The development of construction waste production indicators for the Irish construction industry

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Abstract

This study has produced unit waste production factors (kg/m^2) for new construction in Ireland for 2005. The Environmental Protection Agency (EPA) has estimated that construction and demolition waste (C&D W) has increased from 1.52 million tonnes in 1995 to 16.28 million tonnes in 2006. These estimates are primarily based on C&D W quantities received at licensed and permitted facilities throughout the country. An audit methodology was developed and tested on 54 construction projects throughout Ireland over a two-year period to examine waste production on site. Each project was assessed over a 6-month period providing a 'snapshot' analysis. Average unit waste factors of 70.27kg/m^2 for new residential construction, 86.82kg/m^2 for new private non-residential construction, 138.94kg/m^2 for new social infrastructure construction and 48.48kg/m^2 for new productive infrastructure construction were generated. The generation of unit waste production factors for the different construction activities will enable the industry to benchmark their performance and provide indicators for future improvement.

Keywords: waste, construction, demolition, composition, quantities, audit, Ireland, indicators, methodology, sustainable, built environment.

1 Introduction

The Irish construction industry has experienced unprecedented economic growth over the past fifteen years. Construction output in 2006 was estimated at €35.5 billion representing 24 per cent of Gross National Product (GNP). In the second

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quarter of 2007, it was estimated that 280 300 people were employed directly or indirectly by the construction/civil engineering industry. This accounted for 13.4% of total employment and 22% of all jobs created in the previous twelve months [3].

The growth of the construction industry with all its economic benefits also has had some negative environmental impacts. In 2006, it was conservatively estimated that 16.28 million tonnes of C&D W was produced in Ireland [2]. This represents over half (55%) of the total non-agricultural waste generated. This phenomenal increase can be in part but not wholly attributable to improved reporting and the use of different estimation methodologies. None of these methodologies included data on site waste production.

The government has recognised the seriousness of this issue by setting out targets for the construction industry to recycle and/or recover 85% of this waste stream by 2013 [4]. One of the main difficulties in achieving these targets is the lack of reliable statistics to benchmark C&D W production in Ireland.

This paper will outline research carried out by the Construction Waste and Built Environment research group at the Galway-Mayo Institute of Technology over a two-year period into the generation of data on C&D W production on site by:

- Producing unit waste generation factor (kg/m^2) for the new construction sector.
- Identifying the main components of the C&D W stream on site.
- Developing and testing an audit methodology on 54 construction project throughout the country.

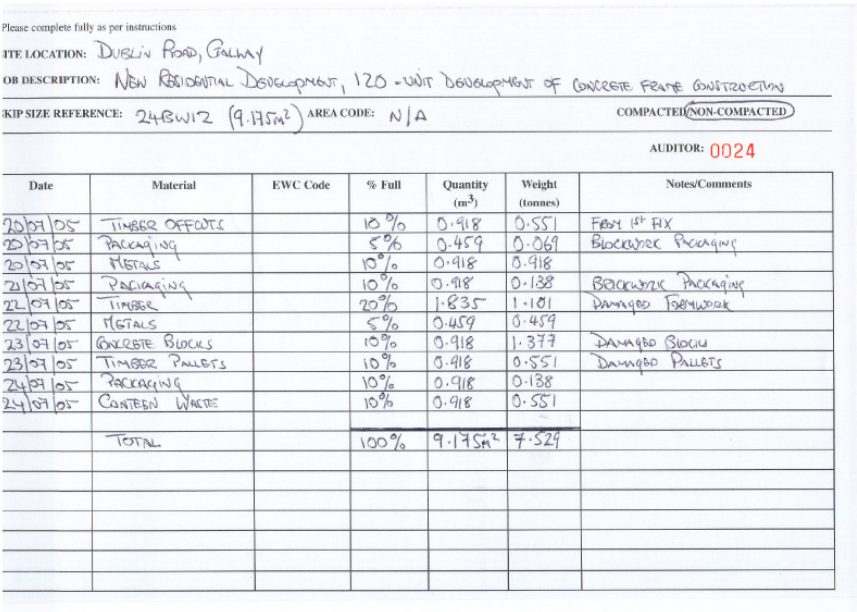
2 Methods

The main resource in this study was the third-year students of the B.Sc. (Honours) in Construction Management in the Department of Building and Civil Engineering at the Galway-Mayo Institute of Technology. Each year the students must complete a 6-month site placement on a construction/civil engineering project. Each student acted as a point source assessor on his/her work placements measuring waste production on site. This provided a waste production 'snapshot' of 54 projects over a two-year period (2004 and 2005).

Prior to testing on site, it was decided to develop a practical audit methodology incorporating the following key considerations [5]:

- Identification of waste management practices on site including skip management, on-site burning and reuse of materials.
- Selection of a method for measuring the waste. A visual assessment of skip contents was used.
- Classification of the C&D W categories. This involved a balance between the accuracy required and the number of different waste materials being produced on site.
- Provision of on-site arrangements. This was dependent on the project type and site constraints.
- Analysis of the data to produce the required results e.g. composition and quantity.

A waste audit book consisting of waste audit sheets (Figure 1) and a supplementary monthly report format was developed and distributed to the students (point source assessors). To ensure reliable data collection, a C&D W module was developed as part of the construction management curriculum consisting of lectures, workshops and site visits.



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ITE LOCATION: DUBLIN ROAD, GALWAY

OB DESCRIPTION: NEW RESIDENTIAL DEVELOPMENT, 120 - UNIT DEVELOPMENT OF CONCRETE FRAME CONSTRUCTION

KIP SIZE REFERENCE: 24BW12 (9.175M³) AREA CODE: N/A COMPACTED/NON-COMPACTED

AUDITOR: 0024

Date	Material	EWC Code	% Full	Quantity (m^3)	Weight (tonnes)	Notes/Comments
20/07/05	TIMBER OFFCUTS		10%	0.918	0.551	FROM 1ST FIX
20/07/05	PACKAGING		5%	0.459	0.069	BLOCKWORK PACKAGING
20/07/05	METALS		10%	0.918	0.918	
21/07/05	PACKAGING		10%	0.918	0.138	BLOCKWORK PACKAGING
22/07/05	TIMBER		20%	1.835	1.101	DAMAGED FORMWORK
22/07/05	METALS		5%	0.459	0.459	
23/07/05	CONCRETE BLOCKS		10%	0.918	1.377	DAMAGED BLOCKS
23/07/05	TIMBER PALLETS		10%	0.918	0.551	DAMAGED PALLETS
24/07/05	PACKAGING		10%	0.918	0.138	
24/07/05	CONTEEN WASTE		10%	0.918	0.551	
	TOTAL		100%	9.175M³	7.529	

Figure 1: Example of a waste audit sheet.

The methodology was a basic skip analysis using visual assessment to identify and quantify all the materials being taken off site in skips/bins/containers. Each audit sheet recorded the following:

a. Auditor name.
b. Date.
c. Site location including postal address.
d. Project description including project category and method of construction.
e. Skip size reference including skip size and name of supplier.
f. Area code identifying the location of the skips.
g. Compacted/non compacted skip contents.
h. Material description including appropriate European Waste Catalogue (EWC) code [6] if applicable.
i. Percentage full by visual assessment.
j. Conversion from percentages to volume (m^3).
k. Conversion from volume to weight (m^3 to kg) using the conversion factors provided in the *Waste Management (Landfill Levy) Regulations 2002* [7] (Table 1).
l. Notes/comments identifying any waste management practices.

Table 1: Conversion factors used [7].

Waste Category	m^3 to tonnes
Inactive or inert waste	x 1.50
Paper and plastics	x 0.15
Cardboard, pallets, plasterboard, canteen waste	x 0.40
Timber/wood	x 0.60
Building and construction, mixed C&D W	x 0.60
Others	x 1.00

This data was collated at the end of each month to produce a monthly report containing the following:

- Name of auditor.
- Project description.
- Total floor area (m^2).
- Phase of the project.
- Completed floor area (m^2) at the end of each month.
- The volume of each waste material generated in that month.
- Number of skips/bins/containers taken off site.
- Volume waste factor (m^3 of C&D W/m^2 of completed floor area).

The submitted data was reviewed each month validating and categorising the factors produced in the monthly reports. The submitted volumes were converted to weights to produce a weight waste factor (kg of C&D W/m^2 of completed floor area). The submission of the monthly reports enhanced the value of the 'snapshot' audits by combining primary data (measurements and causes) and secondary data (demographics such as construction activity, skip sizes and number etc.) to put them in context with the overall framework of the project.

3 Results

3.1 Project categories

Each project audited was divided into categories as used by the EPA in the *National Waste Database Report 2001* [8]:

- New residential (new private and public housing).
- New private non-residential (private and semi-state industry, commercial, agricultural, tourism and worship).
- New productive infrastructure (water and sanitary services, airports, harbours, energy and telecommunications).
- New social infrastructure (education, health, public buildings, local authority services and the Gaeltacht).

3.2 Generation of waste production indicators

Each project 'snapshot' audited was termed a point source assessment (PSA). For each site, the total C&D W produced (m^3) was divided by the completed floor area (m^2) to give the volumetric waste factor (m^3/m^2). The volume of C&D W was converted into kilograms using the conversion factors outlined in the *Waste Management (Landfill Levy) Regulations 2002* [7]. This figure was then divided by the completed floor area to produce the weight waste factor (kg/m^2). A mean was calculated for each category producing the following results:

- The new residential construction category had an average unit waste factor of 70.27kg/m^2 based on 19 audited projects (Table 2).
- The new private non residential construction category had an average unit waste factor of 86.82kg/m^2 based on 22 audited projects (Table 3).

Table 2: New residential construction results.

Reference	Total Waste (m^3)	Total Waste (tonnes)	Completed Floor Areas (m^2)	Waste Factor (m^3/m^2)	Waste Factor (kg/m^2)
PSA 1	109.656	32.605	2 850	0.039	11.440
PSA 2	390.920	140.703	13 104	0.030	10.737
PSA 3	200.164	135.197	9 000	0.022	15.022
PSA 4	86.290	55.572	2 800	0.031	19.847
PSA 5	21.910	9.155	234	0.094	39.124
PSA6	281.010	143.720	4 158	0.068	34.565
PSA 7	197.977	81.848	2 295	0.086	35.664
PSA 8	98.426	83.114	5 400	0.018	15.391
PSA 9	376.850	312.570	7 290	0.052	42.877
PSA 10	210.270	144.281	454	0.463	317.800
PSA 11	755.270	577.124	2 000	0.378	288.562
PSA 12	102.542	63.276	960	0.107	65.913
PSA 13	164.267	63.369	1 375	0.119	46.087
PSA 14	37.612	25.515	1 375	0.027	18.556
PSA 15	297.569	210.958	2 057	0.145	102.556
PSA 16	89.799	65.240	486	0.185	134.239
PSA 17	504.467	435.579	6 942	0.073	62.745
PSA 18	117.630	59.335	1 688	0.070	35.151
PSA 19	736.530	832.588	21 400	0.034	38.906
Totals	**4 799.159**	**3 471.749**	**85 868**	**2.041**	**1 335.182**
Total weight waste factors (kg/m^2)/no. of sites = 1 335.180/19 =					**70.27 kg/m^2**
Total volume waste factor (m^3/m^2)/no. of sites = 2.041/19 =					**0.107 m^3m^2**

- The new social infrastructure construction category had an average unit waste factor of 138.94kg/m^2 based on nine audited projects (Table 4).
- The new productive infrastructure construction category had an average unit waste factor of 48.48kg/m^2 based on three audit projects (Table 5).

Table 3: New private non-residential construction results.

Reference	Total Waste (m^3)	Total Waste (tonnes)	Completed Floor Areas (m^2)	Waste Factor (m^3/m^2)	Waste Factor (kg/m^2)
PSA 1	221.000	86.060	4 391	0.050	19.599
PSA 2	663.500	442.065	14 300	0.046	30.914
PSA 3	1163.040	689.597	16 920	0.069	40.756
PSA 4	415.600	272.820	5 227	0.080	52.194
PSA 5	80.650	45.453	576	0.140	78.911
PSA 6	137.800	87.665	880	0.157	99.619
PSA 7	320.000	218.190	2 000	0.160	109.095
PSA 8	351.800	239.720	1 814	0.194	132.145
PSA 9	980.300	837.595	5 670	0.173	147.724
PSA 10	276.300	369.505	2 200	0.126	167.957
PSA 11	455.150	266.206	900	0.506	295.784
PSA 12	282.910	201.362	700	0.404	287.660
PSA 13	480.015	230.383	7 820	0.061	29.461
PSA 14	59.346	48.730	1 725	0.034	28.249
PSA 15	71.223	37.301	400	0.178	93.253
PSA 16	414.758	233.749	5 090	0.082	45.923
PSA 17	139.560	132.490	5 456	0.026	24.283
PSA 18	20.873	11.237	900	0.023	12.486
PSA 19	34.563	18.959	867	0.040	21.867
PSA 20	344.276	239.842	2 256	0.153	106.313
PSA 21	26.618	9.270	285	0.093	32.526
PSA 22	300.856	182.430	3 425	0.088	53.264
Totals	**7 240.138**	**4900.629**	**83 802.000**	**2.883**	**1909.983**
Total weight waste factors (kg/m^2)/no. of sites = 1 909.983/22					**86.82 kg/m^2**
Total volume waste factors ($kg/m2^2$)/no. of sites = 2.883/22					**0.131 m^3/m^2**

3.3 Composition of 'snapshot' point source assessments

The composition of C&D W varied according to project type/activity. The identification of the individual waste components is essential in establishing waste prevention and minimisation targets. The methodology used aimed to

Table 4: New social infrastructure construction results.

Reference	Total Waste (m^3)	Total Waste (tonnes)	Completed Floor Areas (m^2)	Waste Factor (m^3/m^2)	Waste Factor (kg/m^2)
PSA 1	53.500	34.650	2 080	0.026	16.659
PSA 2	120.169	97.965	5 780	0.021	16.949
PSA 3	356.750	271.415	6 853	0.052	39.605
PSA 4	289.620	119.538	1 817	0.159	65.789
PSA 5	164.000	144.640	404	0.406	358.020
PSA6	124.413	86.947	328	0.379	265.082
PSA 7	150.531	88.543	2 584	0.058	34.266
PSA 8	468.500	351.216	1 344	0.349	261.321
PSA 9	613.080	399.288	2 071	0.296	192.800
Totals	**2340.563**	**1594.202**	**23 261**	**1.746**	**1 250.491**
Total weight waste factors (kg/m^2)/no. of sites = 1 250.491/9					**138.94kg/m^2**
Total volume waste factors ($m3/m^2$)/no. of sites = 1.746/9					**0.194m3/m^2**

Table 5: New productive infrastructure construction results.

Reference	Total Waste (m^3)	Total Waste (tonnes)	Completed Floor Areas (m^2)	Waste Factor (m^3/m^2)	Waste Factor (kg/m^2)
PSA 1	54.133	23.222	295	0.184	78.719
PSA 2	84.413	54.387	975	0.087	55.782
PSA 3	51.768	25.673	2 349	0.022	10.929
Totals	**190.314**	**103.282**	**3 619**	**0.293**	**145.430**
Total weight waste factors (kg/m^2)/no. of sites = 145.430/3					**48.48kg/m^2**
Total volume waste factors (m^3/m^2)/no. of sites = 0.292/3					**0.098m3/m^2**

identify the composition by utilising the appropriate EWC codes [6] combined with a general material description. This produced nine main categories as follows:

- Inert waste (excluding excavated materials).
- Paper, plastics and packaging.
- Timber/wood.
- Plasterboard.
- Canteen waste.
- Building and construction/mixed C&D W.
- Metals (including their alloys).
- Insulation materials.
- Miscellaneous waste.

It should be noted that no excavated material i.e. soil and stones, was included in the results as none were placed in the skip. The inert waste category recorded consists of materials such as concrete, blocks, brick, tiles and ceramics.

3.3.1 Composition results

The composition was expressed in volumes as this identified the waste fractions that occupied the most space in the skips. The biggest contributors in the overall composition of all the audited projects (Figure 2) were: timber/wood (28%); paper, plastics and packaging (17%); inert waste (16%); metals (13%) and building & construction mixed waste (11%).

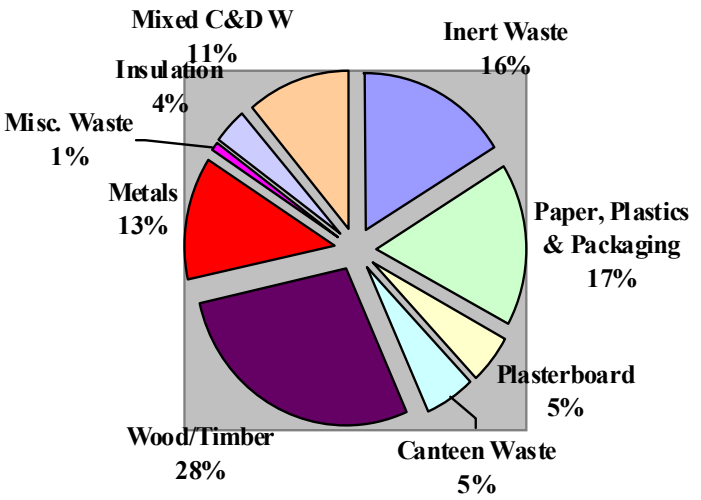

Figure 2: Total project category composition by volume (m^3).

Each individual category followed a similar trend with:

- Wood, inert waste and paper, plastics and packaging accounting for 66% of total waste produced in the *new residential construction* category.
- Wood, metals and paper, plastics and packaging accounting for 65% of total waste produced in the *new private non-residential construction* category.
- Wood, mixed C&D W and paper, plastics and packaging accounting for 68% of total waste produced in the *new social infrastructure construction* category.
- Wood, paper, plastics and packaging and miscellaneous waste accounting for 73% of total waste produced in the *new productive infrastructure* category.

4 Limitations

The main aim of this study was to produce C&D W production indicators for new construction in Ireland. 'Snapshot' audits were carried out on 54 projects during 2004 and 2005 generating average waste production indicators for new construction. The main limitations of the study were as follows:

- Each audit was a 'snapshot' measurement of a project over a six month period with the majority of projects at different phases in the construction process. This affected the results where a project in the initial stages had negligible amounts of C&D W (excluding excavated materials) as opposed to a project 50% completed.
- The number of sites audited (particularly in the *new productive infrastructure* category) was insufficient to provide a high degree of statistical confidence especially in the presence of some extreme observations in each category. The audits should continue to generate larger sampling sizes for each category thereby increasing the statistical confidence in the results.
- The unreliability of the conversion factors used. The original function of the conversion factors as outlined in the *Waste Management (Landfill Levy) Regulations 2002* [7] was to enable landfill operators calculate the amount of landfill levy payable on certain materials. They are not specific to the C&D W stream. This was examined on a new social infrastructure project in the Galway region where a comparison was made between the application of the conversion factors to a visual audit and the actual total weight of the same skips weighed at a waste transfer facility [9]. The total weight of the skips weighed on the waste transfer facility's weighbridge was 71.40 tonnes. The visual audit and application of conversion factors yielded a total weight of 230.35 tonnes, nearly three times the actual recorded weight.
- The use of visual assessment and the estimation of waste bulking or air voids. The auditors had to estimate the variation in the consistency of the skip's total contents by considering: the degree of compaction the waste has undergone (if any); the poor placement of waste materials creating air voids; the irregular consistency of some waste types; and the irregular shape of some waste containers.
- The accuracy of the visual assessment is totally reliant on the expertise and diligence of the auditor. Coventry *et al*. [10] has found that a close correlation can be achieved in visual skip contents when compared to actual skip contents, demonstrating that an experienced auditor can make accurate measurements.

5 Conclusion

The generation of C&D waste production indicators based on Irish construction projects will enable the industry to benchmark their current waste management performance and set targets for future improvement. It is recommended that the methodology discussed in this paper be further developed and used so that the

construction industry can voluntarily audit their own activities, thereby producing accurate and reliable statistics.

Acknowledgements

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