DETERMINING CONSTRUCTION DEBRIS RECYCLING DUMPSTER DENSITIES

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ABSTRACT

Solid waste generated by construction and demolition (C&D) projects account for a significant portion of solid waste generated and landfilled in the United States. The United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) credit system encourages recycling of C&D debris. Data from a new construction project adhering to LEED® guidelines is used to investigate dumpster densities *for construction debris. These are conversion factors from waste collection volumes to waste masses useful for verification of recycling credit goals, estimating waste management needs and optimizing waste management costs. The proper estimation of waste material dumpster density is important in order to combine sustainability with cost effectiveness.*

The field data was generated from a 9700 m^2 (104,000 ft^2) building under construction in Columbia, South Carolina with a precast concrete and brick veneer. The categories of waste investigated were general trash, masonry, wood, steel, and sheetrock. It was found that there are significant differences in many of the conversion factors for this project as compared to factors from other waste material recycling databases.

INTRODUCTION

Sustainable Construction is a rapidly expanding industry within the United States as evidenced by the growing influence of the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED®) rating system. This system provides metrics and awards points for the following six areas of sustainable construction: 1) Sustainable Sites, 2) Water Efficiency, 3) Energy Efficiency, 4) Materials and Resources, 5) Environmental Quality and 6) Innovations in Design (USGBC 2003a). Up to 69 points are awarded within these categories for which two points are available within the materials and resources category for recycling construction and demolition (C&D) debris for new construction. Projects which can attain 26 or more points from the total 69 available can be 'certified' as a LEED® project. In addition, the project can receive *Silver*, *Gold* or *Platinum* certification for obtaining more than 32, 38, or 51 points respectively.

C&D debris is a large portion of the wastes generated in the United States. It was estimated that for 1996 C&D debris from vertical construction and demolition alone (buildings) exceeded 135 million tons (Franklin Associates 1998). Therefore there is great interest in recycling C&D debris and keeping it out of landfills. The LEED® rating system provides a metric for determining C&D recycling amounts for new construction and earning the prestige of being a 'green' building.

The LEED® credits for recycling C&D debris must be verified in order to receive the credits and the rating system allows for verification based on either volume or mass of the materials. There is a table of suggested volume to mass conversion factors in the LEED® version 2.1 reference guide (USGBC 2003b), for six general categories: cardboard, gypsum wallboard, mixed waste, rubble, steel and wood. However this environmental rating system is so new that there are no referenced sources for these conversion factors based on actual construction practices adhering to the LEED® guidelines. There is a need to determine if the suggested LEED® and other conversion factors for the density of recycled construction waste material are applicable to the dumpster volumes and waste management practices at green construction sites.

This study introduces *dumpster density* as a term to describe the volume to mass conversion factors applicable to C&D recycling at new construction sites

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adhering to the LEED® rating system. Dumpster density is defined as the mass of waste material in a dumpster divided by the dumpster's rated volume. The term dumpster density was established to help clarify that the voids within the dumpsters were being taken into account for all calculations. These dumpster densities are important for the calculations necessary for verification of LEED® credits, but are also useful in estimating waste handling needs such as dumpster volumes and container yard space requirements. The dumpster densities are useful in determining cost effective fee structures for waste removal contracts and could be used for recycling cost optimization analyses.

The field data for this study came from a six-story, 9700 m^2 (104,000 ft^2) research and teaching laboratory under construction in 2005 by the University of South Carolina in downtown Columbia, South Carolina. It is being constructed with the goal of receiving a LEED® Silver rating for which a minimum of 33 points is required. Two of these points are expected to be earned in the construction waste management area of the LEED® 2.1 Manual. The construction debris waste stream data from this study is representative of this type of construction in the South Carolina region. The five categories of wastes investigated for dumpster densities included general trash (mixed waste), masonry (similar to rubble), wood, steel and sheetrock (gypsum wallboard). This information is also useful for comparison to other field studies across the country and other types of facilities constructed as the green building boom presents more opportunities for data collection in the future.

BACKGROUND

A frequently cited study related to this research is a 1996 report prepared for the United States Environmental Protection Agency (USEPA) on building related C&D debris in the United States (Franklin Associates, 1998). This USEPA report characterized and quantified waste generated by new construction, demolition and renovation in the United States. It provided estimates of national C&D generation rates utilizing case study data and Census Bureau data. The percentages of C&D debris generated by construction, demolition and renovation activities were separately estimated for residential and nonresidential construction. It further separated C&D debris into composition percentages of material types for several of the activities. These material types include such categories as brick, concrete, roofing, plastics, metals, drywall, rubble, asphalt and wood. The USEPA report did not address the characteristics and costs associated with managing each type of waste during a project where separation is onsite for recycling purposes related to the LEED® credit system. The dumpster density research is a natural follow up to this EPA study by lowering the focus of study down to a detailed look at several types of waste.

The LEED® reference package has a table that lists suggested factors for converting waste on a construction site from volume to mass (USGBC 2003b). Six common construction waste materials are listed: cardboard, gypsum wallboard, mixed waste, rubble, steel, and wood. The conversion factors listed are intended to assist in formulating a waste management plan and verifying credits within the framework of the LEED® rating system. No specific background data or source reference is directly provided for these conversion factors. Construction debris recycling following the LEED® template is so new that field studies such as the one in Columbia, SC are just starting to provide the engineering data to refine these suggested conversion factors. The need also exists to gather data on a wider range of materials in order to provide more flexibility to planners in order to select which materials to sort from the waste stream. Currently it is not possible to determine if the LEED® conversion factors are applicable to waste materials loaded into dumpsters, piled loosely on the ground or having been mechanically compacted at a waste transfer station. This dumpster density study provides an additional source of information to allow a better understanding of construction waste as it is generated at field sites and transported to disposal facilities.

A more detailed source of C&D waste conversion factors is found in a 1991 report submitted to the California Integrated Waste Management Board (CalRecovery 1991). This report covers a broad range of solid waste materials including materials typical to municipal waste as well as C&D waste.The data came from field data collected in one week from two recycling facilities in California, a mail survey to targeted facilities in California and a literature search from many sources outside and inside California.The data

tabulations included many bulk densities of various materials in several more detailed categories such as loose, crushed, whole or semi-compacted. The CalRecovery study included data on concrete (loose and less than 20 cm (8 inch) in size), brick (loose and less than 20 cm (8 inch) in size), sheetrock (loose and less than 0.6 meters (2 feet) in length), and wood (loose and less than 0.6 meters (2 feet) in length) from the recycling facilities which are of interest in this research and will be presented for comparison to the LEED® suggested conversion factors and the research findings. In addition, it contained a listing for 'loose ferrous' (other than containers) from a recycling facility which can be used in the steel C&D debris category. The other ferrous listings from the CalRecovery study are usually for containers such as food containers both in the loose and crushed forms, and are not applicable for C&D debris comparisons.

Several articles have also been published which describe methods to estimate the generation of Construction and Demolition debris and to develop waste optimization tools. Researchers at the University of New Hampshire estimated the overall volume of waste based on building permit value and the general type of construction (new residential development, residential renovation, new commercial development, and commercial renovation) (Yost & Halstead 1996). Specific material properties were not presented. Another article presented an estimating system for quantifying wastes of wood, gypsum drywall, roof asphalt shingles and carpet from C&D projects (Touran et al. 2004).

Two other reports developed workable systems and spreadsheet tools that can be used to estimate the cost of implementing a construction waste management plan (Wang et al. 2004, Mills 2001). Information from research such as the dumpster density study in Columbia, SC could be used in implementing these tools.

In general, literature on solid waste management with regards to municipal solid waste (MSW) and hazardous materials (HAZMAT) is abundant. Construction and demolition debris waste recycling is not well documented. Regulations are also much less prevalent for C&D waste and tend to be more along the lines of recommendations than enforceable laws and standards (SCC 2004). As a result, there is a need for C&D recycling research. No studies were found that describe the characteristics of waste in dumpsters at a new construction site or the costs associated with disposing of these sorted wastes by the dumpster load.

METHODS

The intent of this study was to obtain information that could be useful in refining/validating the suggested C&D debris conversion factors listed in the United States Green Building Council's (USGBC) LEED® 2.1 Manual (USGBC 2003b). The University of South Carolina was constructing a new research and teaching facility in downtown Columbia, SC during 2004 and 2005. Data was collected, observed and recorded on the contents of seven construction debris waste dumpsters over an eleven month period ending in September 2005. This record was combined with data provided from the builders that included volume, weight, tipping fees, handling fees, and disposal (recycling or landfilling) location for most of the waste removed from the construction site. This information is useful in determining how to economically recycle waste while abiding by LEED® requirements to track waste by either weight or volume.

The categories of waste studied were general trash, masonry, wood, steel and sheetrock. General trash was handled as a separate waste material and was not recycled, but was sent to landfills. As the name implies general trash is simply all the material that was left over after the recyclables or reusables were separated out. Note that there were piles of bricks and other materials deemed still usable that were not discarded but piled on the site for use at the site in addition to the materials separated into dumpsters for recycling. The other four material categories plus cardboard were separated into dumpsters with the intent of being recycled. Detailed information on volumes, weights and costs were not available for all the dumpsters investigated or all the materials at all times. Two different waste haulers were used for all the material groups except steel and cardboard (general trash, masonry, wood and sheetrock) during the course of the investigation and each had different waste management billing practices. Only the second of these two haulers generated invoices with detailed information on volume, mass and cost. The steel was hauled by a third recycling contractor and even

though volume and mass information were available, there were no costs to the owners for this service due to the value of the steel. Therefore, cost information for steel was not available for collection and analysis.

All the data on volume and mass were used whenever complete for the five categories investigated. As mentioned, there were also dumpsters for collecting cardboard present at the construction site for the duration of the study. However, there was no hauling and billing information provided on the recycling for the cardboard dumpsters and this category has therefore not been included in the analysis.

The five material categories investigated at the University of South Carolina can be approximately related to five of the six LEED® conversion factor categories (USGBC 2003b). General trash is similar to mixed waste, masonry is similar to rubble for construction debris, sheetrock is another name for gypsum wallboard, and steel and wood are the same for both.

Four of these five material categories studied in Columbia, SC can also be related to the CalRecovery conversion factors as itemized previously with the masonry as a combination of the CalRecovery recycling data on both concrete and brick listed as loose and less than 20 cm (8 inch) in size. The sheetrock and the wood recycling data used from the CalRecovery study were listed as loose and less than 0.6 meters (2 feet) in length). The steel recycling information was taken from the recycling category of loose ferrous other than containers. The CalRecovery study did not include information on general trash, as it was a 'recovery' (recycling) study (CalRecovery 1991).

For comparison, it was also of interest to compare the dumpster densities to the specific gravity of the materials researched. Information on all the source material densities except for general trash, which is too undefined, was taken from a published materials book. These material source densities were provided in an approximate range for brick and concrete, as the many different types of brick and concrete have varying densities. The wood was also presented in an approximate range as the various woods have very different specific gravities. The sheetrock source densities were also given in a range as sheetrock comes in different thicknesses and for various uses with roof sheathing usually less dense than floor gypsum. The steel densities do not vary as much and a single example was used (AISC 1980).

The dumpster densities of each material from the study in Columbia, SC were calculated using the volume and mass information contained on the tipping sheets and material sales receipt for each load as provided by the haulers and the general contractor. The dumpster density for each material was calculated with the equation:

$$\text{Dumpster Density} = \text{Material Mass} / \text{Dumpster Volume} \quad (1)$$

For the calculations the assumption is made that all of the dumpsters were 100% full at the time of landfilling or recycling. To back up this assumption the dumpster contents were physically inspected and photographed approximately three times a week. It was apparent that the dumpsters were generally full at the time of removal, but checking the levels as the dumpsters were removed was not possible. The construction foreman and construction superintendent were questioned about how they coordinated for dumpster pick-up. When the dumpsters were approximately full, the hauling companies were called to pick them up and replace them with empty dumpsters. This first hand knowledge helps to validate the volumetric assumption utilized for the dumpster density calculations. The dumpsters were as full as would be expected under normal construction activities where the policy is to call for a pickup when the dumpsters are close to being full. It is also possible that some of the dumpsters might be also grossly overloaded by the time the hauler arrives for pickup. Whether overloaded, underloaded or exactly full, the data on the dumpster weights should still give a good representative average of typical weights that might be hauled in the representative size dumpsters under typical field conditions with a reasonable amount of construction debris management and oversight.

Rain data was also collected for the Columbia, SC metropolitan area from the local airport data on the internet to see if precipitation was a factor in dumpster densities.

FINDINGS

Table 1 lists the five waste materials researched in the Columbia, SC construction debris study. This table contains a summary listing of typical source material densities for all the categories except general trash, which is composed of so many different materials

that there is no one source material to compare it to. The LEED® conversion factors as currently suggested in the LEED-NC version 2.1 Reference Package are listed in this table for all five categories studied (USGBC 2003b). There is also a listing of each of the bulk densities from the recycling center study in California (CalRecovery 1991). These bulk densities are taken from materials in the loose form and with sizes less than 20 cm (8 inch) for the masonry items and less than 0.6 m (2 feet) in length for the wood and sheetrock categories as previously listed in the methods section.

The data collected from the construction site in Columbia, SC from late 2004 through early fall of 2005 are listed in the last three columns of Table 1. The average dumpster densities are provided, followed by the minimum, maximum and standard deviation of these dumpster densities. The number of data points (dumpster loads for which complete mass and volume data were provided) is listed in the last column for the Columbia, SC study.

The general trash dumpster density in the Columbia, SC study varied significantly from load to load. Factors that may impact this density include the composition of the trash and the amount of water retained in the containers due to precipitation. These densities range from a low of 170 kg/ m^3 (280 lbs/cy) to a high of 910 kg/ m^3 (1540 lbs/cy). The variation in density is expected given the wide variety of waste materials generated during different phases of construction. The average dumpster density for general trash is 360 kg/ m^3 (600 lbs/cy). This is more than 50% higher than the suggested conversion factor in the LEED® Reference Package (USGBC 2003b). Since it is not known exactly where the suggested factor came from, it is difficult to make a good comparison, however, if the general trash conversion factor comes from, for instance, standard municipal mixed waste, then it may also include a significantly higher proportion of textiles, paper and other organic material that may alter the value. Figure 1 is a photo of a dumpster containing general trash at the Columbia, SC construction site.

The dumpster densities for masonry were calculated by dividing the mass by the volume of the loads and this method of calculation assumed that the con-

TABLE 1. Calculated average, maximum, minimum and standard deviation (SD) of dumpster densities from the Columbia, SC study as compared to literature values and density of the solid source material.

Waste Material	AISC (1980) Source Material Density kg/m^3 (lbs/CY)	LEED® Conversion Factor kg/m^3 (lbs/CY)	CalRecovery Bulk Density kg/m^3 (lbs/CY)	Calculated Dumpster Avg. Density kg/m^3 (lbs/CY)	Calculated Density Summary kg/m^3 (lbs/CY)	# of Data Points
General Trash (Mixed Waste)	NA	210(350)	NA	360(600)	Min 170(280) Max 910(1540) SD 170(290)	34
Masonry (Rubble)	1780 to 2370 (3000 to 4000)	830(1400)	960(1610) (Brick) 1100(1855) (Conc)	1000(1680)	Min 720(1220) Max1550(2620) SD 190(320)	15
Wood	400 to 650 (680 to 1100)	180(300)	200(330)	170(280)	Min 80(140) Max 280(480) SD 70(110)	6
Steel	7830(13,200)	590(1000)	260(440)	190(320)	Min 150(260) Max 230(380) SD 30(50)	7
Sheetrock (Gypsum Wallboard)	770 to 1160 (1300 to 1950)	300(500)	230(390)	260(440)	Min 170(280) Max 370(620) SD 100(170)	4

FIGURE 1. Photo of a general trash dumpster at a construction site in Columbia, SC.

FIGURE 2. Photo of a masonry recycling dumpster in Columbia, SC.

tainers were full at the time of recycling. The masonry dumpster density varied significantly from load to load. Factors that impact this density include the composition of the masonry, the amount of water retained in the containers due to precipitation and how full the containers were at the time of disposal. Masonry and concrete work may often occur in different phases throughout a construction project. It was observed that there were increased or decreased percentages of concrete, block, and brick in the masonry dumpster during the study period. These items have significantly different source material densities with the brick usually the lowest and the concrete the highest. The average dumpster density calculated from the study is in between the bulk densities for brick and concrete as found in the CalRecovery study but more than 20% greater than the LEED® suggested conversion factor value.

Figure 2 is a photo of one of the dumpsters intended for recycling masonry at the Columbia, SC construction site. It can be seen that the bricks and blocks are fairly well packed together, which is probably why the calculated dumpster density for masonry is approximately 50% of the average source material density.

The average dumpster density of the six wood recycling loads are shown in Table 1 and are very similar to the values suggested by LEED® and studied in California. The wood dumpster density did vary from load to load and this could be impacted by the amount of water retained in the containers due to precipitation and the various different wood types used, but in contrast to observations made over the course of the study on the masonry and general trash containers, the wood dumpsters did not display much variation in composition. They did, however, vary in wood placement within the dumpsters. If there were a large number of long wood pieces in the dumpster, then a large amount of bridging was noted. This is where a large piece of wood prevented the settling of smaller pieces of wood that could fill in voids in the container. Figure 3 shows a photo of one of the dumpsters used for recycling wood at the construction site in Columbia, SC. Bridging from large pieces of wood scrap can be seen.

Steel was determined to have a relatively light average dumpster density at the construction site in Columbia, SC when compared to the source material density of steel. (The dumpster density is less than 3% of the source material density.) The photo in Figure 4 helps to explain this dumpster density. The waste steel that is generated from new construction comes in a wide variety of shapes and sizes and this photo depicts a good mix of the typical steel waste items. These items did not stack neatly and caused numerous small and large voids in the steel recycling dumpsters. Additionally, there may have been other waste metals of lighter density commingled in the dumpsters as well, but this is not much of a concern for steel recycling as steel recycling is a profitable

FIGURE 3. Photo of a wood recycling dumpster in Columbia, SC with significant bridging.

FIGURE 4. Photo of a steel recycling dumpster in Columbia, SC.

business and magnetic separators are common equipment at recycling centers.

The bulk density of recycled loose steel (not containers) from the California study in Table 1 is 37% higher than the average dumpster density calculated for steel at the construction site in Columbia, SC but still not too much outside of the range of values for this small number of samples. However, the suggested LEED® conversion factor shown in Table 1 is more than 200% greater. Many recycling facilities have compacting equipment, which would rapidly increase the density of a recycled steel load from a loosely placed construction site density and this may explain the much higher LEED® value.

Sheetrock (gypsum wallboard) was determined to have an average dumpster density at the Columbia, SC construction site of approximately 30% of its source material density. Figure 5 is a photo of a typical sheetrock dumpster. The characteristics of sheetrock are such that it tends to break easily and therefore it may lay fairly flat as compared to stronger materials such as steel and wood as the dumpster fills up. This helps avoid a lot of material bridging forming large air voids in the dumpster although significant voids as compared to masonry are still noticeable. Sheetrock also tends to absorb water and exposure to precipitation is likely to cause a significant increase in weight per load. The photo in Figure 5 also shows some shallow standing water in the dumpster. This was observed frequently at the Columbia, SC construction site. However, all the dumpsters had holes punched in the bottom sidewalls to prevent large amounts of standing water from collecting in them and the water level was never significantly higher than depicted below.

One other important observation was related to the management and organization of the waste container yard at a construction site. The clear labeling of the containers is critical and without labeling it is easy to mix materials and alter the densities. Most of the waste containers are filled not by hand but by construction equipment. One load of general trash

FIGURE 5. Photo of a sheetrock recycling dumpster in Columbia, SC.

mistakenly dumped into a recycling dumpster may irrevocably commingle that load and cause it to be renamed to general trash. Dumpster labeling is easy to do initially, but in practice is difficult to maintain as signs may get hauled away and dumped when the full containers are switched out or knocked off and destroyed by construction equipment. The most effective signs at the construction site in Columbia, SC were large and made out of plywood. These signs could be hung and removed from the dumpsters fairly easily. The construction waste management at the site observed during 2005 appeared to be very effective and wastes were generally sorted well.

The methods of sampling used in other publications may not mirror how waste is handled and disposed of on a construction site. Careful sorting of materials by type and size that are loosely stacked at a materials recovery center may not emulate standard construction practices. Other techniques such as landfill sampling may not reflect the waste materials density as it is placed in construction dumpsters. The methodology used for the calculations of dumpster density in this research was specific to a construction project that employed waste management practices specifically designed to comply with LEED® waste management guidelines for recycling. The methodology utilized in this research reflects the behavior of the waste material as it is generated on site, placed into the dumpsters, and transported to the landfill or recycling location. A material's dumpster density is the mass per volume of the waste material as it is randomly placed in a dumpster. There are several factors that can affect the dumpster density of a waste material. These include the percentage of voids, the presence of commingled waste, any deliberate or accidental compaction, absorption of water and whether or not the container is full or compacted. For this study there was no attempt by the researchers to control any of these variables. Normal construction site waste management practices were allowed to proceed without interference. Observations were made to try and determine outside factors that might impact dumpster density and as noted, the dumpsters were, in general, close to being full when removed.

Rain data was collected for the Columbia, SC area during the project study and compared to dumpster densities on specific hauling dates. However, it was a fairly dry summer when most of the data were collected and there were not enough data points to see any conclusive trend in increased weight for the various debris categories over the project timeframe. This is recommended as a topic for further study.

It is also difficult to accurately compare the dumpster densities determined by this study with existing conversion factors because of the wide variation in waste materials. This illustrates the need for clearly defined and sited sources of information and additional studies to compare the generated recycling streams from other types of construction projects. However, there are several useful conclusions that can already be made from this research related to each of the five material categories studied.

CONCLUSIONS

The dumpster densities calculated from the research at the site in Columbia, SC for both wood and for sheetrock are consistent with the values from both the suggested LEED® reference guide and the CalRecovery study. Even though there is a need for further study as the construction industry embraces C&D recycling, it appears that these suggested conversion factors can be used fairly confidently for future project estimation.

The value obtained from the Columbia, SC study for the dumpster density of general trash is substantially higher than the suggested conversion factor (USGBC 2003b). General trash is by far the largest waste stream category by mass and is the one impacting conformance with recycling goals the most as these items are currently landfilled. Therefore, for conservative estimates of recycling goals and strategies, it is suggested that the higher value from this study be used to better reflect the heavier nature of construction trash compared to other trash until more studies can give even better factors.

The calculated dumpster density for masonry is higher than the suggested conversion factor and more consistent with the bulk densities determined in the CalRecovery study. It is important to clearly define masonry waste as mixed brick, block, and concrete or handle these very common waste materials individually. It is recommended that the calculated dumpster density from this study be used as an average for mixed masonry and the separated bulk densities from the CalRecovery study be used when the

masonries are further separated or if there is a higher percentage of concrete. However, further studies are still recommended.

The steel dumpster density in this study was determined to have the most variation from other sources of data and was found to be significantly less than the suggested conversion factors. It is expected that this is because of the lack of compaction at a construction site as compared to a recycling site. Steel may not be as significant for calculating the percent recycling at a construction site as other materials such as masonry, but due to its value, it is important to use more accurate dumpster densities in the economic evaluations of construction waste management plans.

There is one other important aspect to note. This study was for construction debris recycling only, from which there may be a much different waste composition of steel from demolition debris recycling where large heavy beams and other structural components may be recycled. It is therefore recommended that in the future, the conversion factors be further separated into construction debris recycling and demolition debris recycling and that the value of the dumpster density for steel from this study be used only for construction debris recycling calculations. It is felt that this lower value more accurately reflects the density of waste steel generated during construction of this type of building. Including compaction as a practice at construction sites will also alter this. It is recommended that further studies are performed with more attention to detail on the components in the steel dumpster and onsite debris management practices to obtain more information useful for construction managers and LEED® professionals on future projects. Till then, perhaps understanding that the steel dumpster density might be significantly lower than expected may help in providing a better estimate of construction costs, scheduling and contingencies.

The most important conclusion drawn from this research is that the dumpster densities of construction waste materials need to be accurately understood by construction managers and engineers in order to estimate jobs and perform verification of recycling quantities. The conversion factors utilized in the LEED® manual require additional investigation to validate or adjust them to more accurately reflect physical properties of construction waste. When compared to the dumpster densities calculated in this study there are significant differences with the LEED® values. The applicable bulk densities taken from the CalRecovery report, were useful for additional comparison and were generally closer to the values for dumpster densities determined in this study.

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REFERENCES

AISC (1980) *Manual of Steel Construction,* Eighth Edition, American Institute of Steel Construction Inc., Chicago ©1980, First Revised Printing (11/84), 2nd Impression (2/86).

CalRecovery (1991) "Conversion Factors for Individual Material Types," Prepared for the California Integrated Waste Management Board by CalRecover, Inc., Dec. 1991.

Franklin Associates (1998) "Characterization of Building-related Construction and Demolition Debris in the United States," prepared for the United States Environmental Protection Agency, Office of Solid Waste, EPA530-R-98-010.

Mills, T., Showalter, E., and Jarman, D (1999). "A Cost-Effective Waste Management Plan." *Cost Engineering* 41/ 3 (1999), pp 35-43.

SCC (2004). *South Carolina Code of Laws (unannotated) Current through the end of the 2004 Regular Session: Title 44 – Health. Chapter 96. South Carolina Solid Waste Policy and Management Act Article 1. Solid Waste Policy; Specific Wastes.* http://www.scstatehouse.net/code/t44c096.htm.

Touran, A., Christoforou, C., Dantata, N., and Wang, J. (2004) "An Estimating System for Construction and Demolition Waste Management," *Journal of Solid Waste Technology and Management*. 30/2 (2004), pp 81-89.

USGBC (2003a), *Green Building Rating System For New Construction and Major Renovations (LEED-NC) Version 2.1,* United States Green Building Council LEED™ (Leadership in Energy and Environmental Design), Revised March 2003.

USGBC (2003b), *Reference Package For New Construction and Major Renovations (LEED-NC) Version 2.1,* United States Green Building Council LEED™ (Leadership in Energy and Environmental Design), Second Edition May 2003.

Yost, P., and Halstead, J. (1996) "A Methodology for Quantifying the Volume of Construction Waste." *Waste Management and Research,* 14 (1996), pp 453-461.

Wang, J., Touran, A., Christoforou, C., and Fadlalla, H. (2004), "A systems analysis tool for construction and demolition wastes management," *Waste Management*. 24 (2004), pp 989-997.