eventhough it is not as significant and dominant as the number of rooms and arrangements of spaces, the introduction of pitched roofs also plays a role in affecting the total volume of walls. Due to the geometric shape of pitched roofs the upper most floor walls have less area compared to normal flat roofed floors.

Keeping the areal comparison of sold wall work in both exterior and interior walls, an analysis on the distribution of each wall to the total wall area is essential in formulating indicators. *Exterior wall/Interior wall ratio* and *Interior wall/exterior wall ratio* (Figure.9) in all the nine sample building shows the distribution of surface area of exterior wall and Interior wall over the total surface area.

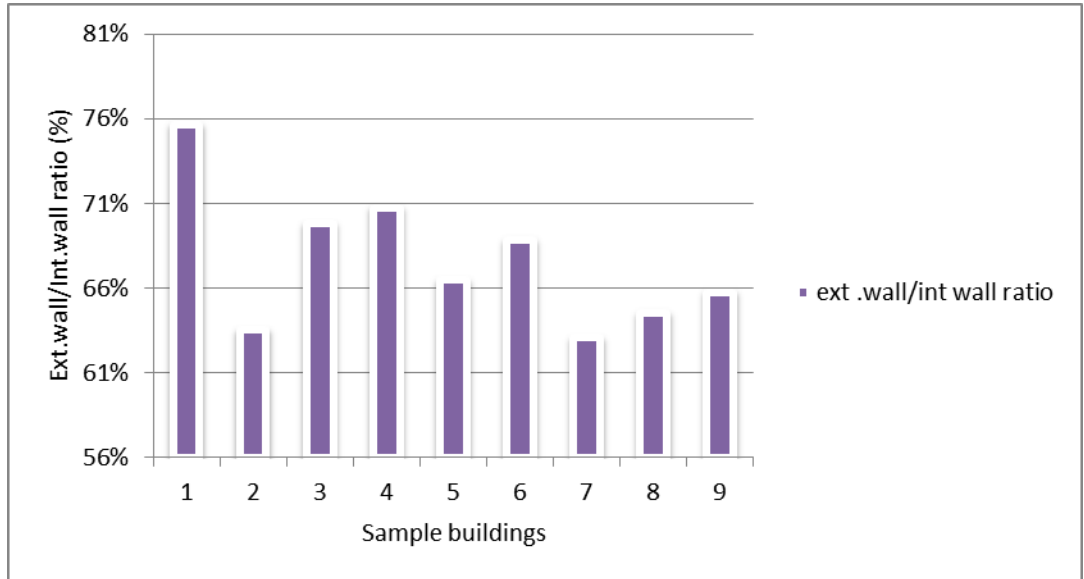


Figure 10 Exterior wall / Interior wall ratio

The distribution of surface area of exterior wall to the interior wall is similar in all samples with minor difference. The number of floor on sample 1 and special design features of the rest individual blocks are considered as factors affecting the distribution .An average from the nine sample shows 69%of total surface area of all the walls in the building is used as an exterior wall while the rest 31% is for interior walls. And this result can be used in estimation of the total mass of wall works that can be produce from any similar attached residential buildings.

Table 5 surface area of exterior wall and interior wall analysis

Bld. sample	Surface area (m ²)			Ext .wall/Int. wall (%)
	Ext. Brick wall	Int. Brick wall	Total wall	
1	298.6	96.3	394.9	76
2	203.4	116.9	320.3	64
3	103	44.6	147.6	70
4	173	71.6	244.6	71
5	206	104	310	66
6	209.8	95.1	304.9	69
7	132.2	77.5	209.7	63
8	213.6	117.5	331.1	65
9	200.6	104.5	305.1	66
			AVERAGE	68
			MIN	63
			MAX	76
			STDEV.S	4

3.2.1.3 Insulation wall:

Insulation wall is a wall located in between the doubled layers of exterior walls. Mostly it is part of the free walls. According to the construction period of the structure, the nature and thickness of material used varies from block to block. In this research all the samples used where energy low new blocks. Therefore the thickness (0.15m) of the insulation was higher than the normal blocks in the city .Since the insulation material is located on the free walls. The *free wall/window ratio* can be used in identifying the solid insulation wall produced from a single block. With the exception of special design features of blocks that is observed on sample 3&7 ,an insulation wall takes an average of 76%(Table.6) of total free wall area.

3.2.1.4 Windows:

Windows are all the openings located on exterior walls. Specifically most of the windows are located on the free walls and depending on the design of the blocks few are located on the roof. Regarding to materials each window has two main parts: wooden or aluminum frame work and glass. *Exterior wall/window* and *free wall/window ratio* can be used for estimating the total area of window covered on the walls (Table 4). *Exterior wall/window* ratio shows the total surface area of window covers 13% of the total exterior wall area .on the other hand 24%of a the free

wall area is covered by the window. In addition *Glass/frame ratio* was formulated in order to estimate the area of the frame work and glass out of the total area.(Table.)Out of the total window area an average of 91% is covered by glass and the rest 9% is covered by the frame.

Table 6 Surface areal analysis of window components

Bld. sample	Surface area(m ²)			Glass/frame (%)
	T. window	Frame	Glass	
1	26	2.08	23.92	92
2	28.2	2.36	25.84	92
3	47	4.33	42.67	91
4	21	1.86	19.14	91
5	26	2.08	23.92	92
6	27.2	2.3	24.9	92
7	27.3	2.3	25	92
8	20.4	1.8	18.6	91
9	21.4	1.9	19.5	91
			Average	91
			MIN	91
			MAX	92
			STDEV.S	0

3.2.1.5 Doors:

Doors are all the openings that are located on the interior partition walls. Wooden doors are mainly used on all the sample buildings .As that of the windows all the doors have two main parts the frame and the door panel. However both the frame and door panel are made of the same material and most of the times have the same thickness as well. The distribution of doors on most residential blocks is common. *Interior walls area/door* ratio shows the total door area covers an average of 14% out of the total interior wall area.

Table 7 Surface area ratio: Ext. wall/windows, Int.wall/door, Ext .wall/Int. wall, free wall/Window

Bld. sample	Surface Area Ratio (%)			
	Ext. wall/windows	Int.wall/door	Ext .wall/Int. wall	Free wall/Window
1	92	89	76	76
2	88	89	64	80
3	69	77	70	31
4	89	84	71	72
5	89	87	66	73
6	89	86	69	79
7	83	85	63	43
8	91	90	65	74
9	90	89	66	80
Average	87	86	68	76
MIN	69	77	63	31
MAX	92	90	76	80
STDEV.S	7	4	4	18

The above table clearly shows the volumetric relation between the three main components of a wall (Solid wall work, windows and doors) are in a close margin for each sample buildings. In addition the ratios indicates that the surface area of an exterior wall can be used as an indicator for the estimation of the amount of materials that can be produced out of the wall work.

With the total surface area of the exterior wall given and using the average values of ratios we have got above (Table .6) , we can use the following formulas to estimate the total surface area of exterior wall, interior walls, windows and door.

- **Surface area of solid wall** (*Ext. wall*) =0.87(*Exterior wall area*)
- **Exterior wall area**=0.68(*Total solid wall area*)
- **Total solid wall surface area**=1.47(*Exterior wall area*)
- **Interior wall area**=0.32(*Total solid wall area*)
 $=0.32(1.47(\textit{Exterior wall area}))$
 $=0.47(\textit{Exterior wall area})$

- **Total area solid wall** (*Int.wall*) = $0.86(\text{Interior wall area})$

$$= 0.86(0.47(\text{Exterior wall area}))$$

$$= 0.40(\text{Exterior wall area})$$

- **Insulation wall area** = $0.24(\text{Free wall area})$

On all the above formulas the *Exterior wall surface area* is used as a common factor in calculating each value. Therefore we can conclude that the *Exterior wall surface area* can be used as an indicator to estimate the quantity of any materials that can be produced from a wall work.

3.2.2 Floor slab, Column & Beam and Roofing analysis

3.2.2.1 Floor slab:

Volume and structure wise floor slab is the most dominant component of residential attached blocks. It takes an average 38 % of the total volume of each block. For the purpose of this study the floor slab is defined as a structural unit of a building which is used as flooring for the major activities of the household. Mezzanine floors which are not common on most blocks are considered as exceptional units. In all the nine sample buildings a floor slab has a thickness of 0.35m including 0.15-0.2m of reinforced concrete, cement mortar, installations and 0.05m cement screed takes the rest. In addition each floor slab depending on the function and esthetical value has an extra layer of floor finish. However, due to the difficulty of taking apart each unit while demolition the slab is taken as one bold unit. Looking the overall composition of a slab, one can clearly say that concrete is the major demolition debris that can be produced from floor slabs. According to the practiced construction technique hollow concrete ribbed slab and solid concrete slab are the two main flooring types that are common on residential attached blocks.. For the purpose of this study the value of solid slab is used.

Floor surface area is considered as a parameter in estimating material volumes acquired from a floor slab. Floor surface area is the summation of surface area of a slab and stair case. The area of a staircase is mainly included on the floor area of upper floors. In general The total floor area of a block depends on the number of floors in a block . However the effect of number of floors on the study samples is insignificant. As seen on the visual analysis of typologies, the number of floors for most attached residential blocks is either two or for few samples three.

Slab /staircase area ratio shows the distribution of the slab and stair case on the total floor area (Table.8).The usable slab floor area takes an average of 98% of the total floor area. The area of staircase is standard on every nine samples with minor difference. The difference on the number of floors does not make a change on the slab to staircase areal distribution.

Table 8 *Analysis of surface area of floor slab and staircase*

<i>Bld. sample</i>	<i>Surface area(m²)</i>			<i>Slab/stair ratio (%)</i>
	Total floor	Staircase	Slab	
1	185	5.2	179.8	97
2	153.5	2.4	151.1	98
3	152.2	2.7	149.5	98
4	122.4	3.1	119.3	97
5	160	2.8	157.2	98
6	168	2.6	165.4	98
7	188	2.6	185.4	99
8	158	2.6	155.4	98
9	150	2.6	147.4	98
			Average	98
			Min	97
			Max	99
			STDEV.s	0

3.2.2.2 Column & beams:

The structural parts of a block that is mainly responsible as a support for the major loads of the structure. Depending on span of structure they support column and beam have different sizes. Regardless of the plot area variation, in most of the sample buildings the total volume of column and beam is similar. It covers an average of 3% from the total volume of the main components. However the location of the individual unit in the block and the total number of floors play significant factor the minor difference on the total volume. The first and the last side units in each block have larger volume of column and beam. The column and beams on all sample buildings are made of reinforced concrete.

3.2.2.3 Roofing:

Next to floor slab and wall work roofing of a block takes an average 9% of the total volume of the main building components. Flat roof and pitched roofs are the two type of roofing that are common on the sample typology. Pitched roof as one bold unit has four main components: the roof cover, tress system, water proofing, and roof finishing. The roof cover which is clay tiles takes the bigger volume. Wooden trusses (0.15m*0.06m) are used for supporting the clay tile, water proof and wooden rafters (0.05m*0.07m) where the clay tile is nailed. The assumed average span for the roof trusses is 1.5m. The type and nature of water proofing and roof finish varies from block to block. Six blocks out of the nine have pitched roofs with different slope. In estimating the volume of roofing materials the area of roof mathematically relates with the slope of a roof and floor area. Keeping the area of floor constant the slope and area of roof are directly related. (Table.9)

Table 3 *Surface area of roof to slope comparison*

<i>Bld. sample</i>	<i>Surface area(m2)</i>			<i>Slope (%)</i>	<i>Roof type</i>
	Total floor	Single slab	Roof		
1	185	63.5	63.5	0%	flat
2	153.5	82	86	35%	pitched
3	152.2	84	63.4	0%	flat
4	122.4	67	67	0%	flat
5	160	80	90	35%	pitched
6	168	84	84	26%	pitched
7	188	92	128	45%	pitched
8	158	67	79	33%	pitched
9	150	63	72	26%	pitched

The flat roof on the other hand has three parts: Water proofing, roof slab and roof finish. Reinforced concert with a thickness of 0.15m is used mostly on roof slabs. The choice of water proofing and floor finish varies from block to block. In most cases the area of flat roof is similar with the area of the upper most floor slab.(Figure 10)

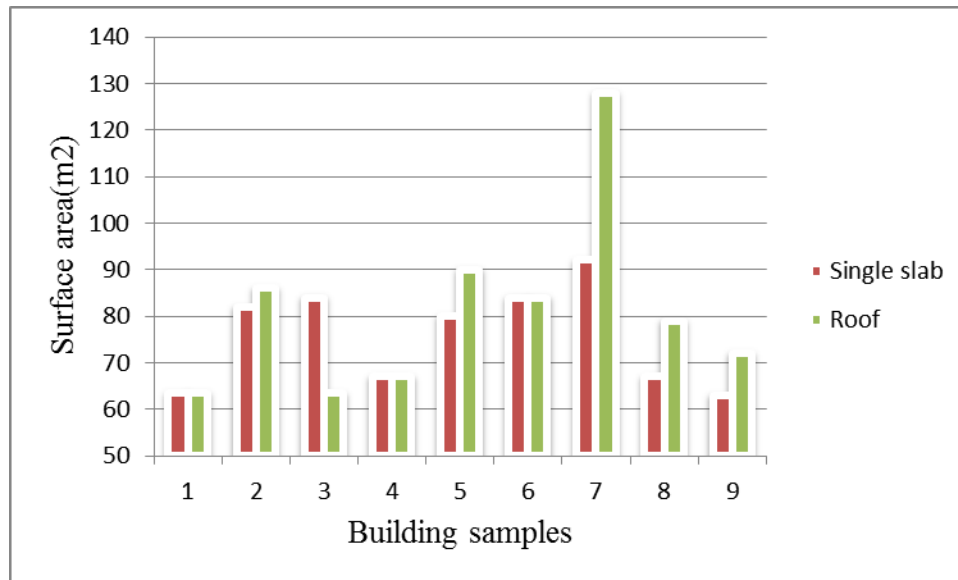


Figure 11 Single slab area to roof surface area comparison

Looking throughout the sample buildings the total roof area is affected by two main factors simultaneously: slab area it covers and the angle of inclination. These factors vary from block to block and sometimes from unit to unit. As a result finding a common ground for the estimation of final products acquired from roof is difficult. Instead the quantities can be estimated on site only by using the slope and span it covers.

3.3 Quantification of demolition volumes

Using the parameters from the analysis of building components, the different possible demolition wastes are quantified by formulating demolition models. The models are formulated based on possible existing combination of materials and their source on different parts of a building. The list of demolition waste from the sample buildings are: Concrete, brick wall, wall finish, Insulation, Floor finishes, glass, frames (wooden, steel), wood (door panel),

3.3.1 Concrete and Floor finish

Concrete: The sources of concrete in the sample builds are floor slabs, column & beams, staircase and roof slab depending on the roof type used. However the use of concrete staircase is not always common on all attached residential blocks. Wooden staircases are also used on some blocks. Depending on the sources of concrete four demolition models were constructed for the estimation of volumes. Surface areal ratio is used in order to determine the distribution of component for each model. (Table 10)

Table 10 Areal comparison of staircase, roof slab and column & beam

Bld. sample	Surface area(m2)				Ratio (%)		
	T. Slab	Staircase	Column & beam	Roof(flat roof)	T. floor	slab/staircase	Column & beam/ T.Slab
1	179.8	5.2	11.7	63.5	185	97	7
2	151.1	2.4	16.02	82	153.5	98	11
3	149.5	2.7	15.84	84	152.2	98	11
4	119.3	3.1	10.8	67	122.4	97	9
5	157.2	2.8	14.4	80	160	98	9
6	165.4	2.6	16.8	84	168	98	10
7	185.4	2.6	17.7	92	188	99	10
8	155.4	2.6	13.6	67	158	98	9
9	147.4	2.6	13	63	150	98	9
					Average	98%	97
					MIN	97	7
					MAX	98	11
					STDEV.S	0	1

The surface area of column & beam and staircase takes an average 9% and 2% of the total slab area and floor area consecutively. Based on these ratios the following equations are formulated for each four model in the estimation of concrete in attached residential buildings:

1. **Model- A** (Floor slab, Staircase, Column & Beam and Roof slab)

$$\begin{aligned}
 V_{TC} &= V_f + V_{cb} + V_s + V_r \\
 &= A_f . T_f + A_{cb} . T_{cb} + A_s . T_s + A_r . T_r \\
 (A_f &= 0.98 A_{t_f}, A_{cb} = 0.09 A_f, A_{cb} = 0.08 A_{t_f}, A_s = 0.02 A_{t_f}, A_r = 0.32 A_{t_f} \text{ (Flat .roof)}) \\
 V_{TC} &= 0.98 A_{t_f} . T_f + 0.08 A_{t_f} . T_{cb} + 0.02 A_{t_f} . T_s + 0.32 A_{t_f} . T_r \\
 &= 0.02 A_{t_f} (49 T_f + 4 T_{cb} + T_s + 16 T_r)
 \end{aligned}$$

Where: V_{TC} =Total concrete volume

A_f, V_f, T_f =Total floor area, total volume, thickness of floor slab

A_s, V_s, T_s = Total area, volume, thickness of staircase

A_{cb}, V_{cb}, T_{cb} =Total area, volume, thickness of column & beam

2. **Model-B** (Floor slab, Column & Beam and Stair case)

$$\begin{aligned}V_{TC} &= V_f + V_{cb} + V_s \\&= A_f \cdot T_f + A_{cb} \cdot T_{cb} + A_s \cdot T_s \\(A_f &= 0.98 A_{t_f}, A_{cb} = 0.09 A_f, A_{cb} = 0.08 A_{t_f}, A_s = 0.02 A_{t_f}) \\V_{TC} &= 0.98 A_{t_f} \cdot T_f + 0.08 A_{t_f} \cdot T_{cb} + 0.02 A_{t_f} \cdot T_s \\&= 0.02 A_{t_f} (49 T_f + 4 T_{cb} + T_s)\end{aligned}$$

3. **Model-C**(Floor slab, column & beam and Roof slab)

$$\begin{aligned}V_{TC} &= V_f + V_{cb} + V_r \\&= A_f \cdot T_f + A_{cb} \cdot T_{cb} + A_r \cdot T_r \\(A_f &= 0.98 A_{t_f}, A_{cb} = 0.09 A_f, A_{cb} = 0.08 A_{t_f}, A_r = 0.32 A_{t_f} (Flat .roof)) \\V_{TC} &= 0.98 A_{t_f} \cdot T_f + 0.08 A_{t_f} \cdot T_{cb} + 0.32 A_{t_f} \cdot T_r \\&= 0.02 A_{t_f} (49 T_f + 4 T_{cb} + 16 T_r)\end{aligned}$$

4. **Model-D**(Floor slab and Column & beam)

$$\begin{aligned}V_{TC} &= V_f + V_{cb} \\&= A_f \cdot T_f + A_{cb} \cdot T_{cb} \\(A_f &= 0.98 A_{t_f}, A_{cb} = 0.09 A_f, A_{cb} = 0.08 A_{t_f}) \\V_{TC} &= 0.98 A_{t_f} \cdot T_f + 0.08 A_{t_f} \cdot T_{cb} \\&= 0.02 A_{t_f} (49 T_f + 4 T_{cb})\end{aligned}$$

Table 4 *Quantification of concrete work in four demolition model*

<i>Construction model</i>	<i>Parameter</i>	<i>Indicator</i>	<i>Equation</i>
A	slab/staircase , column & beam/slab, Roof slab/slab	Total Floor area	$V_{TC}=0.02 A_{ff}(49 T_f+4T_{cb}+T_s+16 T_r)$
B	slab/staircase , column &beam/Slab,	Total Floor area	$V_{TC}=0.02 A_{ff} (49 T_f + 4T_{cb} + T_s)$
C	slab/staircase , column &beam/slab,	Total Floor area	$V_{TC}=0.02A_{ff}(49 T_f+4T_{cb}+16 T_r)$
D	slab/staircase , column &beam/slab,	Total Floor area	$V_{TC}=0.02 A_{ff} (49 T_f + 4T_{cb})$

By using the ratio as a parameter for each model, the volume of total concert produced can be calculated. As the equations show on all four models, the total floor area is used as an indicator. Taking the variation on the type and nature of concrete used for each component in to account, the thickness has been left unknown to make the equation flexible for further models.

Floor finish: in a single block depending on the function of the space, variety of floor finishes is used. The estimation of each product according to their categorization also varies both from space to space and block to block .As a result formulating a common indicator for different materials used is difficult. Instead this project suggests an overall estimation of total floor finish used in each block without categorizing the materials used.

For the purpose of the study all the entire floor slab including the staircase is assumed to have floor finish .With assumption we can use total floor area as an indicator in estimating the total volume. In formulating the equation for calculating the volume slab/staircase ratio is used as a parameter.

$$\begin{aligned}
V_{TFF} &= V_{ffs} + V_{fs} \\
&= A_f \cdot T_{ffs} + A_s \cdot T_{fs} \\
(A_f &= 0.98 A_{ff} , A_s = 0.02 A_{ff}) \\
V_{TFF} &= 0.98 A_{ff} \cdot T_{ffs} + 0.02 A_{ff} \cdot T_{fs} \\
&= 0.02 A_{ff} (49 T_{ffs} + T_{fs})
\end{aligned}$$

Where: V_{TFF} = Total floor finish volume

V_{ffs}, V_{fs} = Total floor finish volume (floor slab, staircase)

A_{ff}, A_f, A_s = Total floor area (Total floor, floor slab, and staircase)

T_{ffs} = Slab floor finish thickness

T_{fs} = Staircase floor finish thickness

3.3.2 Brick work, Insulation ,Glass and wood

Brickwork: Both exterior and interior walls are the sources of brickwork in the sample buildings. Depending on the demolition or renovation of project and the position of individual unit in the block, the amount of brick work produced varies. Three demolition models were made in estimating the volume of brick work for different possible scenarios. The different relation collected from the analysis of wall components were used as parameter in identifying the indicators and formulating equation for calculating the final volumes in each model.

1. Model-A(Exterior wall(2 sidewalls, 2 free walls),Interior walls)

$$\begin{aligned}
V_{TB} &= V_{SEW} + V_{SIW} \\
(V_{SEW} &= V_{SW} + V_{SFW} , V_{SW} = A_{SW} \cdot T_{SW} , V_{SFW} = A_{SFW} \cdot T_{fv}) \\
\text{where : } &T_{fv} = 0.3m, T_{sw} = 0.15m, T_{fw} = 0.1m \\
V_{SEW} &= 0.15 (A_{SW} + 2A_{SFW}) = 0.15 (A_{SEW} + A_{SFW}) \\
(V_{SIW} &= 0.1A_{SIW} , A_{SEW} = 0.87 A_{EW} , A_{SIW} = 0.4A_{EW} , A_{SFW} = 0.76 A_{FW}) \\
V_{TB} &= (0.15(0.87 A_{EW}) + 0.15(0.76 A_{FW})) + 0.1(0.4A_{EW}) \\
&= 0.17 A_{EW} + 0.11A_{FW}
\end{aligned}$$

Where: V_{TB} = Total brick work volume

$(V_{SEW}, V_{SIW}, V_{SFW}, V_{SW})$ = Volume of solid (exterior wall, Interior wall, freewall, sidewall)

$(A_{SW}, A_{SFW}, A_{SEW}, A_{SIW})$ = Surface area of solid (Sidewall, freewall, exterior wall, interior)

(A_{EW}, A_{FW}) = Total surface area (exterior wall, Free wall)

T_{Iw} = Interior wall thickness

T_{fw} = Free wall thickness

T_{Ew} = Exterior wall thickness

2. Model-B (Exterior wall(2 free wall), Interior walls)

$$V_{TB} = V_{SEW} + V_{SIW}$$

$$(V_{SEW} = V_{SFW}, V_{SFW} = 0.3A_{FW}, V_{SIW} = 0.1A_{SIW}, A_{SIW} = 0.4A_{EW})$$

$$\text{where } : T_{fw} = 0.3m, T_{sw} = 0.15m, T_{Iw} = 0.1m$$

$$V_{TB} = 0.3A_{SFW} + 0.1A_{SIW}$$

$$= 0.23A_{FW} + 0.04A_{EW}$$

3. Model-C (Exterior wall(3 free wall), Interior walls)

For this model all the data from the nine sample buildings were analyzed again by converting the values of one of the side wall to free wall values.

$$V_{TB} = V_{SEW} + V_{SIW}$$

$$(V_{SEW} = V_{SFW}, V_{SFW} = 0.3A_{FW}, V_{SIW} = 0.1A_{SIW}, A_{SIW} = 0.4A_{EW}, A_{SFW} = 0.84A_{FW})$$

$$\text{where } : T_{fw} = 0.3m, T_{sw} = 0.15m, T_{Iw} = 0.1m$$

$$V_{TB} = 0.3A_{SFW} + 0.1A_{SIW}$$

$$= 0.25A_{FW} + 0.04A_{EW}$$

Table 5 Free wall to window comparisons for quantifying brick work (Model-C)

Bld. sample	Surface area(m2)		Free wall/window
	Freewall	Window	
1	190.6	26	88%
2	159.3	28.2	85%
3	61.9	47	57%
4	113.5	21	84%
5	138	26	84%
6	156.3	27.2	85%
7	76.45	27.3	74%
8	135.6	20.4	87%
9	143.6	21.4	87%
		average	84%

As the equations show on all three models, the total exterior wall area and total freewall area are used as an indicator. The thickness of wall in each model is assumed as constant

Table 6 Quantification of Brick work in three demolition models

Construction model	Parameter	Indicator	Equation
A	Freewall/Window	Total exterior wall area, Total freewall area	$V_{TB} = 0.17A_{EW} + 0.11 A_{FW}$
	Exterior wall/Interior wall		
B	Freewall/Window	Total exterior wall area, Total freewall area	$V_{TB} = 0.23 A_{FW} + 0.04 A_{EW}$
	Exterior wall/Interior wall		
C	Freewall/Window	Total exterior wall area, Total freewall area	$V_{TB} = 0.25 A_{FW} + 0.04 A_{EW}$

Insulation: In each sample building the insulation of a block covers the entire free wall. The use of free wall/ window ratio is used as a parameter in identifying the final volume. Depending on the location of individual unit in the block the number of free wall varies. Taking this to account two demolition models are formulated for the estimation of volume. The data from (Table.12) is used on Model-B.

1. Model-A(2 free wall)

$$V_I = A_I \cdot T_I, A_I = 0.76A_{FW}$$

$$V_I = 0.76A_{FW} \cdot T_I$$

Where: V_I = *Insulation Volume*

A_{FW} = *Insulation Area*, T_I =*Insulation Thickness*

2. Model-B(3free wall)

$$V_I = A_I \cdot T_I, A_I = 0.84A_{FW}$$

$$V_I = 0.84A_{FW} \cdot T_I$$

Where: V_I = *Insulation Volume*

A_I = *Insulation Area*, A_{FW} =*Free wall area*, T_I =*Insulation Thickness*

Glass and Frame work: the only source of glass on the sample buildings is the windows. The window analysis shows that the window has two parts: frame and glass. The glass and frame takes 91% and 9% of the total area. Free wall /window ratio is used as parameter in estimating the volume of glass and frame work.

$$V_G = A_G \cdot T_G, V_F = A_{FM} \cdot T_{FM}$$

Where: $A_G = 0.91 A_W, A_{FM} = 0.09 A_W, A_W = 0.24 A_{FW}$

$$V_G = 0.91(0.24 A_{FW}) \cdot T_G, V_{FM} = 0.09(0.24 A_{FW}) \cdot T_{FM}$$

$$V_G = 0.21 A_{FW} \cdot T_G, V_{FM} = 0.02 A_{FW} \cdot T_{FM}$$

Where: V_G = *Total glass volume*

V_G, V_{FM} = *Total floor finish volume (floor slab, staircase)*

A_G, A_{FM} = *Total floor area (Total floor, floor slab, and staircase)*

T_G = *Glass thickness*

T_{FM} = *Frame thickness*

Door panel: The door panel is mainly made out of wood most of the sample buildings. The doors are located on interior partitioning walls. Interior wall ratio is used as parameter in

estimating its volume. In case of variation on the material the door panel is made off, the total volume is estimated without categorizing the material type.

$$V_D = A_D \cdot T_D, \quad (A_D = 0.14A_{IW}, \quad A_{IW} = 0.47A_{EW} \quad T_D = 0.1\text{m})$$

$$V_D = 0.14A_{IW} \cdot 0.1 = 0.014(0.47A_{EW})$$

$$V_D = 0,006 A_{EW}$$

Where: V_D = Door panel Volume, A_D = Door panel Area,

T_D = Door panel Thickness, A_{IW} = Interior wall Area, A_{EW} = Exterior wall Area

Table 7 Demolition debris quantifying equations

<i>Demolition debris</i>	<i>Model</i>	<i>Quantifying Equation</i>	<i>Indicator</i>
concrete	A	$V_{TC} = 0.02 A_{ff}(49 T_f + 4T_{cb} + T_s + 16 T_r)$	Total floor area
	B	$V_{TC} = 0.02 A_{ff}(49 T_f + 4T_{cb} + T_s)$	
	C	$V_{TC} = 0.02 A_{ff}(49 T_f + 4T_{cb} + 16 T_r)$	
	D	$V_{TC} = 0.02 A_{ff}(49 T_f + 4T_{cb})$	
Brick work	A	$V_{TB} = 0.17A_{EW} + 0.11 A_{FW}$	Total exterior wall area & Total freewall area
	B	$V_{TB} = 0.23 A_{FW} + 0.04 A_{EW}$	
	C	$V_{TB} = 0.25 A_{FW} + 0.04 A_{EW}$	
Insulation	A	$V_I = 0.76A_{FW} \cdot T_I$	Total freewall area
	B	$V_I = 0.84A_{FW} \cdot T_I$	
Glass		$V_G = 0.21 A_{FW} \cdot T_G$	Total freewall area
Frame work		$V_{FM} = 0.02 A_{FW} \cdot T_{FM}$	Total freewall area
Door panel		$V_D = 0,006 A_{EW}$	Total exterior wall area
Floor finish		$V_{TFF} = 0.02 A_{ff}(49 T_{ffs} + T_{fs})$	Total floor area

Chapter 4 Conclusions

As it was mentioned on the objective, the study provides usable statistically studied indicators for estimating demolition materials acquired from residential attached blocks. In general the indicators used on each material can be divided into two major categories according to the orientation of the building components they are located in.

- A. Horizontal component Indicator (Total floor area, Single floor area): These indicators were used to determine the volume of materials from horizontally aligned elements of a building: Concrete, floor finish, and roofing
- B. Vertical component indicators (Exterior wall area, Free wall area): These indicators were used to determine the volume of materials from vertically aligned elements of a building: Brick work, glass, insulation, framework and wall finish

From the analysis of each building component and formulation of parameters the study emphasizes that the indicators used in identifying volumes is common for most of the materials. Furthermore the following points are concluded from the analysis of building components:

- The distribution of major building parts is similar on all the sample buildings regardless of the size of individual block.
- The total slab and wall volume takes the biggest part of demolition debris that is used as an input for the recycling sector.
- Dead wall to opening and floor surface area ratios were used as a tool in identifying the relation between different components that can be produced out of wall works, floor slabs and few structural parts.
- The location of individual unit in the block, special design features by the private demand of the owners (Open down, mezzanine floor, larger and glazing's, roof design) and the period of construction affects the volumetric distribution of building components.

In terms of quantification of materials the study has particularly focused on creating multiple demolition models that can address one of the problems stated on the beginning of this report: the variation of construction materials from block to block. The demolition models show the possible combination of construction materials in different scenarios. This gives an advantage in

for the quantification of materials selective demolition and renovation projects. The models were constructed mainly for materials that cover bigger part of demolition debris. In addition this methodology expands the option of using common indicators and quantifying equation on variety of residential attached blocks. Moreover looking up to the quantification of materials and formulation and equations the study concludes the following points:

- Total surface area of floor, free standing wall and general exterior wall are the basic building measured component required in estimating the volume of major demolition debris(Concrete, brickwork, insulation, wood)
- Thickness of materials which might vary on the special characteristics of the materials on each block can be considered as a factor in determining the final volume. However materials like exterior and interior wall brick and door panels depending on their application on residential attached blocks stays constant.
- The formulation of further demolition models for an additional possible material composition is handy in narrowing down the variation total volume estimation.

Finally the results from this paper can be used as a plat form in expanding the identification of indicators for other typology buildings and the approach that is used in estimating volume of materials can be used straight with few modifications. Further studies by widening the sample selection on the same typology can provide more accurate data for the different demolition materials extracted.

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