DECONSTRUCTION AND MATERIALS REUSE

Proceedings of the 11th Rinker International Conference

May 7-10, 2003 - Gainesville, Florida, USA

Publication 287

CIB Report

Deconstruction and Materials Reuse

CIB Publication 287

Proceedings of the 11th Rinker International Conference
May 7-10, 2003
Gainesville, Florida, USA

Edited by

Abdol R. Chini, University of Florida

TG 39

CIB, International Council for Research and Innovation in Building Construction
Task Group 39: Deconstruction
http://www.cce.ufl.edu/affiliations/cib

Powell Center for Construction and Environment
M.E. Rinker Sr., School of Building Construction
College of Design, Construction and Planning
http://www.cce.ufl.edu/

DISCLAIMER

The publisher makes no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility or liability in whole or in part for any errors or omissions that may be made.

The reader should verify the applicability of the information to particular situations and check the references prior to any reliance thereupon. Since the information contained in the book is multidisciplinary, international and professional in nature, the reader is urged to consult with an appropriate licensed professional prior to taking any action or making any interpretation that is within the realm of a licensed professional practice.

CONTENTS

DECONSTRUCTION AND MATERIALS REUSE BUSINESS DEVELOPMENT AND MARKETING

Paper 14 **ENVIRONMENTAL IMPACT OF CONCRETE RECYCLING, COMING FROM CONSTRUCTION AND DEMOLITION WASTE (C&DW)**

Beatriz Estévez, Antonio Aguado, Alejandro Josa *(Universitat Politécnica de Catalunya, School of Civil Engineering, Barcelona, Spain)*

Paper 15 **START UP AND DEVELOPMENT OF A FULL SCALE USED BUILDING MATERIALS STORE AND SALVAGE & DECONSTRUCTION BUSINESS IN A SMALL TOWN**

Bruce Odom *(ODOM RE-USE Co., Traverse City, Michigan, United States of America)*

Paper 16 **TECHNICAL DEVELOPMENT FOR DECONSTRUCTION MANAGEMENT**

Chunlu Liu; Sung Kin Pun *(Deakin University, Geelong, Victoria, Australia);*
Yoshito Itoh *(Nagoya University, Nagoya, Aichi, Japan)*

Paper 17 **EVALUATING A DECONSTRUCTION BUSINESS MODEL**

George C. Penn, Steve Knudsen *(Global Energy Options, Wisconsin, United States of America);*
Ingo Bensch *(Energy Center of Wisconsin, Wisconsin, United States of America)*

Paper 18 **THE URBAN EXPLORER CAPSULE – IMPROVEMENT OF REUSABLE BUILDING STRUCTURES MANAGEMENT**

Leszek Świątek *(Technical University of Szczecin, Szczecin, Poland)*

Paper 19 **HOW DO YOU IDENTIFY THE BEST PRACTICABLE ENVIRONMENTAL OPTION FOR CONSTRUCTION AND DEMOLITION WASTE**

Katherine Tebbatt Adams *(Centre for Resource Management, Building Research Establishment, United Kingdom)*

REUSE AND RECYCLING OPPORTUNITIES AND CONSTRAINTS

Paper 20 **BARRIERS IN MINIMISING CONSTRUCTION WASTE**

Rubina Greenwood *(Cardiff University, Welsh School of Architecture, United Kingdom)*

REGULATORY, CONTRACTUAL AND POLICY ISSUES

Paper 34 **WASTE MANAGEMENT PRACTICES IN UNITED STATES GREEN BUILDING PROGRAMS**

Audrey K. Tinker, Dr. Richard A. Burt *(Texas A&M University, College Station, Texas, United States of America)*

Paper 35 **"GREEN" DEMOLITION CERTIFICATION**

G. Bradley Guy, Timothy Williams *(University of Florida, Powell Center for Construction and Environment, Gainesville, Florida, United States of America)*

MILITARY BASE DECONSTRUCTION

Paper 36 **ENVISIONING THE IDEAL BUILDING REMOVAL PROGRAM (FOR CLOSED AND ACTIVE MILITARY BASES)**

Michael Houlemard, Stan Cook *(Fort Ord Reuse Authority, Marina, California, United States of America)*

- **This file could not be converted to PDF. The Word version is saved in the CD as a separate file.**

PREFACE

The demolition of buildings produces enormous amounts of debris that in most countries results in a significant portion of the total municipal waste stream. Deconstruction is emerging as an alternative to demolition around the world. Deconstruction is the systematic disassembly of buildings in order to maximize recovered materials reuse and recycling. While the process of demolition often leads to the mixing of various materials and contamination of non-hazardous components, deconstruction is actually the source separation of materials.

Deconstruction of buildings has several advantages over conventional demolition and is also faced with several challenges. The advantages are an increased diversion rate of demolition debris from landfills; “sustainable” economic development through reuse and recycling; potential reuse of building components; increased ease of materials recycling; and enhanced environmental protection, both locally and globally. Deconstruction preserves the invested embodied energy of materials, thus substituting recovered existing materials for the input of embodied energy in the harvesting and manufacturing of new materials.

The challenges faced by deconstruction are significant but readily overcome if changes in design and policy occur. These challenges include: existing buildings have not been designed for dismantling; building components have not been designed for disassembly; tools for deconstructing existing buildings often do not exist; disposal costs for demolition waste are frequently low; dismantling of buildings requires additional time; building codes and materials standards often do not address the reuse of building components; unknown cost factors in the deconstruction process; lack of a broad industry identity with commensurate standardized practices; buildings built before the mid-1970’s with lead-based paint and asbestos containing materials; and the economic and environmental benefits that are not well-established.

Generally the main problem facing deconstruction today is the fact that architects and builders of the past visualized their creations as being permanent and did not make provisions for their future disassembly. Consequently, techniques and tools for dismantling existing structures are under development, research to support deconstruction is ongoing at institutions around the world, and government policy is beginning to address the advantages of deconstruction by increasing disposal costs or in some cases, forbidding the disposal of otherwise useful materials. Designing buildings to build for ease of future deconstruction is beginning to receive attention and architects and other designers are starting to consider this factor for new buildings. The International Council for Research and Innovation in Building Construction (CIB) Task Group 39 is in the final process of conducting a 4-year study of deconstruction and coordinating an exchange of information among research organizations and practitioners around the world.

The main objective of this conference was to provide information about worldwide building deconstruction and materials reuse programs that address the key technical, economic, environmental, and policy issues needed to make deconstruction and reuse of building materials a viable option to demolition and landfilling. The second purpose of the Conference was to serve as an annual meeting for the CIB Task Group 39 on Deconstruction and the Used Building Materials Association of North America (UBMA).

This electronic Proceedings includes thirty-six fully reviewed papers presented at the 11th Rinker International Conference on Deconstruction and Materials Reuse. The papers discuss different issues of deconstruction and materials reuse in thirteen countries: Australia, Germany, Italy, Japan, the Netherlands, New Zealand, Poland, Spain, Sweden, Turkey, the United Kingdom, the United States, and Venezuela.

Thanks to the following reviewers for their thorough review of the papers and supply of constructive feedback that improved the overall quality of the papers: Katherine Adams, Brent Anderson, Bill Boone, Stan Cook, Philip Crowther, Elma Durmisevic, Mats Eklund, Soofia Tahira Elias-Özkan, Peter Erklens, Beatriz Estévez, John Fernandez, Robert Falk, Byrn Golton, Rubina Greenwood, Peter Goren, Brad Guy, Kevin Grosskopf, Gina Hawkins, Gilli Hobbs, James Hurley, Amnon Katz, Charles Kibert, Jennifer Languell, Elske Linß, Paola Lassandro, Cynthia Moore, Annette Mueller, Larry Muszynski, Lars Myhre, Klaas Nienhuis, Dave Newport, Bruce Odom, Michael Ohlsen, George Penn, Frank Schultmann, Dennis Spors, John Storey, Carlos Suárez, Catarina Thormark, Audrey Tinker, Ali Touran, Tim Townsend, David Wyatt, and Tim Williams.

A wide range of people and groups provided support and encouragement for the organization of this conference. These include US Environmental Protection Agency (EPA), Florida Department of Environmental Protection (FDEP), US Army Corps of Engineers Construction Engineering Research Laboratory (CERL), USDA Forest Products Laboratory (FPL), Alachua County Waste Management Division, City of Gainesville Public Works Department, International Council for Research and Innovation in Building Construction (CIB), RecycleFlorida Today Inc., Building Research Establishment (BRE), French-German Institute for Environmental Research (DFIU), Delft University of Technology, Reconnx, Institute for Local Self-Reliance (ILSR), Southern Waste Information Exchange, and Alachua County Visitors and Convention Bureau. Brad Guy, the Conference Co-Chairperson provided key support in publicizing the Conference, soliciting sponsors and presenters, and providing valuable input in planning and organizing the Conference. Finally, the hard work and effort by Brent Anderson, Callie Whitfiled, Dottie Beaupied, Ryan Courson, and Tim Williams in all the tasks involved in organizing an international conference with more than seventy presentations from fourteen countries and publishing the proceedings with thirty-six fully reviewed papers must be gratefully acknowledged.

Abdol R. Chini Editor

CIB Task Group 39 on Deconstruction

Task Group 39 of International Council for Research and Innovation in Building Construction (CIB) was formed by the Rinker School's Powell Center for Construction and Environment on 5 May 1999 in Gainesville to produce a comprehensive analysis of, and reports on, worldwide building deconstruction and materials reuse programs that address the key technical, economic, and policy issues needed to make deconstruction and reuse of building materials a viable option to demolition and landfilling. The first meeting of TG 39 was on 19 May 2000 in Watford, England, which resulted in the electronic CIB Publication 252, "Overview of Deconstruction in Selected Countries." This publication addresses the subject of deconstruction in eight countries: Australia, Germany, Israel, Japan, the Netherlands, Norway, the United Kingdom, and the United States. The second publication of TG 39 is CIB Publication 266, "Deconstruction and Materials Reuse: Technology, Economic, and Policy." This electronic publication includes ten papers presented at the second annual meeting of TG 39 that took place in Wellington, New Zealand on 6 April 2001. The group met in Karlsruhe, Germany on 9 April 2002 to discuss design for deconstruction and other collateral issues such as recycling potential and materials reuse in eleven countries: Australia, Germany, Italy, Japan, the Netherlands, New Zealand, South Africa, Turkey, the United Kingdom, the United States, and Venezuela. The outcome of this meeting is the electronic CIB Publication 272, "Design for Deconstruction and Materials Reuse." All three publications can be downloaded at the Rinker School's Center for Construction and Environment website (http://cce.ufl.edu/affiliations/cib).

The Used Building Materials Association of North America (UBMA)

The UBMA is a non-profit, membership based organization that represents companies and organizations involved in the acquisition and/or redistribution of used building materials. They represent for-profit and non-profit companies and organizations in Canada and the United States that acquire and sell used building materials such as windows, doors, and plumbing fixtures. The UMBA also represents companies that reprocess and recycle building materials such as concrete and asphalt. Their mission is to help companies gather and redistribute building materials in a financially sustainable manner (http://bcn.boulder.co.us/environmental/ubma/index.html).

International Council for Research and Innovation in Building and Construction

---

CIB General Secretariat:

Office address:	Kruisplein 25-G 3014 DB Rotterdam	tel: fax:	+31.10.411 02 40 +31.10.433 43 72
Postal address:	P.O. Box 1837 3000 BV Rotterdam The Netherlands	e-mail:	secretariat@cibworld.nl http//www.cibworld.nl

---

CIB is a world wide network of over 5000 experts from about 500 organisations, who actively cooperate and exchange information in over 50 Commissions and Task Groups. Their scopes extend to all fields in building and construction related research and development. They are listed on the next page.

They are actively engaged in initiating projects for R&D and information exchange, organising workshops, symposia and congresses and producing publications of acknowledged global repute.

It is in their ability to bring a multi-national and multi-disciplinary approach to bear on the subject matter delineated in their Terms of Reference that is their strength.

CIB Members come from institutes, companies, partnerships and other types of organisations as well as individual experts involved in research or in the transfer or application of research results. More than 130 Universities worldwide have joined.

CIB is an Association that utilises the collective expertise of its membership to foster innovations and to create workable solutions to technical, economic, social and organisational problems within its competence.

Details on Membership and Activities are obtainable from the General Secretariat at the address above.

CIB Task Groups (TG) and Working Commissions (W)
(as of April 1, 2003)

Task Groups
TG19 Designing for the Ageing Society
TG23 Culture in Construction
TG28 Dissemination of Indoor Air Sciences (joint CIB-ISIAQ Task Group)
TG31 Macro-Economic Data for the Construction Industry
TG33 Concurrent Engineering in Construction
TG34 Regeneration of the Built Environment
TG37 Performance Based Building Regulatory Systems
TG38 Urban Sustainability
TG39 Deconstruction
TG40 Informal Settlements
TG41 Benchmarking Construction Performance
TG42 Performance Criteria of Buildings for Health and Comfort (Joint CIB-ISIAQ Task Group)
TG43 Megacities
TG44 Performance Evaluation of Buildings with Response Control Devices
TG45 Performance Indicators for Urban Development (Joint CIB-FIG Task Group)
TG46 Certification in Construction
TG47 Innovation Brokerage in Construction
TG48 Social and Economic Aspects of Sustainable Construction
TG49 Architectural Engineering
TG50 Tall Buildings
TG51 Usability of Workplaces
TG52 Transport and the Built Environment

Working Commissions
W014 Fire
W018 Timber Structures
W023 Wall Structures
W040 Heat and Moisture Transfer in Buildings
W051 Acoustics
W055 Building Economics
W056 Sandwch Panels (joint CIB - ECCS Commission)
W060 Performance Concept in Building
W062 Water Supply and Drainage
W063 Affordable Housing
W065 Organisation and Management of Construction
W067 Energy Conservation in the Built Environment
W069 Housing Sociology
W070 Facilities Management and Maintenance
W077 Indoor Climate
W078 Information Technology for Construction
W080 Prediction of Service Life of Building Materials and Components (Joint CIB-RILEM Commission)
W082 Future Studies in Construction

CIB Task Groups (TG) and Working Commissions (W0)
(as of April 1, 2003)

W083 Roofing Materials and Systems (Joint CIB-RILEM Commission)
W084 Building Non-Handicapping Environments
W086 Building Pathology
W087 Post-Construction Liability and Insurance
W089 Building Research and Education
W092 Procurement Systems
W094 Design for Durability
W096 Architectural Management
W098 Intelligent and Responsive Buildings
W099 Safety and Health on Construction Sites
W100 Environmental Assessment of Buildings
W101 Spatial Planning and Infrastructure Development
W102 Information and Knowledge Management in Building (Joint CIB-UICB Commission)
W103 Construction Conflict: Avoidance and Resolution
W104 Open Building Implementation
W105 Life Time Engineering in Construction
W106 Geographical Information Systems
W107 Construction in Developing Countries
W108 Climate Change and the Built Environment

CIB HOME PAGE

WWW.CIBWORLD.NL

The CIB home page contains the following main and publicly accessible sections:

1. General Information
2. Newsletter
3. Databases

General Information
Included is General Information about CIB in the following sub-sections:

- Introduction, including among others: CIB in the past and present
- Mission Statement
- Membership which includes information on the various types of CIB Membership and on developments in the composition of the CIB Membership
- Organisation, including the composition of the CIB Board and its Standing Committees and of the CIB General Secretariat and links with the CIB Partner Organisations
- Programme of Activities
- Services to Members, and in addition the possibilities for Members to participate in CIB's Programme of Activities
- Fee System and How To Join, including the description of the current Membership Fee Levels and the option to electronically request a Membership Application Form

Newsletters
In this section electronic copies are included of the various issues of INFORMATION, the CIB Bi-Monthly Newsletter, as published over the last couple of years. Also included is an Index to facilitate searching articles on certain topics published in all included issues of INFORMATION

Databases
This is the largest section in the CIB home page. It includes fact sheets in separate on-line regularly updated databases, with detailed searchable information as concerns:

- ± 500 CIB Member Organisations, including among others: descriptions of their Fields of Activities, contact information and links with their Websites
- ± 5000 Individual Contacts, with an indication of their Fields of Expertise, photo and contact information
- ± 50 CIB Task Groups and Working Commissions, with a listing of their Coordinators and Members, Scope and Objectives, Work Programme and Planned Outputs, Publications produced so far, and Schedule of Meetings
- ± 100 Publications, originating to date from the CIB Task Groups and Working Commissions, with a listing of their contents, price and information on how to order
- ± 250 Meetings, including an indication of subjects, type of Meeting, dates and location, contact information and links with designated websites for all CIB Meetings (± 50 each

year) and all other international workshops, symposia, conferences, etc. of potential relevance for people interested in research and innovation in the area of building and construction

Searchable Data: an Example

Searching for certain publications in the Databases in the CIB home page can be done in the following three ways:

1. In the home page itself a pre-selection is included of all recent CIB publications (published in the last 4 to 6 months). By clicking on "New Publications" the respective list will appear. By clicking on a title in this list the information fact sheet about this Publication will appear, including the option for an electronic order if it concerns a publication produced by the CIB Secretariat.
2. In the description of a Task Group or Working Commission in the database "Commissions" a pre-programmed selection is included of all publications produced under the responsibility of each Commission.
3. In the database "Publications" one can search, for example, for all publications on a certain topic, by simply typing the word that covers this topic in the box "Title" in the search page that appears when one asks for this database.

A SYSTEM FOR ESTIMATING RESIDENTIAL CONSTRUCTION AND DEMOLITION DEBRIS

Authors: Ali Touran, James Wang, Christoforos Christoforou, Nasiru Dantata (Northeastern University, Boston, Massachusetts)

ABSTRACT

This paper describes a computerized estimating system that can be used to quantify the weight of wood, gypsum drywall, roof asphalt shingles, and carpet waste generated from new construction and demolition activities in residential construction projects. The system's main input is the housing permit statistics, usually available from various States' websites. An interface is also created between a GIS system and the estimating module that allows the user to generate a spatial distribution of construction and demolition debris over a region.

KEYWORDS: Construction and Demolition Debris; Building Permits; Estimating System; Residential Construction; GIS Interface

INTRODUCTION

The management of Construction and Demolition (C&D) debris has been a focal point in the planning efforts of Massachusetts Department of Environmental Protection (MADEP). In the agency's solid waste master plan, MADEP has set a goal of reducing non-municipal solid waste by 88% by 2010 [1]. As a step towards achieving this goal, MADEP is now planning to implement a complete ban on the disposal of unprocessed C&D debris in December of 2003. Northeastern University, under a research contract with MADEP is studying the potential impact of such policies on contractors and processors in the State of Massachusetts.

As part of this effort, we are interested in quantifying the volume of several C&D materials (specifically wood, asphalt shingles, carpet, and gypsum drywall) generated in building construction every year in Massachusetts. The four items mentioned, have been selected by the State as items of high priority and it is believed that they constitute the largest share of C&D debris (especially volume wise) generated in residential construction. Furthermore, it is understood that most of the ABC (asphalt, brick, and concrete) debris are already recycled and the State intends to focus on items that are not being recycled extensively. The C&D data reported by the states in the Northeast is at aggregate levels without breakdown according to source or type. As an example, the State of Massachusetts estimates that in 1999, approximately 4.7 million tons of C&D debris was generated in Massachusetts, out of which about 20% was disposed in landfills [1]. In a recent CMRA (Construction Materials Recycling Association) meeting in November 2002 at Hampton, New Hampshire, representatives from various New England States reported approximate estimates of the total C&D waste generated in their respective States. In almost each case, they cautioned about the accuracy of the figures and further, no breakdown of the waste according to type and source was offered.

Efforts have been made in the past to estimate volume of various C&D debris. At the national level, the report by Franklin Associates [2] is noteworthy. This report was prepared with the support of the USEPA and provides a methodology for estimating the volume/tonnage of construction and demolition debris. While the general methodology is sound, the sample data used to estimate the waste volume is very limited. The volume (weight) of the samples is then used to estimate the quantity of C&D waste at the national level. Probably the most detailed analysis of the volume of C&D debris is the report by Reinhart, *et al.* [3] which discusses various approaches in quantifying the volume and tonnage of construction and demolition wastes in the State of Florida. The report correctly notes that construction practices in Florida are different from many other parts of the country (notably Northeast in our case). As an example, the extensive use of concrete blocks in Florida is not typical of residential construction practices in northeastern United States. Also, in the Northeast one expects to see a lot more demolition projects compared to Florida where the mean building age is younger than much of the nation [3].

Developing an estimating system for C&D debris that depends on routinely collected data can assist the planning and implementation of C&D policies. Given the scope of our project, we did not embark on methods that required extensive field data collection and sampling. As an alternative, we decided to make use of the existing data. For many years now, various towns and cities report the number of building permits issued. The proposed system estimates the C&D debris volume based on the number of building permits issued by Massachusetts towns. The permit data is routinely collected and can be accessed conveniently via Internet. The proposed system can then be used for various planning purposes by allowing analyst to conduct sensitivity analyses and to estimate potential tonnage diverted from landfills or directed to processing units. Market development for recycling C&D debris will depend to a large degree on the availability and consistent flow of recyclable C&D materials for foreseeable periods. Also, the decision to adopt different engineering practices, such as deconstruction, may depend on the volume of recyclable C&D materials available.

APPROACH

Our objective is to estimate the quantity of the following four C&D materials: wood (lumber and engineered wood), drywall (gypsum boards), roof asphalt shingles, and carpet [4]. The source of C&D debris resulting from building construction can be traced back to the following activities: (1) new construction, (2) demolition, and (3) renovation and repair projects. These projects can be classified as residential or commercial. In this paper we focus on debris generated from new construction and demolition in residential projects only. One can find the Commonwealth of Massachusetts building permit statistics at the following website: *http://www.danter.com/STARTSWATCH/*. In this website, the number of building permits issued every year in various cities and towns is reported. Building permits are broken down into single unit, two-unit, three or four-unit, five or more units. Each of these potential construction projects generates C&D debris. As an example, an estimator factors in around 10% of wood to account for possible waste [5]. A waste factor of 5% for drywalls and 5% to 8% for asphalt shingles has been suggested [6]. Values of 5% to 15% waste have been suggested as estimates of construction material waste in new projects. In case of demolition projects, without source separation efforts, one can consider 100% of material as C&D debris. Unfortunately U.S. Census Bureau stopped collecting demolition permit data after 1995. Because of this, Massachusetts data on demolition permits is not reported. State of Connecticut however, reports demolition permit statistics on an annual basis. We analyzed Connecticut demolition permit data and compared it with Massachusetts. The general trend in building permits in both states is similar. Furthermore, both of these neighboring states seem to be affected by the same economic factors. This allowed us to use Connecticut data for estimating the number of demolition permits in Massachusetts.

Estimating Material Quantities in New Construction
We have used R.S. Means data for estimating the quantity of wood, drywall, asphalt shingles, and carpet in various residential and commercial projects [7, 8]. R.S. Means is a company that specializes in publishing construction cost and productivity data. Specifically we have used *Residential Cost Data (1999)* for estimating C&D waste in new and demolition projects. An example of factors used for estimating these quantities are shown in Table 1.

TABLE 1 – Typical factors used in the proposed estimating system*

	1-story average residence	2-story average residence
Wood (fbm/ft^2)	3.21	3.18
Plywood (ft^2/ft^2)	3.27	3.01
Drywall (ft^2/ft^2)	3.29	5.57
Shingles (ft^2/ft^2)	2.49	1.25
Carpet (ft^2/ft^2)	0.4	0.4

** Based on R.S. Means Residential Cost Data (1999) and converted to quantities per square foot of gross enclosed area of the building.*

Using these factors, number of building permits reported for various towns and cities, and type of residential buildings (number of units per building permit), we estimated quantities for the four items mentioned in Table 1. Then assuming a waste factor of 10 to 12%, we estimated the C&D volume generated from new construction. Assumptions with regard to construction types and multi-unit permits are described in [4]. Although the U.S. Census Bureau estimates that only 98% of all building permits are actually built, we did not adjust our estimate because of other uncertainties involved in the analysis.

Estimating Demolition Quantities
In order to estimate demolition quantities for Massachusetts, we resorted to Connecticut's demolition permit data (Table 2). The ratio of the number of demolition permits over the number of new construction was calculated for the past few years. We assumed that the average ratio for Connecticut is valid for Massachusetts as well.

TABLE 2 – Housing and demolition permit statistics in Connecticut

	1997	1998	1999	2000
No. of New Building Permits	9,349	11,863	10,637	9,376
No. of Demolition Permits	1,193	2,968	2,001	1,790
Ratio	12.8%	25.0%	18.8%	19.1%

This assumption is reasonable because the housing style in two states is very similar. The economic drivers for building construction appear to have impacted both states in similar manner. As an example, Figure 1 shows variations in housing permits in Massachusetts and Connecticut during 1995-2000. It can be seen that these numbers closely follow each other. The correlation coefficient between the housing permits in the two states during this six-year period was calculated as 0.93.

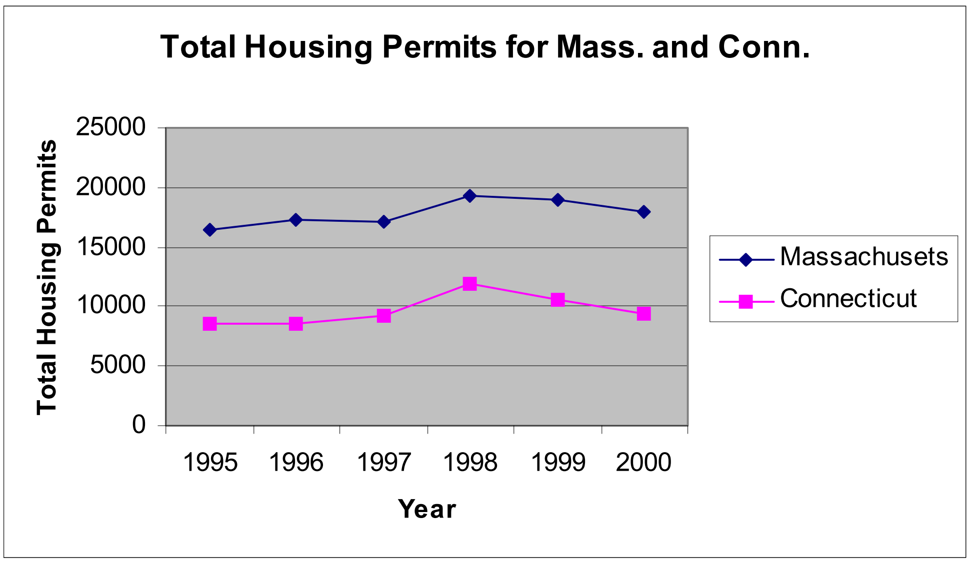


FIGURE 1 – Number of Housing Permits in Connecticut and Massachusetts

Since both states are more or less similar in terms of population density and number of older residences, it seems plausible that the number of demolition permits may vary in similar ways. We used an average ratio of 19% (using Table 2) to estimate the number of residential demolition projects for the Commonwealth of Massachusetts.

RESULTS

The estimating system is developed using an Excel spreadsheet. By entering the appropriate housing statistics, the system calculates quantities (in square feet) of each of the specified material. Using appropriate unit weights for the four building materials and the number and types of residential projects reported in building permit statistics data, we estimated total tonnage of C&D debris for Massachusetts for 2000 (Table 3).

TABLE 3 – Estimates of Residential C&D for Massachusetts in 2000

	Construction	Demolition	Total
Wood (tons)	30,800	56,300	87,100
Drywall (tons)	20,100	38,000	58,100
Shingles (tons)	5,800	11,300	17,100
Carpet (tons)	500	900	1,400
Totals for above (tons)	57,200	106,500	163,700

Because the housing permit data is reported according to towns and cities, one can calculate a spatial distribution for the C&D debris generated. This becomes an effective planning tool for siting of processing plants, allocation of resources to C&D recycling effort, and conducting economic analysis for the C&D recycling activities.

INTERFACE TO GIS

We have created an interface between the estimating system and a GIS (Geographic Information System) that portrays the distribution of C&D debris according to Massachusetts's towns and cities. Massachusetts GIS data is available at *http://www.state.ma.us/mgis/ftpstate.htm.* By tying the volume of C&D generated in each town (which is a function of building permits) to the geographical location of each town, we have developed a spatial distribution of any or all types of C&D waste. Figure 2 is an example of this effort. In this example, darker shades identify areas with larger amounts of C&D debris. As an example of a typical application let us assume that a firm is interested in establishing a processing plant in a specific location in Massachusetts and is interested in the potential C&D volume in the area within a specified radius. The user can identify the location on the map and draw a circle with the appropriate radius on the map. The GIS will select all towns within the circle and the estimating system will calculate the total C&D waste tonnage and present a tonnage breakdown for various material types.

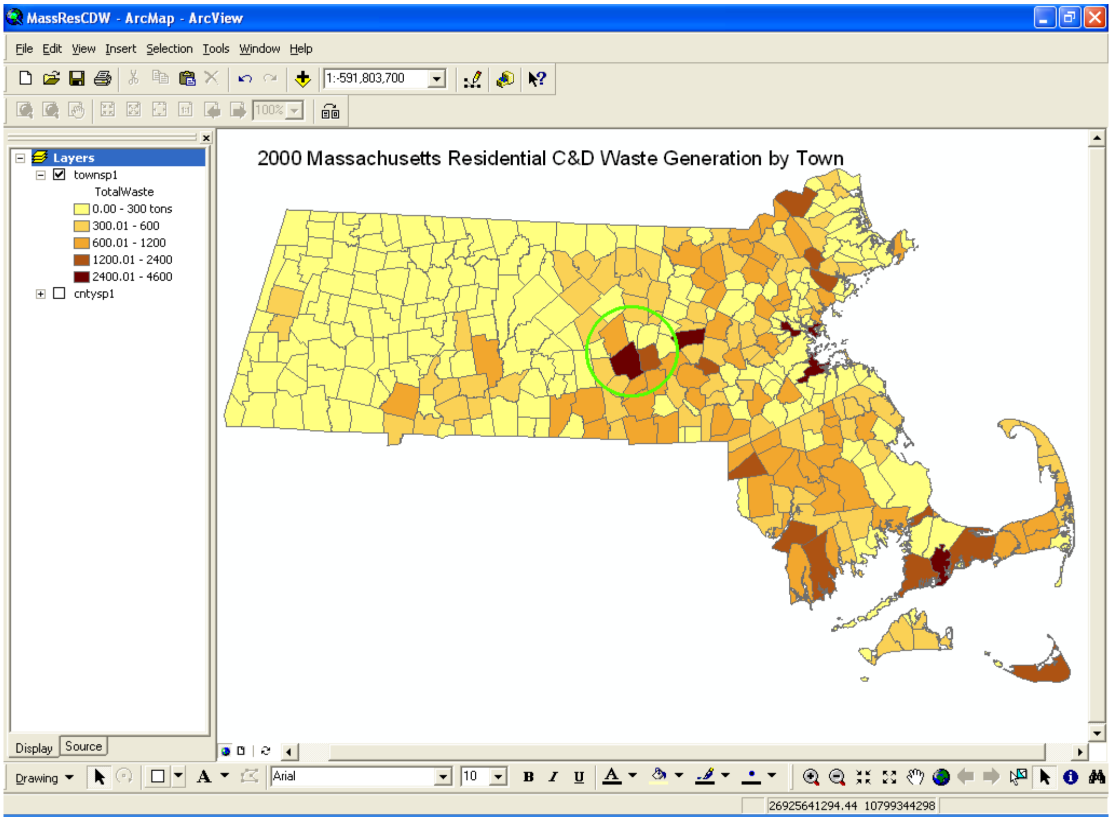


FIGURE 2 – Distribution of C&D waste (wood, drywall, shingles, and carpet) in Massachusetts Towns in 2000

CONCLUSION AND FUTURE WORK

Establishing prudent policies for C&D recycling and planning for the reduction of landfill disposal require reasonable estimates of C&D quantities. The estimating system developed in this work is important because it provides a systematic tool that allows rapid estimation of items of interest in the C&D waste stream. The estimate is a function of building permit statistics, widely available and routinely reported for various states throughout the country. The estimate can be prepared for various periods and locations by using appropriate building permit data. The next logical step in this effort is the verification of the estimates prepared. Unfortunately we are not aware of any source of data in Massachusetts or Connecticut on any of the building materials that we are estimating with this system. Landfill records are not sufficiently specific to allow verification of the wood or drywall quantities. Methods of direct measurement and sampling seem to be reasonable approaches that will help in verifying the system's results.

Another important step is to estimate the quantity of C&D resulting from repair and renovation work. Detailed data on repair and renovation projects is collected by American Housing Survey and reported on the web page of the U.S. Census Bureau [9]. We are currently developing estimates of C&D for repair, remodeling, and renovation projects based on these statistics.

ACKNOWLEDMENT

This project is funded by a grant from the Massachusetts Department of Environmental Protection. This support is gratefully acknowledged. We are also indebted to James McQuade and Peter Allison for their advice and contribution to this endeavor.

REFERENCES

1. *Beyond 2000 – Solid Waste Master Plan,* Executive Office of Environmental Affairs, Department of Environmental Protection, Commonwealth of Mass., December 2000.

2. **Franklin Associates,** *Characterization of Building-related Construction and Demolition Debris in the United States,* prepared for the United States Environmental Protection Agency, June 1998.

3. **Reinhard, D.R., T. G., Townsend, H. Heck, S. Chakrabarti, K. Cochran, and S. Medeiros,** *Generation and Composition of Construction and Demolition Waste in Florida,* Annual Report, State University of Florida, June 2001.

4. **Christoforou, C.,** *A Systems Analysis Tool to Assist Decisions in Construction and Demolition Waste Management,* MS Thesis, Northeastern University, June 2002.

5. **Reiner, L. E.,** *Methods and Materials of Residential Construction,* Prentice-Hall, Inc., 1981, p. 156.

6. **Dagostino, F.R., and L. Feigenbaum,** *Estimating in Building Construction,* Prentice-Hall, Inc., 1999, p. 256 and 291.

7. **R.S. Means,** *Square Foot Costs,* 17^{th} Ed., R.S. Means Co., Inc., Kingston, Mass., 1999.

8. **R.S. Means,** *Residential Cost Data,* 18^{th} Ed., R.S. Means Co., Inc., Kingston, Mass., 1999.

9. **U.S. Census Bureau**, American Housing Survey, *http://www.census.gov/hhes/www/ahs.html*.

THE ELECTRO-HYDRAULIC COMMINUTION FOR THE SEPARATION OF OLD CONCRETE

Authors: Dipl.-Ing. Elske Linß (Bauhaus-University of Weimar); Prof. Dr.-Ing. habil. Anette Mueller (Bauhaus-University of Weimar)

ABSTRACT

The high amount of concrete waste requires the development of processing and reuse. This paper describes an alternative method for crushing concrete. This method uses shock waves, which are generated by an electrical discharge under water, as the tool for crushing. The stress caused acts directly at the interfacial transition zone of the concrete. The stress can be dosed more precisely, because the energy input is at the whole surface. The experiments show that a high percentage of cement paste, free of aggregates, can be produced. From the material science point of view, it is remarkable that the stress-strain behaviour of different types of concrete is reflected in the grading curves and the content of cement paste of the fractions of crushed concrete.

KEYWORDS: Recycling; Concrete; Comminution; Aggregates; Enrichment of Cement Paste, Shock Waves

INTRODUCTION

Recycling of building materials is becoming more and more important. In Germany, about 77,100,000 Tons/a of Construction & Demolition Waste (i.e., 1 Ton/capita*a) were generated in 1998 [1]. On one hand, in regions with a high population density, recycling of building materials can help to reduce the quantity of material that must be deposited. On the other hand in regions with a shortage of raw materials, new sources are opened by recycling building materials.

Regarding concrete debris, there are two main fields of application. Crushed concrete is often used as an aggregate for stabilized or unstabilized sub-bases in road construction. In this case, processing with a jaw crusher or an impact crusher is well established. The produced material almost meets the requirements of the grading curve and composition. The presence of old cement paste in these aggregates seems to be an advantage because it causes a stabilizing effect, compared with inert material as sub-base material [2], [3].

If the concrete debris shall be reused as aggregate for new concrete, processing with the aforementioned crushers, which are developed for natural rock, is possible too, but has some disadvantages. The produced secondary aggregates are agglomerates of the old cement paste and the original aggregates. That causes higher water adsorption and lower strength of the grains. Besides, microcracks, which are the result of initiated but not completed fracture processes, can occur between the two components. To overcome these problems, the comminution by high-performance sonic impulses for processing concrete debris was developed. This technology aims at the production of secondary coarse aggregates that can be used in new concrete without any restrictions. The crushing methods, based on mechanical stresses, are limited regarding the quality of the produced material. They do not cause an optimum separation. The applied high stresses result in extensive destruction, not only of the concrete, but also of the aggregates. This method was developed for its application to concrete, in a joint research project between the Bauhaus-University of Weimar and the Otto-von-Guericke-University of Magdeburg, sponsored by DFG Bonn.

PRINCIPLE OF THE ELECTRO-HYDRAULIC COMMINUTION AND STATE OF THE ART

The tools of the named crushing method are shock waves. The basic principle is the transformation of electrical energy (stored in a capacitor) into mechanical energy of sonic impulses (Figure 1). These impulses are generated underwater by a disruptive electrical discharge. It follows that pressure sonic waves are generated through the surrounding medium (in our case water). If they come across interfaces of different densities, i.e., water and concrete, or aggregates and cement paste, positive and negative interferences occur. As a result, pressure and tensile stresses are generated at these interfaces. The tensile stresses primarily destroy the bond between the aggregates and the matrix. Cracks mainly go along the density interfaces, as shown in Figure 2. One advantage is that the energy input occurs over the whole area. Setting the electrical parameters capacity of the capacitor, the voltage of the charge, the distance between electrodes, and the number of pulses can control the energy.

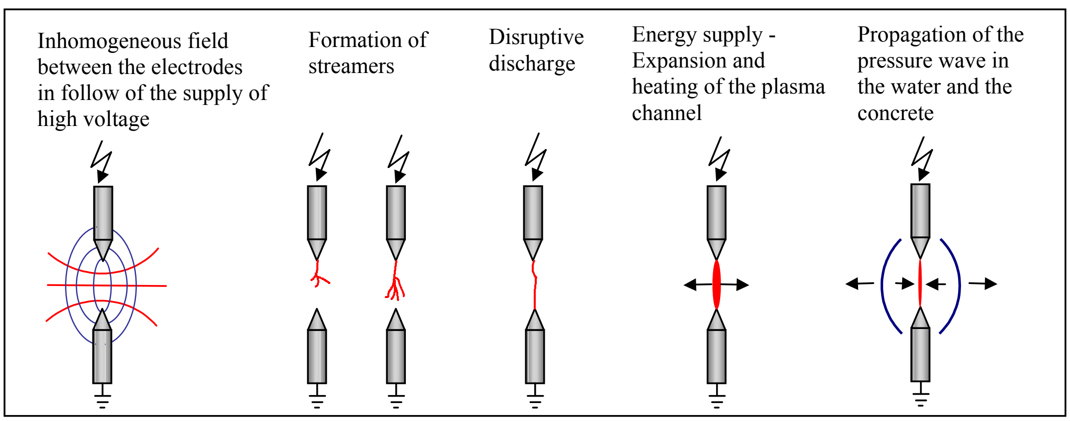


Figure 1 Progress of the comminution by shock waves

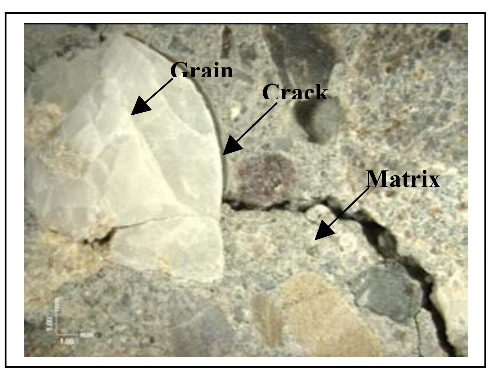


Figure 2 Crack between aggregates and matrix

Test Device

The device used for the experiments is shown in Figure 3. It consists of the electrical equipment and the water-filled container for the processing of the concrete. The precrushed concrete is put into the water-filled container. After closing the container, the treatment is started. During the treatment, the fine material leaves the inside container through the perforation. The container is emptied, and the crushed products are separated from the water by sieving and sedimentation.

During the treatment of the concrete, two things occur. The particle size is reduced, as in a traditional crushing process. An additional effect is the separation between the aggregate grains and the cement paste.

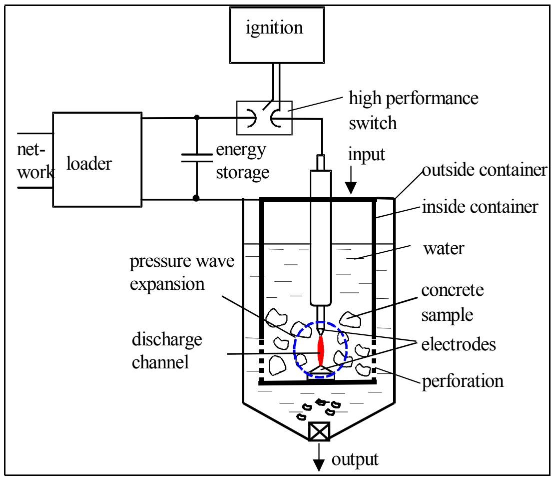


Figure 3 Scheme of the device for experiments [4]

TARGETS OF THE EXPERIMENTS

The targets of the research project can be summarized as follows:

- Investigations of the influences of electrical parameters and inputted electrical energy on the size reduction and separation of concrete.
- Investigations of the influences of concrete properties on the separation.
- Optimisation of the energy balance of the system and the process parameters.
- Comparison of the crushed product with the crushed products of conventional crushing methods.

RESULTS

Parameters for the Evaluation of the Crushed Product

For the verification of the crushing and separation effect, different characteristical values were determined (Figure 5). To evaluate the action of the shock waves as a crushing tool, the reduction of the particle sizes was determined. The particle-size distribution of the crushed product was compared with that of the aggregates used in the original concrete.

For the evaluation of the separation effect, additional parameters were used. These parameters describe the amount of cement stone stuck on the surface of the aggregates after crushing, and the rate of damage/destruction of aggregates by the forces during the treatment.

The content of cement paste was determined by the hydrochloric acid method, according to the German Standard [6] in each fraction. This method does not give evidence of the complete liberated aggregates. The “real” degree of liberation was determined by visual judgement (counting out).

In Table 1, the ranges of values of the used parameters are shown and discussed.

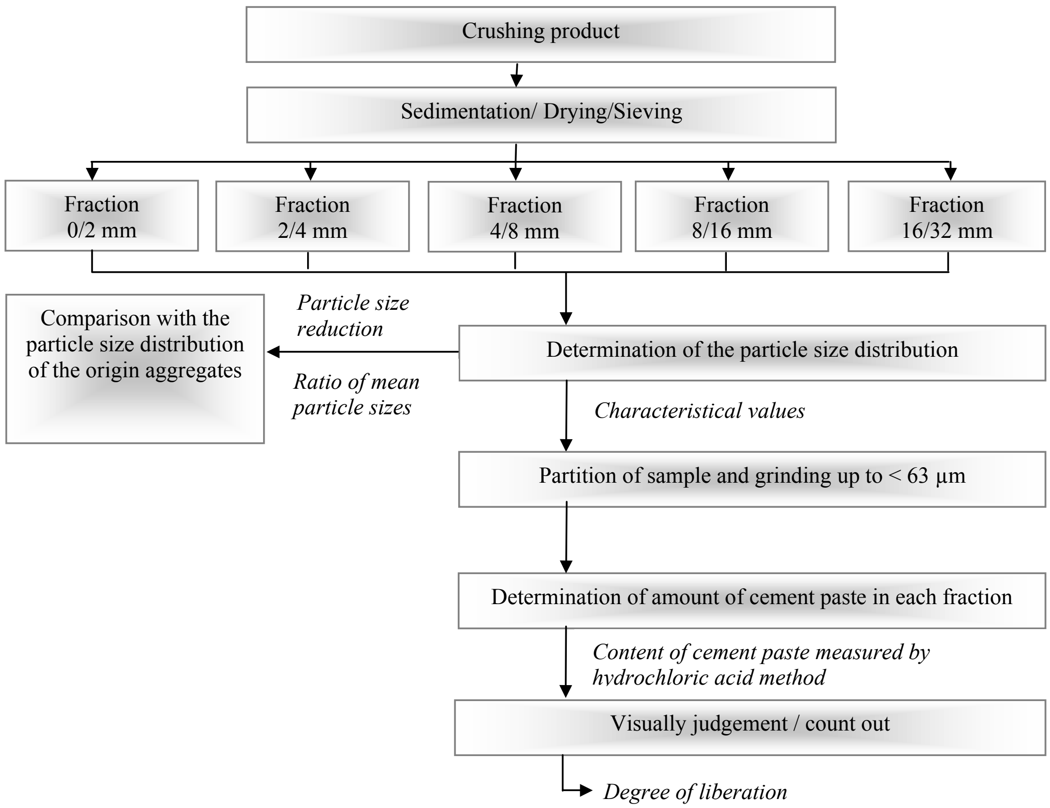


Figure 5 Strategy for the determination of the parameters

Table 1 Parameters for the evaluation of the separation of concrete constituents

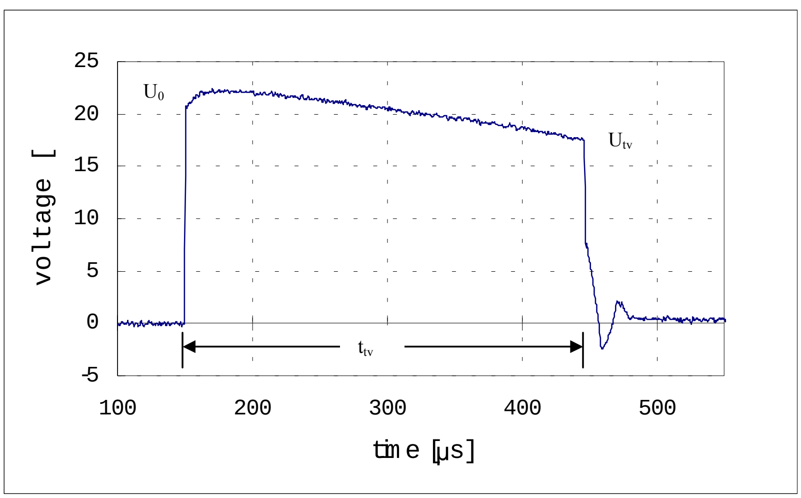
Evaluated effect and used parameters	Typical cases	Explanation	Example
Particle size reduction of aggregates *Ratio of mean particle sizes r_m* $r_m = \frac{x_{m,crushing\,product}}{x_{m,original\,concrete}}$	$r_m = 1$	Ideal case, no damage of aggregates (valid if the grains are cement paste free)	
	$r_m < 1$	Low effect on aggregate; agglomeration	
	$r_m > 1$	Intensive comminution; damage of aggregates	
Separation of cement paste and aggregate	Perfect separation $c_i = 0$	Aggregate grains without any cement paste; ideal case (valid for grains > 2 mm)	

Content of cement paste c in the fractions i *c_i [%]* $c_i = 100 - (HCl\ Insolvab)$	Partly separation $0 < c_i < c_{concrete}$	Aggregate grains with a certain amount of cement paste (valid for grains > 2 mm)	
	No separation $c_i = c_{concrete}$	Aggregates form agglomerates with a composition that agrees with the composition of original concrete (valid for grains > 2 mm)	
Separation of cement paste and aggregate *Degree of liberation D_L* *Content of aggregates without cement paste per fraction*	*D_L = 100 %*	Ideal case; all aggregates are without cement paste on the surface	

Determination of an Optimum Area of Processing

The Influence of the Inputted Electrical Energy on the Size Reduction of Concrete
Setting the electrical parameters can vary the electrical energy inputted, W_{tv}, which is explained in Table 2.

The discharge is divided in the so called pre- and main-discharge. During the pre-discharge, a small part of the stored energy, W_0, is lost in the water, because of the resistance of water, R_w. The main-discharge begins after the disruptive discharge. The converted energy in the spark, which is used for the comminution, is declared as the stored energy, W_0, less the degradation during the predischarge, W_{tv} (Figure 6).



$$W_{tv} = \frac{C}{2} \cdot U_{tv}^2$$
$$U_{tv} = U_0 \cdot e^{-\frac{t_v}{R_W C}}$$

W_0	stored energy
W_{tv}	converted energy (after the degradation during predischarge)
U_0	voltage at the beginning
U_{tv}	voltage after the degradation during predischarge
t_{tv}	ignition dead time
C	capacity
R_w	resistance of water

Figure 6 Explanation of the energy, W_{tv}, as a parameter for the converted energy

Table 2 Examined ranges of the electrical parameters

Electrical control variable	Range
Capacity of capacitor C	6 ... 12 µF
Voltage of charge U_0	20 ... 30 kV
Distance between electrodes s	10 ... 25 mm
Number of impulses n	10 ... 50
Stored energy W_{tv}	1,2 ... 5 kJ
Pressure amplitude p_{max}	up to 100 MPa

The first step was to find out the best agreement between the particle-size distribution of crushed concrete and the particle-size distribution of the original aggregates in the concrete. Figure 7 shows some of the experimentally-achieved particle-size distributions after the processing with shock waves, compared with the particle-size distribution of the original aggregates used in the concrete. The best agreement was found if the material was treated 50 times at a voltage level of 20 kV. By varying the electrical parameters, especially the number of impulses, the particle-size distribution can be shifted to coarser or finer ranges.
The properties of the product were related to the energy converted in the spark gap. The properties of the concrete used in these experiments are characterised in Table 3.

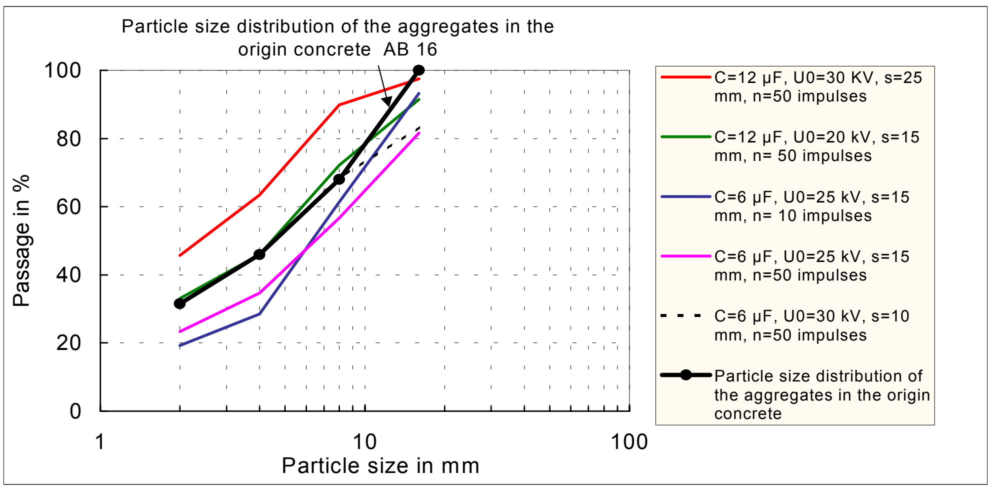


Figure 7 Examples of particle-size distributions between 2 and 16 mm, after crushing with shock waves at different levels of electrical parameters (concrete with compressive strength of 25 N/mm^2)

Table 3 Composition and properties of used-concrete specimens

	Compressive strength: 25 N/mm^2
Cement CEM I 32,5 R	300 kg/m^3
Water	180 kg/m^3
Water/cement ratio	0,6
Aggregate (quartz gravel)	1902 kg/m^3
Particle size distribution of the aggregates	AB 16
Compressive strength	36 N/mm^2
Modulus of elasticity	33,0 kN/mm^2

From the experiments, it follows that the mean particle size, x_m, of the crushed product is mainly influenced by the number of impulses, n, the voltage of charge, U_0, and the interaction between them. Enhancing the number of impulses is more effective at a high voltage level of charge. The distance between the electrodes is less important for the mean particle size. Figure 8 shows the ratio of the mean particle sizes, rm, versus the energy, W_{tv}. From this figure, it follows that the ratio, rm, increases exponentially with increasing energy input. The desired ratio, $r_m=1$, is achieved at an energy of $W_{tv} =$ 44 J/g.

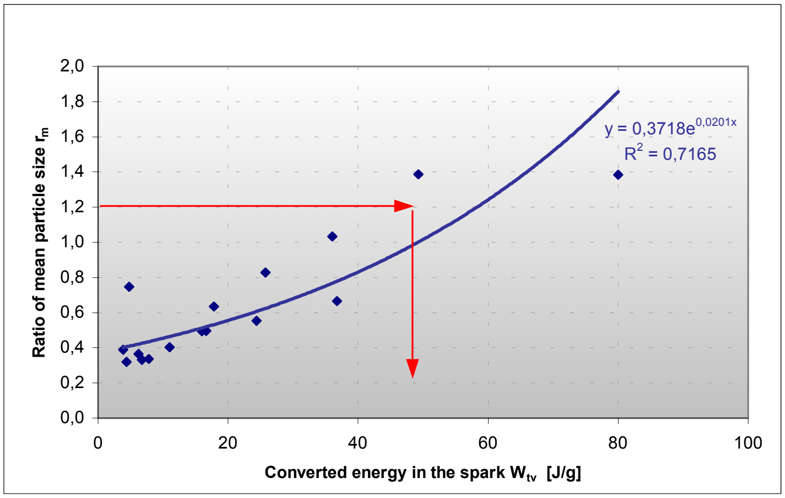


Figure 8 Ratio, r_m, versus the energy, W_{tv} (concrete with compressive strength of 25 N/mm^2)

The Influence of the Inputted Electrical Energy on the Liberation of Concrete Components
The target was also to get the highest liberation of the aggregates (gravel and sand). The degree of liberation, D_L, was determined by visual judgement. At the moment, it is possible to get back about 50 %, in the fraction 2-16 mm, as secondary aggregate, without cement paste at the surface ($D_L \approx 50\%$).

The degree of liberation, for all fractions 2 – 16 mm, increases with increasing energy input. In the fine fraction < 2 mm the content increases against it because in this fraction, the enrichment of cement paste occurs. In Figure 9, the content of aggregates without cement paste stuck is used as indices for the degree of liberation. At an energy of $W_{tv} = 80$ J/g , liberation reaches it highest level. A high energy is necessary to solve the agglomerates in the fraction greater than 16 mm.

Result of the experiments is an optimum working area, in the range of the energy $W_{tv} =$ 44 to 80 J/g.

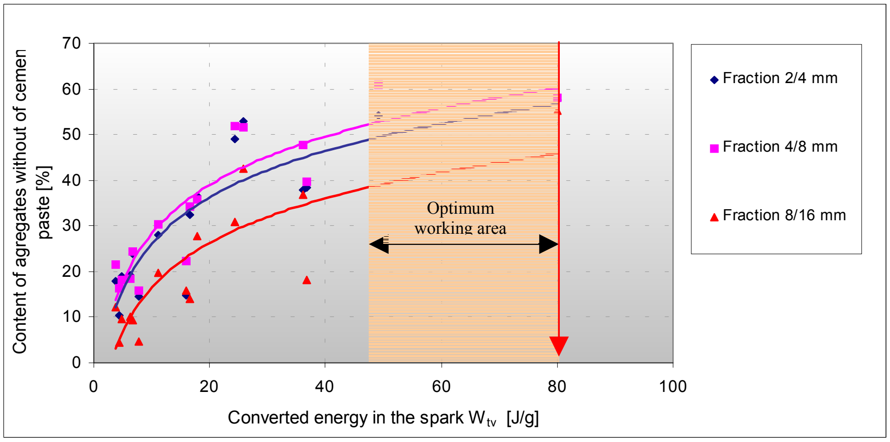


Figure 9 Degree of liberation (Content of aggregates without cement paste) per fraction versus the energy, W_{tv}, for concrete with a compressive strength of 25 N/mm^2

The chemical-evaluated content of cement paste, $_{ci}$, decreases with increasing particle size. In Figure 10, a comparison of the content of cement paste, depending on the particle size of a concrete crushed in an impact crusher and by shock waves, is plotted. The content of cement paste of course particles after crushing by shock waves is about 10 % lower than the crushed product of an impact crusher.

The Change of Conductivity

The conductivity of the water has a significant influence on the process of the discharge underwater. The losses in the pre-discharge become higher with increasing electrical conductivity. Hence, the energy provided in the underwater spark gap becomes lower. With an increasing number of impulses (the time the sample is in the water), the conductivity rises from 548 µS/cm to 2933 µS/cm (Figure 10). The concrete used for this experiment was the reference concrete number 1, which is explained in Tables 4 and 5 in more detail.

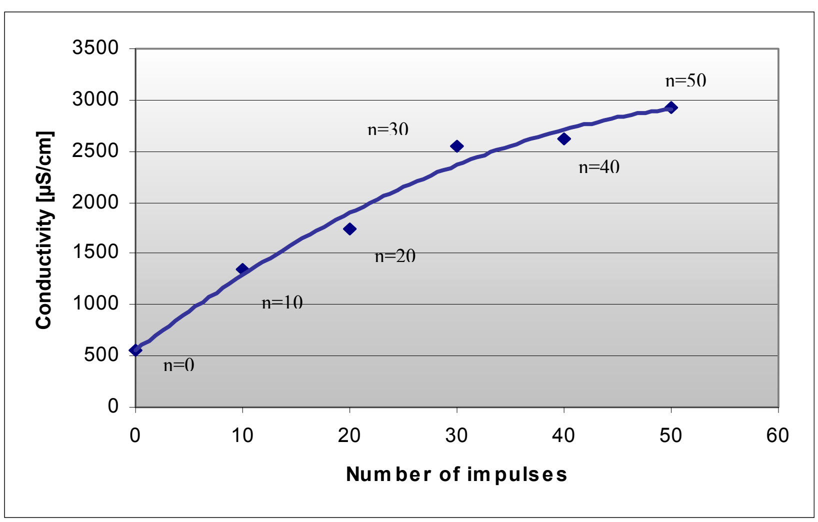


Figure 10 Conductivity of process water independent of the number of impulses (material: concrete 1 from Table 4)

Comparison of the electro-hydraulic comminution with conventional crushing methods

In Figure 11, the particle size distributions of concrete crushed in an impact or jaw crusher were compared to the same concrete crushed by high-performance sonic impulses. The secondary aggregates of the crushing by high-performance sonic impulses are in the favourable range of aggregates (AB16), according to the standard. But, the particle size distribution of the traditional crushing methods are out of the favourable range of aggregates.

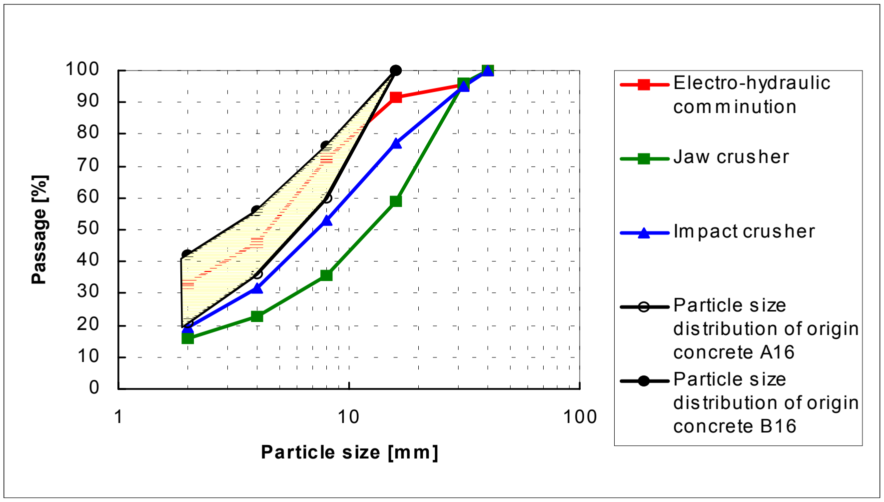


Figure 11 Comparison of the particle-size distributions of concrete crushed by high-performance sonic impulses and by traditional crushing methods [7]

The comparison of the degree of liberation of the aggregates (the aggregates without cement paste on the surface) independent of the particle size is really interesting (Figure 12). Here, the advantage of the crushing by shock waves is most distinct. Figure 12 very clearly shows that the degree of liberation for the crushing product generated by high-performance sonic impulses is increased up to 70 % with increasing particle size. For the jaw or impact crusher, the content of aggregates without cement paste decreases with increasing particle size. The separation by shock waves allows for better and more sensitive separation than do traditional crushing methods.

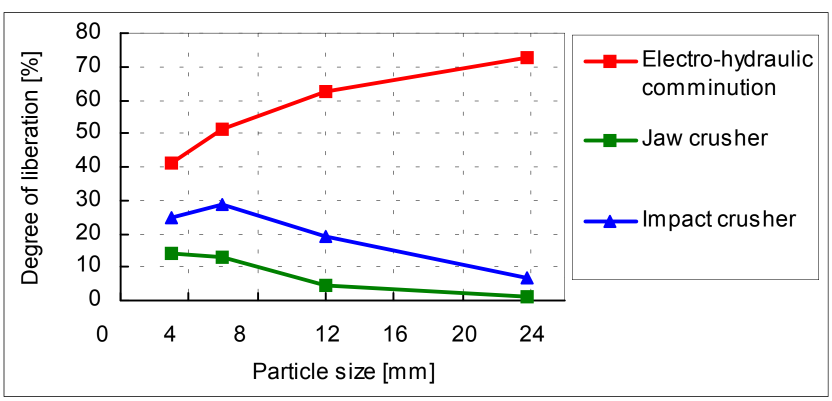


Figure 12 Comparison of the degree of liberation for secondary aggregates generated by jaw and impact crusher, and high-performance sonic impulses [7]

Investigations of Influence of the Kind of Concrete on Properties of Crushed Product
The particle-size reduction and the liberation of aggregates depends on properties of material, especially its strength and elastic behavior.

The middle strength concretes are difficult to crush because they are stringely. The concretes with high strength are very brittle. The explained method is very good when used for high-strength concretes. The crushing tests of concretes with systematically varied compressive strength, but constant raw materials, confirm this result (Figure 13).

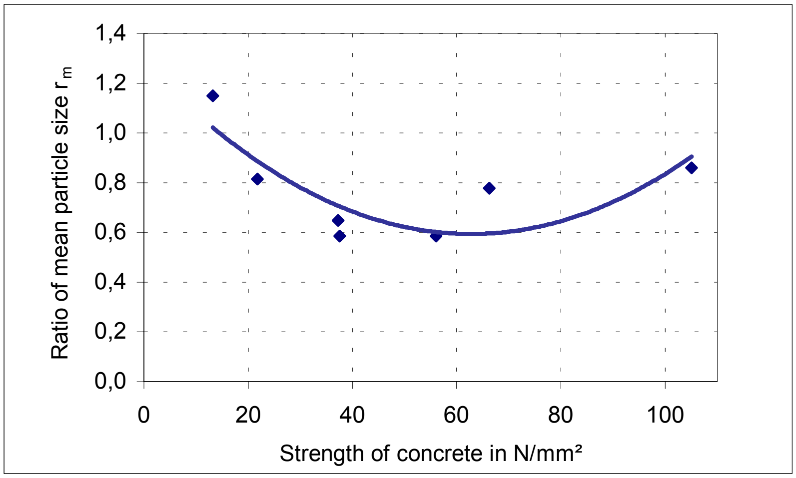


Figure 13 Comparison of treatment of sample for various strengths of concrete

The quality of the interfacial transition zone is, among other things, influenced by the type of cement used. To investigate this, concretes with different types of cement were produced, and crushed by shock waves. Table 4 shows the mixtures of the six different concretes, and Table 5 shows the types of cement used.

Table 4 Mixtures of the concrete examined

Concrete (with)	Cement [kg/m³]	Water [kg/m³]	Silicafume [kg/m³]	Aggregates 2) [kg/m³]
1 (CEM I)	331	192	-	1813
2 (CEM I (NA))	331	192	-	1813
3 (CEM II/B-S)	331	192	-	1803
4 (CEM II/A-LL)	331	192	-	1803
5 (CEM II/A-D)	301	192	30 1)	1808
6 (CEM III)	331	192	-	1803

1) Used: 60 kg/m³ Silicasuspension, “EMSAC 500 DOZ (SF)“ of Woermann, followed by a water reduction of 30 kg/m³
2) Amounts of the fractions: 0/0,5: 14 %; 0,5/1: 8 %; 1/2: 9,5 %; 2/4: 14,5 %; 4/8: 22 %; 8/16: 32 %

Table 5 Types of cement used (Designation according to DIN EN 197-1)

Sign	Name	Designation	Producer
CEM I	Portland cement	EN 197-1-CEM I 32,5R	Karsdorfer Zement
CEM I (NA)[1)]	Portland cement	EN 197-1-CEM I 32,5R-(NA)	HZ Burg-lengenfeld
CEM II/B-S	Slag cement	EN 197-1-CEM II/B-S 32,5R	Karsdorfer Zement
CEM II/A-LL	Portland limestone cement	EN 197-1-CEM II/A-LL 32,5R	Karsdorfer Zement
CEM II/A-D[2)]	Portland silicafume cement	EN 197-1-CEM II/A-D 32,5R	Karsdorfer Zement
CEM III	Blast furnace cement	EN 197-1-CEM III/B 32,5N-NW/HS/NA	Karsdorfer Zement

1) Not explicitly signed as cement with a low content of alkali, according to the producer
2) Manual addition of 10 mass-% silica powder to CEM I

The increase of electrical conductivity of the processed water is attributed primarily to the increase of the hydroxide ions (OH^-) and the calcium ions (Ca^{2+}) in the solution. With an increasing number of impulses, a continual growth of conductive ions in the water can be observed. That can be ascribed primarily to the solved calcium hydroxide (portlandit). The calcium hydroxide can be found in large amounts at the boundary layer between the cement paste and the aggregate, as is generally known. It is solved by the Ca^{2+} ions unsaturated water with increasing liberation. The influence of the content of alkali in the cement on the pH-value of the pores solution is significantly lower than on the crushing by shock waves.

For concretes with Portland cement or with Portland cement with inert additionals, the electrical conductivity of water can be used as degree of the quality of crushing. A high conductivity implies low ratios of crushing and low content of liberated aggregates.

These results cannot be generalized without further ado. These results cannot be generalized because the boundary layer is influenced not only by the cement, but also by the water-to-cement ratio, the type and particle-size distribution of the aggregates, the use of additives, and the age (the degree of hydratation).

The concrete with blast furnace cement (CEM III) showed the highest effectiveness at the crushing by shock waves, because of the low content of calcium hydroxide, with respect to the quantitative (particle size distribution, mean particle size, degree of crushing) and qualitative (degree of liberation) point of view.

The conclusion of these investigations is that the quality of the interfacial transition zone between aggregates and cement paste is very important for the crushing by shock waves. This fact will be investigated in more detail in further works.

Conclusions

The results show that it is possible to use shock as a tool for processing concrete. By variations of the electrical parameters, the converted energy can be varied widely. The number of impulses and the voltage are the main influences on the particle-size reduction and the quality of the crushing product.

For the examined concrete, with strength of 25 N/mm², an optimum treatment is possible at an energy input in the range of 44-80 J/g. About 50 % of the grains greater than 2 mm are free of cement paste.

The processing of middle strength concretes is more difficult than that of high and of low-strength concretes.

Secondary aggregates obtained from the new method clearly show a lower content of cement paste in the coarse fractions, when compared to secondary aggregates crushed in an impact or jaw crusher.

The influence of the conductivity of water is important for the efficiency of this method. One main factor influencing the conductivity is the type of cement used in concrete. It was examined that cement with a low content of calcium hydroxide, like blast furnace cement or composite cements, can be crushed more effectively.
.
In this context, we must think about possible pollution, like salts (chloride, sulfate, nitrate). They can be very unfavorable for the crushing .

FUTURE PROJECTS

Topics of further research will be: the investigation of the process parameters, the optimisation of the energy input, and the influence of more concrete properties on separation.

REFERENCES AND STANDARDS

[1] Selbstverplichtung erfüllt, Baustoff Recycling + Deponietechnik, No. 1—2 2002 ; pp 14-15

[2] Krass, K, Bautechnische und ökologische Aspekte des Betonrecyclings, Betonwerk+Fertigteil-Technik, No.1, 1994, pp 103-108

[3] NATAATMADJA, A, TAN, Y,L, The performance of recycled crushed concrete aggregates, Unbound Aggregates in Road Construction, A.A. Balkema/Rotterdam/Brookfield, 2000, pp 109-115

[4] Zange, R.: Anwendungsbezogenes Prozeßmodell der Wandlung elektrischer Energie in Energie des Leistungsschallimpulses. Dissertation Otto-von-Guericke-University of Magdeburg, 2000

[5] Budelmann, H.: Baustoffeigenschaften. 1. Zwischenbericht, Sonderforschungsbericht 385, Otto-von-Guericke Universität Magdeburg, 1996

[6] DIN 52179 T.1 - 4: Bestimmung der Zusammensetzung von erhärtetem Beton. February 1980

[7] Räß, S.: Vergleich zwischen den Zerkleinerungsprodukte des Verfahrens der Schallimpulszerkleinerung und konventionellen Zerkleinerungsverfahren für Altbeton. Student Research Projekt, Bauhaus-University Weimar, 2002

[8] Müller, M.: Untersuchungen zum Einfluss des Zementes auf die Betonzerkleinerung mittels Schallimpulsen. Student Research Projekt, Bauhaus-University Weimar, 2002

CREATING BUSINESS OPPORTUNITIES THROUGH THE USE OF A DECONSTRUCTION FEASIBILITY TOOL

Authors: Bradley Guy (University of Florida, Gainesville, Florida); Michael Ohlsen (Florida Department of Environmental Protection, Tallahassee, Florida)

ABSTRACT

To integrate deconstruction into the mainstream building industry, a tool has been designed to facilitate the "business" of deconstruction by allowing building or demolition contractors to readily estimate cost and revenue potential from deconstruction. Using the computer-based Deconstruction Feasibility Tool, economic variables such as local labor and disposal costs and salvageable and recyclable materials values can be easily manipulated to determine the optimal level of deconstruction. Armed with this information, a contractor choosing deconstruction can make a more competitive bid on building removal projects.

Currently, the model can be used for wood-framed one and two-story structures, but it provides a template for other kinds of structures, including masonry residential structures, multi-family residential structures and eventually commercial structures, as more real-cost data is available for those building types. This paper will discuss the development, design, and operation of the Deconstruction Feasibility Tool illustrating the model's tremendous business-building potential.

KEYWORDS: Deconstruction; Computer Model; Assessment Tools; Building Material Recovery; Business; Pollution Prevention.

INTRODUCTION

Background

In the past decade the Waste Reduction Section of the Florida Department of Environmental Protection sought to identify effective strategies to reduce the amount of construction and demolition (C&D) debris being generated in Florida. C&D debris remains a significant component of Florida's municipal solid waste stream [1]. Relatively low tipping fees and high rates of growth and development have contributed to the magnitude of C&D waste generation in Florida [2]. Numerous waste minimization options have been explored including the feasibility of building deconstruction to maximize material recovery and reuse.

In 1999, the Department awarded an Innovative Recycling Grant to Alachua County who in turn teamed up with the University of Florida's Center for Construction and Environment (CCE) to deconstruct six (6) houses during 1999-2000. These one and two-story houses represented typical Southeastern U.S. wood-framed residential construction from 1900 to 1950. The goal of the research was to examine the cost-effectiveness of deconstruction and salvage when compared to traditional demolition. The results were encouraging [3].

CCE found that deconstruction can be more cost-effective than demolition when considering the reduction in landfill disposal costs and the revenues from salvage. Their calculations took into consideration a host of regulatory and worker safety issues along with preparing the recovered building materials for redistribution. The major trade-off: deconstruction took appreciably longer than traditional demolition.

Making a Business Case

Since the research had primarily been done in an academic setting, attention turned to addressing how best to encourage deconstruction as a long term, economically viable sector of the construction industry for waste reduction and resource conservation. The first stop: demolition contractors. Within the demolition field, deconstruction was already being considered as an option on a continuum of choices for building owners, to be considered against cost, time, security, safety, social goals, and other factors that effect decisions about the choice best suited to the circumstances [4]. The question became: Why isn't the full range of deconstruction practices being implemented?

Cost is a key issue but not the only one preventing further growth in deconstruction and reuse of materials. After all, the reclamation and recycling industries have been very successful in sourcing valuable components and products for reuse. There are obvious physical barriers such as corrosion, damage and bonds that are worthless or difficult to separate. There are practical barriers that will include a lack of information, skills, markets and design. There are traditional barriers where products are not designed to be deconstructed and reused [5]. All these unknowns and risks leave a contractor unsure in which situations deconstruction will prove feasible.

With a generous grant from the U.S. Environmental Protection Agency's *Jobs Through Recycling* program, the Center for Construction and Environment (CCE) set off to develop a business tool – a computer model – that would aid anyone from a home-owner to a building or demolition contractor to estimate costs and revenue potential from the deconstruction of a wood-framed residential building. The grant also provided seed money to create within CCE a Center of Excellence in Deconstruction based at the University of Florida.

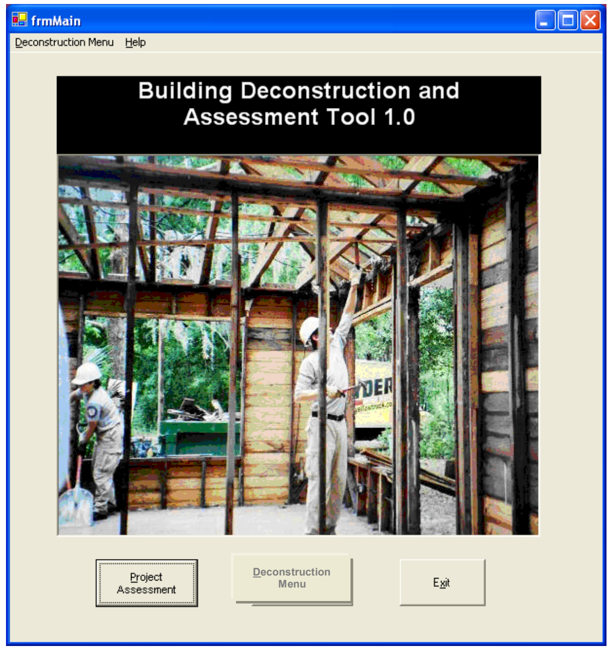
To date, only certain types of existing buildings are considered to be good candidates for deconstruction methods. The technique is best suited for smaller wood- or timber-framed structures; especially housing stock built before World War II; buildings with high-value materials, such as architectural features, rare woods, timbers, fixtures; and buildings without large quantities of painted wood. Few buildings can be totally removed through deconstruction [4]. But as processes improve, the computer model will grow and adapt.

And deconstruction is not only about removal of old buildings. By helping reveal where deconstruction opportunities and process efficiencies exist, the computer model may eventually help architects and building contractors "design for deconstruction" and help standardize industry practices, improve efficiency, enhance site safety, and dramatically increase recovery rates for interior renovations as well as structural removal [4].

GUIDE TO USING THE SOFTWARE (v 1.0)

Main Page

Figure 1 Opening Page



Although designed primarily to be a feasibility tool, the computer model also serves to educate users on the fundamentals of deconstruction. On the opening page, the user has the option to see an overview of the deconstruction process or a comprehensive list of resources on deconstruction. A guide to using the software is also available. These services can all be found by selecting the "Project Assessment" button (Figure 1).

The deconstruction tutorial provides a simplified outline of the deconstruction process discussing various opportunities and considerations including asbestos removal, removal of hazardous materials such mercury switches, salvaging high value items, hand versus mechanical labor, keeping the storage site dry and secure. A resources section has been included to provide a convenient listing of web sites that will give the deconstruction company or building owner quick links to case studies and other technical and regulatory information to help them better understand the opportunities and constraints related to deconstruction.

Preliminary Assessment

Selecting the "Project Assessment" button also allows the user to start a preliminary assessment (see Figure 2 on next page) by entering basic documentary or visually accessible information about a building that does not require extensive research or invasive procedures to determine. This Preliminary Assessment is intended to allow the user to quickly gauge the feasibility of deconstructing the building in a very simplistic manner and determine whether it is worth the effort to continue the process of making a detailed assessment of the building.

Each of the information categories in the preliminary assessment such as age, local tipping (disposal) fees, and basic material types is assigned a relative number of points so that a score can be calculated for the building's deconstruction potential. It is worth noting that this preliminary assessment is intended to look at the building as a whole, independently of any one factor, or other more detailed factors such as the complexity or size of the building. One very high quality building material such as a hardwood floor may be highly recoverable in isolation, but if many other aspects of the building's condition are poor for salvage such as concrete slab, concrete masonry unit (CMU) walls and manufactured trusses, this whole building would still rate poorly as a candidate for deconstruction. The detailed inventory in the next part of the model allows the user to calculate costs and potential salvage for separate elements, singly or in aggregate.

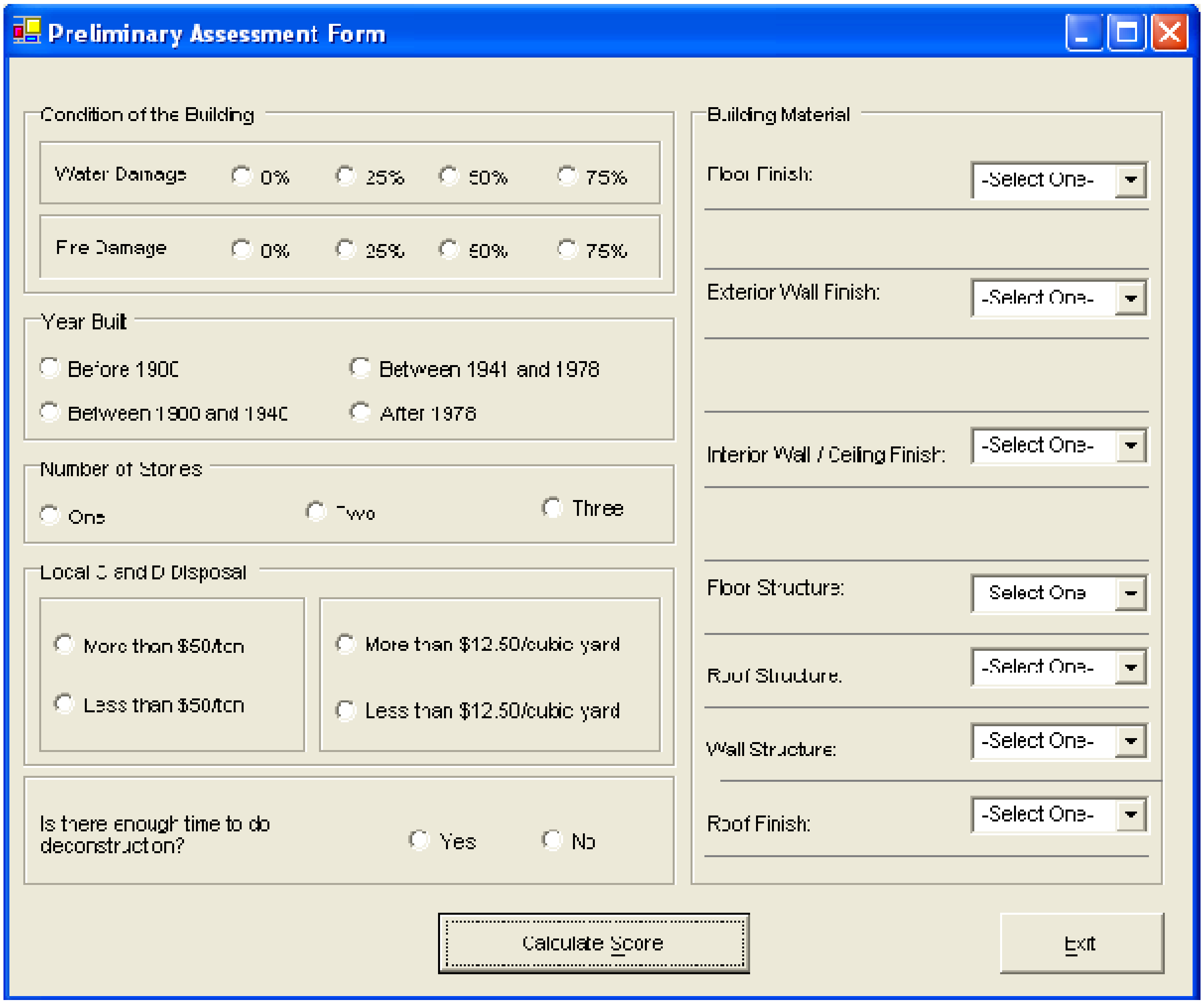


Figure 2 Preliminary assessment using "indicators" of feasibility.

After the Preliminary Assessment form is filled in, the model user clicks on "Calculate Score" and the building's score will appear with an initial recommendation to pursue a more in-depth assessment of either demolishing, deconstructing, or moving the building (Figure 3, next page).

[NOTE: This tool is currently set up to provide a detailed estimate for deconstruction and materials recovery and does not include costs to conduct a demolition or a building relocation. The user is advised to contact a local demolition company and/or building moving company in order to estimate costs for demolition and building relocation and to use these estimates for comparing deconstruction costs and possible costs avoidance and returns based upon avoided disposal and salvaged materials revenues from deconstruction.]

The user has the option of viewing a short series of images describing the process of "Demolition" or "Move It", for building relocation. These images provide the user with a perspective of the opportunities and constraints for these options.

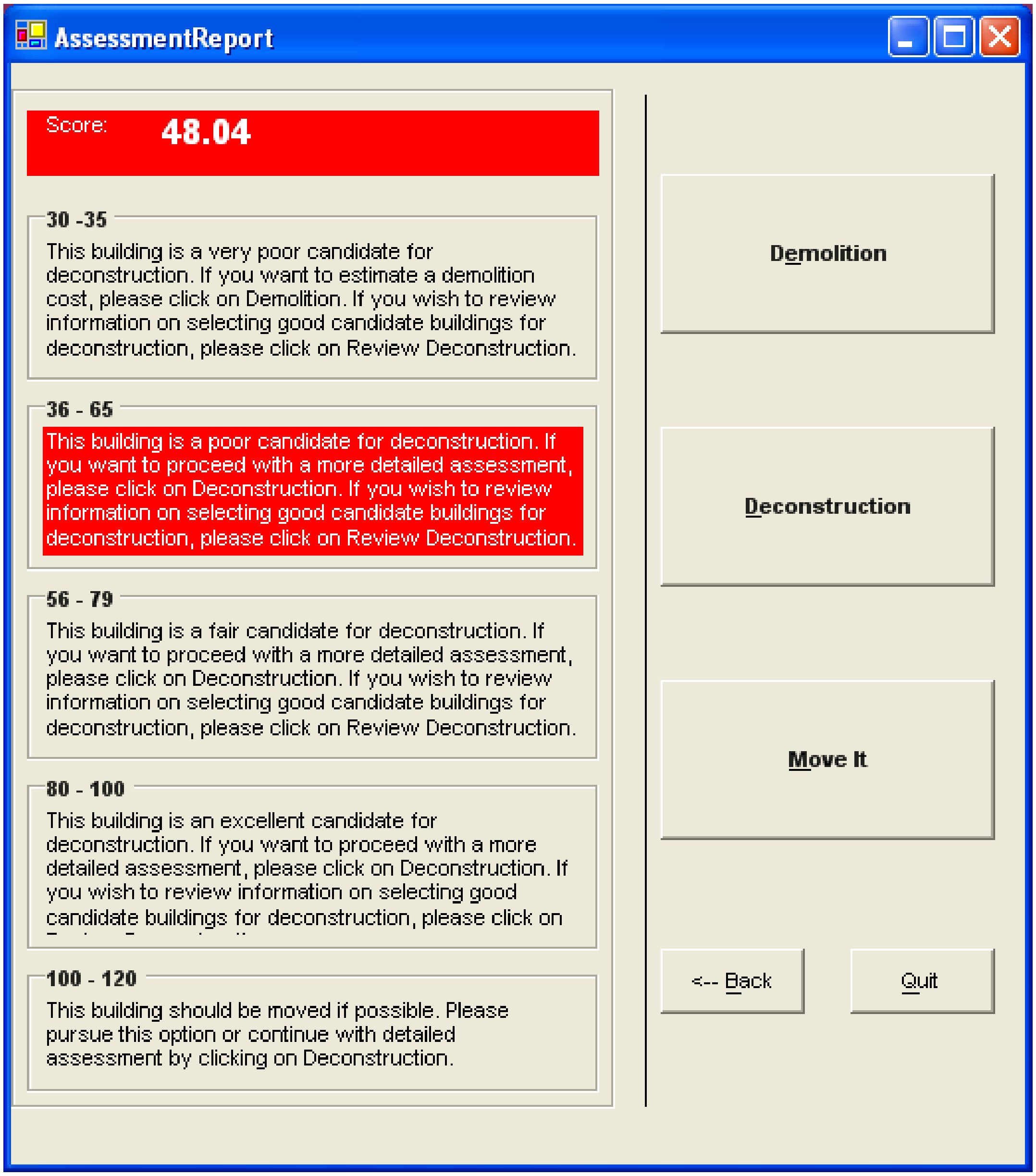


Figure 3 Preliminary Assessment Scoring Summary

If the score for the buildings' deconstruction potential ranks sufficiently high to warrant further investigation, the user clicks on Deconstruction. A series of messages will ask the model user if the building is in a historic district and what kind of regulatory agency will oversee the permitting process. These icons are meant to act as a reminder to the user to insure that research into all preservation; permitting and environmental regulatory compliance measures are taken before any deconstruction is proposed. Further versions of the tool will provide more detailed information on estimating environmental costs.

Recording Building Inventory

After selecting the "Deconstruction" button in the Preliminary Assessment Score form and going through the historic preservation and permitting reminders, the user will proceed to a more detailed quantification of the materials of the building and assign a base dollar value on the salvageable materials. [NOTE: The user can bypass the preliminary assessment altogether by selecting the "Deconstruction Menu" on the opening page (Figure 2).] The building is broken into major and minor components, under these categories, the specific elements and materials types are listed for the user to increase the specificity of the assessment as they wish.

The building is assessed in two ways, by the entire building (and each subsequent addition to the original building) and then by room. For some elements such as exterior siding, the perimeter exterior walls can be estimated as a component of the entire building. For other elements such as interior finishes, each room is assigned up to 6 wall surfaces, 2 ceiling surfaces, and 2 floor surfaces, and the finishes are estimated by room. (Figure 4).

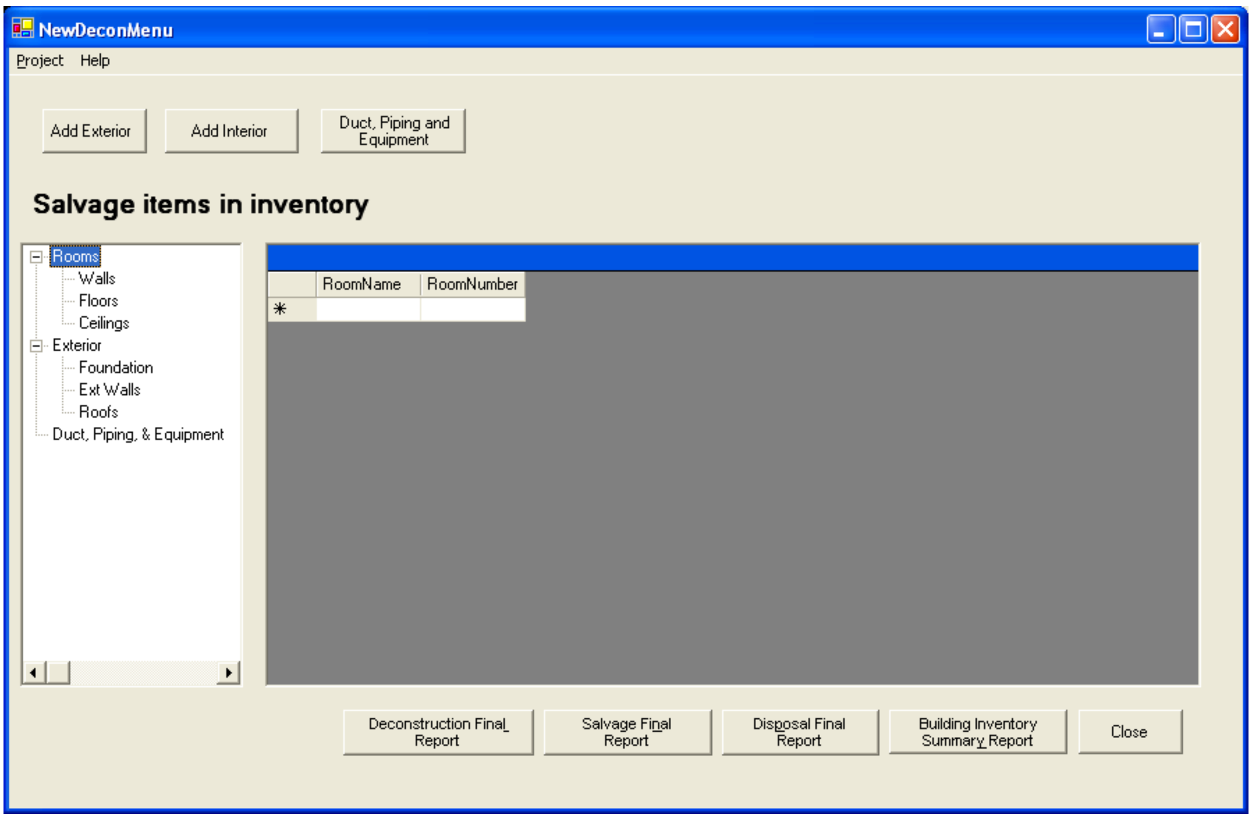
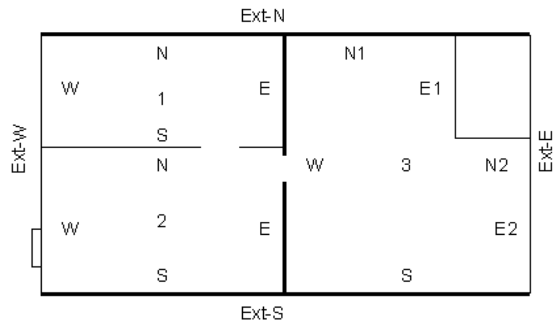


Figure 4 Deconstruction Main Menu

The computer model has been designed around a common sense approach to inventorying a building. The user simply reconstructs the general layout of the building section by section. The user should start by making a sketch of the building in order to have a way to record the building's four main elevations, North, South, East and West. Major elements such as porches should be included as a "room". The sketch should also include major elements such as stairs.

After completing the floor plan sketch, the user labels each room with a number, i.e. 1, 2, 3, … and assigns each wall in each room a designation by compass direction, i.e. N = north, S = south, E = east, and W = west. If the wall has a jog in it such that there is more than one plane or surface facing in one direction, the walls must be labeled with the letter for compass direction, and then numerically, 1, 2, 3… More than one North side wall would result in one wall designation N1 and the next section of north side wall designated N2 (Figure 5).

Figure 5 Example of a floor plan sketch



The floor plan sketch allows the user to input the quantity information for the building finishes, including walls, ceilings, and floors, doors and windows with a location parameter in order to prevent duplication of counting, and in the case of doors and windows, to insure that the area of these elements is subtracted from the areas of the walls where they are located. When entering doors and windows, they are also located by the room number and wall location and assigned a number if there are more than one on a particular wall. The information gathered from the sketch translates fairly straightforward into the computer model (Figure 6).

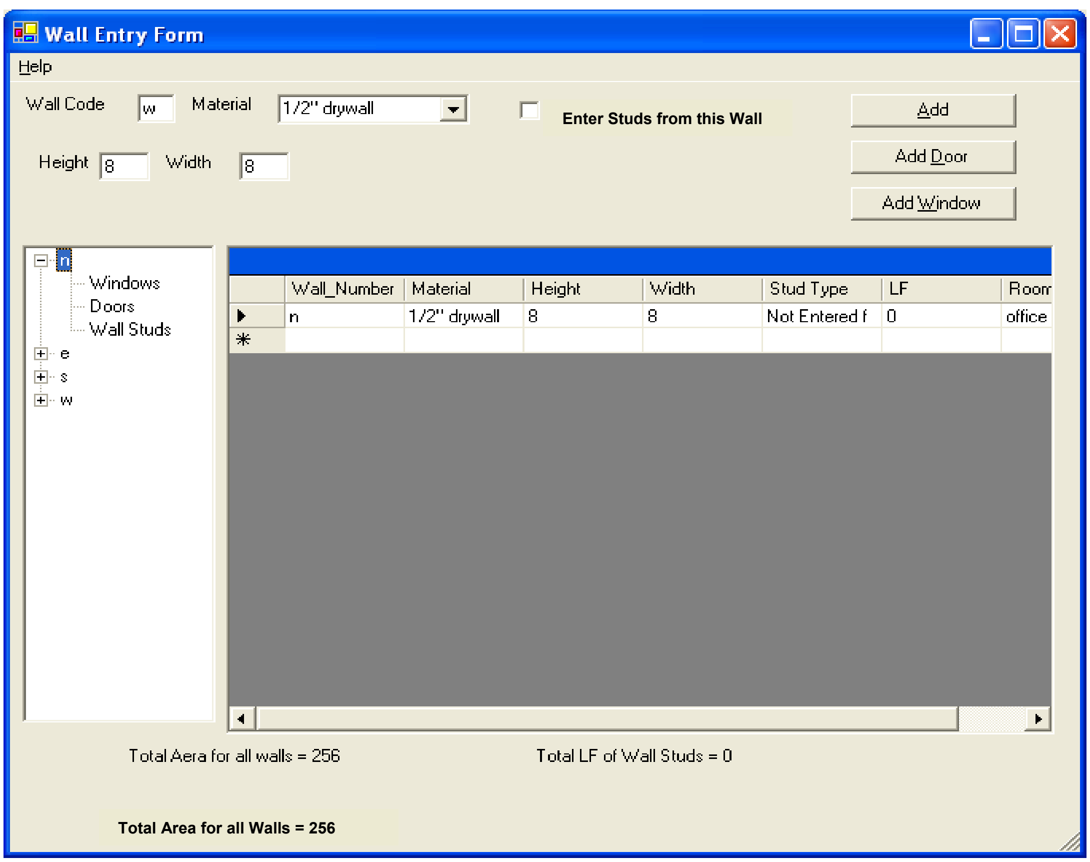


Figure 6 Sample data screen for wall measurements.

Measure areas and type or size of finishes, doors, windows that are associated with a location and entangled in the building structure or other finishes such that they might need to be removed to remove something else, or affect the estimate or materials. An example is a window, which must be subtracted from the area of a wall to calculate total area of wall finish materials. Count items that are not part of finishes or structure and do not need to be associated with a location such as furnishings and appliances, MPE fixtures and casework.

Deconstruction Sequence Logic

It is important to note that although the model allows for the input of the detailed inventory by major building element or types of materials, the deconstruction process does not allow a completely independent disassembly process. In other words, the user could input the removal of a structural wall as an independent cost and salvage operation for the purposes of estimation, but in reality this wall removal will require the co-removal of the supported floor or roof above it. A further version of the tool will provide a warning when the order of inputs violates the deconstruction sequence "logic" and recommendations for the sequence of deconstruction that should be followed for a building in order to insure the final reports reflect a feasible approach.

This room and location tracking system creates a numeric and location database – depending upon the items – that will also act to insure accurate counting and tracking during the deconstruction process.

Fine-Tuning the Data

Once the building inventory is complete with associated materials quantities and prices, there will be a database established with a volume and weight calculation of the whole building with the estimated salvage value based upon the user's estimate of how much salvage will be recovered from each major element. The default version of the tool includes labor times and some estimates of value for individual materials such as 2x4 piece of lumber. The user is free to change salvage percentage, estimated salvage value as they wish. Since the disposals amount is the total of a material minus the estimated amount of salvage, the amount of disposal will be automatically calculated.

Upon completion of the materials quantity estimates, a salvage rate or percentage is assigned to each sub element category to estimate the actual salvage value that can be expected. The salvage factor will first be based on the general level of deterioration determined in the preliminary assessment, and then further refined with each element of the building. For example, in the case of a window or door, the user will assign a salvage factor of 1, since the window only has value as an entire unit. For a wood framed wall, the salvage factor will be a percentage of the wood in the wall. Upon completion of the detailed materials and salvage estimate, the user will then be able to estimate costs based on unit deconstruction rates, estimated labor costs rates, estimated disposal and disposal costs, permitting and environmental assessment costs, and asbestos abatement costs if required. The final report will combine these estimates and variables to determine the cost-effectiveness of a deconstruction.

In addition, the user will have the flexibility to change any variable such as salvage values for components, labor rates and disposal fees, in order to understand macro-level costs and specific materials' revenues which most affect the economic viability of deconstruction in a particular geographic locale. This modeling capability will have use for determining local policy options to increase the feasibility of deconstruction within a particular municipality.

Viewing the Results
Once the user has inventoried the building they are free to select a variety of reports: Salvage Final Report, Disposal Final Report, Deconstruction Final Report, and Building Inventory Summary Report (refer back to bottom Figure 4).

The Salvage Final Report allows the tool user to estimate the total salvage value from deconstruction of the building based upon the quantities and estimated salvage percentages and values that the user has input into the model.

The Disposal Final Report allows the user to input the local area tipping (disposal) fees and hauling costs and calculates the costs of disposal of debris from the project.

The Deconstruction Final Report allows the user to input the cost of worker labor and supervisory labor and the percentage of total time spent in supervision versus labor, in other words a percentage of labor time and costs at the higher labor rate for supervision.

Upon completing all of the final reports for salvage, disposal, and deconstruction labor, the user can then go to Building Inventory Summary Report and see simple summary of the cost-effectiveness of deconstructing the building being assessed.

APPLICATION OF THE COMPUTER MODEL

Successful establishment of deconstruction requires coordination and dedication between several working groups. The groups include government, deconstructors, reusers and retailers [2]. Each group can benefit from using the Deconstruction Feasibility Tool.

Deconstructors: The Demolition Industry
Demolition has become a highly sophisticated business, requiring knowledge of mechanical and electrical systems, engineering, and complex DOT, OSHA, and EPA regulations [4]. In order for a demolition contractor to implement a greater range of deconstruction techniques, they will have to consider additional variables such as: the sequential aspect of the deconstruction process, time constraints, costs, and labor requirements. As these can be daunting tasks, the computer model can help a contractor project different scenarios based on what little information they may have available. These scenarios can quickly show the contractor what level deconstruction is feasible for a given project. This information equates to a more informed and competitive bid.

The key factors in the feasibility of deconstruction are labor costs, which is both an independent variable and dependent on the number of deconstruction tasks and the efficiency of each task, and local disposal costs. Salvage materials values are extremely variable, from dimensional lumber (which may be much less valuable than new lumber) to high value architectural salvage (which may have a unique value).

Attempting to increase salvage per building will always have a point of diminishing returns as the more valuable items are stripped more efficiently than harder-to-access materials, and as less damaged materials give way to more damaged materials [3]. Based on this analysis, the typical disposal fees in a geographic area are an important "indicator" of deconstruction potential and will encourage more "whole house" deconstruction in lieu of selective "cherry-picking" of materials.

Government and Community-Based Organizations

Governmental agencies can work together with regional businesses to support the implementation of deconstruction. Using the computer model, a local government can inventory and assess abandoned buildings and those scheduled for removal to identify good candidates for deconstruction projects and make the information available to the public. Local reuse authorities for closing military bases (such as the one for Ft. McClellan in Anniston, AL) can benefit from modeling the deconstruction process in advance. Government contracting processes, such as Requests for Proposals (RFPs), could include materials recovery requirements, requiring salvage and reuse plan, and or awarding points in bidding process for high recovery rates [2]. Even non-profit community groups such as Habitat for Humanity can benefit from using the model to estimate material quantities available in structures to be removed.

Design and Construction Industry

The practice of Design for Deconstruction (DfD) will allow existing and new building stock to one day serve as the primary source of materials for replacement construction, in effect mining and harvesting existing building stock rather than the natural environment. This resource flow will be encouraged by aging and obsolescent buildings, dwindling natural resources, and declining population in developed countries [6].

The efficiency of the deconstruction process and the cost-effectiveness of materials recovery with highest reuse or recycling value are most influenced by the designer, the architect and engineering team that determines how the building is to be assembled. These designers must understand how their decisions impact disassembly and reuse. The choices and specific uses of materials, the connections between individual materials or components, the inter-relationships of building elements, the designs of spaces and whole-building structure, and even the ability to "read" the building are within the designer's control [6]. Incorporating innovative design principles that anticipate eventual disassembly will dramatically enhance recovery efforts and at the same time increase efficiency and worker safety during a building's eventual removal.

Building design can also be influenced by use of the computer model in another way. Consider a construction project that will use materials recovered from a planned deconstruction. The computer model can estimate the types and quantities of building materials will be recovered. With this knowledge, an architect can more fully design for the use of these materials in the new construction project.

NEXT STEPS IN DEVELOPMENT

There are many factors that can influence the successful implementation of deconstruction such as: labor, scheduling and cost, tipping fees at construction and demolition landfills, hazardous characteristics of demolition waste, markets, material grading systems, time and economic constraints, contractual agreements, and public policy [2]. The Deconstruction Feasibility Tool incorporates several of these factors into a single computer model that generates valuable business information.

Currently, the model can be used for wood-framed one and two-story structures, but it provides a template for other kinds of structures, including masonry residential structures, multi-family residential structures and eventually commercial structures, as more real-cost data is available for those building types.

Opportunities Ahead

In order for complete deconstruction to be successful and profitable, there must be an outlet for the materials salvaged [2]. The computer model may be expanded to include an inventory database to promote local markets for reuse. A network of deconstruction service providers and advocates who can work together to overcome local barriers to deconstruction can be listed in the program as well.

At the time of this writing, the computer model had been field tested in a limited number of situations. These field tests help the software developer fine-tune the algorithms and user-interface to make the computer model more effective. It is anticipated that the model will go through many revisions in the coming years as it is applied to a greater number and variety of building structures.

Future versions of this model will seek to generate a specific material inventory that can be integrated into a business's existing sales inventory. As the model sorts the building from input (e.g. by rooms) then categorize by components (e.g. interior walls) then sort down to material type (e.g. wood), the next step would be to itemize these individual materials by type and unit, say X number of 2x4s.

The model will be made available through the University of Florida's Center for Construction and Environment. At the time being, there is no fee as initial development was funded through federal and state grants. As additional time and resources are put into upgrading the model, it is anticipated that a nominal fee will be charged to offset these additional costs.

Other Computer Models

The deconstruction assessment process that is used in this computer model was developed from the Center for Construction and Environment's experience and was augmented by research on other projects and interviews with a long-time deconstruction specialist, Pete Hendricks from Chapel Hill, North Carolina. Other computer models may prove useful, too.

The French-German Institute for Environmental Policy at the University of Karlsruhe developed a computer-based estimating tool for "selective dismantling" [7]. BRE of Watford, United

Kingdom, created SMARTWaste to provide a mechanism by which waste arising can be benchmarked and categorized by source, type, amount, cause and cost [5]. More information on both of these models can be found in the References section.

CONCLUSIONS

This tool was designed to help encourage deconstructions development into a long term, economically viable sector of the construction industry for waste reduction and resource conservation. For demolition contractors, the computer model serves as a business tool to identify what level of deconstruction is feasible for a given structure. The tool may aid architects and construction contractors in designing buildings that incorporate more recovered material in its construction and can be more readily deconstructed in its removal. Finally, the tool also serves governments and community-based organizations that are interested in fostering sustainable construction practices and need a way of determining the potential for each project.

REFERENCES

1 **Bureau of Solid and Hazardous Waste**, *Solid Waste Management in Florida*, Florida Department of Environmental Protection, Tallahassee, Florida, 2002.

2 **Kibert, C.J. and Languell, J.**, *Implementing Deconstruction in Florida: Materials Reuse Issues, Disassembly Techniques, Economics and Policy*, University of Florida, Gainesville, Florida, 2000

3 **Guy, G. B. and McLendon, S.,** *Building Deconstruction: Reuse and Recycling of Building Materials*, Unpublished report, Center for Construction and Environment, University of Florida, Gainesville, Florida, 2000.

4 **National Association of Demolition Contractors**, *Demolition… The First Step of Reconstruction*, NADC Position Paper, Doylestown, Pennsylvania, 1999

5 **Hurley, J.W. et al.,** *Design for Deconstruction – Tools and Practices*, CIB Publication 272, BRE United Kingdom, 2002

6 **Guy, G. B. and Shell, S.**, *Design for Deconstruction and Materials Reuse*, CIB Publication 272, University of Florida, Gainesville, Florida, 2002

7 **Seeman, A. et al.,** *Cost-effective Deconstruction by a Combination of Dismantling, Sorting and Recycling Processes*, CIB Publication 272, University of Karlsruhe, Germany, 2002

RECOMMENDATIONS FOR THE USE OF AGGREGATES FROM RECYCLED CONSTRUCTION AND DEMOLITION WASTE IN VENEZUELA

Authors: Suárez C.J., Malavé R.E., (School of Civil Engineering, Central-Western University "Lisandro Alvarado", e-mail address: cjsuarez@intercon.net.ve)

ABSTRACT

Research works undertaken in the Civil Engineering Department of the Central-Western University, "Lisandro Alvarado," have proved the possibility of using aggregates obtained from the recycling of construction waste in Venezuela. The following issues have been analyzed: the volume of waste generated in the city, the recyclable percentage to allow the industrialized recycling process, the suitable uses of recycled aggregates, the cost comparison between natural and recycled aggregates, and the technical feasibility of construction waste recycling with conventional crushing and screening equipment. For recycled aggregates, the following physical and chemical properties were evaluated: gradation, loose unit weight, compacted unit weight, fine content, chloride content, sulphate content, and organic matter content. Mechanical properties, including bonding, compressive strength, absorption, and porosity for mortar and concrete mixes prepared with recycled aggregates, were also evaluated. As a result, aggregates from construction and demolition waste are suitable for use in stucco mixes, concrete blocks, and low-strength concrete.

KEYWORDS: Aggregate; Recycled; Mortar; Concrete; Stucco; Blocks

INTRODUCTION

Construction waste reutilization is an application developed from the necessity of rebuilding cities after wars or natural disasters. In addition, this process has been encouraged by new approaches to environmental protection and clean technology development. The worldwide importance reached by the use of construction and demolition wastes has motivated the creation of a RILEM[1] committee to unify standardization criteria of these materials. Physical and mechanical properties, including durability of recycled concrete, have been successfully investigated. However, one of the recommendations of Morel et al[2] is to use concrete made of recycled aggregates in elements of minor importance, such as: masonry mortars, sidewalks, pavements, and stucco works. There are two main reasons for this: first, lack of standards and specifications; second, use of recycled products is still restricted by psychological barriers of builders. Furthermore, there are plenty of natural aggregate sites in Venezuela, as well as waste disposition sites. Therefore, the recycling of construction waste has not yet received enough attention in the country. However, it would be justified today if a significant cost reduction in housing construction can be reached, and indiscriminate extraction of natural aggregates from rivers and creeks can be avoided.

With this background and justification, this paper presents some recommendations for the use of aggregates from construction and demolition waste, adapted to the construction industry in Venezuela. Results from research works conducted in the Civil Engineering Department of the Central Western University in Barquisimeto, Venezuela, are summarized as follows:

- The amount of construction waste generated in the city (0.06 cubic meter per square meter of new construction in town) and the recyclable percentage of it (40%) is enough to allow the industrialization of the recycling process (Hau et al[3]).
- The cost of recycled aggregates is about 35% less expensive when compared to natural aggregates (Cortez et al[4]).
- The recycled aggregates are useable in the production of masonry mortars, concrete blocks, and low-strength concrete (120 Kg/cm2 - 150 Kg/cm2, Cortez et al[4] and Molleja et al[5]).
- The industrialization of the recycling processes is technically feasible, either with conventional crushing and screening equipment, or with specific recycling equipment (Pemía et al[6]).
- The environmental impact of construction waste production and disposition deserves more attention from state and county authorities in charge of city conservation and health (Hau et al[3]).

METHODS

With the purpose of fulfilling the objectives of this research, the following materials were used: Portland cement Type 1, natural aggregate, and industrialized recycled aggregate (this being the variable of study). For all cases, a minimum of five tests was conducted for each sample. Tests were performed following ASTM and ACI specifications.

Aggregates

Aggregates used in this research were classified as follows:

- Natural fine aggregate from mines and riverbeds, traditionally used in the region for stucco works.
- Standard coarse aggregate from riverbeds, processed in crushing plants installed in the area, and commonly used for concrete production.
- Recycled aggregate obtained through standard crushing processes, applied to five samples of building construction waste and one sample of building demolition waste, mixed all together, including non-reinforced concrete, mortar, clay blocks, concrete blocks, and ceramic.

Selected waste was cleaned, and undesirable materials, like timber, paper bags, nails, wire, other metal pieces, and plastic elements, were taken away. Then, waste materials were taken to local crushing plants.

Crushing was accomplished through two pilot tests performing two different crushing processes, thus permitting analysis of resulting aggregates from both wet and dry processes. In the first plant, crushing equipment allowed material washing to eliminate the excess of #200-sieve passing fraction in the fine aggregate. The second crushing allowed the production of recycled aggregates through both wet and dry processes separately. In this case, crushing is performed by means of a primary jaw crusher set for 3”-maximum size resulting particle. This material passes through a screening machine, where products are classified as follows: 1 ¼”-3” fraction goes to a secondary crusher (hammer crusher), smaller fractions plus products from the secondary crusher are also selected in a secondary screening machine. From this, 9/16”-1 ¼” fraction is selected as coarse aggregate for concrete (#1 stone), 3/8”-

9/16” fraction is selected as gravel, and fraction finer than 3/8” is selected as sand or fine aggregate for concrete. In this stage of the process, a sand washing machine can be used to eliminate the excess of #200-sieve passing fraction, thus obtaining the industrialized—as opposed to laboratory procedures—recycled wet process (IRWP) aggregate. Otherwise, the industrialized recycled dry process (IRDP) aggregate is obtained.

Then, standard quarter procedure is applied to the resulting aggregates to get the necessary samples for characterization. Standard ASTM testing for concrete and mortar aggregates were applied, including the following: gradation, loose unit weight, compacted unit weight, fine content, chloride content, sulphate content, and organic matter content.

Mortars

The resulting aggregates were screened separately in a 4 mm sieve to get aggregate for rough stucco works or block laying. Using a 2 mm sieve, finer aggregate was obtained suitable for finishing stucco works, commonly specified for building construction in Venezuela. The passing fraction from each sieve is considered the useable percentage for the specific purpose. Mortar mix for rough stuccowork was proportioned as for normal practical use: 1 volume of cement and 3 volume of 4 mm-maximum size particle aggregate. Finishing mortar mix was proportioned as usual in Venezuela: 1 volume of cement, 1 volume of lime, and 6 volume of 2 mm-maximum size particle aggregate.

Throwing the mortar against a vertical surface and checking that it was able to support its own weight without detaching from the vertical surface determined the bonding of fresh mix. For set mix, bonding was determined applying a compressive test to specimens formed by two blocks, connected with 1.5 cm-wide mortar, at the age of 28 days. Retraction of set mix was determined by comparing cracking of recycled aggregate mortar, thus measuring the amount of cracks as well as their length and width by square meter of surface. This test was performed at 28 days on stuccowork areas of 60 cm x 60 cm and 1.5 cm average thickness. Compressive strength of mortar was tested on 5 cm cube specimens at the age of 7 and 28 days.

Concrete Blocks

Concrete blocks with dimensions 40 cm x 15 cm x 20 cm were fabricated in local, specialized block factories. Six types of mixes were prepared, using aggregates from both natural and recycled origin. Proportion was kept at 1 volume of cement and 10 volumes of aggregate for the first four types of mixes: Mix 1 was an unknown mix corresponding to that used in 7 concrete factories located in the area which produce the average concrete block or control sample; Mix 2 was prepared with standard fine aggregate for concrete; Mix 3 was prepared with industrialized recycled wet process (IRWP) aggregate; and Mix 4 was prepared with industrialized recycled dry process (IRDP) aggregate. Two more mixes were prepared using gravel (4-10 mm fraction) in addition to both standard and recycled aggregates. Mix 5 was proportioned 1 volume of cement, 7 volumes of standard fine aggregate, and 3 volumes of standard gravel; and Mix 6 was proportioned 1 volume of cement, 7 volumes of average industrialized recycled (AIR) aggregate, and 3 volumes of gravel obtained in the recycling process. Concrete blocks were produced with these mixes, and mechanical properties were evaluated and compared with the control sample. Evaluated properties included compressive strength, water absorption, porosity, and weight.

Low-Strength Concrete
Concrete cylinders with standard dimensions (15 cm in diameter x 30 cm high) were tested for design mixes of 150 kg/cm² and 180 kg/cm², using both standard and recycled aggregates. Mix designs were made following ACI standards. Aggregates were kept wet before the mixing process, as recycled aggregates present greater absorption than standard ones. The purpose of this test was to determine the possibility of producing non-reinforced concrete to be used in floor leveling, sidewalks, gutters, and other non-structural applications. Compressive strength at the ages of 7 and 28 days, and porosity were the variables evaluated for these samples.

RESULTS

Aggregates
The recycling of materials from construction and demolition of concrete and masonry elements through an industrialized wet process (IRWP) generates 7.50% less particles smaller than 4 mm, 15.24% less particles smaller than 2 mm, and 2.88% less particles passing the #200-sieve, when compared to the average natural or standard aggregate. Due to the coarse gradation of the resulting aggregate from the wet crushing and screening process, it is suitable for concrete block production and for thicker stucco layers, but not suitable for stucco finishing works. The dry crushing and screening process (IRDP) instead produces up to 80.25% of useable material to perform stucco works with standard finishing quality. Table 1 shows these aggregate properties. Retained material in the 4 mm sieve (4-10 mm fraction) can be used as coarse aggregate in the production of filling mortar for reinforced masonry building and floor leveling. In general, other aggregate properties, such as unit weight, chloride, sulphate, and organic matter contents, met the ASTM and ACI requirements.

TABLE 1: Percentage of Usable Aggregates for Stucco Mixes

Aggregate type	Passing 4 mm sieve %	Passing 2 mm sieve %	Passing #200 sieve %	Max. particle size mm
Average natural	79.25	59.53	8.43	10
Average recycled in laboratory	69.70	41.61	7.65	10
Industrialized recycled wet process (IRWP)	71.75	44.29	5.55	10
Industrialized recycled dry process (IRDP)	80.25	55.69	12.21	10

Mortars
Using a skilled mason mixes from recycled construction waste proved to dry faster and be lighter than mixes with natural aggregates. This improves work efficiency. Mixes prepared with recycled aggregates showed good bonding behavior and acceptable cracking pattern. Fine mortar showed bonding and finishing properties as well.

Compared to a control minimum value of 1.36 kg/cm² from the Office State Architect of California (7), mixes from both wet and dry recycling processes of construction waste showed higher bonding capacities: 3.03 kg/cm² and 2.86 kg/cm², respectively.

Tests also showed higher 28-day compressive strengths for mortar prepared with recycled material in both wet and dry processes (198 kg/cm² and 163 kg/cm², respectively) compared to mortar from natural aggregate of common use for stucco work, which developed 153 kg/cm². Bonding and compressive strength of mortar are given in Table 2.

TABLE 2: Bonding and Compressive Strength of Mortar 1:3

Aggregate type	Bonding kg/cm²	7-day Compressive Strength kg/cm²	28-day Compressive Strength kg/cm²
Average natural	2.05 ± 0.41	109 ± 10	153 ± 15
Average recycled in laboratory	2.29 ± 0.32	173 ± 12	233 ± 13
Industrialized recycled wet process (IRWP)	3.02 ± 0.21	141 ± 13	198 ± 18
Industrialized recycled dry process (IRDP)	2.86 ± 021	116 ± 8	163 ± 11

Concrete Blocks

Blocks made with aggregates from both IRWP and IRDP reached, on average, 30.88 kg/cm², which corresponded to 75.82% of the average compressive strength measured for standard concrete blocks produced by seven different local factories (40.73 kg/cm²). Nevertheless, blocks from recycling showed higher compressive strength than two of the seven factories considered. With the addition to the mix of 27% in volume of gravel (4-10 mm fraction) from the crushing and screening process, blocks showed a significant increase in compressive strength: 40% higher than the average for locally available standard blocks, and only 10% lower than blocks fabricated with natural aggregate, including 27% of gravel.

Blocks from recycled aggregates absorb 65% more water than average standard blocks. However, when adding to the mix 27% in volume of gravel, the amount of water absorbed became only 27% greater compared to the average standard block.

On average, blocks from recycled aggregates are 15% lighter than average standard blocks. When adding to the mix 27% in volume of gravel, the weight of recycled block is about the same of that for standard concrete block.

The average block from IRWP and IRDP is 75% more porous than the average standard block. However, when adding 27% in volume of gravel to the recycled material, porosity values reduced compared to those measured for standard blocks. Table 3 shows recycled and standard concrete block properties.

TABLE 3: Mechanical Properties of Concrete Blocks

Production Process	Compressive Strength kg/cm²	Absorption %	Weight kg	Porosity %
Average local factory	40.73 ± 10.00	6.81 ± 0.51	10.77	16.32 ± 1.52
With natural aggregate proportion 1:10	56.05	5.27	11.00	12.26
With IRWP aggregate proportion 1:10	31.06	11. 45	9.30	28.15
With IRDP aggregate proportion 1:10	30.70	11.02	9.10	28.93
With natural aggregate proportion 1:3:7	62.85	5.96	10.75	13.06
With IRWP or IRDP aggregate proportion 1:3:7	57.01	8.68	10.50	16.15

Low-Strength Concrete
For constant water-cement ratio, concrete made with IRWP aggregates developed a 28-day compressive strength that resulted in 76.48% of the design compressive strength 150 kg/cm², measured for control concrete cylinders prepared with standard aggregates, and 85.50% of the design compressive strength, 180 kg/cm². For IRDP aggregates, maximum 28-day compressive strength resulted in 78.84% of the 150 kg/cm² design concrete strength, and 66.57% of the 180 kg/cm² design concrete strength.

Porosity results showed to be 67.24% higher for concrete from recycling aggregates, for design compressive strength of 150 kg/cm², and 76.1% higher for design compressive strength of 180 kg/cm², whether the recycling aggregates came from IRWP or IRDP. Low-strength concrete properties are given in Table 4.

Table 4: Low-Strength Concrete Properties

Aggregate Type in Concrete Specimen	Design Compressive Strength 150 kg/cm²		Design Compressive Strength 180 kg/cm²	
	Strength kg/cm²	Porosity %	Strength kg/cm²	Porosity %
Standard aggregate	150 ± 3	6.38	181 ± 1	4.07
IRWP aggregate	117 ± 9	10.67	155 ± 5	7.13
IRDP aggregate	120 ± 8	10.63	120 ± 3	7.17

CONCLUSIONS

Construction and demolition waste containing concrete and masonry elements can be recycled through crushing and screening processes to obtain suitable aggregates that can be used to perform stucco works and concrete blocks of acceptable quality. Higher absorption of concrete blocks from recycled aggregate can be a disadvantage in terms of wall permeability; however, as an advantage, bonding between blocks also becomes higher. Wall finishing with stucco from recycled aggregate will improve performance of walls against water absorption. Concrete from recycled aggregates can be used for compressive strength of 150 kg/cm^2 or less; however, its use in structural elements must be avoided because of the lack of standards.

BIBLIOGRAPHY REFERENCES

1. Demolition and Reuse of Concrete and Masonry Proceedings of the Third International *RILEM Symposium. (1993). Denmark*

2. Reuse of Concrete and Masonry Proceedings of the Third International RILEM Symposium, (1993): 71-82.

3. E. Hau, R. Bassantes, R.E. Malavé, "Evaluación de la producción de escombros de construcción en Barquisimeto para ser usados en la elaboración de concreto". *XLVI Convención anual de ASOVAC, Barquisimeto, Venezuela 1996.*

4. J. Cortez, A. De Abreu, H. Pérez, C.J. Suárez, R.E. Malavé, "Caracterización de escombros reciclados para ser usados como morteros de friso en obras de mampostería". *III Encuentro Nacional de Vivienda 95, Barquisimeto, Venezuela (Oct. 1995):* 39-48

5. 1 Molleja, R. Pérez, C.J. Suárez, R.E. Malavé, "Caracterización de mezclas de concreto disecadas con agregados provenientes de la trituración de cilindros de concreto ". *III Encuentro Nacional de Vivienda 95, Barquisimeto, Venezuela (Oct. 1995):* 49-59

6. S. Pemía, M.A. Ramos, C.J. Suárez, R.E. Malavé, "Industrialized Recycling Construction Waste". *MV IAHS World Housing Congress, Ankara, Turkey (May. 1996):* 27-31

7. UBC-Standard Masonry Codes and Specifications 2550 Beverly, Los Angeles, California (1991)

DECISION TOOLS FOR DEMOLITION TECHNIQUES SELECTION

Authors: Arham Abdullah and Chimay J. Anumba (Loughborough University, United Kingdom); Elma Durmisevic (Delft University of Technology, Netherlands)

ABSTRACT

Demolition is an activity in which the construction process is reversed; that is, the structure, or parts of the structure, are disassembled and removed. Sometimes it is misleading to use the word demolition to describe the industry today, since some structures are no longer demolished, but carefully dismantled or deconstructed so that more materials can be reused and recycled. The demolition of any type of structure is unique, due to the shear number of parameters that govern the demolition process. Before selecting any type of demolition technique, the demolition contractor needs to consider a set of criteria and assess their relevance to the demolition work to be undertaken, in order to arrive at the most appropriate demolition technique. Criteria that may be important on one particular demolition project may not necessarily be so on another project. Many factors have to be considered in selecting the best techniques for the demolition work, and require the demolition engineers to have multicriteria decision-making (MCDM) ability. This paper, therefore, discusses the use of the Analytic Hierarchy Process (AHP) as one of the MCDM approaches to develop a tool for demolition techniques selection. The tool was developed to assist demolition engineers to select the most appropriate demolition techniques for any given project. It concludes that, by using this tool, demolition engineers can make more informed decisions on demolition techniques, based on a sound technical framework.

KEYWORDS: Demolition; Deconstruction; Decision Tools; Demolition Techniques Selection Model; Analytic Hierarchy Process (AHP); Multicriteria Decision Making (MCDM)

INTRODUCTION

Demolition engineers are faced with decision problems in the selection of demolition techniques. In practice, the decision is based on the experience, skill, and knowledge of the demolition engineer. Furthermore, there are many elements of the problems, and the interrelationships among the elements are very complicated. According to Abdullah [1], there are six main criteria and several sub-criteria that affect the choice of demolition techniques. The main criteria are: structural characteristics, site conditions, demolition cost, past experience, time, and reuse and recycling. In addition, research done by Kasai [2] suggested that there are eight criteria: structural form of the building, location of the building, permitted level of nuisance, scope of demolition, use of building, safety and demolition period. Both researchers agreed that the decision makers have to keep in mind that health and safety is the main concern in the selection process. The selection of the most appropriate demolition technique will be subject to a unique combination of these criteria.

The characteristics of the problem mentioned involve a multi-criteria, decision-making (MCDM) approach. MCDM is a critical decision tool for many scientific and engineering challenges [3]. It aims to help decision-makers learn the problems and to guide them in identifying a preferred course of action [4]. Decision analysis is used when a decision maker needs to evaluate the advantages and disadvantages of a number of alternative solutions for a given problem. Then, the alternatives can be evaluated in terms of a number of decision criteria.

The Analytic Hierarchy Process (AHP) is a MCDM approach and was developed by Saaty (1977 and 1994). AHP aims at quantifying relative priorities for a given set of alternatives on a ration scale, based on the judgment of the decision maker, and it stresses the importance of the intuitive judgments of a decision maker, as well as the consistency of the comparison of alternatives in the decision-making process [5]. Since its introduction, AHP has been applied to many types of decision problems. Some of the construction engineering applications of the AHP include: its use in project procurement system selection models [6], application of AHP in project management [7], a multi-criteria approach to contractor selection [8], and other engineering problems [9]. The majority of these applications have introduced analytical solutions for problems involving both quantitative and qualitative criteria, similar to the selection process that is the objective of this paper.

The AHP model provides a framework to aid in evaluating complex decision scenarios. Therefore, this paper presents the development of a decision tool for the selection of demolition techniques, using AHP as a theoretical framework. The framework will ensure a better understanding of the problems and criteria, and will ultimately assist the demolition engineer in determining the final selection of the demolition technique. Furthermore, the proposed method provides a systematic methodology to incorporate all relevant criteria simultaneously for the selection of the most appropriate demolition technique in any demolition project.

THE DEMOLITION PROCESS

The demolition process can be divided into four main stages: Tendering stage, Pre-demolition stage, Actual demolition stage, and Post-demolition stage (Figure 1). Although the selection of demolition techniques, the main concern of this paper, is carried out at the tender stage, this section discusses all four main stages to enable a better understanding of the demolition project.

Tendering Stage

The demolition process starts when the client makes a decision to demolish a structure. The demolition contractors are then invited to bid for the job. The contractor has to find out about the site before he or she can prepare a risk assessment. In the UK code of practice for demolition, section 7.1 BS 6187:2000 [10] states that knowledge of the site should be elicited by an initial desk study and followed by an on-site survey to augment the desk study. Off-site features that can affect work on site should also be determined. The next step is to carry out the risk assessment, which identifies the risks associated with the work and planning the removal or reduction of the risks before the work commences. The main part of the demolition process is the selection of the most appropriate demolition techniques.

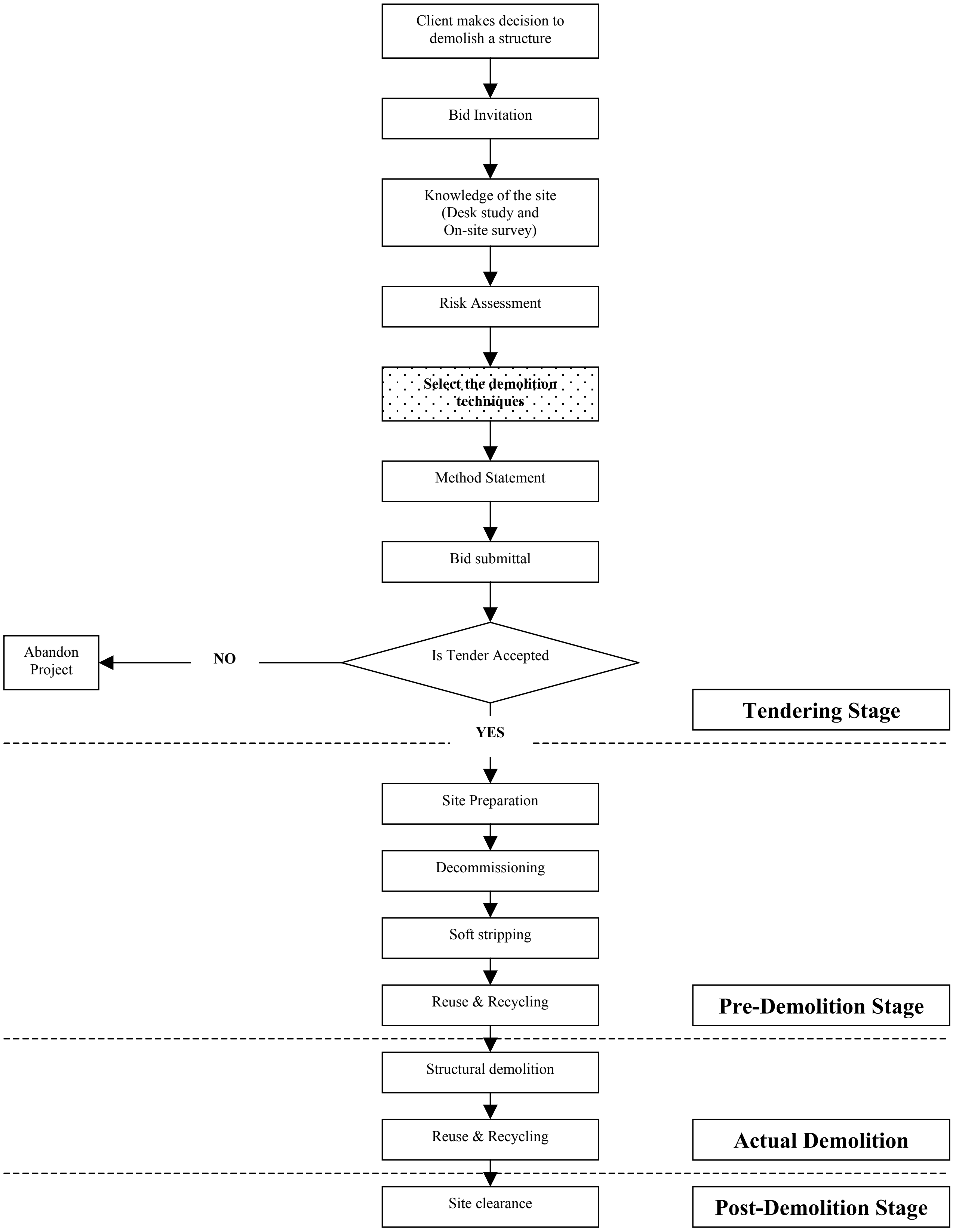


Figure 1: Flowchart for the demolition process

In practice, demolition contractors do not have a structured framework for selecting the demolition technique. They make judgements based on their skills, relevant knowledge on the techniques, and past experience. This has resulted in the need to conduct a selection process for any specific project in a structured and systematic manner. The next process is to produce a method statement. The method statement addresses the site's particular needs (i.e., site preparation), and details the planned sequences and techniques of demolition selected in the previous process. The tender document with the method statement will then be submitted to the client for the contractor evaluation purpose. If the contractor is selected by the client to do the job, they will continue with the next stage, the Pre-demolition stage. If the contractor does not get selected by the client, they have to abandon the project and bid for another job.

Pre-demolition Stage
Site preparation is the first process in the pre demolition stage. The process may include the erection of security fencing, and the setting-up of welfare facilities (e.g., site office, washing facilities and toilet). The next process is the decommissioning process. Decommissioning can be defined as a "process whereby an area is brought from its fully operational status to one where all live or charged systems are rendered dead or inert and reduced to the lowest possible hazard level" [10]. The decommissioning activities include, for example, removal of all asbestos and chemicals (e.g., battery acids and oils), and controlled release of stored energy in strong springs or suspended counterweights.

The process followed after decommissioning is soft stripping. The soft stripping is the removal of non-structural items such as fixtures and fittings, windows, doors, frames, suspended ceilings, and partitions. Some of the product from the soft stripping process can be reused and recycled. Materials, such as wood from windows or door panels, can be reused as building lumber, landscape mulch, pulp chip, and fuel [11]. The bricks can be cleaned and reused, but this is rarely done. Aluminium, stainless steel panels, and copper are the typical recycled metals. Architectural artefacts, such as sinks, doors, bathtubs, and used building materials, are almost always resold. Even the industrial process equipment can be marketed both domestically and internationally.

Actual Demolition Stage
The actual demolition starts when the structural elements are demolished. There are three main types of structural demolitions: Progressive demolition, Deliberate collapse mechanisms, and Deconstruction. These are the alternative techniques that can be selected by the contractor in the selection process, conducted in the tendering stage.

Progressive Demolition
Progressive demolition is the controlled removal of sections of the structure while retaining the stability of the remainder, and avoiding collapse of all or part of the structure to be demolished. Progressive demolition is particularly practical in confined and restricted areas, and may be considered for the majority of sites. The progressive demolition includes: Progressive demolition by hand (hand tools such as an impact hammer, diamond disc cutter, and wire saw); Progressive demolition by machine (Excavator attached with boom and hydraulic attachments, such as pulverisers, crushers, and shears); and Progressive demolition by balling, which involves the progressive demolition of a structure by the use of an iron ball that is suspended from a lifting appliance and then released to impact the structure repeatedly in the same or different locations.

Deliberate Collapse Mechanisms
Demolition by deliberate collapse is the removal of key structural members to cause complete collapse of all or part of a building or structure. This method is usually employed on detached, isolated, fairly level sites, where the whole structure is to be demolished. A sufficient space must be allocated to enable removal of equipment, and to keep personnel at a safe distance. The demolition by deliberate collapse includes deliberate collapse by explosive and deliberate collapse by wire rope pulling.

Deconstruction
The deconstruction technique in this research is defined as the dismantling of a structure, which is usually carried out in the reverse order of construction. It is also known as a top-down technique or, in general terms, the demolition proceeds from the roof to the ground. The demolition contractors should consider reuse of materials such as bricks, roof tiles, timber, and fixtures and fittings, when using this technique. This technique can be used, for example, as part of renovation or modification work and to prepare the way for deliberate collapse. The elements to be removed should be identified, and the effects of removal on the remaining structure should be fully understood and included in the method statement, with the elements to be removed marked on-site. If instability of any of the remainder might result in a risk to personnel on the site or to other people nearby, sections of the structure should not be removed. The deconstruction can be done by hand, machines, bursting, or hot cutting.

The reuse and recycling process can be done after or concurrently with the structural demolition process. With current technologies such as hydraulic excavators attached with pulverisers, concrete crushing, and screening machines, contractors are able to separate demolition debris. This process can maximise the use of resalable materials and subsequently reduce waste disposal costs. Typical recycled materials are metals and concrete debris. The recycled metals are: scrap iron, rebar (reinforced rods in concrete), aluminium, stainless steel, and copper. Concrete debris is pulverised, and can be used as fill material and sub-base.

Post-demolition Stage
The final process is the site clearance, in which the site should be left in a safe and secure condition. Any pits, sump, trenches, or voids must be left filled and securely covered, and the site drainage system must be thoroughly cleaned and tested to ensure that it continues to operate. All contaminants must be left or removed in a manner such that they demonstrate no hazard to health or to the environment. Finally, the planning supervisor should ensure that the Health and Safety File has been compiled and handed to the client upon completion of the work.

METHODOLOGY

To identify the most important decision criteria in the demolition techniques selection process, a postal questionnaire was sent to a sample of demolition engineers across the United Kingdom (UK). The National Federation of Demolition Contractors (NFDC) and the Institute of Demolition Engineers (IDE) provided the sampling frame for this survey. A questionnaire with a cover letter explaining the purpose of the study was mailed to 100 demolition engineers. A total of 67 surveys were returned, of which, 61 contained usable replies. Statistical analysis was carried out to refine these criteria, with the purpose of identifying the relative degree of importance of each criterion [12].

Once the most important criteria in the decision process were identified, structured interviews with six key experts were conducted to reassess and ensure the relevance of the identified criteria. Based on the findings from both surveys, an AHP decision model was built to evaluate the decision-making process for selecting demolition techniques.

THE ANALYTIC HIERARCHY PROCESS

AHP is a decision-aiding method developed by Saaty in the 1970s and published in his 1980 book, *The Analytic Hierarchy Process*. AHP uses a multi-level hierarchical structure of goals, criteria, sub criteria, and alternatives. A set of pairwise comparisons are used to obtain the weights of importance of the decision criteria, and the relative importance measures of the alternatives in terms of each individual decision criterion, and towards the overall goal of the problem. It also provides a mechanism for improving consistency if the comparisons are not perfectly consistent. The strength of AHP is its ability to structure a complex, multi-criteria problem hierarchically, and then to investigate each level separately, combining the results as the analysis progresses [8].

Since its introduction, a number of criticisms have been launched at AHP. Belton and Gear [13] observed that AHP could be subject to rank reversal, when an alternative identical to one of the existed alternatives is introduced. To overcome this problem, they introduced *revised-AHP*, which proposed that each column of the AHP decision matrix be divided by the maximum entry of that column. In 1994, Saaty [14] accepted the variants of the original AHP, and it is now called the *Ideal Mode AHP*. In addition, Dyer and Wendell [15] critiqued the AHP on the grounds that it lacked a firm theoretical basis. Nevertheless, the original AHP, or the ideal mode, is the most broadly accepted method and is considered by many as the most reliable MCDM method [3].

The overall selection process will primarily depend upon the results generated through the use of the AHP model using Expert Choice. Expert Choice is professional commercial software developed by Expert Choice, Inc. [16]. It helps simplify the implementation of the AHP's steps and automates many of its computations such as matrix calculation in pairwise comparisons. It can also perform sensitivity analysis, which is used to investigate the sensitivity of the alternatives to changes in the priorities of the criteria.

MODEL DEVELOPMENT

A demolition project example will be demonstrated here for illustration purposes. Table 1 presents the demolition project's characteristics based on which one of three demolition techniques (Progressive Demolition, Deliberate Collapse Mechanism, and Deconstruction) is selected.

Harker and Vargas [17] point out that there are three principles used in AHP for problem solving: (1) *decomposition* - structures the elements of the problem into a hierarchy, (2) *comparative judgments* - generates a matrix of pair wise comparisons of all elements in a level with respect to each related element in the level immediately above it, where the principal right eigenvector of the matrix provides ratio-scaled priority ratings for the set of elements compared. AHP uses a mathematical technique, eigenvector scaling, for translating pair wise rating into numerical scores representing the importance of each individual criterion and (3) *Synthesis of priorities* - generates the global or composite priority of the elements at the lowest level of the hierarchy, i.e., the alternatives.

TABLE 1: THE PROJECT CHARACTERISTICS

Project Characteristics	Explanations			
Structure Characteristics	1. Height of structure: 12 Storey 2. Type of structure: Building mainly made of Pre-cast panel 3. Stability of structure: Stable 4. Extent of demolition: Full Demolition 5. Previous used of structure: Housing			
Site Condition	1. Health and Safety of persons on and off site:	PD	DCM	DC
	Risk of danger to demolition workers Risk of danger to members of the public	Medium Low	Low Medium	High Low
	2. Environmental: Acceptable Level of Nuisance			
	Accepted level of noise Accepted level of dust Accepted level of vibration	70-74db(A) Significant amount of dust Significant effect of human body		
	3. Proximity of adjacent structure	50 meters		
	4. Accessibility of the plant	Accessible		
Demolition Cost	Demolition Cost (Lump Sum)	PD	DCM	DC
	1. Manpower	£ 50 000	£ 30 000	£ 50 000
	2. Machineries	£ 65 000	£ 70 000	£ 75 000
	Total Cost	£115 000	£100 000	£125 000
	Accepted level of noise Accepted level of dust Accepted level of vibration	70-74db(A) Significant amount of dust Significant effect of human body		
	Proximity of adjacent structure	50 meters		
	Accessibility of the plant	Accessible		
Past Experience		PD	DCM	DC
	1. Familiarity with specified technique	Familiar	Familiar	Not Familiar
	2. Availability of plant and equipment	Available	Available	Available
	3. Availability of expertise	Available	Available	Available
Reuse and Recycling	Level of concern over reuse and recycling	Moderate level of concern		
Time	Proposed project completion date is three months.			
Note: PD – Progressive Demolition DCM – Deliberate Collapse Mechanism DC – Deconstruction				

Decomposition

Saaty [14] pointed out that the hierarchic structure is beneficial to a decision-maker by providing an overall view of the complex relationships inherent in the situation and in the judgment process. It also allows the decision-maker to assess whether he or she is comparing issues of the same order of magnitude. By following the AHP principles, the hierarchy of the problem can be developed as shown in Figure 2. A hierarchy is a tree-like structure that is used to decompose a decision problem. It has a top-down flow, moving from general categories (criteria) to more specific ones (sub-criteria), and finally to the alternatives [16].

The selection of the most appropriate demolition techniques is the goal of the decision makers, and this is located at level 0 of the model to serve as a goal node. Factors affecting the demolition technique selection, which had been classified into six categories, were inserted in level 1 of the model to serve as the main criteria. Level 2 of the model define sub-criteria nodes for categories in level 1. Levels 1 and 2 of the hierarchy consisted of a total of 6 and 17 nodes, respectively. Finally the alternative solution (demolition techniques) occupied level 3 to serve as the choice available to the decision makers.

Comparative Judgments

The second step is to define the priority (or weight) of each criterion by comparative judgment. Muralidhar *et al*. [18] emphasized that the advantage of using a pairwise method is that it allows the decision-maker to focus on a comparison of two objects, and the observation can be made free of extraneous influences. At each level, comparative judgments or pairwise comparisons are conducted for each category with the ones in the adjacent upper level, and the ratings are entered into a comparison matrix. Based on the decision maker's perception, the priorities among the criterion items in the hierarchy are established, using pairwise comparisons. The judgments are entered using the fundamental scale for pairwise comparisons (see Table 2). The elements on the second level (Structure characteristics, site conditions, cost, past experience, reuse and recycling, and time) are arranged into a matrix, and the decision makers make judgments about the relative importance of the elements, with respect to the overall goal of selecting the most appropriate demolition technique.

TABLE 2: SCALE OF RELATIVE IMPORTANCE USED BY SAATY [14]

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrate in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assign to it when compared with activity j, then activity j has the reciprocal value when compared with i.	

- **Goal: to select the most appropriate demolition techniques**
  - **Structure Characteristic**
    - **Height**
    - **Type**
    - **Stability**
    - **Degree of demolition**
    - **Use of the structure**
  - **Site conditions**
    - **Health & safety for the person on and off site**
    - **Acceptable level of nuisance**
    - **Proximity of the adjacent structure**
    - **Site accessibility**
  - **Cost**
    - **Machinery**
    - **Manpower**
  - **Past experience**
    - **Familiarity with a specified technique**
    - **Availability of plant and equipment**
    - **Availability of expertise**
  - **Reuse & recycling**
    - **Level of reuse and recycling**
  - **Time**
    - **Site preparation**
    - **Actual demolition**

Alternatives

Progressive Demolition
Deliberate Collapse Mechanism
Deconstruction

FIGURE 2: HIERARCHICAL STRUCTURE FOR THE SELECTION OF DEMOLITION TECHNIQUES

For example, when judging the relative preference of factors located in level 1, with respect to the goal (level 0), a rating of 1 is assigned in the comparison of structure characteristics and site conditions. This indicates equal importance of structure characteristics and site conditions. In comparing cost with past experience, with respect to the goal, the rating of 3 is assigned. This means that cost is of weak importance of one over past experience. The same procedure is repeated when the rating of 7 is assigned in comparing site conditions with time, with respect to the goal. Intensity of importance (7) assigned for this matrix can be explained, as a site condition is strongly favored if compared with time. All the remaining pairwise comparison matrices among the nodes in the hierarchy can be established by following the same procedure. Table 3 presents the start of pairwise comparison of level 0 with level 1. Similar pairwise comparison tables exist for level 1 with level 2 and for level 2 with level 3.

TABLE 3: START OF PAIRWISE COMPARISON OF LEVEL 0 WITH LEVEL 1

Demolition technique selection criteria (1)	Structure characteristics (2)	Site conditions (3)	Cost (4)	Past experience (5)	Reuse & recycling (6)	Time (7)
Structure characteristics	1	1	3	5	4	6
Site conditions	1	1	5	5	7	7
Cost	1/3	1/5	1	3	2	1
Past experience	1/5	1/5	1/3	1	5	2
Reuse & recycling	1/4	1/7	1/2	1/5	1	1/3
Time	1/6	1/7	1	1/2	3	1
Σ	2.950	2.686	10.833	14.700	22.000	17.333

Synthesis of Priorities

The next step is to undertake a synthesis from the model global goal, which converts all of the local priorities into the global weights of alternatives. Local priority is the priority relative to its parent, or upper, level, while global priority, also called final priority, is the priority with respect to the goal [12]. To check the consistency of the pairwise comparison matrix, the following calculation can be done automatically by the AHP software, Expert Choice, or can be done manually. The calculation of the consistency ratio (CR) will be explained next for illustration purposes.

1. Synthesizing the Pairwise comparison matrix:
   The value 0.339 in Table 4 is obtained by dividing (1 from Table 3) by 2.95, the sum of the column items in Table 4 (1+1+1/3+1/5+1/4+1/6).

TABLE 4: SYNTHESIZED MATRIX OF LEVEL 0 WITH LEVEL 1

Demolition technique selection criteria (1)	Structure characteristics (2)	Site conditions (3)	Cost (4)	Past experience (5)	Reuse & recycling (6)	Time (7)	Priority Vector
Structure characteristics	0.339	0.372	0.277	0.340	0.182	0.346	0.309
Site conditions	0.339	0.372	0.462	0.340	0.318	0.404	0.373
Cost	0.113	0.074	0.092	0.204	0.091	0.058	0.105
Past experience	0.068	0.074	0.031	0.068	0.227	0.115	0.097
Reuse & recycling	0.085	0.053	0.046	0.014	0.045	0.019	0.044
Time	0.056	0.053	0.092	0.034	0.136	0.058	0.072
						Σ	1.000

2. Calculating the priority vector:
   The priority vector in Table 4 can be obtained by finding the row averages. For example, the priority of structure characteristic with respect to the goal (level 0) in Table 4 is calculated by dividing the sum of the rows (0.339 + 0.372 + 0.277 + 0.340 + 0.182 + 0.346) by the number of criteria (column), i.e., 6, in order to obtain the value 0.309.

3. Calculating Weighted Sum Matrix:
   The calculation of weighted sum matrix shown below:

$$0.309\begin{bmatrix}1\\1\\1/3\\1/5\\1/4\\1/6\end{bmatrix} + 0.373\begin{bmatrix}1\\1\\1/5\\1/5\\1/7\\1/7\end{bmatrix} + 0.105\begin{bmatrix}3\\5\\1\\1/3\\1/2\\1\end{bmatrix}$$

$$+\ 0.097\begin{bmatrix}5\\5\\3\\1\\1/5\\1/2\end{bmatrix} + 0.044\begin{bmatrix}4\\7\\2\\5\\1\\3\end{bmatrix} + 0.072\begin{bmatrix}6\\7\\1\\2\\1/3\\1\end{bmatrix} = \begin{bmatrix}2.090\\2.503\\0.734\\0.631\\0.270\\0.462\end{bmatrix} \text{(Weighted Sum Matrix)}$$

4. Calculating λ_{max}:
   This involves dividing all the elements of the weighted sum matrices by their respective priority vector element, then computing the average of these values to obtain $\lambda_{max.}$

$\frac{2.090}{0.309} = 6.764$ $\frac{2.503}{0.373} = 6.710$ $\frac{0.734}{0.105} = 6.990$

$\frac{0.631}{0.097} = 6.505$ $\frac{0.270}{0.044} = 6.136$ $\frac{0.462}{0.072} = 6.417$

$$\lambda_{max} = \frac{(6.764 + 6.710 + 6.990 + 6.505 + 6.136 + 6.417)}{6} = 6.587$$

5. Calculating the Consistency Index, CI:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{6.587 - 6}{6 - 1} = 0.11$$

6. Calculating the Consistency Ratio, CR:
   Using appropriate value of random consistency ratio, RI, for a matrix size of six using Table 5, RI = 1.24.

TABLE 5: AVERAGE RANDOM CONSISTENCY (RI) [14, 19]

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{CI}{RI} = \frac{0.11}{1.24} = 0.09$$

7. Checking the consistency of the Pairwise comparison matrix to check whether the decision maker's comparisons were consistent or not. As the CR (0.09) is less than 0.1, the judgments are acceptable.

Similarly, the pairwise comparison for the remaining sub-criteria and decision alternatives can be calculated to set priorities, in terms of the importance of each in contributing to the overall goal. Table 6 shows the local and global priority of each criterion in the final selection of the demolition technique. As a result, from the pairwise comparison matrices, the overall priorities of the model's main criteria were determined (see Table 7).

TABLE 6: THE PRIORITY OF EACH CRITERION IN THE SELECTION OF DEMOLITION TECHNIQUES

Criterion	Local priority [a]	Global priority [b]	Subcriterion	Local priority [a]	Global priority [b]
Structural characteristic	0.313	0.313	Height	0.395	0.124[c]
			Type	0.288	0.090
			Stability	0.162	0.051
			Degree of demolition	0.092	0.029
			Use of structure	0.063	0.020
Site conditions	0.375	0.375	Health and safety for the person on and off site	0.571	0.214
			Acceptable level of nuisance	0.065	0.024
			Proximity of the adjacent structure	0.241	0.090
			Site accessibility	0.124	0.046
Cost	0.109	0.109	Machinery	0.500	0.055
			Manpower	0.500	0.055
Past experience	0.093	0.093	Familiarity with a specified techniques	0.481	0.045
			Availability of plant and equipment	0.114	0.011
			Availability of expertise	0.405	0.038
Time	0.069	0.069	Site Preparation	0.500	0.034
			Actual demolition	0.500	0.034
Reuse & recycling	0.041	0.041	Level of reuse and recycling	1.000	0.041

[a] Local priority is derived from judgment with respect to a single criterion
[b] Global priority is derived from multiplication by the priority of the criterion
[c] The result is obtained as follows: 0.313 X 0.395 = 0.124

TABLE 7: RELATIVE PRIORITIES OF CRITERIA

Criterion	Relative priority
Site conditions	0.375
Structure characteristic	0.313
Cost	0.109
Past experience	0.093
Time	0.069
Reuse & recycling	0.041

Consistency ratio = 0.09

Table 8 shows that the demolition techniques are now ranked according to their overall priorities, as follows: Deliberate collapse mechanisms, Progressive demolition, and deconstruction. This indicates that the deliberate collapse mechanism is the most appropriate demolition technique for the specified demolition project.

TABLE 8: OVERALL PRIORITIZATION OF THE THREE ALTERNATIVES

Criterion	Relative priority
Deliberate collapse mechanisms	0.490
Progressive demolition	0.318
Deconstruction	0.192

Consistency ratio = 0.04

Sensitivity Analysis
Expert Choice software provides tools for performing sensitivity analysis. The general purpose of the sensitivity analysis is to graphically see how the alternatives change with respect to the importance of the criteria or sub-criteria. There are five types of analyses: Performance Sensitivity, Dynamic Sensitivity, Gradient Sensitivity, Head-to-Head Sensitivity, and Two Dimensional Sensitivity.

Performance Sensitivity
Figure 3 shows the screen-shot of the performance sensitivity graph. It displays how the alternatives (progressive demolition, deliberate collapse mechanism, and deconstruction) perform with respect to all six main criteria. Dragging the criteria bars up or down can temporarily alter the relationship between the alternatives and their criteria.

Dynamic Sensitivity
Figure 4 shows the screen-shot of the dynamic sensitivity graph. It is used to dynamically change the priorities of the criteria to determine how these changes affect the priorities of the alternative choices. By dragging the criterion priorities back and forth in the left column, the priorities of the alternatives will change in the right column. If the decision makers think a criterion might be more or less important than originally indicated, the criteria bar can be dragged to the right or left to increase or decrease the criterion priority, and the impact can be seen on the alternatives. For example, as the priority of one criterion decreases (by dragging the bar to the left), the priorities of the remaining criteria increase in proportion to their original priorities, and the priorities of the alternatives are recalculated.

Gradient Sensitivity
Figure 5 shows the screen-shot of the gradient sensitivity graph. This graph shows the alternatives' priorities one criterion at a time. The vertical solid line represents the priority of

the selected criterion (structure characteristics) and is read from the X-Axis intersection. The priorities for the alternatives are read from the Y-Axis. To change an objective's priority, drag the vertical solid bar to either the left or right. Then, a vertical doted bar showing the new objective's priority will be displayed.

Head-to-Head Sensitivity
Figure 6 shows the screen-shot of the head-to-head sensitivity graph. The graph shows how two alternatives compare to one another against the criteria in a decision. The middle of the graph lists the criteria used in the decision. In this example, the two alternatives are progressive demolition and deliberate collapse mechanism. The overall result is displayed at the bottom of the graph by a horizontal bar, and shows the overall percentage. In this case, the deliberate collapse mechanism is better than the progressive demolition techniques.

Two-Dimensional Sensitivity
Table 7 shows the screen-shot of the two-dimensional sensitivity graph. This graph shows how well the alternatives perform with respect to any two criteria. In this example, the structure characteristic is represented on the X-Axis and the site condition is on the Y-Axis. The alternatives are represented by the circle. The area of the 2D plot is divided into quadrants. The most favorable alternatives, as defined by the criteria and judgments in the model, will be shown in the upper right quadrant (the closer to the upper right hand corner, the better). In this case, it is the deliberate collapse mechanism. While in opposition, the least favorable alternatives will be shown in the lower left quadrant (progressive demolition and deconstruction). Alternatives located in the upper left and lower right quadrants indicate key tradeoffs where there is conflict between the two criteria.

SUMMARY AND CONCLUSION

The selection of demolition techniques by the demolition engineer requires multi-criteria decision-making ability. The nature of the problem requires a systematic approach to evaluate the available demolition techniques against a number of influential criteria. Therefore, this paper has presented the development of a decision tool to select the most appropriate demolition techniques, based on the AHP approach. A software package called *Expert Choice* was used, as it provides a convenient approach to organizing the selection process, and helps to make the decision less complex, more structured, less time consuming, and therefore, easy to use. An example demolition project was used to demonstrate AHP application in the selection process. The tool presented in this paper proved highly effective, and meets its objectives as a decision-making aid for demolition engineers in selecting the most appropriate demolition techniques.

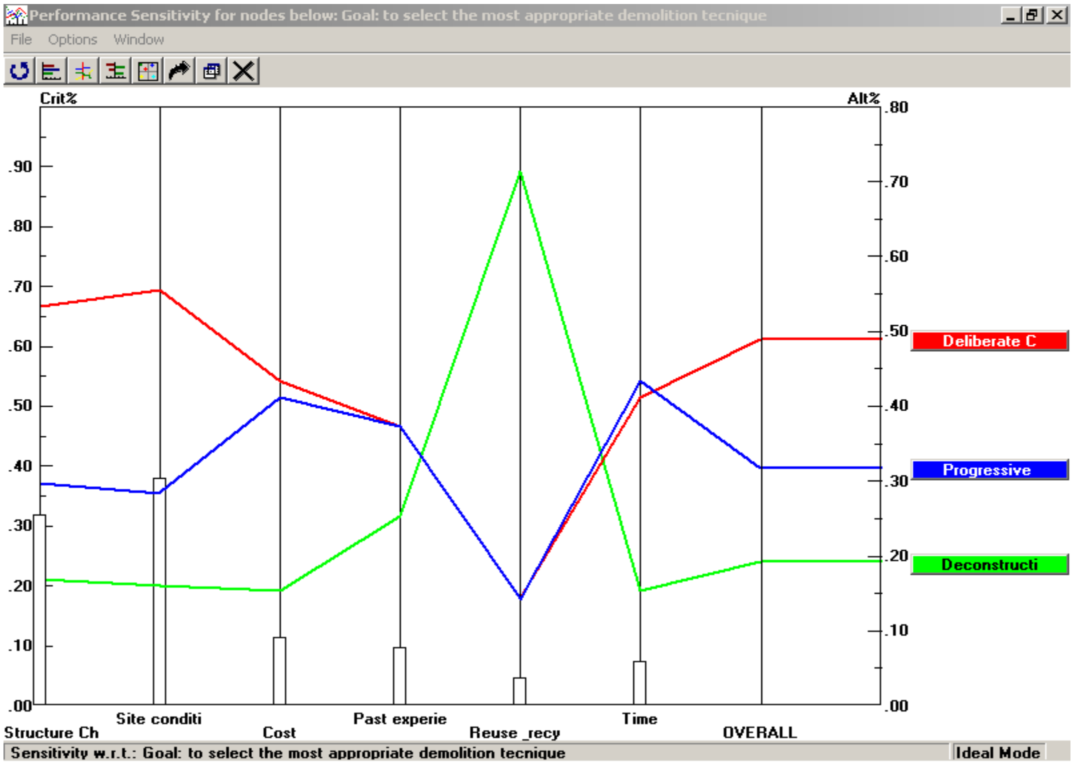


FIGURE 3: PERFORMANCE SENSITIVITY GRAPH

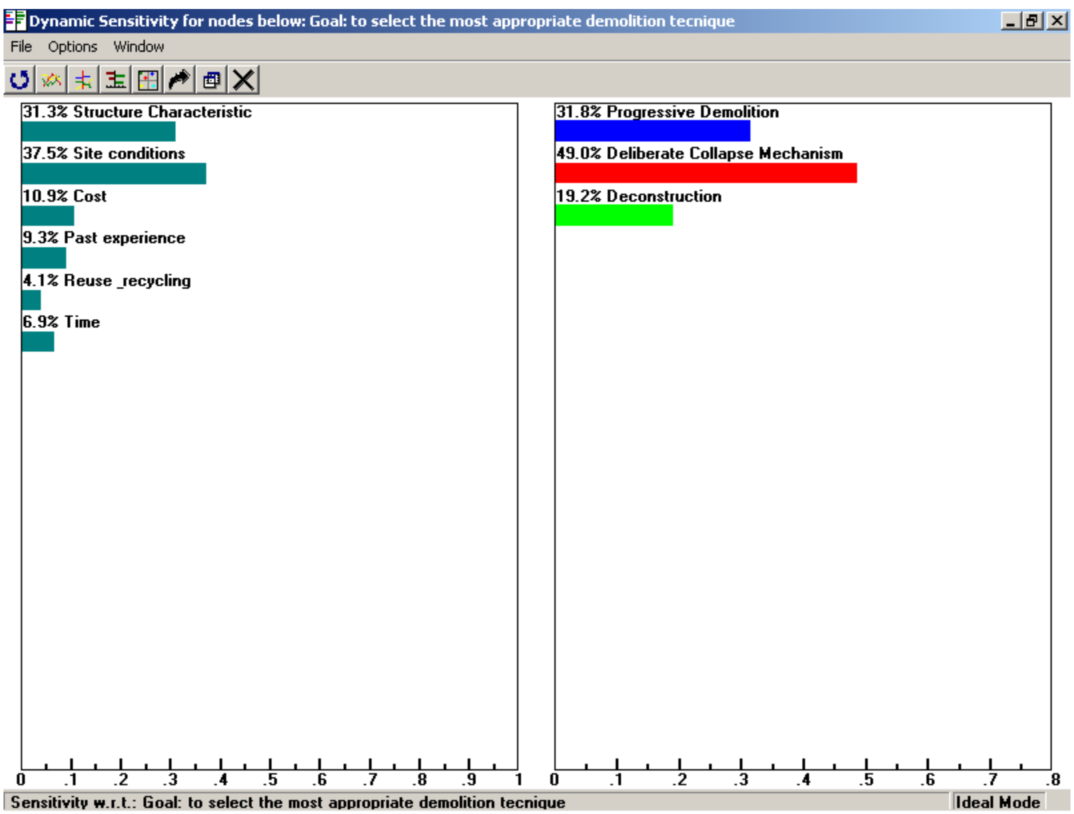


FIGURE 4: DYNAMIC SENSITIVITY GRAPH

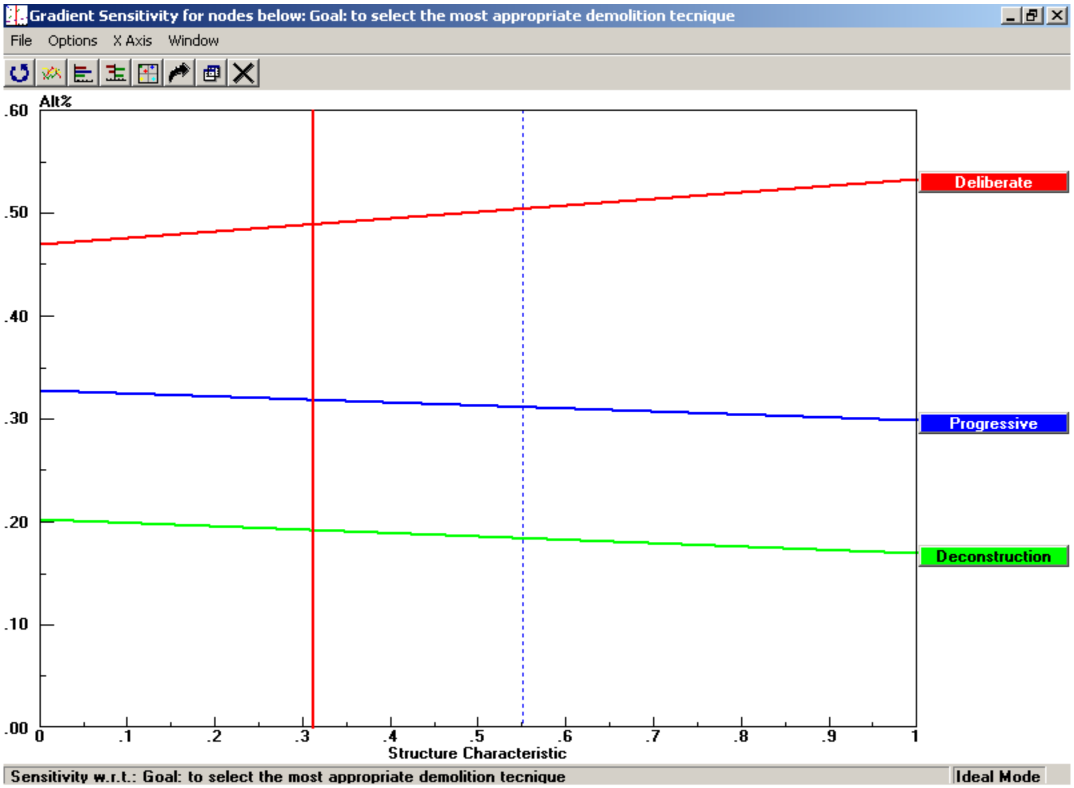


FIGURE 5: GRADIENT SENSITIVITY GRAPH

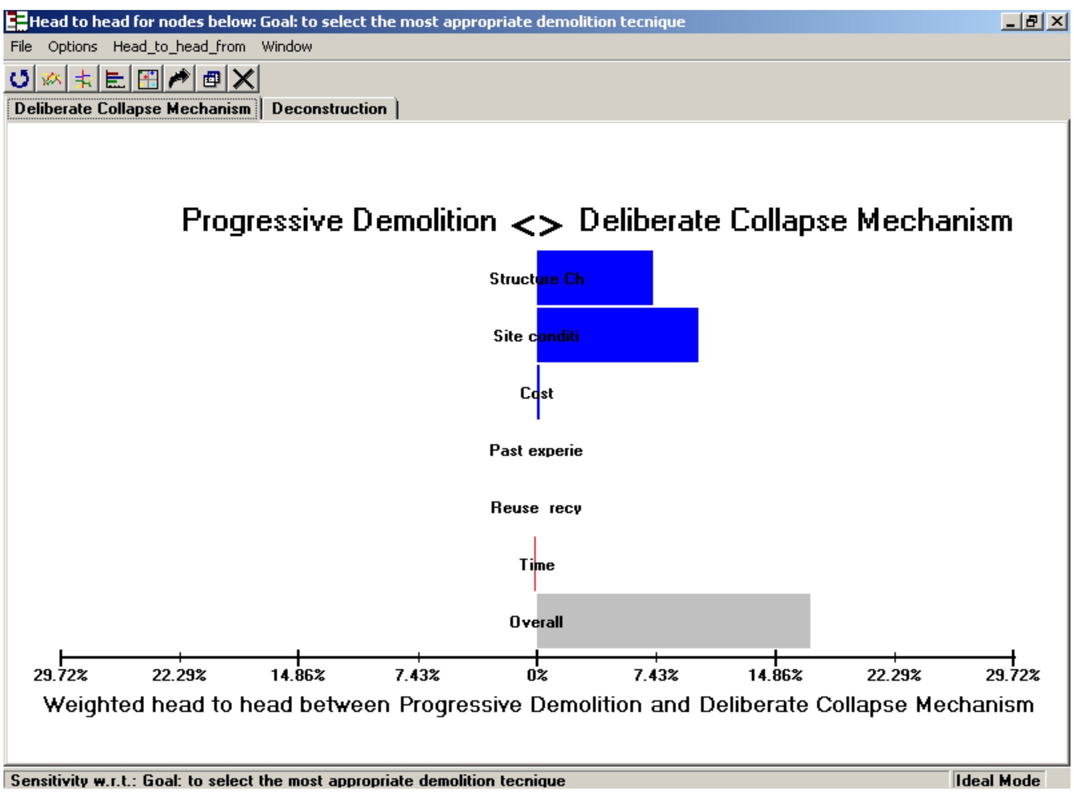


FIGURE 6: HEAD TO HEAD SENSITIVITY GRAPH

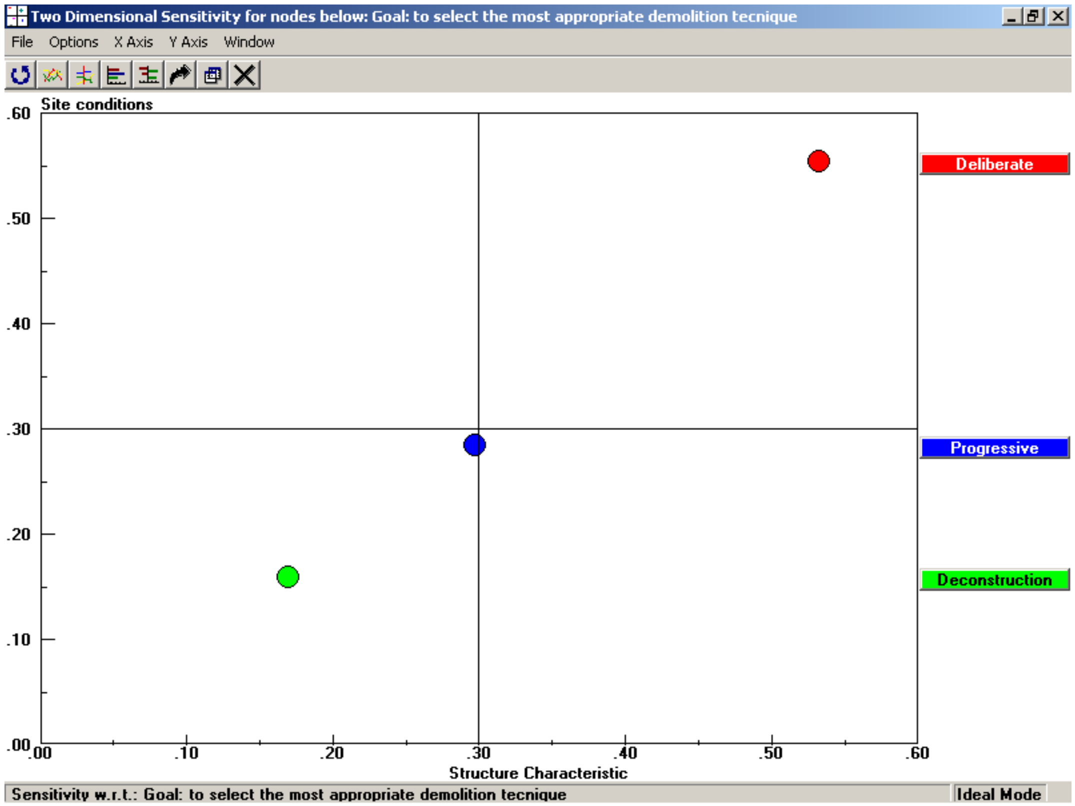


FIGURE 7: TWO DIMENSIONAL SENSITIVITY GRAPH

REFERENCES

1. **Abdullah, A. and Anumba, C.J.** Decision Criteria for the Selection of Demolition Techniques. *Proceeding of the Second International Postgraduate Research Conference In The Built and Human Environment, University of Salford, April 11-12, 2002*, Edited by Sun, M, Aouad, G, Ormerod, M., Ruddock, L., Green, C., and Alexander, K. Blackwell Publishers, 2002, pp. 410-419.

2. **Kasai, Y. (ed.).** *Demolition and reuse of concrete and masonry: Demolition methods and practice: Proceedings of the Second International Symposium held by RILEM (the International Union of Testing and Research Laboratories for Materials and Structures),* Nihon Daigaku Kaikan, Tokyo, November 7-11, 1988, Chapman and Hall, London, 1988.

3. **Triantaphyllou, E. and Mann, S.H.** Using The Analytic Hierarchy Process For Decision Making In Engineering Applications: Some Challenges. *International Journal of Industrial Engineering: Application and Practice*, 2(1), 1995, pp. 35-44.

4. **Zeleny, M.** *Multiple Criteria Decision Making*. McGraw-Hill Series in Quantitative Methods for Management. McGraw-Hill Inc, New York, 1982.

5. **Saaty T.L.** *The Analytic Hierarchy Process: planning, priority setting, and resource*

allocation. RWS Publications, Pittsburgh, USA, 1990.

6. **Alhazmi, T. and McCaffer, R.** Project procurement system selection model. *Journal of Construction Engineering & Management*, 126(3), 2000, pp. 176-184.

7. **Al-Harbi, K.M.A.S.** Application of the AHP in project management. *International Journal of Project Management,* 19(1), 2001, pp. 19-27.

8. **Mahdi, I.M., Riley, M.J., Fereig, S.M., and Alex P.A.** Multi-criteria Approach to Contractor Selection. *Engineering Construction & Architectural Management*, 1(9), 2002. pp. 29-37.

9. **Saaty T.L. and Vargas L.G.** *Models, methods, concepts & applications of the analytic hierarchy process*. International series in operations research & management science, Kluwer Academic, London, 2001.

10. **British Standard Institution.** *Code of Practice for Demolition*, in *BS 6187:2000*. 2000.

11. **National Association of Demolition Contractors**. *10 Common Misconceptions about the Demolition Industry*. Booklet. National Association of Demolition Contractors (NFDC). Doyleston, PA, 1996.

12. **Abdullah, A. and Anumba, C.J.** Decision Model for the Selection of Demolition Techniques. *Proceeding of the International Conference on Advances in Building Technology, Hong Kong, December 4-6, 2002*, Elsevier Science Ltd., 2002, pp. 1671-1681.

13. **Belton, V. and Gear, T.** On a Short-coming of Saaty's Method of Analytic Hierarchies. *Omega*, 1983, pp.228-230.

14. **Saaty T.L.** *Fundamentals of decision-making and priority theory with the analytic hierarchy process*. Analytic hierarchy process series, vol. 6, RWS Publications, Pittsburgh, USA, 1994.

15. **Dyer, J.S. and Wendell, R.E.** *A critique of the Analytic Hierarchy Process*, Working Paper 84/85-4-24. Department of Management, University of Texas, Austin, 1985.

16. **Expert Choice, Inc.** *Expert Choice Software and Manual*, in *5001 Baum Blvd. Suite 725 Pittsburgh, PA 15213*, USA.

17. **Harker, P. and Vargas, L.** The theory of ratio scaled estimation: Saaty's analytic hierarchy process. *Management Science*, 33(11), 1987, pp. 1383-1403.

18. **Muralidhar, K., Santhnam, R. and. Wilson, R.L.** Using the analytic hierarchy process for information system project selection. *Information and Management*, (Feb), 1990, pp. 87-95.

19. **Saaty T.L.** *The analytic hierarchy process: planning, priority setting, and resource allocation*. McGraw-Hill, New York, 1980.

DEALING WITH UNCERTAINTIES IN (DE-) CONSTRUCTION MANAGEMENT – THE CONTRIBUTION OF FUZZY SCHEDULING

Author: Frank Schultmann (University of Karlsruhe, French-German Institute for Environmental Research (DFIU), Hertzstrasse 16, 76187 Karlsruhe, Germany frank.schultmann@wiwi.uni-karlsruhe.de)

ABSTRACT

In this paper, a formal approach is illustrated consisting of fuzzy scheduling models to solve decision-making problems in short-term deconstruction planning. The information provided by the model serves for deriving optimal deconstruction schedules, taking into account weak data resulting from different conditions of construction materials.

KEYWORDS: Deconstruction Management; Uncertainties; Scheduling

INTRODUCTION

In future, decision-making in construction management will not only focus on profitability as its major task but will also have to meet criteria of sustainability, e.g. limiting the discharge of pollutants into the environment. The latter can be supported by applying material flow management, which has been proven as a suitable approach to meet prerequisites for a sustainable development in the construction industry. Material flow management covers the entire value chain of quarrying, production and transport of building materials as well as the construction process itself, followed by the use of buildings and finally their deconstruction and recycling. However, the rapid development of ideas for the end-of-life treatment of buildings has resulted in only few concepts for deconstruction management in this final phase of the building life cycle so far.

To anticipate a deconstruction procedure, numerous different objectives in environmental, technical and economic means have to be taken into account. Thus, alternative scenarios for the end-of-life treatment need to be considered on strategic, on tactical, and on operational level. While objectives in short-term planning are usually modeled using extended time-based objective functions, different alternatives to meet certain targets in the field of sustainability can be modeled by using multiple modes. Mathematically, both aspects can be realized by using project-scheduling models. These models comprise specialized operative planning approaches that can also consider limited capacities and therefore allow to calculate enhanced schedules for numerous different conditions in construction as well as in deconstruction.

However, even when using multiple modes, one major problem in modeling deconstruction processes is the fact that data is not always available to put mathematical models at work. In particular, the duration of deconstruction tasks involving human labor as well as sophisticated technologies is seldom precisely known due to the uniqueness and uncertainties of construction tasks. The use of fuzzy sets proves to be a powerful tool for modeling this weak data. Fuzzy techniques have been well established in mathematical theory; however, fuzzy programming is still hardly used for construction and especially for deconstruction tasks.

In the following, a formal approach is illustrated consisting of fuzzy scheduling models to solve decision-making problems in short-term deconstruction planning.

A FUZZY-SCHEDULING MODEL FOR DECONSTRUCTION

The well-known multi-mode resource-constrained project scheduling problem (MRCPSP) is used as a basis for the following model formulations. For a survey on modeling concepts as well as scheduling algorithms for resource-constrained project scheduling see [1], approaches for modeling deconstruction procedures can be found in [2].

Planning of deconstruction structures

Deconstruction planning aims first at setting up a technology oriented order of the deconstruction activities to be carried out. The technological precedence relations of the deconstruction process can be illustrated by a topologically ordered activity-on-node network, where the nodes represent the deconstruction activities j ($j=1,\ldots,J$) and the arcs indicate the precedence relations between these activities. Regarding the model that will be formulated later, the network contains one unique source ($j=1$) and one unique sink ($j=J$). This can always be guaranteed by introducing a dummy source and a dummy sink, respectively (cf. [2]). Usually each activity can be processed in different ways e.g. using different techniques that can be expressed by different resources. Moreover, each different technique may result in different processing times. Several alternatives for carrying out a job can be modeled by introducing different modes m ($m=1,\ldots,M_j$).

The scheduling model contains resource categories. Activity j in mode m is associated with the usage of renewable resources and the consumption of nonrenewable resources. While renewable resources (e.g. machines, workers) are only constrained on a periodical basis (possibly varying from period to period), i.e. after a deconstruction activity j is accomplished, the renewable resources used by j are available to process another activity. Nonrenewable resources (e.g. financial budget) are limited on the basis of the project's entire duration. Consequently, the consumption of a nonrenewable resource by activity j reduces its availability for the rest of the project. For simplification purposes renewable resources will be used only. Variables for resource usage as well as for constraints are introduced as follows:

q_{jmr}: capacity of renewable resource r, used by deconstruction activity j being performed in mode m for each period the activity is in process and

Q_{rt}: capacity of renewable resource r, $r \in R$, available in period t.

Modeling of uncertain time parameters

Performing deconstruction activity *j* in mode *m* has a nonpreemtable processing time, also referred to as duration, of d_{jm} periods. Due to the uncertainties of these processing times, resulting e.g. from different conditions of the components to be deconstructed, time parameters are modeled as fuzzy sets.

The expectations of a decision-maker concerning fuzzy time parameters like the processing time or the start and finish times of an activity *j* in the mode *m* ($m=1,\ldots,M_j$) can be modeled as a fuzzy set, where set *A* in a base set *X* can be described by a membership function $\mu_{\tilde{A}} : X \rightarrow [0,1]$ with $\mu_{\tilde{A}}(x) = 1$ if $x \in A$ and $\mu_{\tilde{A}}(x) = 0$ if $x \notin A$. If it is uncertain, whether element *x* belongs to set *A*, the model has to be extended in a way that $\mu_{\tilde{A}}$ maps into interval [0,1] with its value representing a membership possibility between poor (low value) and likely (high value). This leads to the definition of a *fuzzy set* [3]:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\} \text{, with the membership function } \mu_{\tilde{A}} : X \rightarrow [0,1] \tag{1}$$

Other definitions needed are the *fuzzy number* which is a normalized convex fuzzy subset of *IR* with exactly one $x_0 \in IR$ such that $\mu_{\tilde{A}}(x_0)=1$; and a *fuzzy interval* which, contrary to a fuzzy number, can comprise more than one $x \in IR$ such that $\mu_{\tilde{A}}(x)=1$. Since the precise form of a fuzzy number can rarely be described by an expert in reality, a practicable way of getting suitable member functions of fuzzy data can be obtained if the expert expresses optimistic and pessimistic information about parameter uncertainty on some prominent membership levels α for each mode *m* in which deconstruction activity *j* could be processed. The α-level set of the fuzzy interval (duration) $\tilde{D}_{jm}$ is defined as:

$$(D_{jm})^{\alpha} = \{d_{jm} \in IR_0^+ \mid \mu_{jm}(d_{jm}) \geq \alpha\} \text{, with } \alpha \in [0,1] \tag{2}$$

In this case, the optimistic (pessimistic) value for the duration of a deconstruction acitvity *j* performed in mode *m* on level α then represents the lower (upper) bound of the corresponding α-level set of the fuzzy interval $\tilde{D}_{jm}$. If *L* levels $\alpha = \sigma_1, \ldots, \sigma_L \in]0,1[$, $L \in IN$ are introduced, the duration can be expressed as:

$$[{}_o d_{jm};\ {}_p d_{jm}] \quad \text{if } \alpha = 1, \tag{3}$$

$$[{}_o d_{jm} - {}_o\delta^{\alpha}_{jm};\ {}_p d_{jm} + {}_p\delta^{\alpha}_{jm}] \text{ if } \alpha = \sigma_1, \ldots, \sigma_L \in]0,1[;\ L \in IN \tag{4}$$

The variables ${}_o\delta^{\alpha}_{jm}$ (${}_p\delta^{\alpha}_{jm}$) denote the expert's assessment for the acceleration (prolongation) of the optimistic duration ${}_o d_{jm}$ (pessimistic duration ${}_p d_{jm}$) for deconstruction activity *j* in mode *m* on level α, with ${}_o d_{jm}$ and ${}_p d_{jm}$ fixed on level $\alpha=1$. Apart from this particular case (α_1=1), two additional levels ($\alpha_2=\varepsilon$=0,1; $\alpha_2=\lambda$=0,6) are considered in the following, according to [3], with:

$\mu_{\tilde{D}_{jm}}(d_{jm}) = 1$	indicates that value d_{jm} certainly belongs to the set of possible values,
$\mu_{\tilde{D}_{jm}}(d_{jm}) \geq \lambda$	indicates that value d_{jm} with $\mu_{jm}(d_{jm}) \geq \lambda$ has a good chance of belonging to the set of possible values,
$\mu_{\tilde{D}_{jm}}(d_{jm}) < \varepsilon$	indicates that the expert estimastes that value d_{jm} with $\mu_{jm}(d_{jm}) < \varepsilon$ has only a very poor chance of belonging to the set of possible values.

With ${}_o d^{\alpha}_{jm} = {}_o d_{jm} - {}_o \delta^{\alpha}_{jm}$; ${}_p d^{\alpha}_{jm} = {}_p d_{jm} + {}_p \delta^{\alpha}_{jm}$; $(\alpha \in \{1, \lambda, \varepsilon\})$, $\mu_{\tilde{D}_{jm}}(d_{jm})$ can be approximied by combining linear functions section-wise (cf. Figure 1).

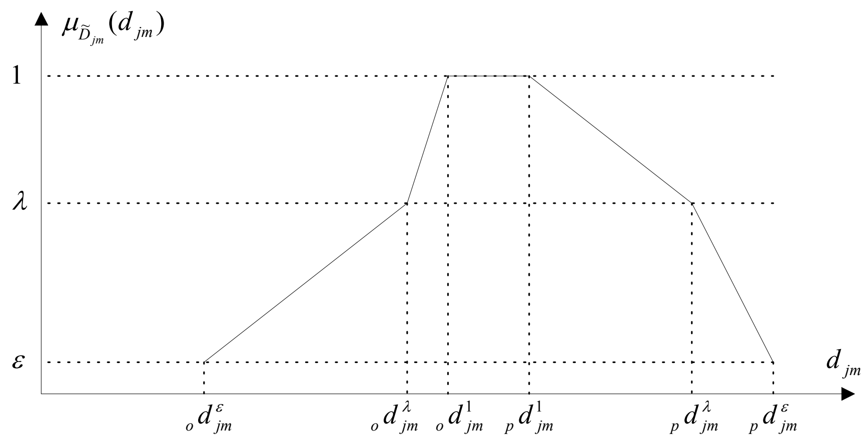


Figure 1 Membership function of the duration $\tilde{D}_{jm}$

A fuzzy interval that can be depicted by a membership function as shown in Figure 1 can be transformed in a six-point convention such that it is represented by six real numbers (cf. [4]):

$$\tilde{D}_{jm} = ({}_o d^{\varepsilon}_{jm},\ {}_o d^{\lambda}_{jm},\ {}_o d^{1}_{jm},\ {}_p d^{1}_{jm},\ {}_p d^{\lambda}_{jm},\ {}_p d^{\varepsilon}_{jm}), \qquad j=1,\ldots J,\ m=1,\ldots,M_j \tag{5}$$

The fuzzy arithmetics that can be applied for such six-point representations are shown in [5].

MODEL FORMULATION

With reference to the resource-constrained project scheduling problem introduced by Pritsker et al. [6], scheduling for deconstruction purposes can be formulated as a binary linear program with the decision variables x_{jmt} (deconstruction activity j is performed in mode m and completed in period t). As proposed by Hapke et al. [7] this problem can be used for fuzzy scheduling as well. In the following, it is assumed that the earliest and latest finishing times, the earliest and latest starting times as well as the durations of the deconstruction activities are given as fuzzy intervals in six-point representations. Using the expert's estimates for optimistic (*o*) and pessimistic (*p*) durations on the three levels α=1, λ, ε, the fuzzy-model can be transformed into six crisp resource-constrained project scheduling problems.

In order to reduce the number of variables in the programming formulation, fuzzy time windows can be calculated using a modified critical path analysis. Critical path analysis requires an upper bound $\overline{T}$ for the makespan of the deconstruction project. It should also be noted that the unique source (j=1) and the unique sink (j=J) comprise zero duration, zero resource usage and consumption, respectively. The earliest and lastest starting and finishing times ${}_kES_j^\alpha$, ${}_kEF_j^\alpha$, ${}_kLS_j^\alpha$, ${}_kLF_j^\alpha$, $k\in\{o,p\}$, $\alpha\in\{1, \lambda, \varepsilon\}$ for the deconstruction activities j=1,…,J can be calculated as:

$$ {}_kES_1^\alpha = 0 \qquad k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{6} $$

$$ {}_kEF_1^\alpha = {}_kd_{11}^\alpha \qquad k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{7} $$

$$ {}_kES_j^\alpha = \max\{{}_kES_i^\alpha + {}_kd_{i1}^\alpha \mid i \in P_j\} \qquad j = 2,\ldots,J,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{8} $$

$$ {}_kEF_j^\alpha = {}_kES_j^\alpha + {}_kd_{j1}^\alpha \qquad j = 2,\ldots,J,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{9} $$

$$ {}_kLF_J^\alpha = {}_k\overline{T}^\alpha = \sum_{j=1}^{J} \max_{m=1}^{M_j}\left\{{}_kd_{jm}^\alpha\right\} \qquad k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{10} $$

$$ {}_kLS_J^\alpha = {}_k\overline{T}^\alpha - {}_kd_{J1}^\alpha \qquad k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{11} $$

$$ {}_kLF_i^\alpha = \min\{{}_kLF_j^\alpha - {}_kd_{j1}^\alpha \mid j \in S_i\} \qquad i = 1,\ldots,J-1,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{12} $$

$$ {}_kLS_i^\alpha = {}_kLF_i^\alpha - {}_kd_{i1}^\alpha \qquad i = 1,\ldots,J-1,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\}, \tag{13} $$

where the modes of the deconstruction activities are labeled with respect to non-decreasing duration for the levels $\alpha = 1, \lambda, \varepsilon$ and for the optimistic and pessimistic expert's assessments. Based on these time windows calculated according to (6)…(13), six crisp scheduling problems can be formulated as follows:

Minimize

$$ {}_k\Phi^\alpha(x) = \sum_{m=1}^{M_J} \sum_{t={}_kEF_J^\alpha}^{{}_kLF_J^\alpha} t \cdot x_{Jmt} \qquad k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\} \tag{14} $$

Subject to

$$ \sum_{m=1}^{M_j} \sum_{t={}_kEF_j^\alpha}^{{}_kLF_j^\alpha} x_{jmt} = 1 \qquad j = 1,\ldots,J,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\} \tag{15} $$

$$ \sum_{m=1}^{M_i} \sum_{t={}_kEF_i^\alpha}^{{}_kLF_i^\alpha} t \cdot x_{imt} \le \sum_{m=1}^{M_j} \sum_{t={}_kEF_j^\alpha}^{{}_kLF_j^\alpha} (t - {}_kd_{jm}^\alpha) \cdot x_{jmt} \qquad j = 2,\ldots,J,\ i \in P_j,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\} \tag{16} $$

$$ \sum_{j=1}^{J} \sum_{m=1}^{M_j} q_{jmr} \sum_{\tau=t}^{t+{}_kd_{jm}^\alpha-1} x_{jm\tau} \le Q_{rt} \qquad r \in R,\ t = 1,\ldots,{}_k\overline{T}^\alpha,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\} \tag{17} $$

$$ x_{jmt} \in \{0,1\} \qquad j = 1,\ldots,J,\ m = 1,\ldots,M_j,\ t = {}_kEF_j^\alpha,\ldots,{}_kLF^\alpha,\ k \in \{o,p\},\ \alpha \in \{1,\lambda,\varepsilon\} \tag{18} $$

The objective function (14) minimizes the completion time of the unique sink and therefore the makespan of the deconstruction work. Several further criteria, like minimizing the average completion time, the average weighted tardiness of the activities, as well as minimizing the net present value or leveling of resources, might also be considered [2]. But, since minimizing the makespan is by far the most important objective of scheduling deconstruction activities, the discussion of other objective functions is omitted. With constraints (15) it is ensured that each deconstruction activity j is processed exactly in one mode and that one completion time is assigned. Constraints (16) ensure that deconstruction precedence relations are respected. Constraints (17) take into account that per period the capacity restrictions are met.

The problem (14)…(18) can be solved by using exact or heuristic approaches. Here, the model is solved by a branch and bound algorithm, the basic ideas of which were originally introduced by Talbot [8], [9]. Patterson et al. [10] proposed an enumeration procedure of the branch and bound type and Sprecher [11] accelerated and generalized the algorithm. A slightly modified version of this algorithm has been proposed by Schultmann [12]. The algorithm generates exact solutions as far as regular measures of performance (cf. [11]) are considered. An example of a regular measure of performance is the objective function (15).

As a result of the solution procedure, schedules are generated which represent optimistic and pessimistic time assessment on the given α-levels. Thus, the result is a minimal project duration for each of the six crisp problems (14)…(18) which represent the fuzzy interval of the minimal project duration (Table 1).

Table 1 Solutions for the crisp scheduling problems (14)...(18)

problem no.	1	2	3	4	5	6
k	o	o	o	p	p	p
α	ε	λ	1	1	λ	ε
duration of the deconstruction project	${}_o\Phi^{\varepsilon^*}$	${}_o\Phi^{\lambda^*}$	${}_o\Phi^{1^*}$	${}_p\Phi^{1^*}$	${}_p\Phi^{\lambda^*}$	${}_p\Phi^{\varepsilon^*}$

APPLICATION

The application of the proposed model is sketched using the simplified deconstruction network depicted in Figure 2.

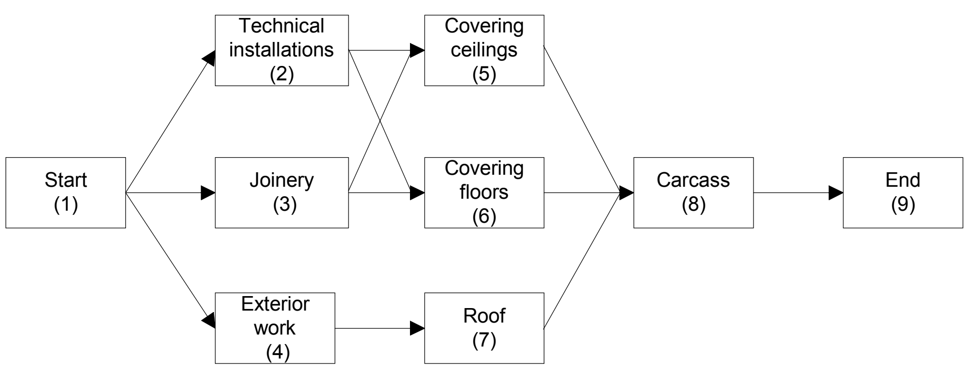


Figure 2 Example of a deconstruction network (simplified)

In order to derive the fuzzy-durations of the deconstruction activities, extensive empirical analyses were carried out on several deconstruction sites and deconstruction time parameters were investigated (cf. Figure 3). Additionally, experts' assessments for possible acceleration as well as prolongation factors were analyzed.

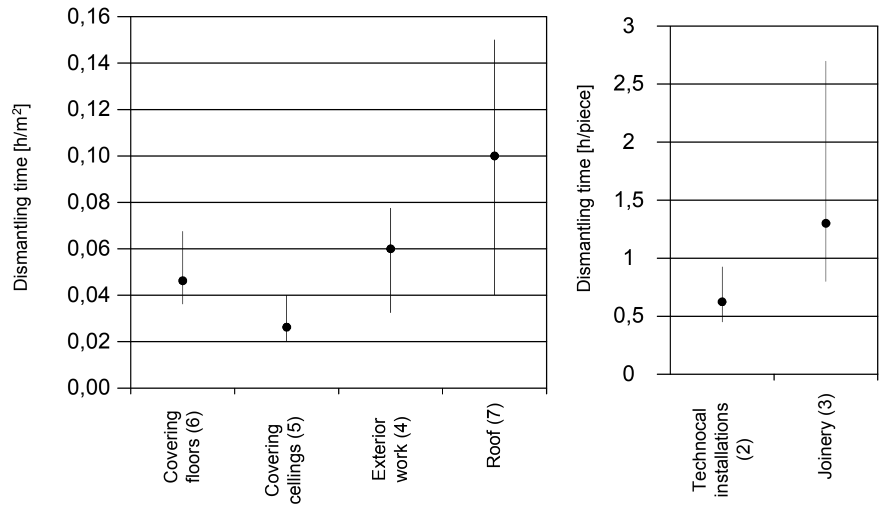


Figure 3 Deconstruction times and deviations (excerpt)

The results of the application are presented as follows: The resource demands, the capacity limits and the fuzzy-durations of the deconstruction activities are illustrated in Table 2. For simplification purposes, only three different types of resources (workers, tools and containers) are used. Figure 4 depicts the completion time of the deconstruction project.

Table 2 Resource demand, capacity limits and durations of the example

j	m_j	Resource demand (Capacity limits) No. of workers (Q_1=10)	No. of tools (Q_2=6)	No. of containers (Q_3=10)	Duration [h] $\tilde{D}_{jm} = ({}_o d_{jm}^{0,1},\ {}_o d_{jm}^{0,6},\ {}_o d_{jm}^{1},\ {}_p d_{jm}^{1},\ {}_p d_{jm}^{0,6},\ {}_p d_{jm}^{0,1})$
1	1	0	0	0	(0,0,0,0,0,0)
2	1	2	4	6	(11,13,14,16,20,24)
	2	4	5	6	(5,6,7,8,10,12)
	3	6	6	7	(3,4,5,5,6,8)
3	1	3	4	4	(17,21,25,28,43,59)
	2	5	5	4	(11,13,15,17,26,36)
	3	7	6	7	(7,9,11,12,18,25)
4	1	1	1	2	(4,5,7,8,9,10)
	2	2	1	2	(2,3,4,4,5,6)
	3	2	2	5	(2,3,4,4,5,6)
5	1	2	2	2	(43,47,50,56,71,85)
	2	2	3	4	(43,47,50,56,71,85)
	3	3	3	4	(28,31,33,37,47,56)
6	1	3	1	2	(13,14,15,17,21,25)
	2	3	3	5	(13,14,15,17,21,25)
	3	5	3	5	(7,8,9,10,12,15)
7	1	4	1	2	(7,11,16,18,22,27)
	2	6	3	4	(5,8,11,12,15,18)
	3	10	3	4	(3,5,6,7,9,11)
8	1	10	5	8	(63,78,92,102,158,214)
	2	10	6	10	(63,78,92,102,158,214)
	3	10	8	12	(63,78,92,102,158,214)
9	1	0	0	0	(0,0,0,0,0,0)

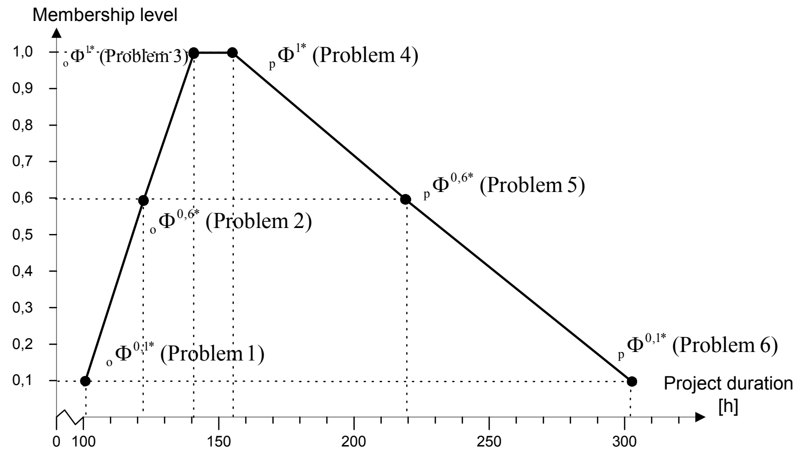


Figure 4 Membership function of the project's makespan

As the decision maker is usually interested in a crip value instead of a fuzzy interval, a defuzzyfication function as shown in [5] can be applied. By doing so, the deconstruction project shown here can be completed after 177 hours.

CONCLUSION

The model introduced serves for deriving optimal deconstruction schedules, taking into account weak data resulting from different conditions of construction materials as well as different working conditions. The approach has already been successfully applied to the deconstruction of buildings. Nevertheless, concentrating on processing times, which are modeled as fuzzy intervals, the model only covers a subset of the uncertainties decision makers are confronted with in practice. Accordingly, further uncertainties like fuzzy due dates, fuzzy capacity constraints, uncertain composition of the components to be deconstructed or fuzzy precedence relations have to be considered and incorporated in the model. Despite of all dimensions still to be considered, the most important obstacle for fuzzy deconstruction planning in practice is the generation of adequate data for deconstruction processes.

REFERENCES

[1] **Brucker, P., Drexl, A., Möhring, R., Neumann, K. and Pesch, E.** *Resource-constrained project scheduling: Notation, classification, models, and methods*. European Journal of Operational Research 112 (1999) 1, pp. 3-41.

[2] **Schultmann, F. and Rentz, O.** *Scheduling of deconstruction projects under resource constraints*. Construction Management and Economics 20 (2002) 5, pp. 391-401.

[3] **Rommelfanger, H.** *Fuzzy Decision Support Systeme. Entscheiden bei Unschärfe*. 2nd edition, Springer, Berlin, Heidelberg, New York (in German), 1994.

[4] **Hapke, M. and Slowinski, R.** *Fuzzy priority heuristics for project scheduling*. Fuzzy Sets and Systems 83 (1996), pp. 291-299.

[5] **Hapke, M. and Slowinski, R.** *Fuzzy Set Approach to Multi-Objective and Multi-Mode Project Scheduling under Uncertainty*. Scheduling under Fuzziness. Slowinski, R.; Hapke, M. (eds.). Springer, Berlin, Heidelberg, 2000, pp. 197-221.

[6] **Pritsker, A.A.B., Watters, L.J. and Wolfe, P.M.** *Multiproject scheduling with limited resources: A zero-one programming approach*. Management Science 16 (1969), pp. 93-108.

[7] **Hapke, M., Jaszkiewicz, A. and Slowinski, R.** *Fuzzy project scheduling system for software development*. Fuzzy Sets and Systems 21 (1994), pp. 101-117.

[8] **Talbot, F. B. and Patterson, J. H.** *An efficient integer programming algorithm with network cuts for solving resource-constrained scheduling problems*. Management Science 24 (1978), pp. 1163-1174.

[9] **Talbot, F. B.** *Resource-constrained project scheduling with time-resource tradeoffs: The nonpreemptive case*. Management Science 28 (1982), pp. 1197-1210.

[10] **Patterson, J. H., Slowinski, R., Talbot, F. B. and Weglarz, J.** *An algorithm for a general class of precedence and resource constrained scheduling problems*. Advances in Project Scheduling. Slowinski, R. and Weglarz, J. (eds.). Elsevier, Amsterdam, pp. 3-28, 1989.

[11] **Sprecher, A.** *Resource-Constrained Project Scheduling - Exact Methods for the Multi-Mode Case*. Springer, Berlin, Heidelberg, New York, 1994.

[12] **Schultmann, F.** *Kreislaufführung von Baustoffen - Stoffflussbasiertes Projekt-management für die operative Demontage- und Recyclingplanung von Gebäuden*. Erich Schmidt, Berlin (in German), 1998.

AN INSTRUMENT FOR CONTROLLING IMPACTS IN USE AND DISMISSION PHASES

Authors: Francesca Giglio, Alberto De Capua, ASTEC Department, (Faculty of Architecture Reggio Calabria, Italy)

ABSTRACT

The document explains part of the results obtained by a research conducted for the thesis of PhD in technology of architecture from the title "The control of the impacts in use and dismission phase." This project focuses on definition of a driven path for the evaluation of technical solutions finalized to the global recycling. The specific objective of this research is to furnish a support tool that appraises impacts that design phase technical solutions and global recycling have in use and dismission phases.

This tool is an evaluation system of requirements of maintainability, reparability, recyclability, disposability, etc. that measure the replaceablity and recoverability of the proposed technical solutions. The goal is to furnish a driven path that allows, through the individualized parameters, appraisal of the technical solutions analysed, compared to demands of replaceablity and recoverability. An appropriate strategy to address the waste problem must take account of all life phases of a product, including indirect phases as production, design and the consumption.

KEYWORDS: Demolition and Use Phases; Environmental Impact; Global Recycling

INTRODUCTION

Considering economics and the environmental impact from building activity, the availability of raw materials and the increase of the construction and demolition wastes (C&D) represent two problems of remarkable interest that result from production of materials and products as the realization of whole building manufactured articles. In fact, the production of construction and demolition wastes does not concern only the final phase of building's life, but it involves all the phases of the life cycle: design, construction, use, maintenance, restructuring, and demolition. However, demolition has the greatest responsibility for production of waste in this category. To resolve these problems, the demolition should be increasingly replaced by deconstruction and reuse.

The recycle process in the building sector finds its origin in the moment of deconstruction, total or partial, of a building. The run followed by the materials of deconstructed building up to the re-employment in a productive process can be divided into three phases [1]:

- the demolition phase and the materials' harvest;
- the treatment phase;
- the re-employment phase

If the objective is to reach an elevated quality of the materials of recovery, it is useful to observe that an elevated standard of recycling can be reached only by guaranteeing a high quality of the discards on the yard of demolition. This is true for the lithoid fraction that often represents more than 80% by volume of the wastes produced in Italy .

The operations of building demolition should be scheduled to increase the possibility of re-use of structures, components and materials. This is only possible by changing the demolition phase into deconstruction in Italy. The technical and functional building life can be extended by improving its quality and sustainability through the choice of materials, components, constructive systems, and flexible building structure.

To this general condition is added an additional contingent, represented by the actual state of the techniques of separation of the different materials. This unresolved condition adds complicating factors:

- the application of processes of recognition and separation of the materials without any criterion of preventive separation is extremely complex, from the technical point of view;
- the employment of recycled materials because of associated high costs to the separation and purification treatments can become a fiscal liability.

The desired motive for addressing these factors looks toward the deconstruction with the purpose to get a "global recycling" standard of the materials and components. The evaluation of the possibility of "global recycling" of a material has to not only consider its possible reuse in the natural cycle, but also the possibility to globally recycle wastes produced during the life cycle of the same product.

It's possible to shape three runs:

1.) Path of Linear Life of a Product:
This is a path that has happened in past and that foresees the extraction of raw material to one "initial stadium" (primary deposit); the product realization, the use and the disposal. This type of path is a linear process, that conducts sooner or later to a street without exit (See Fig1).

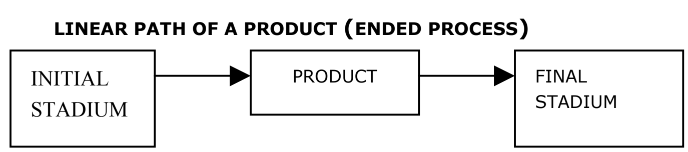


Figure 1

2.) Life Cycle Partially Closed of a Product:
To obviate to the linear path, this life cycle begins to consider recycling. It departs from a natural resource (initial stadium) to extract raw material from which a product is manufactured. This is included in a recycling process of the same product or the materials, with the purpose of re-using single components or the whole product or materials as many times as possible. At the end, however, the product is ultimately disposed. Also, this method doesn't succeed in considering the global processes and is therefore an ended path (See Fig2).

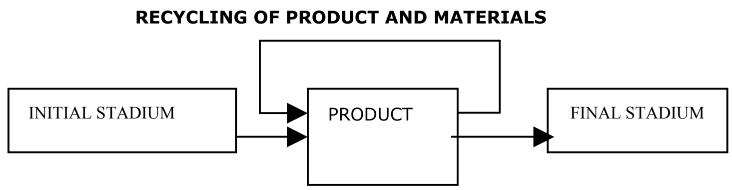


Figure 2

3.) Life Cycle Closed of a Product:
In a global optic, the term of recycling becomes more emphasized in this life cycle. To effect a cyclical path that departs from the extraction of raw materials, it shifts from the production and use of material that is ultimately disposed, but to a framework where the material returns to the final stadium or to the natural resource (initial stadium). This product is inserted again in a natural cycle. The products that cannot be used anymore can be inserted again therefore without problems in the earth's natural cycle. Even if the discarded materials can seem without value to us (for example a deprived wooden discard of chemical treatments) they can serve to microorganisms as source of sustenance. Global recycling means, therefore, the reintegration of the flows of materials used by the man in the natural cycles (See Fig3).

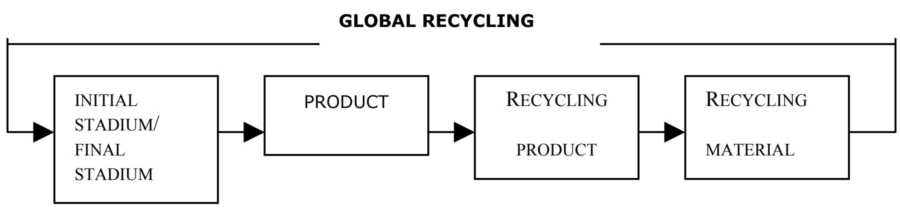


Figure 3

As it regards the materials three possibilities of recycling can be individualized [2]:

1) *Material Globally Recyclable*
They are the materials that can be inserted again in the natural cycles: they make part of it all the renewable raw material present in nature, maintained in a natural state. It means that I can withdraw material from the nature and to leave them in their natural state or to mechanically modify them. These materials are able without problems to be inserted again every in his own natural cycle.

2) *Material in Partial Way Globally Recyclable*
The second category concerns only the material partially recyclable. For instance a brick of raw clay turned into a cooked brick: during the process of cooking the chemical structure of material transforms him, the cooked brick is not more soluble in the water as the brick of raw clay is. It's possible to define material partially recyclable all the renewable minerals mechanically and chemically treated. Also the cement is partially a recyclable material.

3) *Material Not Globally Recyclable*
The third category globally contains not all the materials recyclable. They are material not coming from renewable organic materials as the oil, the methane and the coal. These materials or their by-products cannot be inserted again in the natural cycles anymore.

To close the loop minimizing the negative results of these processes is necessary to adopt a series of operational criterions that interest all the life phases of a product and above all, all the operators. From the technical point of view the assemblage to dry it mostly represents the shared constructive attitude for the practice realization of the objective of the trasformability-adaptability and the reversibility of the constructive operations.

The assemblage to dry it behaves a completely different designing approach; we are in presence of a discipline of a certain complexity, relatively new, with still little experience in Italy, and still less in literature. The construction to dry, introduced in the years '80 of last century in the tertiary sector finds however in the residential sector a cultural opposition [3].

Despite the fact that the use of such technologies in the residential housebuilding is backer in comparison to the tertiary sector, to the goals of the objectives of the research it is useful to draw some considerations; in everybody three examples that follow the strategy of the independent wraps has been adopted: the static functions are acquitted by a carrying structure to loom in rolled steel, while the external wrap and those inside, climbed on autonomous sub-structures in galvanized steel, they collaborate among them for the obtainment of the thermal performances and acoustics. The external hull constitutes the barrier to the air and the water, and includes the integral thermal covering "to coat": with the increase of the insulators' thickness the energetic consumptions of the building can be adjusted to the normative applications or of the designer. The inside hull, represents instead the interface toward the inhabited environments, and it contributes to the acoustic performances of the whole wrap. The use of coverings in chalk plates dressed again on metallic sub-structures allows to mould the inside space according to the necessity of the consumers and the formal language of the designer [4].

To the goals of our study dress again, therefore, particular importance the strategies of prevention and minimization of the building wastes that put in evidence the importance of the design in the choice of the materials, component and in the use of executive techniques.

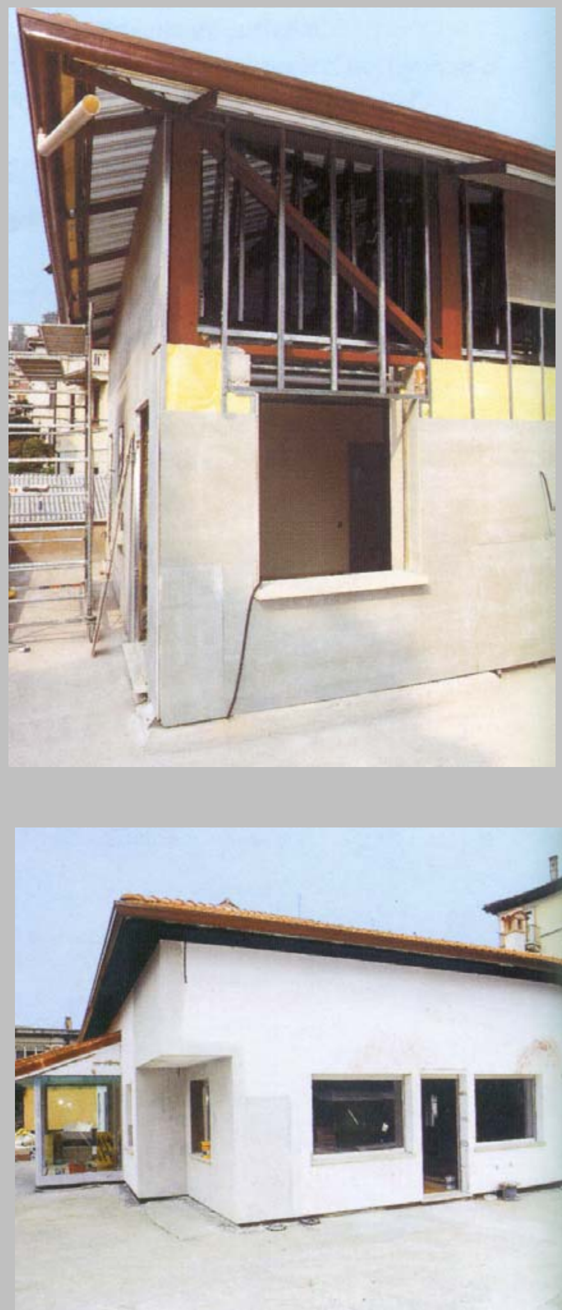


Fig 1-2 Mansion of new building, Italy

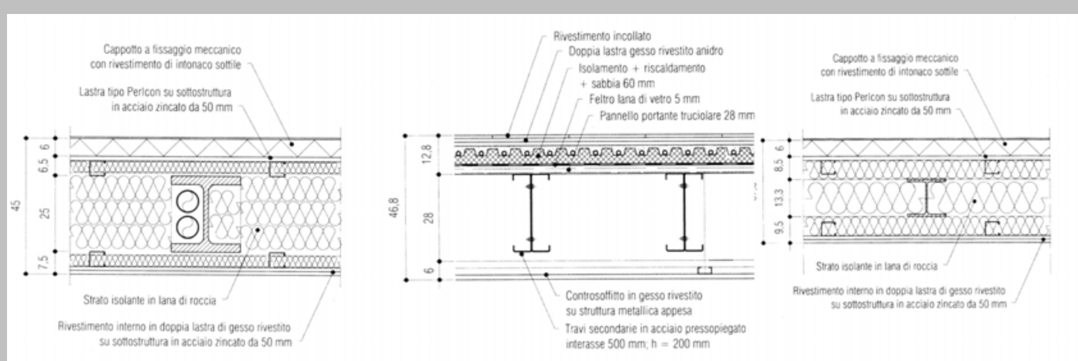


Fig 3-4 **Mansion of new building, Italy**

Fig 5-6 **Mansion of new building, Italy**

THE CASE STUDY

The research analyzings the building patrimony for the years '60 to today, considering 4 cases study and appraising the degrade of their structures and technical elements. The analysis of the state of fact, is articulated through cards of relief that analyze the technical elements selected for every analyzed typology. The analysis on the case studies has shown that the technical elements more degraded are: perimeter walls, inside partitions and installations. The following technical elements are those mostly submitted to maintenance invaded, interventions that represent the greater percentage of C&D wastes.

THE OBJECTIVES

A design framed in the optics of the component's and the building's life cycle allows to operate some choices directed toward a separation of the component to the end of the useful life. The designers should adopt constructive systems easily dismountable, using materials and products that allow an easier separation. Giving preference to recycled materials, to simple materials, not composite, reusable, limiting the use of hills, varnishes, can be avoided that the separation of these materials becomes problematic. It's important, besides, the components' deconstruction modality, so these are not damaged, and this depends on connections' types of the structures: chemistry (hill, adhesive), physics (welding) or mechanics.

To the light of such considerations, the specific objective of research it's to furnish a tool of support that appraises, in phase of design, the impacts that the technical solutions, finalized to the global recycling, have in use and dismission phases [5].

The tool is an evaluation system of requirements what maintainability, reparability, recyclability, disposability, etc. that measure the replaceability and recoverability of the proposals technical solutions. It wants to furnish a driven path that allows, through the individualized parameters, to appraise the technical solutions analyzed in comparison to the demands of replaceability and recoverability.

THE EVALUATION MODEL

Before defining the model, through experiences and indications of the current literature, of the Directives EEC and of the norms UNI (*Unificazione Norme Italiane),* have been defined the technical alternatives requirements that will fulfil to satisfy the new individualized requirements classes of replaceability and recoverability. The model delimits the field around the evaluation of the technical alternatives of Perimeter Walls, inside Partitions and Installations described through abacuses.

The individualized analyzed demands for the replaceability are:

- Facility of intervention, to which corresponds the evaluated requirements: Inspectability, reparability, polishability, and replaceability

- Flexibility of use, to which corresponds: installation equipment, modular coordination, relocationability

For the recoverability:

- Management to which correspond: durability, reliability
Reusability to which corresponds: construction materials recyclability, datachability, the components' separability, components' homogeneity, issues absence and harmful substance, antisepticability.

The tool specific innovations are represented by:

- The criterions of evaluation of the requirements obtained by the analysis of the alternatives: Necessity to measure the requirements in objective way has brought to the necessity to individualize objective "Criterions of evaluation", defined through the analysis of the technical alternatives and their components, in operation of every single requirement
- The cards of evaluation of requirements
The model evaluation founds on the use of express parametric staircases in twelfth; the staircases are divided in "indicative synthetic of performance" 0,1-3-6-9-12 to which it corresponds a judgment that goes from Scarce to Excellent (0,1 scarce; 3 middle; 6 enough; 9 good person; 12 excellent).
- The synthetic graphs for the reading of the levels of performance (real) and of requirement (ideal) of the single technical alternatives in comparison to their potentialities of replaceability and recoverability [6]:

THE EXPERIMENTATION

The experimentation it's represented by the application of the model of evaluation to a case study and, particularly, to the classes of technical elements previously individualized. Are appraised on the case study the potentialities of replaceability and recoverability of some technical solutions of interventions suggested by the production.

THE RESULTS

The definition of a tool of evaluation reported to the final phases of the building lifecycle has brought to the attainment of the objectives set by the research. The tool of evaluation drives, therefore, the designer in his choices in comparison to alternative technical solutions of intervention on the pre-existing one that has less impacts in use and dismantling phases through their potentiality of replaceability and recoverability, contributing to the reduction of the environmental load.

CONCLUSIONS

An appropriate strategy to contain the wastes problem it has to turn to all life phases of a product, inclusive those indirect phases as production, design and the consumption.
Some problematic knots in Italy that prevent the development of more concrete actions in terms of recovery of building wastes are:

- the production of discards a little checked
- the lack of installations treatment
- the lack of incentives for the recovery in terms of costs of the dumps
- taxes of disposal
- distances of the dumps in comparison to the those of the installations treatment,
- the absence of a regulation that foresees the selection in the yard
- the obligatory recycling of some fractions and their insertion in the specifications of contract
- the absence of tools of control what the permissions of demolition
- the necessity of the definition of norms, tools and suitable technical specifications.

The prevention, reduction and disposal problem of the construction and demolition wastes can be faced in different ways, also in consideration of the fact that such refusals will not only produce in the period of construction but also during the operations of maintenance and restructuring.

To the light of these considerations the experimentation phase has put in evidence the complexity of information that a designer has to manage in the most appropriate choice of a technical solution and, in special way, in a choice that can reduce environment impacts. The proposed tool has a strong operational character, fundamental to be able to be one "guide" for the designer in comparison to his choice of materials and products that use non renewable resources or that can be reusable resources. Through evaluation of the alternatives has emerged in fact that:

- The production continues to introduce in the building sector material synthetic (how part of building components) of which are not known the duration, the maintainability, the recyclables, the costs in energetic terms and the potential dangerousness to level of polluting issues.
- The complexity of the building components is result of the assemblage of different materials, as for example fixtures, external coats, and systems of waterproofing.

THE POTENTIAL USERS

Particularly the tool is turned to:

- Designers that, operating in circles in which he is developing, or they are already developed, innovative urbanistic tools and particularly careful building rules to the environmental context, have the demand of evaluation tools in comparison to the environmental qualification of the pre-existing.

In line with the Italian legislation on the public jobs the demand of instrumentations of support is created to the designer in comparison to the new requirements required in the design phase.
- Designers to which is required, previous building concession, a technical relationship on the management of Construction and Demolition wastes, and therefore, on the scenery end-life discard's material .
- Corporate body managers of public residential house building that can use the tool as it drives in the choice of innovative technical alternatives in comparison to the traditional ones that satisfy requirements of replaceability and recoverability

REFERENCES

1 **Rigamonti, E.** " Il processo di riciclo delle macerie: dalla demolizione al reimpiego" in *Il riciclo dei materiali in edilizia*, Maggioli, Rimini , 1996

2 **Lofflad, H.** "Ipotesi per un riciclaggio globale," in Tondi A., Delli S., *La casa riciclabile* , Edicom, 1998

3 **Hendriks Ch. F., Nijkerk A.A., van Koppen A.E.** *The Building Cycle*, Aeneas technical publishers, The Hetherlands, 2000

4 **Baglioni, A.** "Costruzioni e recupero dei rifiuti," in *Ambiente Costruito*, 1997

5 **De Capua A**. *Nuovi paradigmi per il progetto sostenibile*, Gangemi, Roma, 2002

6 **Lannutti C.** *Il controllo prestazionale del componente edilizio*, Gangemi, Roma, 2000

OVERTURE PROJECT DECONSTRUCTION IN MADISON, WI ACHIEVES 74% RECYCLING RATE

Authors: Sonya Newenhouse, Ph.D. (Madison Environmental Group, Inc); Jenna Kunde* (WasteCap Wisconsin, Inc.); Amanda Fuller** (Madison Environmental Group, Inc);

* 2647 N. Stowell Avenue, Milwaukee, WI 53211. 414-961-1100 wastecap@wastecapwi.org
**22 N. Carroll Street Suite 310, Madison, WI 53703. amanda@madisonenvironmental.com

ABSTRACT

Construction of a new 400,000 square foot Arts Center in downtown Madison, Wisconsin, resulted in demolition of six buildings. After an initial site visit with PL&F Architects (the architect firm for the Overture Project), WasteCap Wisconsin (a nonprofit organization providing businesses with waste reduction and recycling assistance) was hired to coordinate and document Overture's uniquely extensive reuse and recycling efforts during the first phase of demolition. WasteCap subcontracted with Madison Environmental Group, Inc. (a local environmental consulting company), to help with the coordination and documentation process. The project achieved a 74% reuse and recycling rate. Non-profit organizations toured the buildings and tagged items for reuse, including solid wood doors, light fixtures, high quality windows, handicap rails, oak trim, sinks and counter tops (total value $18,131). One unique reuse accomplishment was the mapping and removal of one building's limestone façade for reuse. Recycled materials included concrete, metals, carpet, and ceiling tiles. This is the first project in Wisconsin to recycle ceiling tile and one of the first to recycle carpet. The avoided disposal costs were $240,000, which covered the costs of reuse and deconstruction. Overall savings were $30,000.

KEYWORDS: Deconstruction; Reuse; Recycling; Overture

INTRODUCTION

The Overture Foundation is very active in the community and interested in being good corporate and environmental citizens. Toward this end, they invited WasteCap Wisconsin, a nonprofit organization that provides businesses with waste reduction and recycling assistance, to conduct a site visit at the property to assess opportunities for reuse and recycling. The assessment showed that there were many unique opportunities to reuse and recycle demolition materials.

WasteCap Wisconsin, Inc. was hired by the Overture Foundation to coordinate and document the reuse and recycling efforts of the Overture Deconstruction Project. The deconstruction, planned to create space for a new 400,000 square foot art center took place between March 1 – June 1, 2001. Six downtown buildings including Bank One, Yost Department Store, Teen Loft, Rosino's Pizza, Army/Navy Store, and Miller's Eats & Treats were deconstructed with responsible waste management procedures. WasteCap Wisconsin subcontracted with Madison Environmental Group, Inc. (a local environmental consulting company) to provide on site assistance with the work described in this report which includes: 1) Coordinating the reuse activities, 2)

Coordinating the recycling activities, 3) Documenting the reuse and recycling results, 4) Documenting the process through pictures and description, 5) Evaluating the process through interviews, and 6) Assisting with press opportunities. The results were outstanding – 74% of all the deconstructed building materials were reused and recycled.

Background Information on the Overture Project

Jerry Frautschi created the Overture Foundation in 1996 for the primary purpose of supporting arts and culture in Madison and Dane County. The development of the Overture Project is the Foundation's major focus. In July of 1998, Mr. Frautschi announced a major civic gift to benefit the cultural arts in downtown Madison. The Overture Project will promote excellence in the arts and stimulate a downtown Madison renaissance. Mr. Frautschi has donated approximately $100,000,000 for this project, which is the largest building project in recent history of Madison, Wisconsin.

The project consists of two phases of construction, together totaling approximately 400,000 square feet. Phase 1 construction commenced June 2001 and will be completed by January 1, 2004. Phase 1 work consists of the construction for the new Overture Hall performing arts center, rehearsal rooms and circulation space. Phase 2 construction is expected to commence January 1, 2004 and be completed by January 1, 2006. Phase 2 work consists of renovation of Oscar Mayer Theater, Isthmus Theater, and construction of the new Madison Arts Center. The grand lobby and level of finishes will establish these buildings as a world-class facility for the performing arts.

In order to begin building the new arts center, six buildings along N. Fairchild Street were deconstructed in the spring of 2001 (Figure 1). The next section summarizes the reuse and recycling efforts that took place, representing the responsible waste management practices.

Buildings to Deconstruct, Fairchild St. from Mifflin St

Figure 1
Photo of buildings before deconstruction and a drawing of the new Overture Arts Center

SUMMARY OF RESULTS

Seventy percent of the materials from the deconstructed buildings were recycled, 4% was reused, and 26% was landfilled (Table 1). Concrete accounted for the majority of the recycled materials (4920 tons). The remaining materials recycled included metals (166 tons), carpet (7 tons), and ceiling tiles (9 tons). The majority of the reusable materials consisted of a 267-ton stone façade salvaged from the Bank One building. The remaining reusable materials were either donated to local nonprofit organizations or sold to salvage companies, and are detailed in Table 2.

Table 1: Truck Loads, Volumes, and Weights of Reusable, Recycled, and Landfilled Materials from Deconstruction Phase of Overture Project.

Material	Truck Loads	Estimated Volume (Cubic Yards)*	Weight (Tons)	Percent of Total Weight
Reusable:				
Fixtures & Furniture	19	272.1	25.9	0.3%
Stone Façade	NA	118.5	267.0	3.7%
Total Reusable	**19**	**390.6**	**292.9**	**4.0%**
Recycled:				
Ceiling Tile	1	24.7	8.8	0.1%
Carpet	2	3,513.0	7.0	0.1%
Metal	67	2,215.7	166.2	2.3%
Concrete	358	9,839.0	4,919.5	67.6%
Total Recycled	**428**	**15,592.4**	**5,101.5**	**70.2%**
Landfilled:				
Construction Debris	319	2,687.4	1,881.2	25.8%
Total Landfilled	**319**	**2,687.4**	**1,881.2**	**25.8%**
Grand Total	**766**	**18,670.4**	**7,275.6**	**100.0%**

* Cubic yards were calculated using the following conversion figures:
Reusable Fixtures and Furniture Items: see description below (Sources: U-Haul Co., Penske Truck Rental)
Stone Façade: 2.23 tons/cubic yard (Source: J.H. Findorff & Son)
Ceiling Tile: 0.36 tons/cubic yard (Source: Armstrong Floors & Ceiling Systems)
Carpet: 0.002 tons/cubic yard (Source: DuPont Flooring)
Metals: 0.075 tons/cubic yard (Source: Samuel's Recycling)
Concrete: 0.5 tons/cubic yard (Source: J.H. Findorff & Son)
Construction Debris: 0.70 tons/cubic yard (Source: J.H. Findorff & Son)

Table 2: Values, Weights, and Volumes of Reusable Materials (Fixtures & Furniture) Received by Nonprofit Organizations and Reuse Buyers from Overture Project.

Recipient	Estimated Value	Truck Loads	Estimated Weight (Tons)*	Estimated Volume (Cubic Yards)*
Nonprofit Organizations:				
Atwood Community Center	$ 2,515	2	2.6	37.0
Design Coalition	$ 1,434	3	2.1	36.0
Goodwill Industries	$ 145	1	0.7	7.9
Habitat for Humanity	$ 1,979	3	4.7	59.2
Saint Vincent de Paul	$ 1,997	3	8.4	95.2
Teen Loft	$ 6,061	2	2.0	10.5
Woodland School	$ 4,000	1	1.8	3.6
Nonprofit Total	**$18,131**	**15**	**22.3**	**249.4**
Reuse Buyers:				
Pieter Godfrey	$ 175	3	2.6	16.0
Dan Wietz	$ 150	1	1.0	6.7
Reuse Buyer Total	**$ 325**	**4**	**3.6**	**22. 7**
Grand Total	**$18,456**	**19**	**25.9**	**272.1**

* Weights and volumes were estimated using the capacities of moving trucks. See description in Section 4.

COORDINATION OF REUSE AND RECYCLING

Meeting with Partners

In December 2000, PL&F Architects (the local architect firm for the Overture Project) invited WasteCap Wisconsin to conduct a volunteer site visit to identify recycling and reuse opportunities for the deconstruction phase of the Overture Project. WasteCap wrote a report of recommendations following the site visit, which was presented to the Overture team at a January 2001 meeting hosted by PL&F. At this meeting, Findorff (the general contractor) agreed to pursue the reuse and recycling activities suggested in the report. WasteCap submitted a proposal to coordinate and document these activities, using Madison Environmental Group, Inc. as a subcontractor due to their expertise and proximity to the job site. The Overture Foundation generously approved WasteCap's proposal. Project partners are pictured in Figure 2. Following is a description of the reuse and recycling process.

Figure 2 Pictured from left to right:

Mark Jenssen (PL&F Architects), Sherrie Gruder (UW Extension), Mike Huffman (Overture Foundation), Jenna Kunde (WasteCap Wisconsin), Jim Yehle (Findorff), Sonya Newenhouse (Madison Environmental Group).

Coordinating Reuse Activities

Reuse Days with Nonprofits
WasteCap Wisconsin and Madison Environmental Group organized two "Reuse Days" to donate reusable items from the deconstructed buildings to local nonprofit organizations. Nonprofits with the capacity to collect, transport, and store the items were invited to participate. These organizations included Habitat for Humanity, Goodwill Industries, St. Vincent de Paul, and the New Teen Loft. Organizations that learned about this process through word-of-mouth were also invited and include: Design Coalition, Atwood Community Center, and the Woodland School. The Overture Foundation and Findorff provided the support and labor for processing the items.

On February 26, 2001, the participating nonprofit organizations identified and marked items in the Bank One Building for reuse. Participating organizations also completed a form listing the items and location of the materials they wished to reuse. In order to reduce liability, Findorff deconstructed the items (such as detaching doors and light fixtures) and neatly placed them into separate storage areas for each organization. The following week the organizations collected the materials with trucks and volunteers. On April 4, 2001, this process was repeated for items in the Yost Building (a former department store).

Figure 3
Atwood Community Center Staff and Volunteers with Reusable Carpet.

The organizations were able to reuse more than 1,000 items, including 80 solid oak doors, hundreds of light fixtures, oak flooring, cabinets, counter tops, drinking fountains, bathroom soap dispensers, 18 large boxes of wooden hangers, and more.

Reuse Buyers
In addition to the seven nonprofit organizations, WasteCap Wisconsin and Madison Environmental Group worked with two salvage buyers. After the nonprofits had selected materials for reuse, the buyers identified and bid on a few remaining items. A buyer from Milwaukee bid on building materials such as wood paneling, trim, and counter top laminate. A buyer from Madison bid on the iron stair case railing from the Yost building and a few furniture items. The first buyer's insurance policy allowed him to deconstruct and remove the items without Findorff's assistance.

Stone Façade
The University of Wisconsin-Extension Solid and Hazardous Waste Education Center coordinated the Bank One stone façade reuse efforts. The 267-ton Indiana limestone façade from the Bank One building was removed piece by piece and is currently stored in a protected location. Prior to deconstruction, each stone was labeled and the façade was mapped and professionally photographed, so that it can be erected on another building.

Figure 4
Removing Stone Façade from Bank One building.

The University of Wisconsin-Extension contacted a number of potential buyers regarding the limestone façade. Madison Gas & Electric, former owner of the Bank One building, seriously considered reusing the façade at their transformer station on Park and Dayton Streets and at their downtown office building. However, MG&E's architect advised against using the stone, feeling that it did not fit the design intent. The Children's Museum expressed interest in the stone, but does not yet have a site for it. Several downtown developers were called who do not currently have a project appropriate for its use.

Coordinating Recycling Activities
With the assistance of WasteCap Wisconsin's extensive network, Madison Environmental Group facilitated locating markets to recycle the carpet and ceiling tile. In fact this is the first project in Wisconsin to recycle ceiling tile and one of the first to recycle carpet. The ceiling tile was carefully removed, stacked onto pallets, shrink wrapped, and transported to Armstrong Floor & Ceiling Systems. Armstrong will recycle the tile into new ceiling tile. The carpet was removed

and hauled to dumpsters on site and then transported to Nonn's Flooring in Middleton. Nonn's works with Dupont who recycles the carpet into other flooring products or automobile parts.

DOCUMENTATION OF REUSE AND RECYCLING

Documenting Reusable Materials

Estimating Values
We sent each of the nonprofit recipients a list of the items they received, and requested that they estimate the used retail value for each object. Totals are reported in Table 2.

Estimating Weights and Volumes
We recorded the number of truckloads and size of truck for each recipient. Truck rental companies provided the maximum load capacity of various size trucks. Assuming that a full load of reusable materials represented 75% of the load capacity, weights were calculated by multiplying number of truckloads by 75% capacity. For example, Atwood Community Center had two full loads of a 15-foot truck. The maximum load capacity of a 15-foot truck is 3500 lbs. Therefore, the estimated total weight of Atwood's reusable items = 2 * .75(3500 lbs) = 5250 lbs. The volumes of reusable materials were based on truck dimensions and a similar assumption of 75% capacity.

Figure 5
St. Vincent de Paul truck

This method applied to all organizations except Woodland School, who received 18 large, high quality windows. In this case, volume was calculated using the windows' dimensions, and an employee at United Building Center estimated provided the weight estimate. All weights and volumes of reusable materials are reported in Table 2.

Documenting Recycled and Landfilled Materials
Materials recycled and landfilled were documented using monthly hauling records from Madison Crushing & Excavating (deconstruction subcontractor to Findorff). Tons and truckloads of each type of material were entered into a spreadsheet, and totals for the entire deconstruction period were calculated. Totals are reported in Table 1. Volumes of each material were also calculated, using conversion figures provided by team members and vendors.

Figure 6
Recycling Metal from Bank One Building

Photograph Documentation
Throughout the deconstruction phase, March 1 – June 1, Madison Environmental Group staff took photographs to document the responsible waste management process.

EVALUATING THE PROCESS THROUGH INTERVIEWS

Madison Environmental Group interviewed seven people involved with the Overture Project deconstruction phase. The interviewees represented the Overture Foundation (1), PL&F Architects (2), Findorff (3), and WasteCap Wisconsin (1). They were asked to describe the most satisfying, challenging, and unique parts of the project, as well as suggestions for improvement to the reuse and recycling efforts, and how they felt about the communication process among the partners.

Figure 7
Steve Schuchardt and Jim Yehle, J.H. Findorff & Son, Inc.

All partners reported satisfaction with the process, viewing it as a successful and innovative reuse/recycling effort. Three people described the satisfaction that came from witnessing a positive change in the construction industry and giving a good name to construction. Another three interviewees felt satisfied that the project facilitated the reuse of materials to local nonprofit organizations. Other satisfying aspects included the high profile nature of the project, that it will serve as a model for future deconstruction projects, that it was the first ceiling tile recycling in the state of Wisconsin, and simply seeing materials being reused rather than discarded.

The interviewees faced various challenges depending on their role in the waste management project. Partners on the organizing end of the project mentioned time management, coordination, and the uncertainty of cost effectiveness as challenges. Construction managers experienced difficulties in working with subcontractors and felt that educating the construction workers as to the reasons for their extra efforts would be helpful. Two of the interviewees mentioned the difficulty of finding markets for the materials, specifically for the carpet, ceiling tile, wood, and the Bank One stone. Finally, the construction worker we interviewed reported that physically removing the carpet was a challenge.

Figure 8
Jenna Kunde, WasteCap Wisconsin

The partners identified several unique aspects of the project, including the community involvement with the "Reuse Days", the ceiling tile and carpet recycling, the positive press and visibility of the project, the documentation of the entire process, and the reuse of the stone façade. One interviewee pointed out the uniqueness of piloting a large deconstruction effort in Wisconsin. Another mentioned the uniqueness of having a contractor who was flexible and cooperative and to have an owner willing to provide community groups access to the site to reuse materials.

Based on their experience during the deconstruction phase of the Overture Foundation project, the interviewees offered suggestions for improving the recycling and reuse activities. Suggested improvements for recycling include better organization for the ceiling tile pick-up, and better communication among partners regarding responsibility for contacting the carpet and ceiling tile recycling companies.

Regarding the reuse activities, three partners suggested that more time scheduling and organizing the "Reuse Days" would have been helpful. More specifically, two people thought that the nonprofits organizations should have been better briefed ahead of time, so they would know more specifically what types of items were available from the buildings. One person involved in the reuse days suggested excluding the salvage companies from future reuse events. Another suggestion was to better identify industrial users for some of the building items. Two people thought that the "Reuse Days" ran smoothly, and offered no suggestions for improvement.

Two interviewees expressed disappointment that it was not possible to reuse the concrete as aggregate backing for the new building, as planned. They could not think of an idea for improvement, recognizing that it was not cost effective and not suitable from an engineering aspect to reuse this material in the new building.

Finally, the interview addressed the communication process among the partners in the waste management project. Four of the seven people interviewed expressed the need for more formal agreements in order for everyone to fully understand their roles and responsibilities from the beginning. Specifically, two people mentioned that it was not clear whose responsibility it was to contact the carpet recycler. Communication difficulties were also identified with the abatement contractor.

Overall, the partners were very pleased that a new and untested process had proceeded smoothly and yielded such high results – recycling and reusing 74% of the deconstructed building materials – in a limited time frame. The challenges and suggestions listed above can easily be improved upon for future projects, and the Overture Foundation hopes that this experience will assist others in conducting responsible reuse and recycling deconstruction efforts.

Following are some quotations that capture the partners' satisfaction with the project:

"It was nice to see the work that WasteCap put into [the reuse activities], at the tagging day ceremonies. That was clearly a step above what we were able to do on earlier projects."

"Just like the Milwaukee County stadium, [Overture] is a very visible and successful project that makes people aware of it. It's kind of in the air and people realize there's an expectation for that. It can't be ignored now."

"[The most satisfying part of the project was] pulling together the building materials reuse organizations with the contractor and owner to … turn what was an economic and environmental liability into an economic, community, and environmental asset."

"I think it's really great that you took all the photos and now have the photo album to share. A picture is worth a thousand words, and I think that photo album will be useful at all sorts of things – presentations and sharing the story with others."

"Now I know for future projects that I'm already paying for them to separate out [the materials]. So if we have to separate it out, we can just take different materials to different places for recycling. It makes it easier for the owner to make the decision to do recycling."

"[The most satisfying part of the project was] giving a good name to construction, instead of just doing demolition, and knocking it down… It's satisfying that it is a little bit more caring, giving a better name to the industry."

"It's nice to have a cooperative owner who allows the time and money to let this happen."

ASSISTING WITH PRESS OPPORTUNITIES

WasteCap Wisconsin and Madison Environmental Group, Inc. assisted Overture's Communications Specialist with information and photographs for several articles and two press conferences about the deconstruction project. Thanks to these efforts, the press conferences also resulted in multiple television reports on this project. To date, the responsible waste management practices of the Overture Deconstruction Project have been highlighted in 10 articles in local press, one article in a national company newsletter, and one article in a national magazine. The WasteAge and Atwood Community Center articles were unsolicited. Sonya Newenhouse also presented the results of this project at the Great Lakes Pollution Prevention Roundtable on July 13, 2001 in Madison, WI.

In addition to the positive press received, Jerry Frautschi received an "Orchid" award for the deconstruction efforts by Wisconsin's Environmental Decade – a Wisconsin nonprofit organization. This is a high honor among the environmental community in Wisconsin.

FINANCIAL CONSIDERATIONS AND CONCLUSIONS

Table 3 presents the costs associated with waste management for the Overture Deconstruction Project. The total waste management costs are estimated at $320,007. Removing the stone façade accounted for more than one third of the total cost, at $113,409. Hauling and tipping fees for construction debris also accounted for a third of the total cost. The labor to remove reusable fixtures and furniture cost $3,000. Though the labor cost for removing ceiling tile and carpet are identified as $36,025, interviews suggest that some of this cost would have occurred regardless of recycling activities.

Table 3: Waste Management Costs for Deconstruction Phase of Overture Project.

Material	Tons	Labor Cost	Equipment Cost	Hauling Cost*	Tipping Fees **	Material Revenue***	Total Cost	Cost per Ton
Reusable:								
Fixtures & Furniture	25.9	$ 3,000	$ 0	$ 0	$ 0	$ 325	$ 2,675	$103.28
Stone Façade	267.0	$ 76,915	$33,819	$ 0	$ 0	$0	$110,734	$414.73
Total Reusable	292.9	$ 79,915	$33,819	$ 0	$ 0	$ 325	**$113,409**	**$387.19**
Recycled:								
Ceiling Tile & Carpet	15.8	$ 36,025	$ 3,741	$ 2,360	$ 0	$ 0	$ 42,126	
Metal	166.2	--	--	$ 8,375	$ 0	$1,662	$ 6,713	$40.39
Concrete	4919.5	--	--	$44,750	$ 5,411	$ 0	$ 50,161	$10.20
Total Recycled	5101.5	$ 36,025	$ 3,741	$55,485	$ 5,411	$1,662	**$ 99,000**	**$19.41**
Landfilled:								
Construction Debris	1881.2	--	--	$39,875	$67,723	$ 0	$107,598	$57.20
Total Landfilled	1881.2	--	--	$39,875	$67,723	$ 0	**$107,598**	**$57.20**
Grand Total	7275.6	$115,940	$37,560	$95,360	$73,134	$1,987	**$320,007**	**$43.98**

*Hauling costs for concrete, metal, and construction debris were calculated by multiply $125 (Madison Crushing & Excavating's hauling fee) by the number of truckloads (358 loads concrete, 67 loads metal, 319 loads construction debris). Hauling fees for carpet were paid to Dupont Flooring Co.: $420 for container delivery and $1,940 hauling fee for each load (2 loads). Armstrong Floor & Ceiling Systems charged no hauling fee for ceiling tiles.

** Dane County Landfill's tipping fee is $36.00 per ton (Findorff took 96% of construction debris to Dane County Landfill). Wingra Stone Co. charges $1.10 per ton tipping fee for concrete.

*** Samuels's Recycling pays $10 per ton for sheet metal bought from contractors

Table 4: Avoided Landfill Tipping Fees and Hauling Costs.

Material	Tons	Landfill Tipping Fee / Ton*	Avoided Tipping Fee	Avoided Hauling Cost ($21.20/ton)**	Total Avoided Landfill Costs
Fixtures & Furniture	25.9	$36.00	$ 932.40	$ 549.08	$1,481.48
Stone Façade	267.0	$36.00	$ 9,612.00	$ 5,660.40	$15,272.40
Ceiling Tile	8.8	$36.00	$ 316.80	$ 186.60	$503.40
Carpet	7.0	$36.00	$ 252.00	$ 148.40	$400.40
Metal	166.2	$36.00	$ 5,983.20	$ 3,523.44	$9,506.64
Concrete	4,919.5	$24.00	$118,068.00	$104,293.40	$222,361.40
Total	**5,394.4**		$135,164.40	$114,361.32	**$249,525.72**

* Findorff took 96% of the total tons of construction debris to Dane County Landfill, whose tipping fee is $36.00/ton (the other 4% went to Madison Prairie Landfill, who charges a tipping fee of $38.50/ton). Madison Prairie Landfill charges a lower tipping fee for concrete, $24.00/ton.
** Hauling Cost per ton = $39,875 / 1881.2 tons = $21.20 / ton

Had all of the above materials been taken to the landfill rather than recycled or reused, the cost to Findorff would have been $249,525.72. This calculation is based on the assumption that if the concrete was not recycled, it would have been responsibly disposed of in a construction site landfill at $24 per ton.

Adding the avoided landfill costs to the project's actual landfill costs (construction debris; Table 3) yields the potential total waste management cost of the project, had all materials been landfilled:

Actual Landfill Cost	+	Avoided Landfill Cost	=	**Potential Total Cost**
$107,598.00	+	$249,525.72	=	**$357,123.72**

Subtracting the actual total waste management costs (Table 3) from the potential total cost yields the amount of money that the project saved by recycling and reusing materials:

Potential Total Cost	-	Actual Total Cost	=	**Project Savings**
$357,123.72	-	$320,007.00	=	**$37,116.72**

The project savings do not include consulting costs to coordinate and document the reuse and recycling efforts. WasteCap Wisconsin's consulting fees totaled $8,250.00. These savings also do not include potential revenue from the sale of the stone façade.

In conclusion, this was a successful pilot project demonstrating deconstruction reuse and recycling. The project achieved a 74% recycling rate, the recycling reduced deconstruction costs, and we learned how to improve the deconstruction recycling process for future projects.

For more information on reusing and recycling construction and demolition waste, contact WasteCap Wisconsin, Inc. at (414) 961-1100 or visit their web site at www.wastecapwi.org. They also have publications on construction and demolition debris including a 16-page guide for reusing and recycling construction and demolition debris.

Also visit Madison Environmental Group's website at www.madisonenvironmental.com for more information.

ACKNOWLEDGEMENTS

Many thanks to those who contributed to the success of this project: Mike Huffman of the Overture Foundation; Mark Jenssen and Garrick Maine of PL& F Architects; Larry Thomas and Jim Yehle of J.H. Findorff & Son; and Sherrie Gruder from University of Wisconsin Extension.

DECOMMISSION OF MANUFACTURING FACILITIES - A RECYCLING SUCCESS STORY

Author: Dennis A. Spors, M.S. (Eastern Michigan University, 118 Sill Hall, Ypsilanti, MI 48197, Phone: (313) 925-8157 E-mail: vonspor@aol.com)

INTRODUCTION

The manufacturing base, particularly for automotive assemblers and suppliers in North America, is changing at a rapid pace. In the last 10 years, we have witnessed the relocation of manufacturing capacity within North America and then overseas. Foreign manufacturers have set up operations in the United States, Canada and Mexico while their suppliers have shifted operations to Mexico and then to the Far East.

Much of what drives these fundamental changes is economics. Foreign manufacturers such as Nissan, BMW, Mercedes Benz, Honda, Toyota, Volvo, Hyundai and Volkswagen have set up operations in new assembly and powertrain plants in the Southeast and Mexico. It is projected that their combined sales will exceed the traditional “Big Three” sales in the near future. The new arrivals chose to construct new facilities in right-to-work states, which offered large incentives to establish operations on “Greenfield sites.”

I have been a part of the BMW, Toyota and Mercedes-Benz projects. These companies were not looking to inherit an existing operation but rather create a lean manufacturing environment based on their own manufacturing philosophies. They also requested that their key suppliers establish operations in proximity to facilitate just-in-time delivery.

Several things these new facilities have in common are their lower operating cost, increased environmental safeguards and the lowest possible capital costs for building envelope and process equipment. According to a January 2002 article in Bizzsites.com, the cost of new facilities ranges around \$75 - \$95 per square foot.[1] Chrysler claimed \$54 per square foot for the Jeep Liberty Plant in Toledo, Ohio. Even if we adjust some of the costs labeled as production, this is very low.

Federal and state regulations govern many processes such as the paint shop operations. The latest environmental controls are part of the design. Many of the European manufacturers are conditioned to a higher environmental standard and bring those concepts with them when they relocate. New facilities have greater flexibility and their energy consumptions for operations like the welding of bodies have been greatly reduced.

Due to process efficiencies and automation, automotive assembly and component manufacturing don’t require the number of people they once did. This translates into a small overall footprint for the process itself as well as a decrease in associated people spaces. Less people equate to less

---

[1] Dan Emerson, “Efficiency Tune-Up Drives Transportation Manufacturing,” **Bizzsites.com**, January 2002, p.2.

initial square footage for parking, bathrooms, lockers, cafeterias, team rooms, administrative space. These spaces are usually the most expensive in terms of building cost. By reducing these areas, the initial capital cost of the plant is reduced. Subsequent yearly maintenance costs are also lower when compared with older facilities.

Automotive Industry Magazine reports there is an overcapacity of more than a million units currently in North America. "We've got more factories than we need," Don Malacuk, Director of Business Location Services for Arthur Andersen LLC in New York, said. "Some of the older ones might get reclaimed. It depends on where they are and what they make and where the auto manufacturers think the market will grow. [2]

In the case of older facilities, mostly located in the industrial northeast (rust belt), it is hard to get a renovation strategy to "pencil" with the economics of a new facility. Typically buildings from the 1940's and 1950's are too large for their mission. In some cases, one new smaller plant can provide the required capacity of two or three older industrial monuments. They usually have environmental issues where clean-up costs are substantial. The utility systems are aging and less efficient. Depending on the company, work regulations or other organized labor issues may be a factor.

Therefore, with all the dynamics against renovating older facilities, major companies are searching for options. Possible strategies may include abandoning in place; attempting to sell the facility, as is; demolition of the buildings, site remediation and what we refer to as the Decommissioning Process.

Any kind of corporate morality would preclude leaving such an eyesore. The various Federal, State and City laws prohibit any business entity with deep pockets from just walking away from such a potential mess. Cities will no longer accept transfer of ownership for $1.00.

Old factories with their pits, trenches and decaying roof strata, are very dangerous places. The sites usually have a variety of environmental issues, as metals and petroleum are part of their processes. These liabilities stay with the original owner short of going out of business.

Relocating the process and other assets, and leaving the factory standing, is also an option. The costs associated with this strategy include on-going insurance, security, and utilities (water pipes freeze in winter without heat), as well as maintenance of roofs, electrical and plumbing. Local and state taxes continue to be assessed whether the facility produces or not.

An alternative option showing more and more benefits is that of the Decommissioning Process. By the Decommissioning Process, we mean looking at the facility options organically rather than as stand-alone operations. It is only when all the elements are combined into a program that real advantages are realized.

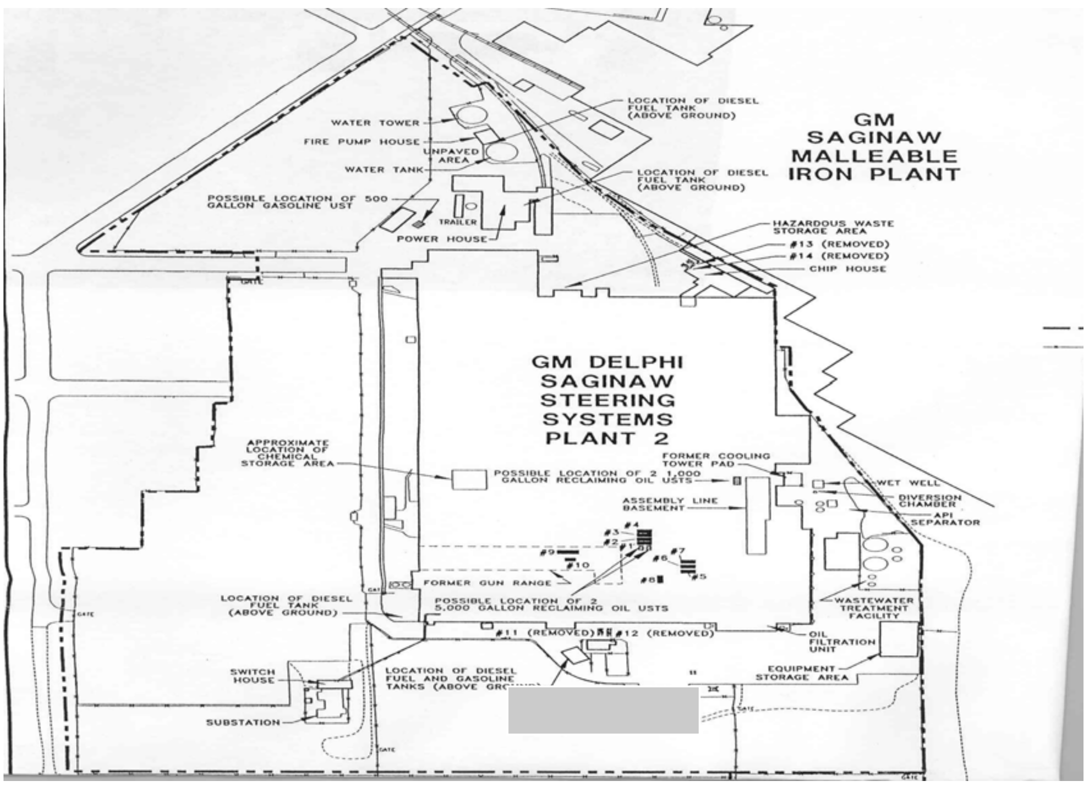
---

[2] Susan E. Avery, "Destination Workforce," **Bizzsites.com**," January-February, 1997, p. 5.

DECOMMISIONING PLAN

This exact process is what was accomplished at the Steering Gear Plant # 2 in Saginaw, Michigan. This aging 600,000 square foot facility started life as 50-cal.machine gun plant during World War II. Over the past 60 years, it had been added onto several times during its life as a General Motors facility. Plant #2 was later transferred to a component manufacturer. By the time plant was closed July 1, 2001, the work force averaged about 1800. Most of these workers were assimilated into other facilities.

The purpose of the facility was to manufacture steering gear. This is a machining and heat treatment intensive process. The cutting of metals involves various lubricating fluids moving from process pit to process pit via a network of trough ways. In recent years treatment plants had been installed and the waste hauled away. The heat treatment process also involved insulated furnace and cooling and quenching fluids. All the issues associated with a manufacturing facility of this age were in evidence.



After studying and costing various options, the Decommissioning Process looked on paper to have the most promise. The actual costs and cost avoidance figures were refined and other alternatives sought. In September of 2001, the financial analysis indicated a payback to the owner in less than two years.

Deactivate and Demolish Facility

Activity Type	Item Description	One Time	On-Going (2 years)	
Project	Asbestos Removal	$110,000		
	Lights/CFC/PCB	$75,000		
	Demolition	$350,000		
	Parking Lot Drainage	$15,000		
	Security	$12,000		
	Management	$70,000		
	Scrap Sales	($295,000)		
	Asset Sales	($200,000)		
	Pumping / Cleaning	$250,000		
Business	Real Estate Tax		N.C.	
	Personal Property Tax			($198,000)
	Municipal Assessments		N.C.	
	Operating Permit			($50,000)
	Security			($100,000)
	Utilities			($150,000)
		$387,000		($498,000)
Net to Owner (savings)				($111,000)

The estimated cost of lowering such a facility was far less than the owner had previously experienced. The building and property had been for sale for over a year without much interest. It is doubtful anyone was interested in assuming the various liabilities that may have accompanied the site.

Our review included an estimate of project asset worth, the scope and cost of remediation activities, a estimate of scrap assets, the cost of demolition, the cost of backfilling pits and trenches, cleaning of pits and trenches and the tax implications of taking the facility down.

DECOMMISSIONING IMPLEMENTATION

Once the decision was made to proceed on this basis, a lump sum contract was executed. A defined program management process was implemented. The scope of activities involved the initiation of asset sales, environmental remediation, pumping and cleaning of deep pits and miles of connecting trenches, removal of copper, demolition and removal of other metals such as steel and aluminum. Other work included negotiations with the City of Saginaw on the tax structure and public relations with the community.

The assets at the site were left over from previous auctions and, according to the owner, did not hold much potential. They included old pumps, switchgear, motors and dated compressors. But since beauty is in the eye of the beholder, it was only necessary to find a source that needed this vintage equipment as spares. Items such as office furniture, lockers and pre-engineered offices create no interest. From these “second hand assets” another $200,000 was realized. Sales and the pick-up process took several months, typically longer than most auction services are willing to wait for revenue.

The environmental remediation largely centered on asbestos removal and the light fixture ballasts and bulbs. Remediation was carefully scheduled with asset sales and some interior demolition in preparation for a major teardown. This stage of the process started with an environmental safety plan and strict adherence to the program schedule.

Selective demolition completed during the winter months included disconnecting sold equipment, removing copper bus bars and conductors and capping all utilities.
The environmental team drained old hydraulic fluids and other contaminants.
Equipment was environmentally cleaned and tagged as part of it preparation for shipment.

The demolition of the actual building was also a coordinated operation. To maximize the value of the components of the building, each was separated and prepared to maximize scrap value. Material was hauled both by truck and by rail to smelters and foundries.

During this process, additional hazardous materials were identified and remediated without slowing down project progress. An interesting sidelight is the identification of radioactive material in a few scrap loads. This was detected at the recycling yard and turned out to be the numbers on the gauge faces of some equipment.

Demolition of the building continued for 9 months. As the building was brought down, pits and trenches would be identified for cleaning. Following pumping and cleaning operations, these open cavities were backfilled with recycled brick and concrete. 16,000 tons of steel, pipe, siding, ductwork and miscellaneous metal were sent to recycling facilities. This was in excess of what had been anticipated. The abandoned overhead and in trench utilities were largely responsible for the extra tonnage.

The idea behind backfilling all pits and trenches, which required 12,000 tons of material, was that each opening represented a life threatening hazard to potential trespassers. Others had recommended hauling all the concrete and block away and then importing material from a gravel yard. We looked at the concrete foundations and bricks as assets and it was better from a liability position to leave them on site. We either crushed materials on-site or had a concrete recycling company break it down into gravel. They recycled the reinforcing steel inside the concrete. Every pit and trench was filled. Every standing wall was sloped and miscellaneous areas were leveled.

During the demolition process, the facade facing the public was maintained until late in the project. When a Saginaw News reporter came to survey the site and write the newspaper article Historic Plant Comes Down, the reporter didn't even realize much had happened. A positive public relations effort was also part of the Decommissioning process. By pointing out that 95 percent of the existing facility was being recycled, the plant demolition took on a whole new meaning. As we pointed out, "Yesterday's plant could be tomorrow's steering gear," referring to the owner's other plants.

The positive press assisted negotiations with city. The City of Saginaw saw the demolition of the plant as a positive and a chance to begin again with a future facility. As part of the on-going dialogue, we presented planned and updated schedules that indicated our stages of completion versus the assessment dates. We met these dates and the tax assessments were predictable amount. Since the plant was down before the December 30, 2002 assessment, the personal property tax was eliminated.

AFTERMATH

Today the former plant is a large open space that may be combined with adjacent properties for development. As a shuttered plant, it had created little interest to a buyer but in its current configuration, it is far less intimidating. Given new ”Brownfield” legislation, there will certainly be some creative uses for the space. Until then, the owner’s costs have been minimized.

The goal of the owner, the city, our project team and that of recycling were combined successfully. The owner’s exposure and on going costs were dramatically reduced. The recycling efforts actually helped pay for the project. A very small percentage actually ended up at a landfill and consisted of drywall and flooring. Most of the deconstruction stories I have read about involve historic buildings and their contents. This is an example of a commercial viable alternate. It is not a cure for all of our environmental issues but it is a significant advancement of the traditional approach.

DECONSTRUCTION CASE STUDY IN SOUTHERN ITALY: ECONOMIC AND ENVIRONMENTAL ASSESSMENT

Author: Paola Lassandro (National Research Council of Italy, Institute for Technologies of Construction ITC-CNR, Bari Section)

ABSTRACT

The paper will analyse how context affects the real possibilities of building materials' reuse and recycling. A deconstruction Case Study in Southern Italy of some big residential buildings gives the opportunity to verify the deconstruction thesis in a real context, to study alternative scenarios to assess the most advantageous one in economic and environmental terms, and to define the profiles of every scenario.

The scenarios' definitions will take into account alternative dismantling techniques and the possibilities of managing C&D materials in relation to the operators and the presence of landfills, surface quarries, and recycling centres in the territory.

KEYWORDS: Recycling; Reuse; Unauthorised Buildings

INTRODUCTION

The ideas on building materials' recycling with appropriate techniques for selective and controlled demolition can be verified in relation to their real applicability only when we face real case studies. The economic, social, and environmental characteristics of the context can significantly influence the technical-economic feasibility of an intervention, based on the CDW materials' recycling.

At the macro-context level, the national laws and the different awarenesses of environmental issues influence the possibility to manage and recover CDW. There is a big difference of opinion on CDW recycling in different countries of the EU. The main aspects regarding these differences are natural resources, transport distances, economic and technologic situation, and population density [1].

Moreover, the real feasibility requires a micro-context assessment, due to the existence of regional or local lows and specific context characteristics. For example, for the inert debris from CD, we have to concentrate our analysis within a radius of few kilometres [2], that is about 30 km, in relation to transport costs and inert debris value.

The economic definition of an intervention aimed to recycle and reuse materials/components can be based on the following evaluations:

- costs of different possible demolitions (controlled or selective demolition, deconstruction, cherry-picking of materials);
- costs for transport of CDW;
- waste disposal fees and waste treatment centres' fees;
- eco-taxes, e.g. in Italy there is a different eco-tax in each region;
- costs for treatment of CDW in the construction site;
- incomes from the reuse of materials/components (salvage value).

All these costs depend on the context characteristics, such as the presence of local qualified companies specialised in controlled and selective demolition and appropriately equipped (laser systems, special diamond blades, and water-demolition techniques, etc.).

The deconstruction of a whole building or of its parts is more labor-intensive than a mechanical demolition [3] in terms of working hours, specific skills, and safety measures for workers. That causes about a 20% increase in costs (according to Italian cases studies), compared to traditional demolition. These costs have to be put into the balance-sheet with the incomes from resale of recovered materials and components.

Regarding transport costs, they depend, almost in a linear way, on the distance between the construction site and the CDW treatment installation, and on the dimensions of dump trucks in relation to the surrounding places (streets dimensions, the closeness of schools and hospitals etc.). According to Italian cases studies, the transport costs, loading and unloading included, can affect the total cost of demolition by 40% in relation to the kind of demolition and related costs. As a consequence, after the valuation of the waste quality that makes the reuse more or less advantageous, the presence of a treatment installation near the construction site is an indispensable condition in assessing the opportunities of waste transport into places that are different from landfills. The census of the CDW recycling installations made by ANPAR (National Association of Recycled Aggregates Producers) shows that most of the installations are concentrated in the North Italy, with the number of installations decreasing in the Middle and becoming very low in the South and in the islands (Figure 1).

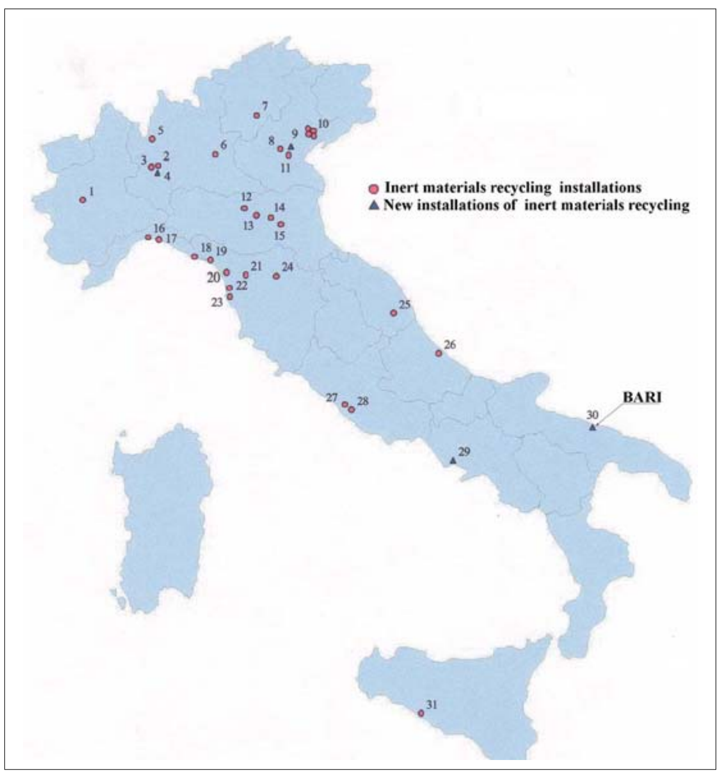


Figure 1 ANPAR (National Association of Recycled Aggregates Producers) census of inert materials recycling installations.

Lacking fixed installations for CDW treatment, an alternative solution may be the use of mobile crashing plants. But, the quality of recycled materials is lower, as these plants are usually not equipped to eliminate the possible present light fractions. In any case, the produced recycled materials for their granulometric (0-70 mm) and geometric characteristics (more edges than in the natural aggregates) can be used with very good results for road embankments and subgrades.

There are different kinds of mobile treatment plants for construction sites, from the smallest ones, useful only for the fragmentation of stones, marbles, granites and CD waste, to the ones with the complete cycle, equipped with magnetic separator and screens for the differentiated selection of granulates. The problem is, again, the context characteristics. The use of mobile equipment with a close cycle requires the availability on the construction site of wide space (about 10.000 square metres) to accumulate recyclable materials. It is also necessary to assess dust and noise level that can be tolerated and allowed in relation to the activities in the surrounding area. The advantage of mobile plants' use is not in the treatment costs, but especially in the cutting down of transport costs. In fact, a fixed treatment installation asks fees comparable to the necessary costs for the use of mobile plants. Moreover, the fee can also be reduced if the quality of CDW is good.

The further positive aspect is that the customer or company, according to a previous contract, can remain the owner of recycling materials that can be used directly for other building works. Moreover, if the customer is a public organisation, such as a Municipality, the time intersection of two different public works can be planned in advance, or at least some Municipality's stoking areas of CDW materials can be predisposed to tend to a complete close-cycle of those materials.

A particular subject is the eco-tax. In Italy, a special tax (called "eco-tax") was introduced for the disposal into landfills according to the national law n.549/95 art. 3, to promote the decrease of CDW production and their recycling and recovery of energy and raw materials. In particular, every region has to fix the amount of the tax between 1,03 Euro and 10,30 Euro per ton of CDW. As a consequence, the eco-tax that can be saved with CDW recovery is different in each region, according to the regional political aims and the awareness of environmental issues (e.g. it is 4 Euro per ton in Apulia, 7,75 Euro per ton in Emilia Romagna and 1,33 Euro in Tuscany).

Regarding the salvage value, the more materials that are selected, the higher the salvage value that can be obtained. Also, the energy quantity contained in the materials is important. For example, the iron obtained from crushing reinforced concrete structure and performing magnetic separation can be sold to the ferrous materials collecting centres. This represents a sure income in the balance sheet for materials recycling. Instead, the wood recovered from CDW can be income, or a further expenditure, in relation to the kind of treatment installation and selection methods.

The revaluation of the recovery materials market would positively influence the net income for selective demolition, but certainly the increase in disposal fees would have a more direct and immediate effect on the choice of the most advantageous demolition method. The local disposal fees in a geographic area are an important "indicator" of deconstruction potential, and will encourage more "whole house" deconstruction in lieu of selective "cherry-picking" of materials [3]. In fact, in Italy, disposal fees are lower than in other countries (especially in

North Europe), and the eco-tax changes in each region. The eco-tax in the Southern Italian regions is the lowest.

In addition to the economic issues, some environmental indicators must be taken into account. Therefore, it can be useful to consider different scenarios that have to be assessed, according to economic and environmental parameters. The definition of environmental balance can be based on the indicators connected with the following issues:

- load of the CDW on the environment;
- consumption/safeguard of the natural resources;
- availability of raw materials;
- availability of secondary raw materials;
- impacts connected with the transport of CDW materials, in terms of consumption and harmful emissions;
- acoustic impacts and pollution from dusts connected to the different solutions of demolition.

The assessment of the real advantages of materials' recovery can be achieved, thanks to a multiple criteria analysis of costs/benefits for the different scenarios in relation to the characteristics of context. Based on these considerations, a case study of possible demolition and CDW recycling is presented.

THE CASE STUDY

The aim of the study is to delineate some alternative scenarios for the demolition of three unauthorised buildings in Bari (a city of the Apulia region in Southern Italy), and to assess the most advantageous scenario in economic and environmental terms.

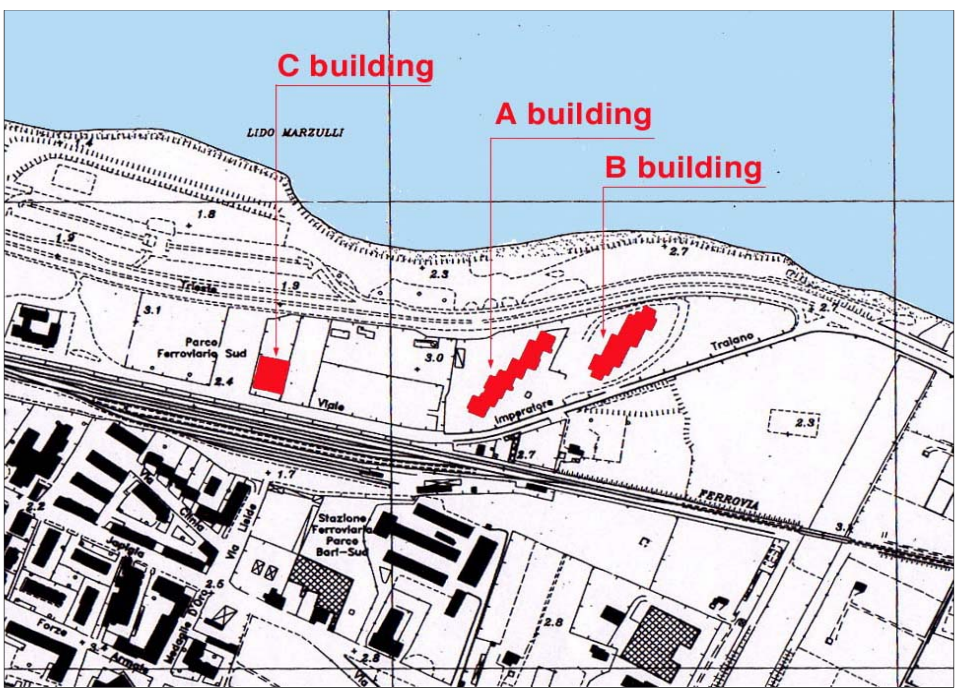


Figure 2 Location plan of the three unauthorised buildings

The three buildings are part of an unauthorised dwellings and offices unit, built along the cost within the town limits. Work was stopped in 1997, but judicial procedures have not yet identified the competence for the demolition - the Bari Municipality or the Magistrate's Court.

The three buildings have a strong environmental impact on that area, in that they are near a beach, a strategic point in environmental terms. The buildings are visible as a long barrier (called by environmental movements a "sluice-gate") from almost all the Bari waterfront for their location and shape. But at the same time, the question involves strong local, socio-economic interests.

Figure 3: View from the beach

Figure 4: View from the street

The three buildings (indicated as A, B, and C) have volumes of about 78.000, 68.000 and 24.000 cubic meters, respectively, and their height is of about 45 meters.
The works are not complete:

- reinforced concrete structures consisting of pillars, beams, reinforced concrete/ hollow tiles mixed floors) in B building;
- reinforced concrete structures and hollow tiles curtain walls in A building, and in a part of C building.

Table 1 Debris percentage on the buildings volume.

BUILDING	A	B	C	Tot.
VOLUME (cubic metres)	78.000	68.000	24.000	170.000
MATERIALS VOLUME (cubic metres)	14.000	8.400	3.900	26.300
DEBRIS PERCENTAGE ON THE BUILDINGS VOLUME	18%	12%	16%	16%
DEBRIS VOLUME AFTER DEMOLITION (cubic metres)				80.000

Table 2 Materials and quantities

BUILDING	A	B	C	Tot
REINFORCED CONCRETE (cubic metres)	7.400	5.700	2.700	15.800
HOLLOW TILES (cubic metres)	6.600	2.700	1.200	10.500
TOTAL DEBRIS AFTER DEMOLITION (cubic metres)	14.000	8.400	3.900	**26.300**

Table 3 Composition of materials

BUILDING	A	B	C	Tot
REINFORCED CONCRETE	53%	68%	70%	60%
HOLLOW TILES	47%	32%	30%	40%

As our analysis shows, the buildings are made almost exclusively of "basis materials"(concrete, iron, and hollow tiles) that can be easily reused. There are no finishes, plants, windows, and doors. Therefore, it is not necessary to use expensive techniques of selective demolition or deconstruction in order to separate those components from the concrete structures. The CDW are already partly selected. Therefore, different scenarios can be outlined in relation to the possible demolition techniques and real recycling opportunities. In particular, the definition of scenarios has to take into account:

- the technical and operative possibilities for the different types of demolition;
- the real possibilities to manage the demolition materials in relation to the operators (companies, Customers, users, politicians);
- the presence of landfills, surface quarries, and recycling centres in Municipality territory.

Figure 5 A Building

Figure 6 B Building

The economic definition can be based on the following evaluations:

- local costs for the use of different demolition techniques;
- costs for transport of CDW;
- waste disposal fees and waste treatment centres' fees;
- eco-taxes in Apulia region;
- costs for treatment of CDW in the construction site;
- incomes from the reuse of materials/components (salvage value), according to the local market.

The definition of "environmental balance" can be based on the indicators connected with the following issues:

- load of the CDW on the environment;
- consumption/safeguard of the natural resources;
- availability of raw materials;
- availability of secondary raw materials;

- impacts connected with the transport of CDW materials (consumption and harmful emissions);
- acoustic impacts and pollution from dust, connected to the different solutions of demolition.

After a preliminary study, other more specific indicators can be introduced, thanks to a citizen's participation process, to define specific profiles of the environmental impact for each scenario.

At the present stage, the following scenarios have been built:

Scenario 1: Traditional demolition and dumping of the CDW in landfills.
This represents a reference scenario, "witness scenario", since it is generally the most adopted in these cases. Considering dimensional and typological characteristics of the buildings and the surrounding context, the scenario is based on the demolition with mines and the dumping of CDW in the nearest landfills that have to be chosen among those with an adequate receptivity.

Scenario 2: Controlled demolition and dumping of the CDW in a fixed treatment installation.
This scenario is based on the use of demolition techniques that allow the production of two principal homogeneous fractions of materials: reinforced concrete and mixed concrete-hollow tiles. These fractions can be treated in fixed fittings and then used to make reusable aggregates for no-structural concrete, road subgrade, and fillings.

The scenario assessment should also consider different opportunities for these materials' management in relation to possible conventions between the Municipality and the other operators in the sector.

Scenario 3: Traditional or controlled demolition and crushing of the materials in the construction site with mobile plants of treatment.
This scenario is based on the demolition with mines, or in a controlled way, and a subsequent use of a treatment plant in the construction site. This equipment can produce usable aggregates for subgrade and fillings. The assessment of the scenario should verify the opportunities of making the recycled materials available for new public works of the Municipality or of other public local Agencies (e.g., for the projects that have been introduced into the "Investment program of the public works- years 2002-2004"). The scenario also allows assessment of the option of CDW reuse, after the treatment of the materials, for improvement works in the same area.

After a preliminary assessment, the results are as follows:

Scenario 1.
It is possible to use demolition with micro-mines, as there is an area almost completely free from buildings within a range of about 100 kilometres. The presence of railway does not necessarily represent a problem if, during the explosion, the trains are stopped and some devices are used for the protection of the railway-tracks. The dimensions and the typological characteristics (number and dimension of pillars, beams span, number of floors, the lack of finishes, plants, windows, and doors) make the use of the micro-mines demolition method quite easy. There are landfills within a range of 7 kilometres from the construction site and the disposal fee is quite low, about 9,50 Euro per CDW ton (5,50 Euro for waste management

and dumping costs plus 4 Euro for eco-tax). The total costs for the demolition and dumping of the CDW in landfills are about 1.014.738 Euro (plus VAT). But in environmental terms, this scenario is not good, as there is considerable production of dust during the explosion, and the 26 tons of CDW are not reused.

Scenario 2.
It is possible to use excavators equipped with hydraulic pincers on a 50 metres long arm, to separate the concrete pieces from the mixed concrete-hollow tiles debris. There is only one inert materials recycling centre near the construction site. The treatment fee is about 4 Euro per ton. There are not other recycling centres in the surrounding area. It is also possible to use big dump trucks, as the area is easily accessible. In environmental term, it is a very good scenario; but in economic terms, it is not so advantageous, because the demolition process is more expensive than the traditional one (about 19%) and the treatment costs (4 Euro per ton) are comparable with waste management and dumping costs (5,50 Euro per ton) of landfills. But, we can save eco-tax (4 Euro per ton) by dumping the CDW in a fixed treatment installation.

Scenario 3.
The third scenario results the most advantageous in economic terms for the following reasons:

- there is a free area of about 10.000 square metres in the construction site;
- the transport costs from the construction site to a fixed recycling installation can be saved;
- the near quarries are not a problem, as the recycled produced aggregates have a competitive price;
- the Municipality is still the owner of the aggregates and iron (salvage value = 412.611 €);
- the Municipality can use the aggregates for other public works or in the same construction site for area improvement.

In environmental terms, the only problems may be the dust and noise produced during the materials' treatment by mobile plants. But, there are not particular activities in the area that could be damaged or annoyed by dust and noise, especially during autumn and winter.

Table 4 Demolition Costs for the three Scenarios

Scenario 1				
	Unit	Unit Cost	Quantity	Cost
Demolition with mines. To evaluate for the total volume (empty spaces included).	€/m3	1,65	170.000	280.500
Load on dump tracks	€/m3	1,59	78.999	125.608
Transport with dump tracks for 50 quintals to CDW treatment installation	€/q	0,08	585.221	46.818
Landfills: Waste management and dumping costs	€/ton	5,60	58.522	327.725
Eco-tax	€/ton	4,00	58.522	234.088
TOTAL				**1.014.738**

Scenario 2				
	Unit	Unit Cost	Quantity	Cost
Demolition with excavators equipped with hydraulic pincers on a 50 metres long arm, including the primary crashing (40/50x40/50 centimetres blocks) and iron separation. To evaluate for the total volume (empty spaces included).	€/m3	6,20	170.000	1.054.000
Load on dump tracks	€/m3	1,59	78.999	125.608
Transport with dump tracks for 50 quintals to CDW treatment installation	€/q	0,08	585.221	46.818
Dumping of the CDW in a fixed treatment installation	€/ton	4,00	58.522	234.088
TOTAL				**1.334.906**

Scenario 3				
	Unit	Unit Cost	Quantity	Cost
Demolition with excavators equipped with hydraulic pincers on a 50 metres long arm, including the primary crashing (40/50x40/50 centimetres blocks) and iron sepation. To evaluate for the total volume (empty spaces included)	€/m3	6,20	170.000	1.054.000
Secondary crashing to 0,70mm	€/m3	12,91	26.333	339.959
TOTAL				**1.393.959**
Salvage value				
Inert materials value and Iron value	€			**-412.611**

THE UNAUTHORISED BUILDINGS AND THE MATERIALS RECYCLING

As illegal buildings are often in a places with environmental value (by the sea, by the rivers, in the countryside etc.), the demolition of unauthorised constructions and the recycling of their materials offer the possibilities to give back to nature the territory and materials. Moreover, the unauthorised buildings are often not completed, and therefore it is easier to recycle their materials. The phenomenon of illegal buildings has spread throughout Italy, but half of the unauthorised constructions are in the Southern Region of the nation. In particular, according to CRESME (Centre for Economic, Sociologic Researches and of Building Market) data, the Southern regions of Campania, Apulia, and Sicily share the supremacy of the illegal buildings. According to the same data, during 2002, among the new 162.407 buildings, almost 19.000 were illegal, equal to 11,7%. The materials recycled from unauthorised buildings can reach a considerable proportion, therefore it should be taken into account in relation to the necessity to pull down illegal constructions.

CONCLUSION

The study of the demolition and the materials' recycling of the three buildings in the city of Bari, called "Punta Perotti" buildings, is still at a preliminary stage because of the complex legal procedures that have already lasted for about 6 years. As this preliminary study shows, Scenario 3 results the most advantageous in economic terms and in environmental terms for the context characteristics, but the economic advantage is not so evident. Therefore, the

Government should introduce further incentives in order to increase the number of materials recycling centres, especially in Southern Italy and in the islands [4], at the same time increasing the disposal fees or the eco-taxes. In fact, a material recycling is considered within sustainable development strategies, as it allows decreased waste, use of natural resources, CO2 emissions, energy consumption, and the number of surface quarries on the territory.

Regarding the case study, we hope that it will soon be possible to pass to the executive project and to the real materials recycling. As the events of "Punta Perotti" buildings catch the attention of newspapers and TV, an operation of this kind can have great social relevance because it can influence the public opinion about recycling practices. In other words, it can promote other positive actions in environmental and economic terms.

REFERENCES

1 **Dorsthorst, B. J. H. and Kowalczyk, T.** Design for recycling, *Proc. of the CIB Task Group 39 – Decostruction Meeting CIB World Building Congress, CIB Pubblication 272*, Karlsruhe, Germany, 6 April 2002, pp.71-81.

2 **Bressi, G**. La gestione dei rifiuti da costruzione e demolizione. *Recycling* n.2, 2002, pp. 105-115

3 **Guy, B.** *Building Deconstruction Assessment Tool*, Proc. of the CIB Task Group 39 – Deconstruction Meeting CIB World Building Congress, CIB Pubblication 266, Wellington, New Zealand, 6 April 2001, pp.125-137.

4 **Antonini, E.** *Residui da costruzione e demolizione: una risorsa ambientalmente sostenibile*. FrancoAngeli, Milano, 2001.

RE-USE OF BUILDING COMPONENTS (TOWARDS ZERO WASTE IN RENOVATION)

Author: Peter A. Erkelens (Technische Universiteit Eindhoven, The Netherlands)

ABSTRACT

The enormous amount of waste produced during building and renovation is a serious environmental problem, which is worsening as building activities increase over the years. This paper investigates, in a case study, the possibilities for reducing waste production in renovation activities. A different approach to the planning phase results in more materials being left on the site or being re-used, and a change in floor plans leads to more re-use of materials, less waste, and less need for new materials. The achievable reduction of environmental impact is calculated with Life Cycle Analysis (LCA) calculations. The environmental impact of this renovation project could be lowered by 5-10%, which is promising for other ones. More precise data on impact of waste reduction will be obtained if LCA is improved. Better coordination during demolition will provide for more re-use.

KEYWORDS: Building Components; Environment; Housing; Renovation; Re-use; Waste

INTRODUCTION

Huge amounts of waste are produced during building and renovation of buildings, not only in the Netherlands, but also in other countries. This phenomenon is the reason for looking more critically into these processes, as they create many unwanted situations. This paper presents a different approach to building projects, particularly renovation projects, in order to reduce some of the negative effects like waste.

Ten percent of the materials used in building and construction end up as waste. But waste does not end there; it actually increases several-fold during the lifetime of a building due to maintenance, renovation, and finally, demolition. Also, in other parts of the world this building and construction waste is a matter of concern. Smith (1) noted that in the USA, 20% of the total materials were wasted. Typical construction generated 20-35 kg of solid waste per m^2 of floor space. Vingerling (2) reported that the total amount of building and construction waste produced in the Netherlands per annum could be used to build 30,000 houses. In 1997, the reported amount of building and construction waste was 16.1 million tons (3), and 23 million tons in 2001.

Building and construction is one of the engines of the economy considering their contribution to the Gross Domestic Product, Gross Fixed Capital Formation, and employment. The general expectation is that economic growth will continue into the future. Due to the strong relationship between building activities and economic development, there will be an increased need for more and bigger housing and utility buildings (4). This, in turn, will demand more building materials. From the environmental point of view, the above-described situation will cause more:

- Depletion of resources. The built environment accounts for up to half of the raw materials taken out of the earth (5);
- Waste; and
- Emissions, pollution, etc.

In the Netherlands, a report published as far back as 1988 by Zorgen voor Morgen (Take care for Tomorrow) (6), revealed an alarming picture of the environment. It indicated grim consequences for agriculture, traffic, industry, and households. The following year, in response to this report, the Dutch government launched the National Environmental Policy Plan, which is still in force today (7), and is of interest to other countries as well. This plan presents three basic concepts for an environmental policy that supports the idea for sustainable building and construction:

- Integrated life cycle management of materials;
- Energy reduction through higher efficiency, use of renewable raw materials, and reduction of energy consumption; and
- Quality improvement of products and processes, minimization of the use of resources, and where necessary, the use of renewable resources.

CONTEMPORARY SOLUTIONS

The building construction industry is taking a number of measures to address this situation.

Dematerialization

One of the solutions can be found in dematerialization (8), which leads to the use of less materials and, consequently, to less waste. Other ideas are deconstructable buildings and components that can be easily decoupled from the building.

Recycling

Buildings can be comprised of products that are designed for recycling. Löfflad (9) investigated the possibility of using globally recyclable materials. He distinguished three categories of materials: global recycling material (straw etc.), conditional global recycling material (bricks), and not-global recycling material (plastics). If well designed, he found that 90% of a house can be built of global recycling material. For new construction, the proposals from (8) and (9) may be useful; yet for renovation of existing buildings, this is just a partial solution, as we have to deal with a partial replacement of existing materials.

Better management

In the Netherlands, housing alone contributes to 3.1 million tons, or 20% of the waste. Half of this waste comes from renovation activities. In the near future, the number of houses to be renovated will exceed new houses. This means that, unless special measures are taken, waste created by renovation will increase even further. Currently, qualitative and quantitative data on waste, from both renovation and new construction, is available only at the national level. Moreover, detailed data per housing project is limited, and very little data is available for renovation. Here, it is worth drawing attention to three studies. Stroband (10) monitored a building project of 57 new houses, and managed to achieve a 41% reduction of waste, compared to a reference project, through better management during execution. Although the research was restricted to new buildings, the result demonstrates the feasibility of reducing waste. Nunen (11) investigated the re-use of concrete floor and wall elements from a demolished apartment building. This was a feasible option, and the environmental impact reduction compared to new was 35%. A similar approach is documented by Vries (12) on a building project in Maassluis. An apartment building was topped off and the lowest two stories were converted into detached housing. Although the reported cost reduction was 10%, the environmental impact reduction was lower than expected because of the need for additional stabilizers.

Industrial Flexible and Demountable (IFD)
A different, but still ongoing type of research under the framework of IFD-research is the re-use of foundations of demolished apartment buildings: the so-called IFD today project (13).

A NEW APPROACH

For buildings that have to be renovated, the solutions of dematerialisation, recycling, better management and IFD are not adequate, as renovation is very different from new construction. These are a few of the reasons why we promote a different approach to the renovation process. The proposed process order should be:

1. Initiative, the brief;
2. Inventory of spatial qualities of the building, qualities of the components, etc.;
3. Making provisional renovation designs;
4. Development of various scenarios, different activities over the coming use-period;
5. Checking with LCA on the design proposals;
6. Making an improved design, including IFD and details for deconstruction; and
7. Monitoring the demolition / deconstruction of the components of the building prior to actual construction.

This will be elaborated in more detail below.

Ad 1. Initiative
The client should be willing to accept this different approach of the renovation process, which can be further detailed in the architects brief. He may think of additional costs, although this is questionable, as it depends mainly on how this project is handled during the process.

Ad 2. Inventory of qualities
The basic issue is to make an inventory of the spatial qualities of the building, and to inventory the existing building components and their connections. What are the possibilities of taking out/ deconstruction without demolition? What is the environmental impact of taking away a component and re-using or discarding it, and what is the impact of using a new one?

Ad 3. Design for zero-waste
With the abovementioned inventory at hand, the architect can draw floor plans, cross sections, etc. He can oversee the consequences of his design decisions. For the specification of building

materials, components, etc., he can use the ‘Zero waste model’ that was developed at the Eindhoven University (14). The purpose of this model (Figure 1) is to depict the material flow in a renovation project and the preferential order of application.

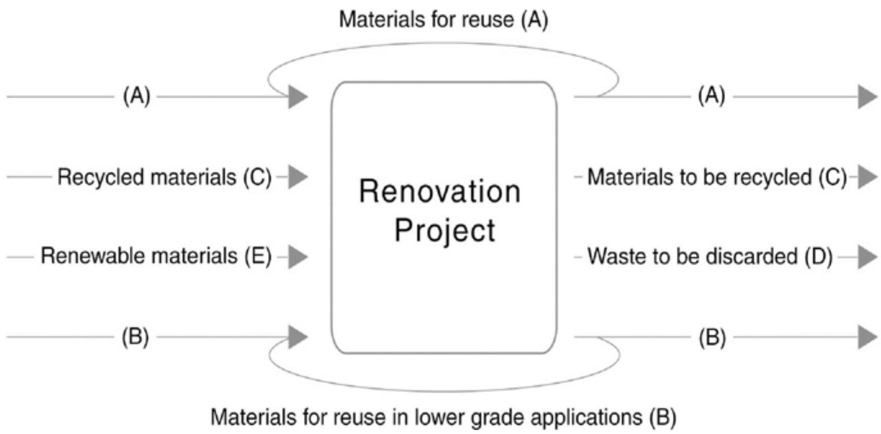


Figure 1 Zero-waste model (14)

At the right hand side are the out-coming materials. Materials in flow (A) are re-used for the same application in this renovation project or in other projects. Those from flow (B) are re-used for a different application here or elsewhere. (C) will be recycled and flow (D) is discarded as waste. On the left hand (input) side are materials for re-use from flows (A) and (B). Flow (C) consists of recycled materials and flow (E) has new materials. In the case of new materials, the preference is for renewable materials. The goal is a maximum reduction of the materials flows, knowing that transport has generally the greatest impact. In summary, the following preferences for materials use are indicated:

1. Materials for re-use (A);
2. Materials for re-use in a different application (B);
3. Recycled materials (C) ;
4. Renewable materials (E); and
5. Non-renewable materials (only if unavoidable).

The following definitions apply:

Re-usable materials are materials that do not require any treatment apart from cleaning. Recyclable materials are materials that may be used as raw material for the production of new materials.

Ad 4. Scenario development
Improvements of existing buildings can be made in different time intervals over the use period. One can think of maintenance as necessary to keep the building functioning as it is. Renovation is the next option, whereby the building is partly renewed and used for the same purpose. Another (extreme) option is demolition and construction of a new building at time interval T3 (Figure 2).

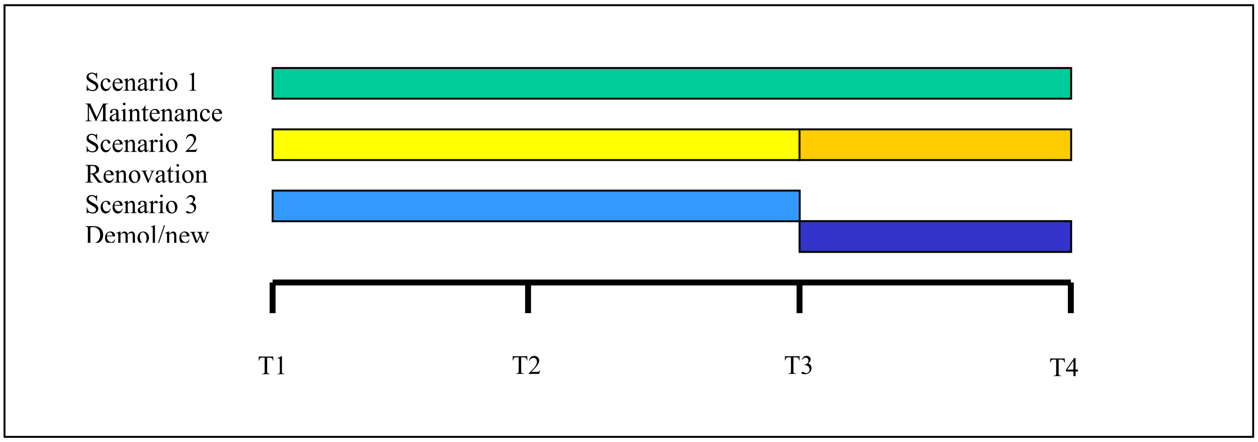


Figure 2 Life-span scenarios for maintenance, renovation, and renovation/new building

Ad 5. LCA studies
The various design options and scenarios can be investigated based on their environmental impacts through LCA studies. As this still is a rather complex issue, one has to limit the number of options.

Ad 6. Improved design
With the LCA results from the different designs and scenarios one can select the ones most promising for the environment. Of course, there are also other factors involved, which may be a reason why the final design is less favourable for the environment. By doing so, one is more aware of the environmental consequences of changes in the designs. Possibilities for IFD and deconstruction are worthwhile to be included in this phase of the process.

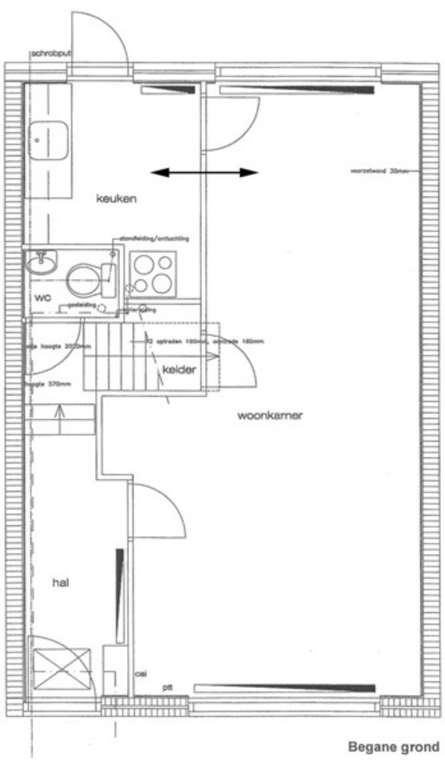
Ad 7 Monitoring deconstruction
During the project preparation, one can develop ideas on re-use of components and materials and make them a part of the project philosophy. However, construction practice is different. That is why it is important to monitor the demolition phase.

CASE STUDY AND ANALYSIS

Initiative and inventory of qualities
In a case study done by a number of our MSc. students, we tested the different steps of the described "new approach." As this was a renovation project already being executed, we were able to compare our proposals with the ideas of the project architect, and with the real situation on site.

The project consists of 248 houses (Figure 3). These houses were built in 1949, and were partially renovated in 1977. The family houses have two stories and an accessible attic. There are three bedrooms, one of twelve m^2 and two of seven m^2, respectively, a dining-sitting room combined with a kitchen of 34 m^2, a bathroom, and a toilet (see Figures 4 and 5). The exterior walls are of masonry work, and the interior has B2 concrete blocks. The floors consist of prefabricated concrete and there is a ceramic-tiled roof on bituminised hardboard panels placed on concrete girders and rafters. The actual renovation is planned for 2002/2003, under the supervision of a project architect.

Figure 3 Typical street in Lievendaal



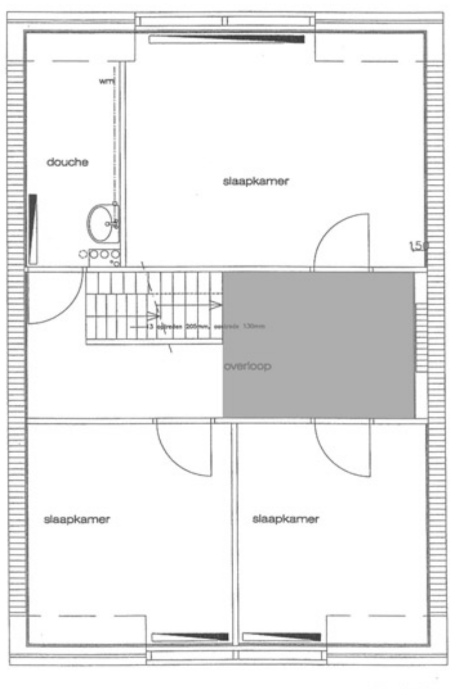


Figure 4 Existing ground floor **Figure 5** Existing plan of the first floor (15)

Design for zero-waste
Based on the existing plans, various designs were prepared, taking into consideration the ideas of minimization of demolition, maximum re-use of out-coming products, etc.

Scenario development for renovation
In the second part of the research, six scenarios were developed for the renovation.
Table 1 depicts the lifetimes of the various building components, which are applicable to this project. As can be seen, the lifetime variation is from 25 years to 50 and 75 years, respectively.

<table>
<tr><th>1949</th><th>1977</th><th>2001</th><th>2026</th></tr>
<tr><td colspan="3">Foundation, facades, floors,
wall plates, purlins</td><td></td></tr>
<tr><td>Windows and frames
Internal door/frames
Ceiling plates</td><td colspan="2">Windows and frames
Internal door/frames
Ceiling plates</td><td></td></tr>
<tr><td colspan="2">Roofing-plates, tiles, rafters
External finishing of dormer window
Roof gutters, rain-water pipes</td><td>Roofing plates, tiles, rafters
External finishing of dormer window
Roof gutters, rain-water pipes</td><td></td></tr>
<tr><td>Internal walls
Shower, toilet, kitchen, wall tiles
Mains, installations</td><td>Internal walls
Shower, toilet, kitchen, wall tiles
Mains, installations</td><td>Internal walls
Shower, toilet, kitchen, wall tiles
Mains, installations</td><td></td></tr>
</table>

Table 1 Renovation Scenarios

LCA studies
The aim was to find out how the waste production of a renovation project could be reduced by an improved renovation design and by re-use of materials, and what its environmental impact would be. The ECO-Quantum program calculated this impact. The reference scenario (#1) assumed that the houses would be preserved by maintenance for another 25 years. Consequently, the environmental impact was calculated for the planned renovation with new materials (scenario #2). We then looked into the re-use of out-coming materials, whereby scenario (#3) assumed a maximum re-use, and scenario (#4) represented a more realistic percentage of re-use. In scenario (#5) the original renovation plans were critically reviewed and altered, further limiting the production of waste. In particular, the changes in circulation space, location of the staircase and the corridor, resulted in an improved dwelling layout. This scenario assumed the maximum re-use of materials, while scenario (#6) assumed a realistic amount of re-use (15).

Environmental impact calculations gave the following results (Table 2). The figure for maintenance is set at 100 relative environmental impact points. In the case of maximum re-use, the impact of the renovation by the project architect was reduced from 152 to 129 points, and the revised plan gave a reduction from 152 to 122. A more realistic re-use percentage of materials leads to higher totals, 142 and 147, respectively.

Scenario	Description	(Relative) environmental impact points
#1	Maintenance	100
#2	Renovation by project architect to plan	152
#3	Renovation by project architect maximum re-use	129
#4	Renovation by project architect realistic re-use	142
#5	Renovation revised maximum re-use	122
#6	Renovation revised realistic re-use	147

Table 2 Relative environmental impacts of six renovation scenarios. Maintenance is set at 100, causing the lowest impact.

Improved design

As a result of the LCA's of the six scenarios, the following plans were developed, which can be considered as an optimum. The façade, internal walls, roofs, and installations give the highest environmental impact. The revised renovation plans give less impact points due to simple measures like re-use (10% less impact of roofing and 50% of inner walls). A better layout and shorter mains, etc., could save materials (figures 6 and 7).

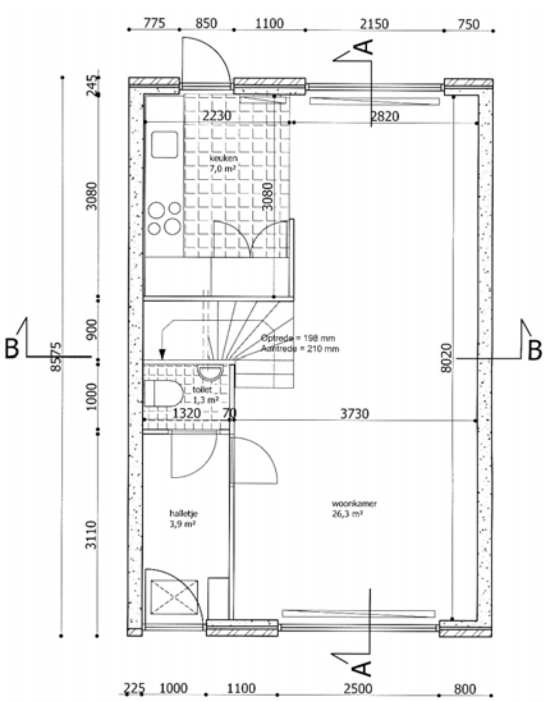


Figure 6 Improved design, ground floor

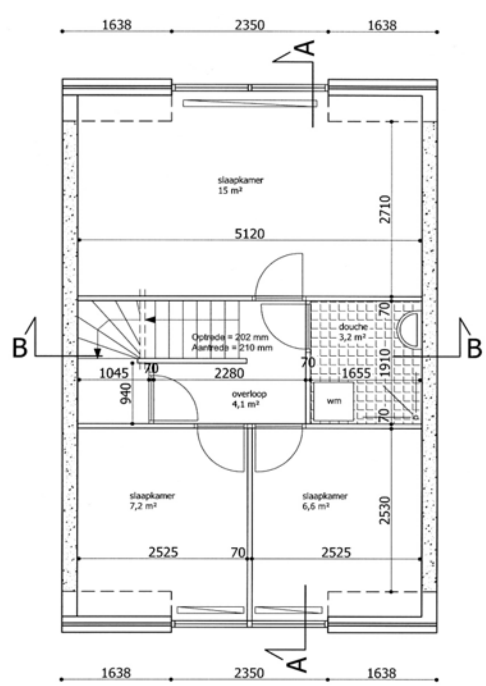


Figure 7 Improved design, first floor

Monitoring deconstruction

To collect the detailed data on waste production, three students carried out on-site measurements on one house over a period of three days. (16) This house functioned as a test house during the renovation. They monitored the out-coming materials, caused by demolition of parts of that house. The materials were counted and categorized by visual inspection on their re-use potential: re-use in this project, re-use elsewhere, use for a different application, or discard (Table 3).

Distinguished categories of removed components	Number of different components	% of total
Re-use in this project	29	47
Re-use elsewhere	15	24
Useful application	12	20
Burning	1	2
Discarding	5	7
Total	62	100

Table 3 Categories of removed building components.

Sixty-two different out-coming components were counted of which 29, or 47%, were considered to be re-usable in the same project. In addition, a check was done on the degree of treatment before the components could be re-used. There were four categories of treatment: no treatment, cleaning, light treatment, and intensive treatment. This was only applied to those in the category, "Re-use in this project" (Table 4).

Categories of treatment before re-use	Number of different components	% of total
No treatment	11	38
Cleaning	6	20
Light treatment	8	28
Intensive treatment	4	14
Total	29	100

Table 4 Treatment categories for re-usable components

Out of these 29 different components, 38% did not need any treatment, and 20% only needed cleaning. In conclusion, on average, one-third of the different out-coming components can be re-used in the same project. By applying other selection criteria, such as appearance and satisfaction to the contemporary requirements, this total may be lower.

Some observations during the demolition phase are of interest:

-The demolition contractor did not work "neatly"
-The labourers demolished parts of the house at a high speed within three days
-Supervision was absent
-The work methods for demolition were focussed on "rescuing" building components (causing unnecessary breakage of components)
-Many components were fixed, so they were not demountable
-Demolition was done "oversized," more than was indicated on the drawings, with an increased materials flow (Figure 8).

Figure 8 A bathroom with some demolished components, but… too many.

With another type of contract, together with proper instructions of the labourers, it was felt that far more different components and building materials could be available for re-use.
Figures 9 and 10 depict the final result of the renovation by the project architect.

Figure 9 Renovated roof with PV panel

Figure 10 The project site, Lievendaal, after renovation (left) and before renovation (right)

CONCLUSIONS

1. If the project architect could use precise, as-built drawings and lists of the used materials and their expected environmental impacts at an early stage, he or she would be able to decide which materials should stay in place, and which should be removed before he or she actually starts the design work for the renovation. The case study demonstrated the viability of this option. The housing project in this study can be considered representative of more than these housing estates. In order to obtain more data, estates with different types of housing should also be surveyed.

2. Although just one case was investigated, the results are promising. More materials and components can be re-used if both demolition methods and labour instructions are adapted. Reduction of demolition to a minimum will not only result in less waste, but also in less need for new materials.

3. The achieved reduction of the environmental impact is limited to 5-10 (152-147; 152-142) points only, which may give the impression that this exercise of re-use and reducing waste is just marginal. However, the conclusion still holds that comparison of renovation scenarios, through programs like Eco-Quantum, is a feasible option.

REFERENCES

1 Smith, M., Whitelegg, J., Greening the built environment, Earthscan, London, 1998.

2 Vingerling, J.J., Afvalpreventie op de bouwplaats, Lecture notes, Technische Universiteit Eindhoven, 1994.

3 RIVM LAE, Monitoring prioritaire afvalstoffen, data 1997, Report, The Hague,1999.

4 Erkelens, P.A., Extending service life of buildings and building components through re-use, In: (no Eds) Proceedings 9DBMC Conference, Brisbane, Australia, on CD-ROM, 2002 paper, 6 pages

5 Milford, R. Pro-active approach Theme 1: sustainable construction. CIB Information 2/02 p. 33, 2002

6 RIVM, Zorgen voor Morgen, Nationale milieuverkenning, 1985-2000, Report, The Hague, 1988.

7 MVROM, National Environmental Policy Plan, NEPP (Nationaal Milieu Beleidsplan) Report, The Hague, 1989.

8 Kibert, C. J., Deconstruction as an essential component of sustainable construction, in: (no Eds) Proceedings CIB World Building Congress, April 2001, Wellington, New Zealand, on CD-ROM, paper NOV 54, pp. 1-11, 2001.

9 Lofflad, H., Das globalrecyclingsfähige Haus, PHD. Thesis, Bouwstenen, nr. 66 Technische Universiteit Eindhoven, 2002.

10 Stroband, J., Israels, E.G., Direct hergebruik van componenten in de woningbouw, Report, Bekker & Stroband, BOOM, 1991.

11 Nunen, H. van, Hergebruikt bouwen met naoorlogse systeembouw in: Renovatie & Onderhoud, Juni, Vol. 26, TenHagen & Stam b.v., The Hague, pp. 10-12, 2000.

12 Vries, T. de, Aftoppen en weer opbouwen, Renovatie en Onderhoud, Vol. 26, jan/feb, pp. 22-25, TenHagen & Stam b.v., The Hague, 2001.

13 Hendriks, N.A., Balancing between functionality and extreme flexibility, in: (Ed. Erkelens P. A. et al), Beyond Sustainable Building, Bouwstenen nr. 65, pp. 21-24, Technische Universiteit Eindhoven, 2002

14 Erkelens, P.A., Zero Waste renovation, Internal research report, Technische Universiteit Eindhoven, 2000.

15 Rond, K. de, Milieu vriendelijk renoveren, MSc. Thesis, Technische Universiteit Eindhoven, 2002.

16 Gort, R., Communications, Bouwcarrousel, 2001.

17 Klundert, M. v.d, et al, Renovatie, Milieu en Afval, BSc Thesis Technische Universiteit Eindhoven, 2001.

DECONSTRUCTION OF EARTHQUAKE-DAMAGED BUILDINGS IN TURKEY

Author: Soofia Tahira Elias-Ozkan (METU, Ankara, Turkey)

ABSTRACT

Turkey has suffered major natural disasters during the past few years, in the form of devastating earthquakes in its southern and northwestern regions. Thousands of homes and businesses were destroyed in these thickly populated urban areas, while the death toll rose to more than sixteen thousand. The degree of damage to the buildings varied from totally collapsed structures to slightly damaged ones. Consequently, there were thousands of dangerously damaged buildings that had to be demolished and their rubble cleared, along with the debris of those that had collapsed completely.

A study was conducted in the disaster-stricken areas to record demolition, site clearance and salvaging activities, prior to re-building and rehabilitation works. It was observed that a fair amount of deconstruction was going on, even in the precariously tilted buildings, in order to recover as much building material as possible. This study is based on a visual record of the deconstruction and demolition works undertaken by the municipality, the private sector, and the individuals, after the earthquake in northwestern Turkey.

KEYWORDS: Deconstruction; Demolition; Recovery of Building Material; Recycling; Earthquakes; Turkey

INTRODUCTION

Turkey has experienced several major earthquake disasters in the last decade, which have caused devastating losses of life and property. Apart from intermittent tremors along major fault lines, intense earthquakes occurred in Erzincan (1992), Dinar (1995), Adana (1998), Marmara (August 1999), Düzce (November 1999), Corum (2000) and Afyon (2002). Of these, the earthquakes in the Adana and Marmara regions were the most severe, causing varying degrees of damage to more than 80,000 buildings each.

The city of Adana and its environs were struck with an earthquake disaster in June 1998. According to the authorities concerned, some 4,000 houses were completely destroyed and another 4,000 had to be demolished because they were unsafe for habitation. Meanwhile, another earthquake of magnitude 7.2 on the Richter scale shook the Marmara region on the 17th of August 1999. The resulting devastation was incomparably greater than any experienced before. Tens of thousands of people were killed or injured. Thousands of buildings were razed to the ground and more were rendered uninhabitable. Severely damaged and semi-collapsed structures had to be demolished and the rubble cleared away. This was an extremely difficult, dangerous, and time-consuming task. The resulting pollution in the form of noise, dust, debris, and smell was a physiological as well as psychological health hazard. Figure 1 shows the damaged buildings along one of the main roads in Adapazari a few days after the earthquake in the Marmara region. Figure 2 shows the same road a few weeks later, portraying the resulting chaos after the demolition and site clearance work started.

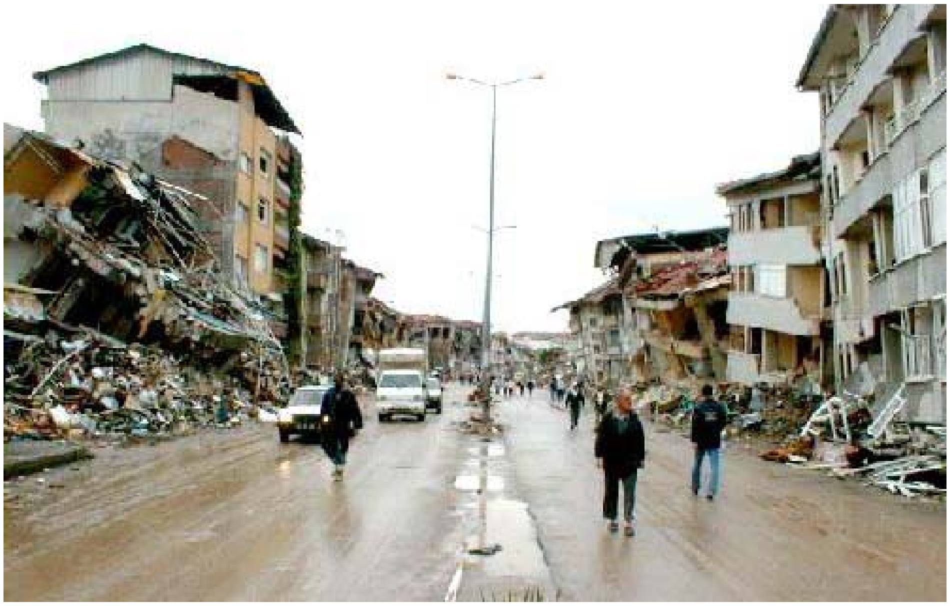


Figure 1: Extensive damage caused to the buildings located on one of the main roads in Adapazari, as a result of the devastating earthquake of 1999 in the Marmara region **[ii]**.

Figure 2: Another view of the main road, shown in Figure 1, after demolition work had started on the dangerously damaged buildings **[iii]**.

Buildings in the Marmara region could be divided into five categories according to the degree of damage caused by the earthquake of August 17, 1999:

a. *Totally collapsed structures*: buildings that were completely razed to the ground into huge mounds of rubble (Figure 3).

b. *Partially collapsed structures*: buildings with some parts left still standing, but so precariously as to require immediate demolition (Figure 4).

c. *Severely damaged structures*: buildings with irreparably damaged structural elements; Figures 8 and 14 show two such buildings.

d. *Moderately damaged structures*: buildings with some structural and other damage rendering them unsafe, if not uninhabitable, in case of after-shocks (Figure 3).

e. *Slightly-damaged structures*: buildings with damaged glazing and/ or superficial cracks that were repairable.

The rubble of the first category took top priority and, accordingly, was the first to be cleared away. The second category was pulled down next, and those belonging to the third category were evacuated and earmarked for demolition. The fourth category consisted of buildings whose structure was unharmed but required major repair works. The fifth category did not need more than a few minor repairs, which were not urgent.

Figure 3: A moderately damaged building next to totally collapsed ones after the earthquake in the Marmara region **[ii]**.

RESEARCH METHODOLOGY

Data regarding the Adana and Maramara earthquakes was collected from the Devlet Istatistik Enstitüsü (DIE - State Institute of Statistics), from the Chamber of Civil Engineers in Adana, from the province of Sakarya's official website, and from the Afet İşleri Genel Müdürlügü (AİGM - Directorate-General of Disaster Affairs). In this connection, sites of various earthquake disasters in the southern and northwestern regions of Turkey were also visited to gather information with regard to demolition processes and the use or disposal of demolition waste. It was anticipated that particulars of recovery, re-use, and recycling practices pertaining to building materials and components might also be obtained. A trip to Adana was undertaken in February 1999, and the quake-stricken areas in the Marmara region were visited during the months of September and October 1999.

The visit to Adana was scheduled after the area had been cleared of all the debris. It was therefore not possible to make any observations related to the process of demolition, site clearance and dumping of rubble, or recovery of building materials. However, demolition and site clearing operations were underway when the devastated settlements of the Marmara region, i.e. Adapazari, Gölcuk and Degirmendere were inspected. It was thus possible to record the efforts of individuals while they were salvaging their belongings from the debris, as well as the process of recovering building materials and fittings from buildings that had been declared severely damaged or uninhabitable, and that were scheduled to be pulled down.

FINDINGS

The following information, with regard to the Adana quake, was gathered during a visit to the AIGM on 17.05.99:

a. A total of 9,048 houses and 441 workplaces were demolished or were in irreparable condition. 19,949 houses and 1,334 workplaces were extensively damaged and 48,764 houses and 3,017 workplaces were slightly damaged.
b. Approximately 4,000 severely damaged buildings were assessed to be a source of danger as they stood, and were demolished by local authorities while the rest were left to be demolished by the owners, the cost being too high to be borne by the Municipality alone.
c. As the residents/owners themselves salvaged material that had any re-use value, no records were available in this regard.
d. Debris from the sites of disaster was cleared away by the Municipality, the State Water Works department, the Department of Agriculture, and the residents, working in conjunction.
e. The rubble was disposed of in landfills and other areas that needed leveling.

Data regarding the Marmara region was obtained from the province of Sakarya's website. A total of 24,662 houses and 5,090 workplaces were completely or partially demolished; 18,911 houses and 3,665 workplaces were moderately damaged, and 27,692 houses and 2,828 workplaces were slightly damaged. Pertinent figures for the different types of damage to buildings in Marmara and Adana are presented in Table 1 below. Although the total number of buildings that suffered damage in both the regions is approximately the same, a closer look at the distribution of the data shows that the number of collapsed or severely damaged buildings in Marmara were three times as many as those in Adana. This is an indication of the greater magnitude of the earthquake in Marmara.

Table 1. Damage caused by the two earthquakes in Turkey.

Degree of damage	**Adana (1998)**	**Marmara (1999)**
Collapsed/severely damaged Buildings	9,489	29,752
Moderately damaged	21,283	22,576
Slightly damaged	51,781	30,520
Total	82,553	82,848
Source of data	AGIM	www.sakarya.gov.tr

Deconstruction and/or Demolition of Earthquake Damaged Buildings
Demolition, site-clearance, and salvaging activities were observed in Gölcük, Adapazari, and Degirmendere five weeks after a devastating earthquake had hit this region. These towns were revisited a fortnight later, and on-going recovery and recycling operations were visually documented. It was observed that, where possible, damaged buildings were being deconstructed before demolition work started.

Second-hand dealers were also seen collecting demolition waste materials along with abandoned household equipment, probably with the intention of selling them for re-use elsewhere. Recovery and recycling activities in disaster areas were evident in the form of accumulated building material from demolition debris and damaged buildings, heaped at various locations in the quake-stricken towns.

Modes of Recovery
Manpower was employed to retrieve personal belongings, household effects, and building components from the damaged buildings and debris. Machines employed for building demolition and site clearance can be enumerated as follows: excavators, cranes, bulldozers, loaders, power shovels, pneumatic drills, and dump trucks.

Debris of wholly-collapsed buildings was scooped up by loaders and deposited into large trucks, to be towed away to dumping sites designated by the local authorities. Since the building had, in essence, turned into a huge mound of rubble, it was not possible to retrieve any thing intact from it, except roofing tiles.

Partially-collapsed buildings were pulled down with the help of excavators, cranes, and bulldozers, while the rubble was carried away by dump trucks. However, prior to demolition activities, selective recovery of building materials was observed. Likewise, selective recovery of building materials and personal belongings was also witnessed in buildings that had been earmarked for demolition at a later date. Section 3.1.2 enumerates the different types of material recovered from damaged buildings, while Figures 4 to 6 show a semi-collapsed building in Adapazari, where selective demolition was in progress.

Figure 4: Semi-collapsed buildings in Adapazari, which were to be demolished soon [ii].

Figure 5: Recovery of building material from the severely damaged building in Figure 4; the structures beyond have been already been deconstructed and demolished **[i]**.

Figure 6: Deconstructing earthquake-damaged buildings: Selective demolition in progress on the building shown in Figures 4 & 5 **[i].**

Most of the demolition work was being done by excavators, which worked their way in from the front to the rear of the structure. This approach not only caused immense pollution but also was also dangerous. Moreover, the debris created by such haphazard demolition made recovery of materials even more difficult. Figure 7 shows demolition work in progress on a severely damaged building.

Figure 7: A semi-collapsed structure being pulled down in Adapazari **[iii]**.

Some buildings were demolished by pulling out their columns one-by-one, starting from the ground floor and moving upwards (Figure 8). The movement of the excavators was limited by the high-tension cables passing overhead; at one point during the demolition work, the arm of one excavator got entangled in the power lines and was in danger of bringing them down too. Had a top-down technique been adopted to demolish the structure, much of the building material could have been recovered for re-use elsewhere.

Figure 8: Columns of a building being pulled out in Gölcük **[iv]**.

Damaged sections of buildings were being removed without taking into consideration the support of the upright portions. Figure 9 shows two such buildings in Adapazari with partially-collapsed sections; notably, there were two upstanding structures on the top floor of the building to the left. When the site was visited two weeks later, it was observed that, because the collapsed sections at the front had been removed in the accustomed manner, the rear had collapsed too, bringing down with it the structure on the roof (Figure 10).

Figure 9: Partially-collapsed buildings with penthouse on the structure to the left **[v]**.

Figure 10: Removal of collapsed sections of the building shown in Figure 9 led to the collapse of an upstanding one at the rear, bringing down the penthouse with it **[i]**.

Salvage operations were carried out even in semi-demolished buildings tilted at precarious angles. Figure 11 shows recovery of building materials from one such building in Adapazari, while Figures 12 and 13 show recovery efforts in a similarly damaged building in Gölcük. The soft story of this building had buckled under, and the whole structure had tilted to one side. Construction workers were employed for selective dismantling of buildings that were severely damaged, with the aim of salvaging as much of the building materials and components as possible, before the municipality excavators and bulldozers moved in to demolish them. Figure 14 belongs to another earthquake-damaged building in Gölcük; selective recovery of fittings and fixtures was also witnessed here**.**

Figure 11: Dismantling the roof of the building in Figures 9 & 10 above **[i]**.

Figure 12: Building material being recovered from a dangerously damaged building: roof tiles stacked in the foreground (Gölcük) **[i].**

Figure 13: Rear view of the building in Figure 12 shows men working in this dangerously tilted structure to dismantle building components and fixtures; salvaged fenestration units are seen collected in the foreground **[i].**

Figure 14: Deconstructing a severely damaged, newly constructed building in Golcuk: Bath tub being lowered from the 5th floor of the building whose ground floor had buckled under **[i].**

Materials Recovered
Materials and equipment being recovered from the debris, and buildings destined for demolition, can be classified into the following two groups: personal belongings and building materials.

i. Personal belongings: Goods belonging to this group can be listed as furniture, carpets, curtains, appliances, clothing, memorabilia from homes, and merchandise from shops. It should be noted, however, that this group of recovered materials was considered outside the scope of the investigation.

ii. Building materials: Materials that can be cited in this group are all types of steel and aluminum components, fenestration, steel reinforcement, hardware, fittings, bathroom and kitchen fixtures, roof tiles, cabinets, grill-work, roofing timber, planks, and doors. Notably, building material and components salvaged through selective demolition in disaster-stricken areas was similar to that recovered from pre-planned demolition of buildings in cities [1]. Characteristically, recovery efforts were concentrated towards salvaging those building materials, which, as in the case of intentional-demolition projects, had a resale value in the market for second-hand goods. Likewise, material that was ordinarily dumped into landfills was also destined to end up in dumps after the steel reinforcement had been recovered from it.

Disposal of Rubble:
Although it had not been possible to witness the demolition, recovery, and site clearance activities subsequent to the earthquake of June 1998 in southern Turkey, the following information regarding disposal of debris was gathered from representatives of the Chamber of Civil Engineers and from city officials in Adana:

a. Squatter settlements on the outskirts of the city had suffered widespread damage. Hence, being illegally built, all such housing was demolished to clear up the area. Rubble from demolished structures in these settlements was spread out to level off the land, which was to be covered later with a layer of earth, in order to convert it into a green area.

b. Rubble from demolition of collapsed and severely damaged structures in other areas was dumped alongside and into the Ceyhan and Seyhan rivers. This narrowed the riverbed; hence, some of it was retrieved later and used as hardcore for road building along the riverside. Figure 15 shows rubble dumped along the banks of the Seyhan River in Adana; note the road-roller leveling off a layer of retrieved rubble as hard-core for the under-construction road.

According to the province of Sakarya's official website [2], after the earthquake in the Marmara region, 1,200 trucks took 40 days to remove 2,500,000 tons of debris. A news item from the Turkish daily "Aksam," as quoted on the Arkitera website [3], reports that a local recycling firm is reclaiming dumped rubble from the Kum Ocaklari Lake near Adapazari. During the past one year, after separating metal and plastics from the debris, 500,000 tons of rubble has been processed into hard core for road-building. Moreover, reinforcement steel that was recovered from this demolition waste is being sold at the rate of $100 per ton. It is estimated that this work will continue for at least another year.

Figure 15: Rubble from the demolished earthquake-damaged structures was initially dumped along the banks of Seyhan River in Adana **[i]**.

CONCLUSION

Building components that already have a resale potential in the market were being recovered, even from perilously tilted buildings in the afflicted areas. In fact, while demolition and site-clearance work was in full-force, recovery efforts of individuals and professional teams to salvage personal belongings or construction material from damaged or demolished buildings occurred concurrently.

The priority was to remove the dangerously damaged structures as fast as possible; hence, demolition work proceeded at a great speed, seemingly regardless of the safety of the demolition squad or passers-by. At times, debris from partially collapsed structures was removed prior to the demolition of the upstanding portions. This posed a danger to the surroundings, since the rubble might have been supporting some un-collapsed section(s) of the building. Contrary to the prevalent practice of demolishing a structure from its sides inwards with excavators, as observed in Adapazari and Gölcük, it would have been safer to adopt a top-down demolition technique.

Furthermore, debris from thousands of demolished structures was disposed of without much forethought. Most of the rubble was dumped into a river in Adana, and into a lake in the Marmara region. Consequently, additional resources had to be wasted in order to retrieve this rubble and put it to a more environmentally friendly use.

REFERENCES

1. **Elias-Ozkan, S.T.** An overview of demolition, recovery, reuse and recycling practices in Turkey. *Proceedings of the CIB TG39 - Deconstruction Meeting, Karlsruhe, Germany, April 9, 2002*: CIB Publication 272 - Design for Deconstruction and Materials Reuse, **pp. 128-138. (**http://www.cce.ufl.edu/affiliations/cib/4-2002.html)

2. **Province of Sakarya's Official Web-Site**. www.sakarya.gov.tr

3. http://www.arkitera.com.tr

Photo Credits:

i Author

ii Dept of City and Regional Planning (CD). *17 Agustos 19991 Korfez Depremi* (17^{th} August 1991 Marmara Earthquake), Middle East Technical University, Ankara, Turkey, 1999.

iii www.basbakanlik.gov.tr/deprem/deprem.htm

iv Mert Yilmaz

v Aydan Balamir

VALUING THE PRE-DEMOLITION AUDIT PROCESS

Author: James W. Hurley (Building Research Establishment, UK)

ABSTRACT

The aim of pre-demolition audits is to provide valuable information that can be used by client, architect, engineer, construction contractor and manufacturing industry to optimise the existing buildings as part of the decommissioning, deconstruction and demolition process. The deconstruction case study audits performed by the Building Research Establishment (BRE) for a Government-funded project are the first of their kind in the United Kingdom (UK) for a range of building types. This paper presents a summary of these results and proposals to increase the reuse of construction materials following demolition.

The seven pre-demolition audit case studies bring together research and information from a large number of sources as well as site survey information. Each case study also benefits from the incremental development of the auditing and valuation process that made significant changes during the two-year project. The case studies have assisted project teams to reduce the cost of disposal of the old buildings, realise financial benefits from reclaimed materials and quantify the environmental benefits of reusing and recycling.

The final report delivered to UK Government in 2002 included pre-demolition audits, reclamation valuation surveys and environmental quantifications for a select range of materials and products expected to be generated from the demolition of the existing buildings and structures. Together these indicate key demolition products, their potential for reuse, the potential range of economic value (revenue) from resale, and the environmental rewards in terms of Ecopoints and Hectares of selectively logged Amazonian rainforest over one year. Together this information provides an indication of what environmental rewards can be realised by the UK construction industry through informed waste management practices.

KEYWORDS: Deconstruction; Pre-demolition Audit; Reclamation Valuation; Environmental Quantification

INTRODUCTION

This paper reports on the technical, economic and policy issues that must be addressed to make reclamation and recovery of building components and materials a viable alternative to landfilling. The key recommendation to Government is for future projects to include a pre-demolition audit, a reclamation valuation survey and an environmental quantification of the building structure and contents prior to tender. This would complement the Demolition Code of Practice BS6187-2000, the Construction (Design and Management) Regulations 1994 (CDM) and the Health and Safety Executive (HSE) Health and Safety in Demolition Work. It would also maximise the potential of the former structures, encourage high-grade recycling or reuse and reduce dependence on landfills. Naturally this approach will require drivers in the form of regulation and the co-operation of clients and developers.

This paper includes results of pre-demolition audits, reclamation valuation surveys and environmental quantification of a select range of materials and products expected to generate from the demolition of existing buildings. Together these indicate the key demolition products, their potential for reuse, their economic potential (revenue) and environmental rewards in terms of Ecopoints and Hectares of selectively logged Amazonian rainforest. The information can help the project teams reduce the cost of disposal of the old buildings, realise financial benefits from reclaimed materials and quantify the environmental benefits of reusing and recycling. The audit process has progressed over two years to the level of detail as provided for the Whipps Cross University Hospital (WCUH) site in London. One thing is clear - the level of detail in the audits required for one project will be dissimilar to that of another project due to the nature and style of the structures.

In most cases of demolition, the best chance for reuse will be in the new development, which would be pioneering in itself. This will require imagination and the co-operation of a strategic partnership in order that the essence of the former buildings is captured into the new. Ideally this would optimise the potential outlined in this paper, but in real terms some materials will have to be recycled (hopefully up-cycled) off-site or sent to landfill.

PRE-DEMOLITION AUDIT RESULTS

Prior to demolition, it is useful to categorize a site not only in terms of the location of hazardous materials and chemicals (see BS6187-2000) but also the type and condition of the structure and internal fixture and fittings. SMARTWasteTM (Site Methodology to Audit, Reduce and Target Waste) has been developed by BRE to provide a robust and accurate mechanism by which wastes arising can be benchmarked and categorised by source, type, amount, cause and cost. This tool has been adapted to perform pre-demolition audits and provide case studies for this project. A pre-demolition audit provides a list of key demolition products (KDP) that can be assessed using a reclamation valuation survey and translated into embodied energy and hectares of rainforest as an indicator of environmental quantification.

SMARTWaste audits have been completed for construction, demolition, refurbishment, manufacturing and pre-fabrication. The data is a springboard to identifying and prioritising actions to reduce waste (producer responsibility), reuse at source (proximity principle), and maximise recovery to extend materials' life-cycle. The benefits of the software tool are to identify the potential true cost savings of projects and maximise the reduction, reuse, recycling and recovery options of materials. Further examination of the software provides a range of features such as instant reporting tailored to clients needs, sharing of information, establishing environmental performance indicators, and development of integrated material waste management strategies.

Undertaking pre-demolition audits is an interesting task but challenging where little or no information is available. Some demolition projects may have a wealth of blueprints and sectional drawings that can be of great help to interpret the construction techniques used in the structure and where and what materials have been used. In these circumstances much of the interpretation and audit can be completed as a desktop study and complemented by visits to confirm the blueprints. However for most projects this information is not available and must be gathered through a combination of audits and site visits. In all cases it is necessary to visit the site to investigate the quality, condition and fixture of the products and components and to witness their financial value and availability for deconstruction and reuse. Time spent on site is dictated by the nature and size of the buildings and the availability of information.

The results included in this paper build on the results presented at the TG39 meeting in Germany in 2002. For some of the case studies it was sufficient to concentrate on the overall volume of mass materials and ignore the furnishings and fixtures, in others a detailed account of decorative and furnishings was included. It was felt that this was a necessary process to go through in order to discover which was the most appropriate method or protocol to use for auditing. In retrospect, it identified the variable nature, condition and quality of the buildings and key demolition products that each needed specific audit requirements. The result was the ability to concentrate on products of value and suitable quality for deconstruction and reuse and not on the complete structure. In this way the audits serve to provide reasonable information that can be commercially accessed. In the six case studies doors, floors, windows and cladding were included. Asbestos materials were excluded from all the audits, as were chemicals, underground services, electrical appliances, and hospital equipment.

Multi-Storey Housing
This was a 22-storey building in Liverpool that was demolished following the strip-out phase using a controlled explosion technique. A pre-demolition audit was undertaken to show the volumes of waste materials and products within and embodied into the buildings.

Housing
This was a 3-storey block of housing in Manchester that was demolished using traditional demolition techniques of soft-strip followed by mechanical pulverisation. A pre-demolition audit was undertaken to show the volumes of waste materials and products within and embodied into the buildings.

Factory
The Sanderson factory complex near the centre of Uxbridge, West London. This factory was used for manufacturing textiles, and was split into two parts covering an area of 18,324m^2. Approximately two-thirds of this building was the factory itself (12,636m^2), with the remaining third being a warehouse (5,688m^2) used for storing products produced in the factory. The warehouse also contained a number of offices.

Multi-Storey Offices
This is a collection of six 5-storey buildings in London that are currently being refurbished over a 5-year programme. A pre-refurbishment audit was undertaken to show the volumes of waste materials and products within and embodied into the buildings. This was a very detailed audit including all furniture, fixtures and fittings. Some graphs generated for this project are included later in this paper.

Factory
This case study was undertaken on behalf of Norfolk County Council, Norwich City Council and Bovis Lend Lease. The aim of the study was to investigate the possibilities of Deconstruction

and reuse of construction materials from demolition of the former Nestle chocolate factory in Norwich - otherwise known as Chapelfield.

Hospital

The aim of this case study was to provide information that could be used by the Whipps Cross University Hospital (WCUH) project team to optimise the existing buildings as part of the hospital redevelopment. This is a 10-year, phased programme that started in 2001. Some of the recommendations in this paper are based on the pre-demolition audit of the WCUH site carried out by BRE, the first of its kind for a hospital in Europe.

Figure 1-4 show the overall results of one case study in terms of quantities and optimal reuse-recycling potential for all material groups and a detailed example for metal materials (these graphs were included in the previous TG39 paper).

Figure 1: Overall quantity of materials from the multi-storey offices

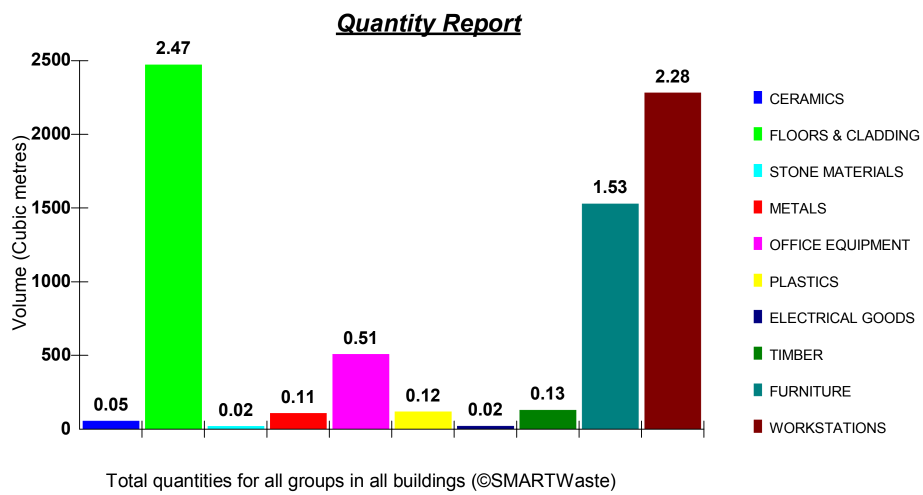


Figure 2: Reuse / Recycling of materials from the multi-storey offices

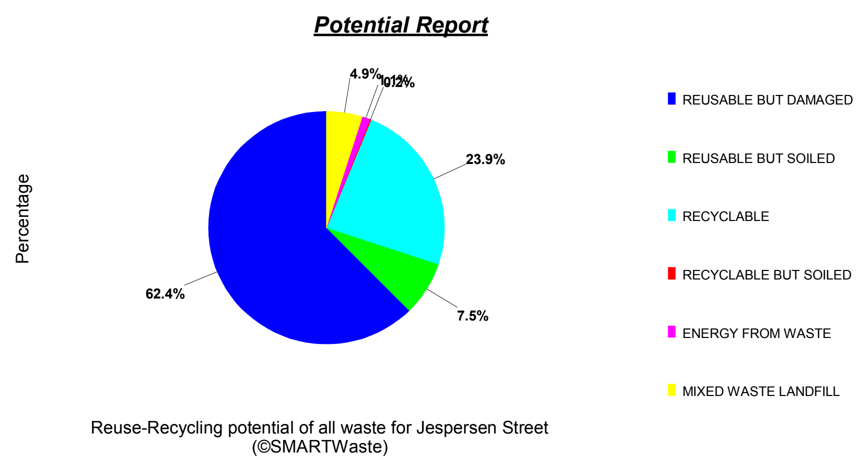


Figure 3: Overall quantity of metal materials from the multi-storey offices

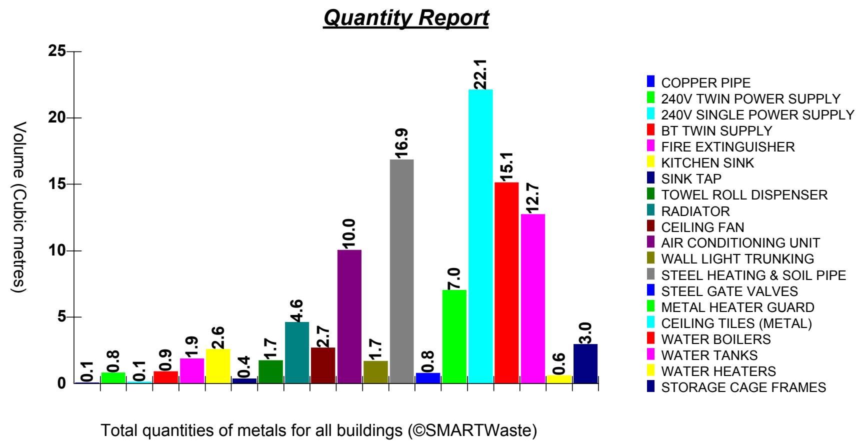
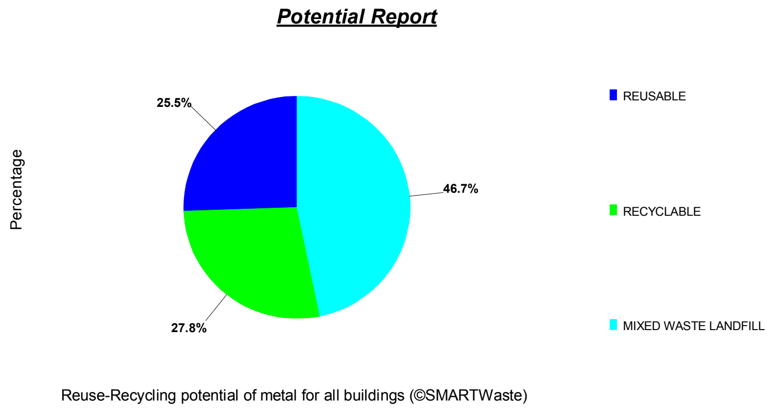


Figure 4: Overall potential for metal materials from the multi-storey offices



In addition, tables were prepared for the audits and proportionate examples of two types of table are included in Figures 5-6 below.

Figure 5: Example of the detailed audit of materials from the multi-storey offices

BUILDING FABRIC	Dimensions (cm)			Waste Potential	B13	B8	B36	Haddon	Howland	Maple	Total
	length	width	depth								
Air conditioning unit	90	90	20	Mixed landfill	0	4	51	2	5	5	62
Aluminium partitions (m)	100	269	7	Recyclable	24	34	211	162	71	0	502
Aluminium window frame	268	125	13	Recyclable	159	168	133	277	252	0	989
Ashfelt roof (m^2)	100	100	1	Mixed landfill	283	250	0	461	747	0	1741
Battery emergency light	38	14	9	Mixed landfill	7	8	12	7	9	3	46
Brick & concrete cladding	126	84	25	Inert landfill	159	168	133	277	252	0	989
BT twin supply	15	9	5	Mixed landfill	204	164	400	251	214	109	1342
Carpet (m^2)	100	100	2	Mixed landfill	260	0	890	0	0	0	1150
Carpet tiles	50	50	1	Mixed landfill	6240	8960	24920	12628	11880	3976	68604
Ceiling fan	80	80	10	Mixed landfill	8	12	18	0	4	2	42
Ceiling tiles (fibrous)	60	60	2	Mixed landfill	9066	22555	15356	8771	2376	0	57924
Ceiling tiles (metal)	60	60	2	Reusable	0	0	3072	0	0	0	3072
Ceramic tiles (m^2)	100	100	1	Inert landfill	132	176	408	469	168	72	1403
Circular light (large)	46	46	10	Mixed landfill	16	35	4	14	8	3	78
Circular light (small)	30	30	10	Mixed landfill	29	65	17	5	35	0	147
Copper pipes (m)	100	1	1	Recyclable	92	84	148	100	88	32	528
Double electric socket 240V	15	9	5	Mixed landfill	212	213	376	259	129	0	1189
Fire door & frame	218	108	10	Energy from waste	21	19	34	8	2	16	96
Fire extinguisher	50	14	14	Reusable	32	20	40	35	40	26	191
Fire hose	57	57	28	Mixed landfill	0	0	1	0	12	0	13
Kitchen cupboard	100	70	40	Energy from waste	18	26	12	23	23	2	96
Kitchen sink	105	53	33	Mixed landfill	4	0	2	6	2	2	14
Lift hardwood door frame	198	22	3	Recyclable	37	40	40	35	20	0	170
Metal heater guard (m)	100	20	1	Recyclable	483	576	938	763	625	127	3512

Figure 6: Example of Key Demolition Product Targets for the multi-storey offices

	Dimensions (cm)			Waste Potential	Total	Target	Achieved
INTERNAL FURNISHINGS	length	width	depth			%	%
Ceiling to floor cabinet	240	103	54	Energy from waste	64		
Circular table	120	120	73	Reusable	149		
Coffee table	120	60	43	Reusable	12		
Corner desk workstation	200	80	73	Reusable	815		
Desk partition (desktop)	180	49	3	Reusable	275		
Desk partition (large)	120	120	5	Reusable	479		
Desk partition (medium)	120	80	5	Reusable	21		
Desk partition (small)	120	40	5	Reusable	314		
Desk partition (X-Large)	160	120	5	Reusable	69		
Desk shelf	180	32	2	Reusable	598		
Dexion-style shelf units	220	100	32	Recyclable	216		
Dishwasher	120	80	70	Reusable but soiled	3		
Double comfy chair	200	80	70	Reusable but soiled	33		
Double filing cabinet (mid)	120	105	47	Reusable	282		
Double filing cabinet (small)	80	70	47	Reusable	173		
Double filing cabinet (tall)	196	105	47	Reusable	170		
Electric fan	50	35	26	Reusable	361		
Fancy oblong table	180	80	73	Reusable	66		
Fridge	120	80	70	Reusable but soiled	21		
Hat stand	190	5	5	Reusable	57		
Industrial cooker	100	90	90	Reusable but soiled	3		
LCD projector	40	25	12	Reusable	3		
Metal frame plywood table	114	86	74	Recyclable	918		

The results for each of the six buildings audited are aggregated in the Figures 7-8 below to show the overall variation between the types of wastes being generated and the reuse / recycling potential for the key demolition products. Naturally the variation in materials will be determined by the construction type but the reuse/recycling potential will be as much about how the materials were bound together as well as the quality and condition of the materials. These are most important indices to record during the audits in order that appropriate decisions can be made. Figure 7 shows that the most common materials were hard, inert fractions such as concrete, stone and ceramics. Timber was also significant in some buildings and, when considered, the furniture, furnishings and fixtures could also be of significant size.

Figure 7: Variable percentage quantity of materials from the six case studies

	Multi-storey housing	Prefab Housing	Factory	Multi-storey offices	Factory	Hospital
Ceramic	2.3		9.3	1	16	67
Metal	3.1	0.4	2.8	1.5	2	1
Furniture	2.3			59.9	1	
Plastic	0.6	1.1		1.7		1
Concrete	86.8	85.2	86.5	34.1	78	12
Timber	3.5	7.7	1.4	1.8	2	19
Miscellaneous	1.4	5.6			1	
Total	100	100	100	100	100	100

Figure 8 shows that there is commonly substantial opportunity to reuse as well as recycle. Despite this fact the great majority of materials will be down-cycled and neither up-cycled nor reused. Although recycling is much more preferable than combustion or landfill, we should continue to find greater opportunities to reclaim and reuse key demolition products where possible and account for this both economically and environmentally.

Figure 8: Variable percentage potential for reuse / recycling for the six case studies

	Multi-storey housing	Prefab housing	Factory	Multi-storey offices	Factory	Hospital
Reusable	2.9	69.9	6	41.8	12	74
Recyclable	89.9	23.9	89	27.3	86	24
Combustion	5.3	1.3		3.4	2	1
Inert landfill				17.1		
Non-hazardous landfill	1.2	4.9	5	10.4		1
Hazardous landfill	0.7					
Total	100	100	100	100	100	100

VALUE THE AUDITING PROCESS

Reclamation Valuation & Environmental Quantification

In order to appreciate the 'potential' to reuse and recycle there is an urgent need to include a value of the various costs for demolition, deconstruction and soft strip. This should include costs for both plant and staff time. This will not be an easy task and will require weightings for geographical and technological variations. There is also an environmental cost to consider that is even more difficult to ascertain. The reclamation valuation surveys herein were undertaken by Salvo (who represent the reclamation industry) and attempt to provide indicative revenue for materials and components that could be reclaimed for reuse. Similarly, the environmental quantification provided by BRE provides an indication of the environmental rewards to be realised from reusing and recycling. Reclamation valuations and environmental quantifications were undertaken for two of the case studies; Whipps Cross University hospital and Nestle factory. A number of assumptions were made for the studies. The common assumptions were:

- All reclaimed items have been removed from the building without damage, and not been damaged during any transport or processing to enable reclamation.
- The installation of reclaimed items has involved the same environmental impact and wastage of materials as the installation of new items.
- The service life of reclaimed items is the same as new items.
- Most reclaimed items have been removed from site, taken to a separate site to be processed and stored, and then transported to a new development.
- All transport has been based on UK Government Transport Statistics providing typical loads and distances for different materials.

The aim of the environmental quantification is to quantify the environmental rewards for reusing or recycling construction materials, as opposed to allowing post-demolition materials to enter the waste stream and using newly manufactured construction materials. The assessment was undertaken using the BRE Environmental Profiles Methodology, which uses a level playing field approach to assess environmental impacts over the whole life cycle. The assessments therefore take account of any environmental impacts associated with transport, manufacturing and processing, maintenance and replacement, and disposal at the end of life. These are based on typical UK scenarios. The BRE Environmental Profiles Methodology measures 12 Environmental impacts:

Climate Change	Acid Deposition	Ozone Depletion
Human Toxicity to Air	Low Level Ozone Creation	Fossil Fuel Depletion
Human Toxicity to Water	Ecotoxicity to Water	Eutrophication
Minerals Extraction	Water Extraction	Waste Disposal

For this study an overall measure of the environmental impact known as Ecopoints was used. 100 Ecopoints is equivalent to the overall environmental impact of one UK citizen over 1 year. The study also provided a measure of Embodied CO_2 in terms of the hectares of Amazonian rainforest that would be needed to sequester the same amount of CO_2 from the atmosphere. This study has taken the amount of carbon sequestration provided in the Intergovernmental Panel on Climate Change (IPCC) report for selectively logged rainforest in Amazonia of approximately 2.5 tonnes of Carbon per hectare per year. Interestingly, a hectare of sustainably managed English oak would also absorb 2.5 tonnes of carbon per hectare per year.

Figure 9: Overall reclamation valuation and environmental quantification for WCUH

	Reclamation Valuation				Environmental Quantification		
ALL PRODUCTS (m^3)	STTOD - sold to the trade, own dismantling	STTG - sold to the trade at the gate	SOS - sold on SalvoWeb	RVO - reuse value on-site	Ecopoints	Hectares pristine Amazonian rainforest per year	Hectares heavily logged, sustainably managed rainforest per year
24,515 m^3	£456,995	£2,107,442	£6,952,402	£4,227,529	119,121	2,516	1,060

As an example of what can be achieved, Figure 9 provides a summary for WCUH. These show the economic potential for 24,515 m3 of key demolition products that could realise an income of between £456,995 - £6,952,402 depending on the form of deconstruction used. Avoiding landfill disposal by reusing or recycling the KDP could save a further landfill tax charge of £34,000 which could easily triple by the end of the project. This would also reduce the estimated 3,064 lorry journeys required for the disposal of the demolition waste and minimise the number of lorries required to deliver new materials to site. These benefits may be used to complement any planning applications that are required. Similarly, reuse and recycling can help realise environmental rewards that are similar to the environmental impact of 1,191 people over 1 year or the amount of carbon sequestered by 1,060-2,516 hectares of rainforest. Figure 10 provides individual examples of the 39 KDP audited at WCUH.

Figure 10: Reclamation valuation and environmental quantification for select KDP

PRODUCT	Reclamation Valuation				Environmental Quantification		
	STTOD - sold to the trade, own dismantling	STTG - sold to the trade at the gate	SOS - sold on SalvoWeb	RVO - reuse value on-site	Ecopoints	Hectares pristine Amazonian rainforest per year	Hectares heavily logged, sustainably managed rainforest per year
Leaded cupola (intact)	-£32,000	£0	£24,000	£80,000	0	0	0
Dressed red rubbers (brick)	£2,800	£7,000	£18,200	£5,600	263.2	6.44	2.716
Handmade reds (brick)	£452,696	£1,810,783	£5,885,045	£2,716,175	85106.801	2082.40045	878.229755

In order to appreciate the detailed value in Figures 9-10 above, a brief description for one of the KDP is explained. Handmade red bricks are quite commonly used in the pre-1920's buildings at WCUH. The value of one handmade red brick dismantled by the demolition team to sell off-site will be only 5p, whereas to dismantle it and sell it to the trade on-site will be 20p. Sold via the Salvo website it is estimated that each of this type of brick could fetch 65p; to replace a new brick being used for the new hospital is 30p. It is estimated that approximately 9-million handmade red bricks are available for reuse with an economic potential between £0.5-million and £5.9-million. These are significant figures to consider.

The approximate environmental quantification -or reward- for adopting reuse of the handmade red bricks on- or off-site is significant. Each of the handmade red bricks is equal to 0.0094 Ecopoints – the impact of one UK citizen over 50 minutes. Similarly, one brick is equivalent to the Carbon sequestered by 0.00023 hectares of pristine Amazonian rainforest or 0.000097 hectares of heavily logged, sustainably managed rainforest over one year. The potential environmental rewards for reclaiming and reusing the handmade red bricks from WCUH is equivalent to the environmental impact of 851 people over 1 year or between 878 - 2,082 hectares of pristine / sustainable logged rainforest per year.

Process Mapping

However, to realise the potential to reuse and recycle there is an urgent need to value the various costs for demolition, deconstruction and soft strip for both plant and staff time. This is not a simple task and will require weightings for geographical and technological variations. There is also an environmental cost to consider which is even more difficult to ascertain. Recently, BRE has been undertaking process maps of the demolition process for both the Department of Trade and Industry (DTI) and the Waste and Resources Action Programme (WRAP) projects using the baseline principles of the Calibre tool. The following provides a brief insight into the process mapping of the soft strip process at the former Nestle factory in Norwich.

Many items were removed, including partitioning panels, cupboard doors, single doors double doors, wardrobes, shelves, doorframes, architectural timbers, handrails, unique wardrobes and skirting boards. Steel shelves were also removed and used for storage of the items removed from the building. All nails were removed from items. Doors were also removed in one of two ways, firstly with all the fixings attached, secondly with all the fixings removed. At all times the disturbance of asbestos panels was avoided.

Process mapping provide a better understanding of the barriers and opportunities to deconstruct and helps to clarify the roles and responsibilities of participants, having real-time feedback of activities involving all levels of staff. It also helps to identify and eliminate disruptive patterns and process bottlenecks, thereby improving site organisation and developing more expedient design solutions. The process mapping helps the process become more efficient, more competitive, and more predictable in the delivery of the product and improves performance. The following table shows select results of the process mapping and average times.

Type	Dimensions (m)	Volume (m3)	Average Time (min)	Staff	Equipment
Partitioning Panel	2.9 x 1.2 x 0.05	0.17	12	2	Screw driver, steel bar
Other Panels	2.9 x 1.2 x 0.05	0.17	3	2	Screw driver, steel bar
De-nailing	1.5 x 0.060 x 0.010	0.0009	0.5	1	Pillar
Cupboards doors	0.685 x 0.520 x 0.025	0.54	4.5	1	Screw driver
Single door With fixings	1.9x0.640x0.045	5	5	1	Screw driver

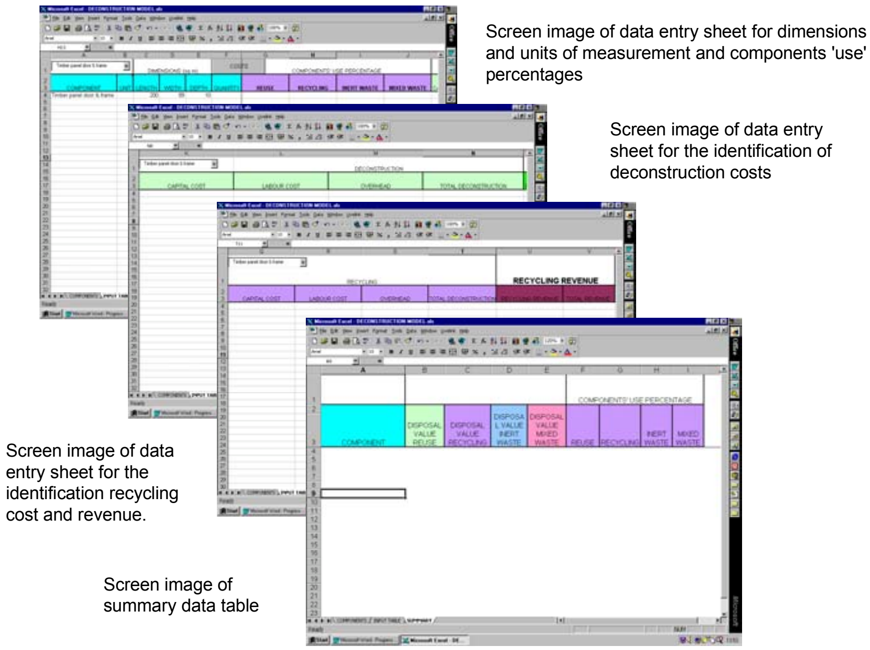
Yet what is the additional cost of adjusting the process? How is it we can choose one process over another and what value should we place on that change? BRE has recently developed a procedure and cost model to make an economic assessment of the cost and benefits of deconstruction and reuse of building materials. Discussions with industry highlighted that, whilst the principle of the model and that the procedure are sound, significantly more development and research is required to create a model that would add value to the industry.

The foundations of the cost model are based on basic principles of economic theory. Economics is a study about how scarce resources are allocated in a world where there are constant demands. Factors of production are usually classified into four different groups of entities; Land, Labour, Capital and Enterprise. The deconstruction cost model adopted an approach based on the economics of allocation of scarce resources, and created a methodology that can measure the quantities of scarce resources that have to be employed to deconstruct and then reuse construction components and materials in a way that can maximise the economic value added.

The model uses costs and prices as a method to rank the various ways to deconstruct and opportunities for re-sale of the building components. Prices are used to perform the allocation system, as they provide the information and incentives needed to make rationale economic decisions in order to arrive at the optimum outcome. A prerequisite of a tool is that it is capable of ranking decisions based on a defined measure. The cost model fitted this description as it attempts to rank alternative approaches to deconstructing a component- the defined unit of measure is cost. A more complex model could include benchmark prices that each factor of production can command, typical costs for deconstruction, including for example, typical labour rates, and cost of hiring capital. A more complex model would add value if it also considered how influences such as building design, construction methods, location, infrastructure would affect the cost and income earned by deconstruction and reuse. A predictive cost model for deconstruction and reuse of materials can be developed but it needs to be practicable and usable.

The model creates a systematic approach for identifying and summing the costs of deconstruction products, and add value to the Whole Life Cost (WLC) arena by creating a better understanding of the costs and revenues incurred when a KDP has reached the end of its (current) economic life. Maximising the disposal value of a component may have significant cost savings for the construction industry clients. Including the disposal value in WLC calculations of an asset help ensure that procurement of construction products are chosen which offer best value.

Figure 11: Screen Dumps of the Deconstruction Cost Model (included in previous paper)



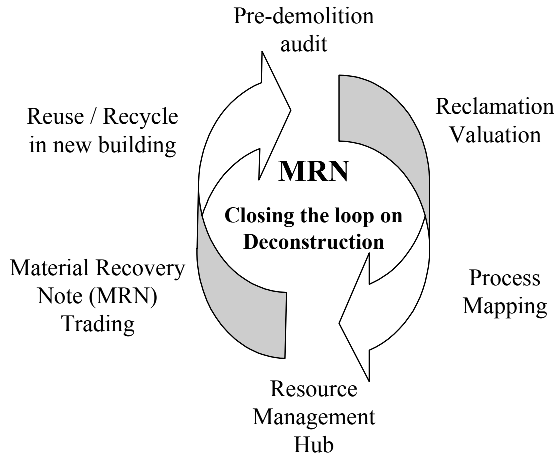
The cost model is one possible way to the economic benefits of reusing salvaged buildings rather than sending them to a landfill.

Funding Change – Material Recovery Notes

Material Recovery Notes (MRN) are an idea, a potential opportunity to extend the principles of packaging recovery notes (PRN's) to reclaimed materials. It is well known that the PRN system has helped to develop the recycling industry; the MRN system could provide similar assistance to the reclamation industry. However, this is merely an idea arising out of the industry's apparent willingness to develop the reclamation and reuse of construction materials if there is sufficient demand, supply, time and collaboration. The MRN system could provide this framework.

The MRN system would aim to close the loop on deconstruction and minimise the level of demolition to materials earmarked for recycling, composting, recovery of energy or landfill (including inert supplies which are a necessity). The MRN system would also help the WLC model to accommodate multiple life materials rather than one-life accounting. Despite best efforts, WLC models are lacking sound, reasonable data for their models, hence the urgent need to gather this information before we unnecessarily demolish our historic buildings and architectural products and resign them to landfill or at best down-cycling as crushed or chipped materials. The MRN system would be able to capitalise on pre-demolition audits, reclamation valuations, environmental quantification and process maps described in this paper. Figure 12 shows the basic principles of the closed loop approach.

Figure 12: The MRN - Closing the Loop on Deconstruction



To support the MRN system a key demolition product template should be developed, whereby the information gathered on a particular product could be advertised in advance of, or following, the deconstruction process. Vital information from the pre-demolition audit, reclamation valuation, environmental quantification, process mapping, WLCcomparator, risk analysis, method statement, specification, cost and comparable revenue could be made available to potential purchasers. Once a purchase was made the MRN trade would be completed along with the environmental rewards.

The MRN system and key demolition product template is not entirely a new concept as the reclamation industry has been trading architectural and antique products and materials for many years. Salvo has played a significant role in the development of this trading and quality control and it is anticipated that a national resource management hub will align itself, and capitalise on, existing and developing systems. However, it is necessary to consolidate all this information under one umbrella and draw upon the range of information, regulation and specification to assist trading and reuse of suitable products and materials. In this way it will be possible to provide a portal to engineers, architects, specifiers and clients in need of reassurance that they are making sound business decisions that the City and insurers will approve.

To conclude this paper, it is paramount to recognise that Client-led initiatives will be required to achieve a reasonable level of reclamation and reuse of materials. A Form of Tender should include the requirement of a pre-demolition audit, reclamation valuation and environmental quantification of the former structures. These should then stipulate which key demolition products the project team wish to ring-fence for reuse on site and stored on land set-aside or rented locally for temporary processing and storage. Ideally the land will be organised by the demolition contractors themselves as part of the tender. Invitations should make it clear that preference may be given to tenders with voluntary method statements that maximise the reclamation of building materials. The remaining materials not earmarked for reuse on site should then be advertised locally and nationally in order to capitalise on the best practicable environmental option. In this way it will be possible to maximise potential and reduce our dependence on landfill.

For the purposes of this paper, BRE has provided pre-demolition audits, reclamation valuation surveys and environmental quantifications of a select range of materials and products expected to generate from the demolition and deconstruction of a range of buildings. These tools constitute a valuable advance in determining how clients can appreciate the nature, make-up and value (economic and environmental) of their structure prior to demolition. In itself, this paper does not answer all the questions or provide a complete analysis of the potential to deconstruct and reuse construction materials both on- and off-site. What it does provide is an incentive to identify KDP and their potential/value for reuse, and what are the environmental rewards in terms of Ecopoints and sequestered CO_2 from hectares of Amazonian rainforest. Together, this information provides a sound foundation to build on and offer opportunity where it exists.

REFERENCES

Anderson, J. Deconstruction – Key Demolition Products, BRE Client Report, 2002

Bart te Dorsthorst, Integral Chain Management, Deconstruction closing the loop conference, BRE May 2000.

CIB TG39 Deconstruction. Conference Proceedings UK, 2000

CIB TG39 Deconstruction. Conference Proceedings New Zealand, 2001

CIB TG39 Deconstruction. Conference Proceedings Germany, 2002

Crowther, P. Developing Guidelines for Designing for Deconstruction. Deconstruction closing the loop conference, BRE May 2000.

Fletcher, S. L., Popovic, O. and Plank, R. Designing for future reuse and recycling. Deconstruction – closing the loop, BRE conference, May 2000.

Hobbs, G. and Kay, T. Reclamation and Recycling of Building materials: industry position report. IP7/00, BRE March 2000.

Hobbs, G., Collins, R. Demonstration of reuse and recycling of materials. BRE paper IP 3.97, February 1997.

Hurley, J.W. McGrath, C. Fletcher, S.L. & Bowes, H.M. Deconstruction and reuse of construction materials. BRE418 Report. April 2001.

Hurley, J.W. Selective deconstruction of timber products, BRE Client Report, 2002

Hurley, J.W. Maximising the effective use of construction timber waste, BRE Client Report, 2002

Hurley, J.W. Policy paper on deconstruction, BRE Client Report, 2002

Hurley, J.W. Pre-refurbishment audit of the Fitzrovia project, BRE Client Report, 2001

Hurley, J.W. Pre-demolition audit of the Nestle site, BRE Client Report, 2002

Hurley, J.W. Pre-demolition audit of the Whipps Cross Hospital, BRE Client Report, 2002

Ruch, M., Schultmann, F., Sindt, V., Otto, R. Selective Dismantling of Buildings. The state of the art and new developments in Europe. Second International Conference Buildings and the Environment, June, 1997, Paris.

Schultmann, F.; Rentz, O. Development of a Software Tool for the Optimal Dismantling and Recycling of Buildings. Proceedings of the Symposium Computers in the Practice of Building and Civil Engineering, Lahti, Finland, 3-5 September 1997, pp. 64-68.

Symonds. Construction and Demolition Waste Management Practices, and Their Economic Impacts, Report to DG X1, European Commission 1999.

Task Group 3 C&D Waste Management, Recommendations for the Management of Construction and Demolition Waste, Report to the Working Group on Sustainable Construction (Sept 2000).

BRE Information Papers and Digests, available from Construction Research Communications Ltd, 151 Rosebery Avenue, London EC1R 4QX, Telephone +44 (44)20 7505 6622, Fax: (44)20 7505 6606, E-mail crc@construct.emap.co.uk

IP3/97	Demonstration of reuse and recycling of materials
Digest 433	Recycled Aggregates
IP1/96	Management of construction and demolition waste
IP5/94	The use of recycled aggregates in concrete
IP12/97	Plastics recycling in the construction industry
IP 14/98	Blocks with recycled aggregate: beam and block flooring
IP 7/00	Reclamation and recycling of building materials
Digest 447	Waste minimisation on a construction site
BR418	Deconstruction and reuse of construction materials

ENVIRONMENTAL IMPACT OF CONCRETE RECYCLING, COMING FROM CONSTRUCTION AND DEMOLITION WASTE (C&DW)

Authors: Beatriz Estévez[*a] , Antonio Aguado[a], Alejandro Josa[a]

[a] Universitat Politécnica de Catalunya (UPC), School of Civil Engineering (ETSECCPB), Jordi Girona 1-3, Módulo C1, E-08034 Barcelona, Spain

ABSTRACT

This paper presents the results of a research study on the environmental impact produced by the recycling of concrete originating from construction and demolition waste (C&DW). The aim of the study was to implement a life cycle inventory (LCI) of the concrete recycling phases. It was carried out in Spain, with data collected from the various recycling processes involved in the mobile crushing plants operating in Catalonia. The values have been compared with the environmental impact produced during the extraction processes of natural resources (gravel and sand) from different European databases. The main emissions (CO_2, NO_x, SO_2, SO_x, and dust) with major influence on the greenhouse effect, acidification, and eutrophication were considered. The recycling waste processes generate lower environmental impact than the natural aggregate extraction. The amount of CO_2 emitted is approximately 3,000 g per ton of recycled aggregate, while this value varied from around 6,900 to 7,700 g per ton for the gravel and sand extraction processes considered.

INTRODUCTION

In the EU, the current annual production of construction and demolition waste (C&DW) is on the order of about 180 million tonnes, of which, about 28% is recycled (EU, 1999). Several countries have implemented Action Programmes to increment the amount of recycled material. (Lauritzen, 1997). These countries included Spain, where 25 to 30 % of C&DW was being recycled by the year 2000, and where the Environment Ministry has proposed an Action Programme (BOE, 2001) to increase these values, so as to recycle at least 40% by 2005, and 60% by the year 2006.

In the composition of conventional demolition waste, a high proportion of the weight is formed by concrete. Average values of 35% of the total C&DW were estimated in 1990, with predicted values of 40% by the year 2000. (D. Medio Ambiente, 1995). This means that at least 72 million of the EU´s yearly production of 180 million tonnes of C&DW comes from concrete waste. These figures illustrate the large weight and volume of concrete waste generated annually in the EU. To make a comparison with a parallel activity, in the year 2000, the automotive industry recycled more than 14 million tonnes of steel (Steel Recycling Institute, 2002) coming from discarded automobiles. This circumstance may reasonably be considered as one of the bases for the implementation of several steel recycling inventories originating in different sources. If we consider that the construction industry generates more recycled wastes than the motor industry, this brings home the importance of creating a life cycle inventory for the recycling of concrete.

The authors had access to the following databases: BUWAL 250 (PRé Consultants B.V. 1997), Data Archive (PRé Consultants B.V. 1997), y LCAiT (CIT Ekologik 2001). The amount of available data is limited due to the restricted-access policies often exercised by the industry. The greater part of the life cycle inventories (LCI) developed at present focus on obtaining raw materials, production, transport, and energies. A limitation of environmental information regarding recycling processes has been identified. The majority of recycling process inventories has been applied to materials having a short useful life, and which are consumed in great quantities, such as glass, paper, and plastic. Nevertheless, there does not yet appear to be awareness of the need for recycling inventories for construction materials, which have a longer lifetime. In this field, the relative scarcity of inventories is noticeable. Despite the important period of time which must elapse before a concrete structure becomes eligible for recycling, the expansive growth of demolition waste and modern policies regarding the desirability of recycling justify the interest of the environmental study of concrete recycling.

LIFE CYCLE ASSESSMENT AND THE SUBSYSTEM ARTICULATION

Environmental life cycle assessment (LCA) was developed from the idea of comprehensive environmental assessments of products, and was conceived in Europe and the USA in the late 1960s and early 1970s. Nevertheless, the application of this methodology grew mainly in North Europe in the early 1990s where, apart from technical feasibility and economic efficiency, environmental considerations play an increasingly important role in many industrial sectors.

Modern environmental policies with regulations, such as the European Directive on Integrated Pollution Prevention and Control, require the overall prevention and reduction of emissions and other impacts on the environment (IPPC, 1996).

In simple terms, the Life Cycle Assessment of products (LCA), or Life Cycle Analysis of products, is the evaluation of the contribution of all the processes involved in the manufacture of a product to a selected list of environmental effects. The basic concept of product LCA is that the entire life cycle is considered, including all of the environmental effects that result from each activity, ranging from the extraction of resources to the processing of final waste. This includes: identifying and quantifying energy and materials used, and waste released into the environment, assessing the environmental impact, and evaluating opportunities for improvement.

The LCA methodology can generally be used to support decisions about a purchase, guide the improvement of product processes, or to enable product approval and selection. Although the purpose of an LCA is to determine only the environmental impacts of a product, the aforementioned decisions or actions can be based on environmental, social, or economic aspects, or on any other similar considerations related to a product and its production.

Inventory analysis is the process of compiling the amount of natural resources and energy taken in by the system, and the amount of waste discharged to the environment from the system. This is the component of an LCA in which the product system is analyzed. A life cycle is made up of a range of processes; each with associated side effects, often termed environmental interventions. To summarize all of these, an inventory table, or Life Cycle Inventory (LCI), is needed. This is a list of all primary and other energy consumption values, emitted chemicals and chemical compounds, quantities of waste, amount of space used, etc.

To implement a Life Cycle Inventory, a clear definition of the boundaries and the functional unit is important, as it influences the outcome of an LCA study.

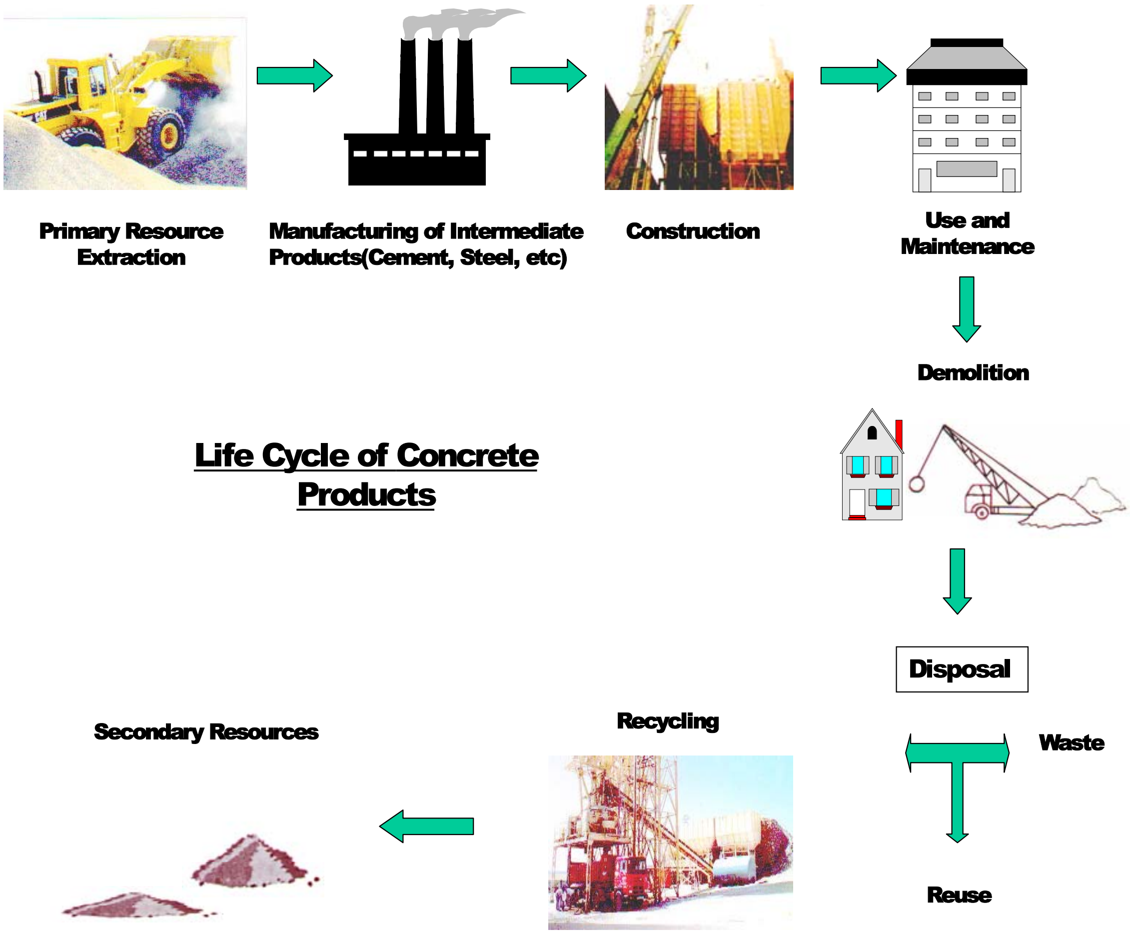


Fig. 1 – Complete Life Cycle of Concrete Products

Figure 1 shows the complete LCA (from cradle to grave) of any concrete product. This system, as shown in Figure 1, can be defined as being composed of various subsystems existing in sequential order, where the output of each subsystem makes up the input of the next one, each being linked by a transport system. Thus, a concrete recycling subsystem uses the outgoing materials from the preceding demolition process as input of materials, and it produces the recycled aggregates as output. The sum of all subsystems makes up the total system. The complete life cycle described in Figure1 begins with the extraction of aggregates from natural quarries (primary aggregates), and culminates in the production of aggregates from the recycling process (secondary aggregates). Both types of aggregates are applicable to making concrete.

The system boundaries determine the extent to which the inventory takes into account parameters from the supporting product systems and from the environment. In Figure1, the specific context of the subsystem in concrete recycling is defined.

Figure 2 illustrates this subsystem, in which there are some inputs, some processes, and some outgoings.

Its boundaries may present different configurations. For instance, it may include only concrete recycling processes, or it may also include the obtaining of material via the demolition processes, and/or the transport system linking subsystems, and/or the final transport of aggregates.

The subsystem defined here can be classified as the *gate to gate* type, because it only includes the recycling processes relative to concrete.

Inputs of the Subsystem
The resources (materials) come from the preceding demolition subsystem it in the linear chain of the Life Cycle set out in Fig. 1. So as to adhere to the defined boundaries, the energy resources considered shall be only those involved in the subsystem's own processes, and shall not include the energy involved in previous processes of demolition or transport.

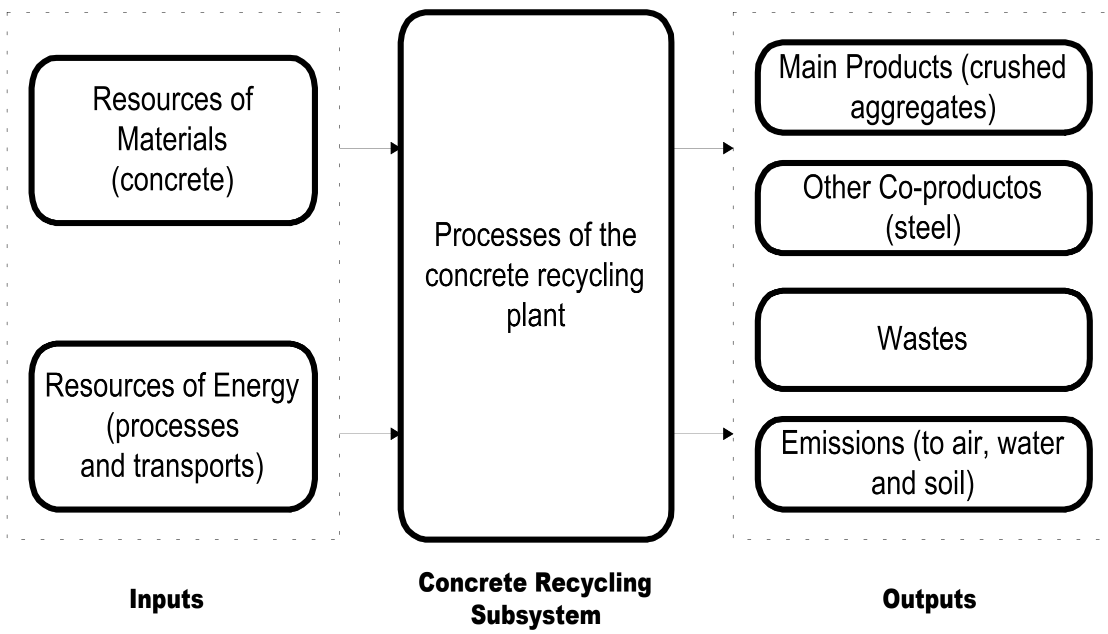


***Fig. 2** – Concrete Recycling Subsystem*

The Subsystem Processes
The processes of the subsystem are those which make possible the obtaining of a product (secondary aggregates) from concrete waste. Concrete recycling plants carry out various processes, such as classification and separation of materials, crushing of concrete waste, and internal transport.

The Outputs of the Subsystem
The outputs consist of the principal products, the secondary products, the emissions and the residues or waste. The principal products consist in aggregates of varying gauges. Secondary products are all those which, while forming part of C&DW, do not belong to the group of petreous materials but are still capable of being recycled and re-used. Principal among these are the different types of materials derived from the classification and selection processes, such as plastic, glass, metals, etc. Reinforced steel, which has not been possible

to separate from the concrete in the separation process, and is later removed by an electromagnet in the crushing process, is considered a secondary product. Other outputs taken into account are the emissions to the environment (the ground and water) and, in some cases, the production of solid wastes.

The flow of input and output to the subsystem implies that generation of environmental burdens originates in the different processes. These must comply with a law of the equilibrium of burdens, in order to ensure the equilibrium of the system. The equilibrium of burdens, E_i, may be expressed as in equation [1]:

$$\Sigma E_i \text{ (inputs)} + \Sigma E_i \text{ (processes)} = \Sigma E_i \text{ (products)} + \Sigma E_i \text{ (wastes)} \qquad \text{equation [1]}$$

INVENTORY

The methodology applied in implementing the inventory is comprised of the stages recommended by the International Organisation for Standardisation (ISO) 14041:1998. Data presented has been compiled from that available in the four recycling plants located in Catalonia. To determine the quantity of emissions corresponding to energy consumption of the different phases of the recycling subsystem, the calculations have been supported by the SimaPro 4.0 program, determining the pollutant emissions derived from the consumption of 1 Kg. of fuel oil (calculated according to data from INDEMAT 96).

Main characteristics of the inventory subsystem

According to the subsystem articulation presented above, the system boundaries respond to the *gate to gate* type, as defined in the description of the subsystem articulation. The functional unit is defined as the recycling of one tonne of concrete proceeding from C&DW. The prime materials are concrete waste not containing any other mixture of material, contaminated fractions (plaster, glass, etc.), or other inert fractions (brick, tiles, etc.).

The subsystem processes

The subsystem processes have been defined through fieldwork, consisting of data collected in the four recycling plants in Catalonia. Three of these plants produce mixed aggregates derived from concrete waste, while one plant produces aggregates for concrete with purity close to 100%. This company has been used as a reference in this work. It has a mobile crusher plant, and the internal transport is carried out by means of front-loading shovels.

The outputs of the subsystem

The main products are aggregates of three gauges: fractions > 45 mm (rank aggregates 1), fractions of 20-45 mm. (rank aggregate 2), and fractions of 0-20 mm. (rank aggregate 3).

The secondary products are the fractions of steel reinforcing removed from concrete waste by electromagnet at the mobile crushing plant. In some cases, prior to the recycling processes, small amounts of metal fractions can be taken out of the waste by manual separation (see grey option in Fig. 3).

The waste is composed of materials that lack commercial value and cannot be recycled as new products. Nevertheless, in the process of concrete recycling, all of the outputs (aggregates and steel) have positive economic value, and no waste is generated.

Emissions: Calculation of the environmental emissions originating in the subsystem is based on the law of equilibrium of environmental burdens, expressed in equation (1).

The environmental burdens, corresponding to the inputs and processes of the subsystem, are a direct consequence of the energy consumption associated with these. According to the boundaries established, input energies are considered to be those associated with each one of the processes carried out in the recycling plant. Consequently, it has been necessary to determine and quantify the types of energy used in each process. Fossil fuel (fuel oil) is the energy source for the mobile crushing plant and the front-loading shovels. Aggregate production is between 80 and 100 tonnes per hour, and the average consumption of fuel is about 25 lt per hour for the crushing, and about 20 lt per hour for the front-loading shovels. These values have been validated by visiting different companies in Catalonia.

In calculating the emissions, the environmental burdens associated with the subsystem processes were obtained from Table 1, which shows consumption per litre and per MJ of fuel oil for each of the phases of the subprocess, by reference to the functional unit.

Using the values in this table and using the inventory of emissions corresponding to the consumption of 1 Kg. of fuel oil (SimaPró 4.0) as a reference, the environmental burdens associated with the processes of the subsystem have been calculated. Based upon these values and by application of equation (1), the environmental loads associated with the output elements may be determined. An allocation method must be taken into account, because this is a multi-output system. First, considering that the subsystem produces main products (aggregates), plus a secondary one (steel), and does not produce waste, equation [1] takes the form:

$\Sigma\ E_i$ (inputs) $+\Sigma\ E_i$ (processes) $=\Sigma\ E_i$ (rank aggregates1) +
$\Sigma\ E_i$ (rank aggregates2) + $\Sigma\ E_i$ (rank aggregates3) $+\Sigma\ E_i$ (steel) [1]

Phases of the concrete recycling subsystem	Fuel	Average consumption	Power (MJ/t.concrete)
Transport	fuel oil	0.25	9.635
Crushing	fuel oil	0.37	14.26
Internal transport	fuel oil	0.25	9.635

Table 1*- Energetic Resources of the different phases defined in the concrete recycling subsystem*

The next step is to apply an allocation criterion. If allocation cannot be avoided, then an appropriate method has to be chosen to allocate the burdens in a multiple-function system. Most of the approaches proposed allocate burdens in proportion to some physical property or economic value. Physical properties used as a basis for allocation may include mass, energy or exergy content, volume, and molecular mass. In this application, an allocation method in proportion to mass has been applied. According to (Ekvall, 2000), (Azapagic, 1998), (Huppes, 1994) (ISO 14041: 1998), a multiproduct allocation model for LCA is feasible only if it is a linear homogeneous model to describe system behaviour. This approach assumes that changes in the burdens, and the resulting environmental impacts, are directly proportional to changes in functional outputs. In such a linear homogeneous model applied to the system, the total environmental burdens, E_i, are related to the functional outputs, m_j, by a set of equations of the form:

$$E_i (m_1\ m_2\ \ldots\ldots\ m_n) = \Sigma\ A_{ij}\ m_j \qquad [2]$$

The subsystem under consideration fits reasonably well under a linear homogeneous behaviour model and the hypotheses of physical causality since, if the mass of the products is increased, more energy will be required and consequently the environmental burden will be increased. This means that changes in the burdens are directly proportional to changes in functional outputs. On this basis, equation [2] could be applied for the calculation of results.

ΣE_i (inputs) $+\Sigma E_i$ (processes) $= \Sigma\ A_{ij}\ m_j = \Sigma\ E_i$ (rank aggregates1)
$+\Sigma\ E_i$ (rank aggregates2) $+ \Sigma\ E_i$ (rank aggregates3) $+\Sigma\ E_i$ (steel) eq.[1a]
In matrix form, eq. [1a] can be written as:

$$\begin{bmatrix} E1 \\ E2 \\ . \\ Ei \end{bmatrix} = \begin{bmatrix} a11 & a12 & . & a1j \\ a21 & a22 & . & a2j \\ . & . & . & . \\ ai1 & ai2 & . & aij \end{bmatrix} * \begin{bmatrix} m1 \\ m2 \\ . \\ mj \end{bmatrix} \qquad [1b]$$

In matrix A_{ij}, the dimension, i (rows), is the total of contaminating substances emitted into the air, water, and ground by the processes. The j dimension (Columns) is the total amount of outputs delivered by the process. The dimension of vector m_j, which also coincides with the number of outputs or products of the subsystem and its elements, corresponds to the different proportions of mass of each product. In the case under consideration, the definition of vector m_j involves establishing the following values:

- m_1, mass proportion of fraction > 45mm. (aggregates grade 1)
- m_2, mass proportion of fraction 20-45 mm (aggregates grade 2)
- m_3, mass proportion of fraction 0-20 mm. (aggregates grade3)
- m_4, mass proportion of steel fraction

When an equilibrium of masses is met, the sum of all these values must be equal to the functional unit, which is one tonne of mass, or $\Sigma\ m_j = 1$. These values may vary according to market demands, which determine the volume of production in the different grades. Generally speaking, the aggregates that find the greatest commercial application are the coarser grades. In Catalonia, production of these fractions is usually around 75% of the total. In the recycling plant adopted as reference for this study, the average values of the aggregate mass produced by one tonne of recycled concrete are:

- mass proportion of fraction > 45mm. (rank ag.1)… = 35%
- mass proportion of fraction 20-45 mm (rank ag. 2)…=40%
- mass proportion of fraction 0-20 mm. (rank ag. 3)… =25%

In order to determine the steel mass that is produced as a by-product of the subsystem, the partial results of a study generated by the Junta de Residus (Waste Management Board, part of the Catalan regional government) has been taken into account. The study is part of the

Guide of application of decree 201/94 (Junta de Residus, 1995), and includes a comparative evaluation of concrete and steel mass in demolition waste from different origins. From this study an average value of 22 Kg. of delivered steel per tonne of recycled concrete has been determined.

On the basis of these values, the mass coefficients of the vector m_j are as follows:

$m_j = (0.342 \quad 0.391 \quad 0.245 \quad 0.022)$

With the vector m_j determined above, and the application of eq. [1b], the environmental burdens allocated to the different outputs of the subsystem have been determined.

Analysis of Results

The aim of this study is to analyse and validate the results obtained from the Life Cycle Inventory developed, and to compare them with those obtained from other references. Since no other concrete- recycling inventory was available for a comparison of results, the analysis was based on a comparison of the extraction processes of primary resources (sand and gravel). The specific inventories available for the study are provided by SimaPro 4.0 (Pré Consultants, 1997), and correspond to the denomination, *Gravel I* and *Sand I* . The unit of comparison is the production of 1 tonne of aggregates (primary and secondary) useful for concrete production. SimaPró inventories treat data in two sub-systems, the transport and the quarrying and processing of primary aggregates.

For the comparison, it must be taken into account that the energetic resources of the different inventories considered came from different sources. While SimaPró inventories consume electric energy for the quarrying and crushing of primary aggregates, and fuel oil for transport, the concrete-recycling inventory consumes only fossil fuel in all of the processes.

Output Data Analysis

The analysis considers the emissions with the highest percentages in the categories of environmental impact:

- CO_2, due to its major influence on the greenhouse effect and induced climatic change on a global level.
- NOx, due to its contribution to acidification and eutrophication on a regional level.
- SO_2, due to its contribution to acidification on a regional level.
- Dust, due to its important visual and direct impact on the image and health of the environment and its inhabitants on a local scale.

Table 2 shows the amount of the emissions described above for the different inventories under comparison.

Emissions to Air (g/ton.)	Inventory of concrete recycling		Inventories of SimaPró 4.0			
			Gravel I (g/t)		Sand I (g/t)	
	Transport	Crushing	Transport	Electricity	Transport	Electricity
CO_2	1704.44	1261.3	4920	2820	4920	1950
NO_x	26.36	19.5	94.2	5.36	94.2	5.49
SO_2	1.62	1.2	12	0.419	12	11.2
Dust	0.17	0.126	0.49	0.0371	0.49	0.873

Table 2 *– Emissions to air from extraction processes of primary aggregates and from production of secondary aggregates.*

From a comparative analysis of the results, the following conclusions have been drawn:

CO_2 Emissions
The main CO_2 emissions are a result of the transport processes in all of the inventories. In the primary (natural) aggregates, the CO_2 values due to transportation processes are about 63% of the total for gravel, and about 71% of the total for sand; while in secondary (recycled) aggregates, the CO_2 values due to transportation processes represent about 57% of the total. This important difference between the rate of CO_2 values due to transportation processes by primary and secondary aggregates should be attributed to the different amount of fuel consumed. Regarding the crushing processes, the quantity of CO2 emitted due to crushing is 1261 g per tonne for recycled concrete; whereas in primary aggregates, it reaches approximately 1950 g and 2820 g per tonne for sand and gravel, respectively. This leads to the conclusion that the difference in CO_2 emissions could be attributed to the number of processes included in the subsystem dealing with natural sand and gravel, which include quarrying as well as grinding or crushing, with an increase in the amount of energy required.

NO_x Emissions
The total NO_x emissions due to recycling of concrete are 45.86 g per tonne. This value represents approximately 50% of the total emissions due to quarrying and processing of primary aggregates (about 99 g per tonne). These NO_x emissions are mainly an output of the utilization of fossil fuel. Thus, primary aggregates produce 94.2 g of NO_x per tonne due to transport processes, while only 5.36 and 5.49 g of NO_x per tonne are due to electricity consumption for gravel and sand, respectively. On the other hand, secondary aggregates produce 26.36 g of NO_x per tonne due to transport processes, and 19.5 g of NO_x per tonne in the crushing process.

SO_2 Emissions
The emissions of SO_2 produced in the processing of recycled aggregates reaches 2.784 g per tonne, which represents 22.4% and 12%, respectively, of the emissions produced in the production of natural gravel and sand. The quarrying and grinding processes for sand generate twice the amount of SO_2 emissions than those for gravel. This is explained by the kind of energy resource utilized in each case.

Dust Emissions
The numerical estimation of dust levels takes into account the amount of electrical energy and fossil fuel consumed in the processes. It uses the typical dust emissions from each country´s

power-generation plants, and the emissions corresponding to each type of fossil fuel used in the production of thermal energy. The emissions of mechanical actions (the action of the crushing plant, the sand grinders, etc.) must be included to provide more realistic results.

CONCLUSIONS

- The processes of quarrying, crushing, and grinding of natural aggregates produces a greater environmental burden than the processes of crushing and recycling of concrete, especially concerning CO_2. This is probably due to the fact that, in all processes of producing natural aggregates, the extraction processes must also be considered, with the consumption of energy implicit in these.

- The importance of reducing the consumption of fossil energy is emphasized in order to reduce potential impacts on the environment.

- The major part of the environmental burdens produced in the different systems is the result of transport. These processes are responsible for the most energy usage and emissions of gases and particulates. These involve emission of the principal gases responsible for the greenhouse effect (CO_2), with higher values in the production processes of primary (natural) aggregates than in recycling processes. The transport distances play an important role in the results. The distances considered in the inventories of production processes of primary aggregates are bigger than those considered in the recycling processes.

- Within the context of this study, it could be stated that the building industry could contribute to a sustainable development by reducing the emissions of CO_2, if they were to consider recycling as the better option over production of primary aggregates.

- Nevertheless, comparative analysis of the inventories for the production of primary aggregates (SimaPró) and the inventory for concrete recycling show limitations. The system boundaries of the different inventories are not homogeneous. This makes analysis difficult.

- The data used in the implementation of concrete recycling inventory is representative of Spain, while the inventories of SimaPro have been made with data from another geographical region. Thus, the data that have been compared above came from different sources, which makes the extrapolation difficult.

- The quantity of information available in databases existing in the market, and included in this study, is limited. This is due partially to the lack of specific inventories in this area, and partially to difficulty in accessing and obtaining existing information.

BIBLIOGRAFY

- **Azapagic A. and Clift R., (1998).** Allocation of environmental burdens in multiple-function systems. Journal of Cleaner Production. 7 (1999) 101-119.

- **(BOE, 2001).** Plan Nacional de residuos de la construcción y demolición 2001-2006. Publicado el 12 de julio de 2001 en el Boletín Oficial del Estado

- **CIT Ekologik. (2001).** CIT Chalmers Industriteknik. www.LCAiT.com

- **D. Medio Ambiente, (1995).** Programa de residus de la construcció a Catalunya, ISBN: 84-393-3906-2. Gestora de Runas de la Construcción y Departamento de Medio Ambiente de la Generalitat de Cataluña.

- **Ekvall T., (2000).** Allocation in ISO 14041- a critical review. Journal of Cleaner Production. 9 (2001) 197-208.

- **E.U. - (1999).** Construction and demolition waste management practices, and their economic impacts by Symonds, in association with ARGUS, COWI and PRC Bouwcentrum. European Commission.

- **Huppes G.** (1994), A general method for allocation in LCA. Proceedings of the European Workshop on Allocation. Leiden

- **IPPC, (1996).** European Council Directive 96/61 /EC of 24 September 1996 concerning the integrated pollution prevention and control. Official Journal L 257, 10/10 /96, p. 26 – 40.

- **ISO 14041:1998 (E).** Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis. International Standard.

- **Junta de Residuos, (1995).** Guía de aplicación del Decreto 201/1994, regulador de los residuos de demolición y otros residuos de la construcción. Generalitat de Catalunya. Departamento de Medio Ambiente.

- **Lauritzen E. & Jorn Hahn, N. (1997).** Producción de residuos de construcción y reciclaje. Articulo publicado en el número 8 de la revista Residuos.

- **PRé Consultants B.V. (1997).** SimaPro Database Manual.

- **Steel Recycling Institute**. www.recycle-steel.org

START UP AND DEVELOPMENT OF A FULL SCALE USED BUILDING MATERIALS STORE AND SALVAGE & DECONSTRUCTION BUSINESS IN A SMALL TOWN

Author: Bruce Odom (ODOM RE-USE Co., Traverse City, MI)

ABSTRACT

The used building material start-up business in a small town should begin with asking where all the materials go. Recommendations for associations and valuable contacts to seek out are followed by the few distinctive operating differences between for profits and non-profits. Store location, size, layout and pricing of materials for the beginner as well as an emphasis on marketing and public relations are discussed. How to dispose of surplus inventory, what materials to turn down, and how to gain access to important commercial salvage are all covered. Deconstruction tools of the trade and transportation are also briefly discussed.

INTRODUCTION

This paper will present a step-by-step description of the process of starting a used building material business. The essential elements of a used building materials store are retail warehouse space, access to commercial/institutional jobsites, skilled crew to remove and sell materials, and equipment to transport materials. All of these elements are crucial. Remove any one element and the business will fail. This paper will also discuss key contacts, cultivating relationships with potential customers/suppliers, marketing, and media relations.

GETTING STARTED

Seeking out advice from business people you may know, as well as other owners and managers of this type of store, is an obvious first step. The Small Business Administration also has S.C.O.R.E., a volunteer group of retired business professionals who counsel businesses.

The Used Building Materials Association published a short booklet about five years ago titled “Points to consider when opening a used building materials store.” The U.B.M.A. was originally headquartered in Winnipeg, Manitoba and it remains jointly participated in by Canadian and American businesses. Environment Canada (the E.P.A. of Canada) is to be applauded for the investment they made to launch this very important trade association. The U.B.M.A. office recently moved to Washington D.C. [1].

The aspiring used building material store operator should also know the local builders' habits. Do contractors all throw everything away from remodels and demolition jobs? Are there an existing retail outlet, charity or regular flea market up and running? Is any business or charity dealing with the easy to sell (cabinets and architectural pieces) or moderate sellers (hollow doors, sinks, and lights)? Is there a choice of landfills/incinerators to use if you choose to dump? Are these waste disposal facilities making any effort to divert any wood waste? Who might be interested in collaboration (a trade organization, thrift store, waste hauler or recycling center)?

If there is no existing local full service used building material re-use facility (a store that carries a wide variety of lumber, fixtures, cabinets, doors, windows, some plumbing, electrical, and hardware and that salvages from job sites and deconstructs homes and other small buildings) an aspiring business has its first green light. If there is already a full service re-use business in operation, it's a judgment call if they are doing a good job at it or if there is room for improvement. Chances are there is room for one more. If done slowly, a store could be supported by a local population of 40,000 once established. So a larger community of 120,000 could conceivably support two to three stores.

ASSOCIATIONS AND CONNECTIONS IN THE CONSTRUCTION TRADE

When Mr. Odom first moved to Traverse City, he visited the local food co-op. They were in the throes of a move into an old lumberyard, remodeling the facility and needing all the volunteers they could get. A food co-op is an excellent place to meet recycling folks, and during a remodel there were many "green minded" carpenters to meet and visit with. Mr. Odom eventually hired one of these carpenters, sub-contracted out with another, and made numerous friends and business associates that he has today. The general contractor on site also became one of his best suppliers and a customer of deconstruction and salvage services.

The Home Builders Association is an important association to join in that it helps overcome two of the major challenges of running a used materials store: credibility and access to the "good jobs." Many small commercial contractors are homebuilders and H.B.A. members. Meeting these gatekeepers to the lucrative deconstruction jobs in an informal setting is ideal and affordable.

The initial process of building a business relationship is somewhat tentative, often taking a year to build a rapport before doing the first deconstruction job for a contractor. Odom gradually got into the type of work only after his retail store was established and running in a predictable manner, initially they were known for picking up materials and salvaging only.

PROFIT VS. NON-PROFIT

The advantage of a non-profit is the ability to offer customers a tax deductible receipt, as well as the halo effect that no one individual is making a profit on the donations of others. The disadvantage might be working for a volunteer board of directors, slower reaction time to a business opportunity, and ownership of potential profits.

Odom RE-USE Company, a for profit business, works closely with a non-profit to their mutual benefit. A small Catholic charity, the Father Fred Foundation, initially referred donors of building materials to them, which they picked up, transported and sold. Odom RE-USE Company gave donors a trade credit, as do other stores. The donors passed this along to the Father Fred Foundation where the credit can be used by "in need" clients of Father Fred in the store. They bring in a permission slip from the charity authorizing them to select a specific item, and Odom helps them load it up. This arrangement works well for both parties, as all business transactions should.

For building material waste reduction to have a lasting impact to the degree it potentially can, it will have to stand on its own with credibility as a viable if not vigorous economic enterprise, as opposed to some neglected charitable cause. This is not to in any way take from the most impressive strides made by non-profits. Odom did learn the business working at one for years. Non-profit organizations have tremendous accomplishments that are admirable. They blaze many trails, but not all the ones for-profits can travel.

OBTAINING MATERIALS AND MERCHANDISE

Donations or Trades

The obvious first contact is the local county resource recovery, recycling or solid waste coordinator. This person may know most if not all the answers to the above questions. Also inquire at lumberyards, Goodwill, Salvation Army or St. Vincent DePaul.

Befriending a transfer station operator is a good early strategy. The local transfer station near Traverse City has friendly operators who set aside good looking "waste" brought in for disposal. In using this station, Odom RE-USE Company often brought in a full pick-up truckload for disposal and left with a half-truck load of other materials for sale. Although this didn't save the business in cost of disposal directly, the later sale value of the materials gained often paid for much of the trip and sometimes balanced the dump fees entirely.

Value Village, a franchise of used clothing stores is an impressive model for the used material entrepreneur. This for profit business buys donations in bulk from non-profits who collect the materials, thus affording Value Village a cheap steady source of materials. They in turn provide a steady low skill job base for the disabled or disenfranchised. The donor receives doorstep service and a tax-deductible receipt, as well as the satisfaction of doing the right thing.

What to turn down and what to take is a perennial question. The goal of waste reduction dictates: take an item if a customer can be found for it and the business remains viable. A store can accept materials that it knows are difficult to sell and then give them away only if necessary. Obviously this is a limited number of items in a given period. Not so obvious is which ones end up selling and which ones end up being given away for free. As a matter of fact, that group of materials is in flux, hinging on luck and timing. It boils down to who saw it in the amount of time the store could afford to store it.

For example, at Odom RE-USE Company a careful senior once brought in a house's worth of -- matching storm windows, carefully packed in the cartons the new replacements arrived in. All were clean and many were of matching sizes. The store was very full of windows at the time, but these usually hard to sell single pane windows were taken anyway. The rationalization was they would have a better chance than average due to the matching sizes and orderliness of the package. These windows were displayed for only an hour when one of the first people to notice them bought close to every one of them, for a fair price, *and* took them with him. The right person saw them well within in the amount of time it was affordable to store them.

A reusable building materials store that insists on clean, reusable-as-is materials will get them. In absence of such a policy a store will be a dumping ground for the public.

Commercial Salvage
Commercial salvage jobs are essential to survival and should be sought out at every opportunity, with every ploy imaginable. Access to these jobs requires patience, diligence, and the ability to react on one day's notice with the full strength of the company. Overnight notice for a large out of town job is woefully common for a start-up business. As an unknown, reusable building supply businesses are the last ones thought of for deconstruction projects.

Originally contacts are word of mouth through friends or contractors. Additionally there are plan centers where you join an association for the privilege of accessing this commercial bid information. Odom RE-USE Company has had just as much success calling contractors cold out of the phone book to introduce the services of the salvage crew, as finding jobs from the plans center. It is advisable to pursue all avenues.

With volume too large, and materials too chrome covered for the contractors own crew to be interested in taking, these commercial jobs are often lucrative sources of supplies to small owner-operator retailers or offices of small businesses. Mirrors, track lighting, slatwall, displays, shelving, cashier wraps, storage systems, bathroom safety grab bars, and marble wall tiles are just some of the materials involved. For example, the mirrors from commercial salvage are often larger and thicker than residential. They require cutting for most to re-use but not always. Horse trainers once bought up all the large mirrors Odom RE-USE Company had and installed them in their practice arena.

Mr. Odom once drove up to the Upper Peninsula of Michigan to attend a pre-bid meeting for a school remodel. There he gave a short explanation to attendees about the services provided by his company. While he were not awarded that job, a contractor present that day called the store up months later to ask them to salvage some high quality maple science room cabinets from Sault Ste. Marie, Michigan The cabinets were a very high demand item and sold quickly.

Ultimately, it is establishing relationships and a reputation as a professional who gets the job done fast that wins more business. Fortunately, as time rolls on, contractors will contact the used building materials store themselves—and call early—because the business helps them get rid of their waste and augment their labor pool at the same time. Non-profits also may give them a tax-deductible receipt.

Deconstruction
The deconstruction of a small building, residence or other structure, gives the used building materials store a source of material it would otherwise have little of: framing lumber. Generally, there is plenty of other material, such as tongue and groove solid wood paneling, plywood, oak, fir and pecan flooring or other architectural features that don't show up that often from salvage jobs.

Bidding deconstruction jobs pits the manual technique against the machine. Odom RE-USE Company competes with many small excavator owner-operators in the Traverse City area, winning about three bids a year out of approximately ten. They get paid around $7,000 to $8,000 to take down a 1,700 square foot house. Some excavator owner-operators competing in the area have their own construction debris landfills. With landfill rates at $16.50/cubic yard this is a big advantage.

For comparison, the Rebuilding Center in Portland, Oregon, works constantly with multiple crews on deconstruction and wins most of their bids. Aside from population density differences with lots more work all around them, this success is due in no small part to the tax deductible receipt they provide customers for materials harvested from the deconstruction job, a clear advantage they have over for-profits. In addition, Bellingham and Seattle, Washington stores receive considerably more in payment to deconstruct a house than does a small town operator.[2]

STORE LOCATION, LAYOUT AND SIZE

Location

As far as distinctions between small town businesses and large towns, there is less volume and a greater ramp up time in a small town from what has been observed of other big city start-ups. For perspective, Traverse City, Michigan has a community population of about 30,000 including the prime city of 14,000 and several adjoining townships. The county is about 80,000. Customers travel from as far away as 150 miles to shop at Odom RE-USE Company, regulars live within 25 miles, and once-a-month shoppers live within 50 or 60 miles. It helps that Traverse City also has virtually all the big box stores that are not to be found for a range of some several counties in any given direction.

Based on his experience in choosing the location for three used building materials stores, the author has the following observations: Start-ups rely more on high-visibility to succeed in a small town and start-ups can survive high-market rent levels if they can last four or five years. However, he recommends businesses avoid paying rent if it’s possible to put together the price of the down payment on a building.

Rent levels are a number the market arrives at based on a multitude of trials and error that are ongoing daily. What the site can provide in the way of business income is factored into the rent. Buy or rent the most centrally located, visible, easy to find, easy to park in and easy to sell from building that is within budget. An old lumberyard works, but likely is in rugged shape. Be realistic about how much time you can spend patching up the building, not to mention heat expense in cold climates. One should expect to pay 15% to 25% of your revenue in rent or mortgage, but markets vary widely. In an informal poll taken at the U.B.M.A. conference in Portland, Oregon in October 2001, it was found that Odom RE-USE Company’s $5.60 per square foot rent per year was higher than average, compared to towns of different sizes with buildings located in many different types of neighborhoods. At the time, the rent rate in Seattle was $6.00, Ann Arbor, Michigan was $7.50, Bellingham, Washington was $2.20, and

Springfield, Massachusetts was $2.10. Odom RE-USE Company pays all utilities but no real estate tax. In 2003, Odom RE-USE Company's rent is up to $6.45 per foot annually.

Store Size

The store can range from 8,000 square feet to 25,000 square feet and larger plus yard storage. Several stores in larger cities hover in the 20,000 square foot range. A store is viable somewhere from 8,000 to 10,000 square feet. Going beyond that in size depends on three things: handling framing lumber in an efficient manner, how quickly good material comes along, which is generally related to size of town, and how disciplined management is about discounting, giving away and/or throwing away stale inventory. Odom RE-USE Company's 9,600 square foot store is profitable after four years of work and has no outdoor storage. However, the store needs 5,000 more square feet of either indoor or outdoor storage. Then, even if a forklift wasn't used, at least vehicles could get closer to the piles, instead of snaking 12' long rafters through the store as they do now on carts.

Display and Layout

"An item well displayed is already half sold." This is the mantra of seasoned retailers. Do whatever possible to make a display out of things that don't show well without one. Even a few minutes invested is time well spent.

One of the first improvements needed in a used building materials store is removable door and window storage racks. These can be constructed out of salvaged materials if any is available yet. Eventual storage of over 500 doors is not uncommon for a store, and this is made easier by removal of at least the knobs from the doors, if not the hinges also. It also protects the doors from damaging each other. Set up aisles to give direct access to the door and ideally leave a straight path from large items to the exit. The heaviest and most often sold things, like solid core doors, should be close to the loading door. Lighter or less frequently sold items can be in either areas of low ceiling height, on a second floor if there is one, or toward the back of the store. Although toilets sell well, they are best kept hidden away for aesthetics, while the occasional porch column or Victorian spindle is worthy of placement near the cashier.

Surplus and Junk

Set a finite space for the low value stuff and turn down, give away or discard surplus. At any given moment 10% and up of a used building materials store inventory is junk and another 10% more would never be missed. Tidiness is imperative in this business. As retailers, these businesses need to remember to keep the merchandise accessible. In large stores in bigger cities one often sees heaps of materials, windows stacked 30 or 40 deep leaning against a wall, and lofts stuffed to bursting with materials you can't see. They may have more store than they have staff to work, an easy slope to slip down. How a re-use business chooses to dispose of their waste and surplus is a defining moment as to what they believe in.

If you do nothing else to manage stale inventory have a *Free Friday* or a give away day. One Friday a month, Odom RE-USE Company gives away stale inventory by putting it all outside the front door in the parking lot. This is done every month, regardless of weather, for regularity is key to the success of this surplus reduction plan. They give away about one large utility trailer load of materials, and most of what remains is metal and easily recycled. They sprinkle two or three good, but in surplus, items just to sweeten the pot. Regulars have been coming to *Free Fridays* for years. First it was only customers who would tie a giant cabinet to the roof of their old compact car, but that has now broadened to include customers of more affluence driving new pickup trucks.

This event is valuable not only for the photo opportunity it provides for the local news section, but it also builds familiarity across boundaries. Upon seeing the Odom RE-USE Company logo on an employee's jacket in the grocery store, checkout clerks who have no interest in building materials see the name and say, "Oh, you're the ones who have *Free Friday*."

- You can give away just about anything.
- People like a routine.
- The press likes it.
- It is memorable.
- It solves a waste disposal problem in a constructive way.

Pricing
Trial and error is how some businesses start out pricing used building materials, and they quickly learn which items sell fast. Other stores use a flat 50% of comparable new formula in their pricing strategy. There was a routine at the RE Store in Bellingham where staff members would silently estimate a price for a newly arrived item individually, then take the average. Ideally, the bias each human has for an item, due to the fact that each person had their own areas of special interest, be it carpentry, art and crafts, antiques or newer light fixtures, was culled out in the process. Regardless of pricing method, if something sells within hours of receiving it, the next time it could be priced higher. The popular material has to help carry the unpopular in a self-sufficient store, so the sales staff shouldn't be shy about pushing the limit on the popular materials. It's important to do; otherwise the volumes of lower grade materials handled would have to be turned down. Some stores get more than 50% of comparable new—and up to 70%—for framing lumber because cosmetics are irrelevant, it's all about function.

Another effective pricing method is to ask the customer. A regular customer will be more than happy to provide the store with advice on what a fair price on an item is. They will see this request as a reasonable person wanting to be fair. This obviously doesn't work to the store's advantage if the customer has shown an interest in buying an item first.

Lastly, if it's in the store too long, reduce the price or give the item away for free. An average of four or five weeks display time for most materials (with the exception of doors and windows) is a good target. Doors and windows require a larger stockpile to meet the wide demand in size, finish and style the public is looking for, and therefore a longer storage time to accommodate the odd style or size. Running the county's largest warehouse of used building materials is not the goal, rather waste reduction is.

Customer Service
When you error with customers, and it is the store's mistake, double the compensation to them if possible. Deliver it free, give them their money back and a credit, or give them two for one. Do whatever it takes to show that you value them and want to be given another chance. This is

another defining moment for a business of any size. On the other side of the coin: only the reasonable and polite customers are always right. Rude, unrealistic customers are not. With this type, apologize that you're not meeting their expectations, give up little, and then write them off.

TOOLS OF THE TRADE

The pneumatic denailing gun is a priceless tool for removing nails from hardwood flooring and lumber paneling. It helps considerably for denailing framing, but even the new model is too weak to do the job completely on 50% of the framing nails; pry bars and hammers are still needed to finish the job. However, denailers are a worthy investment in spite of the limitations.

The sheetrockers cart is helpful for materials in narrow aisle stores. It measures 38" long, about 22" wide, has two large wheels in the center, and has one smaller wheel at either end so it rocks or pivots on its center wheels. A tall handle on one side and a sloped deck leaning into the handle makes it perfect for plywood, lumber, and 90 lb. solid core doors. This cart can deftly maneuver any aisle wide enough to walk down and can be pushed with one hand, even with long loads.

Today Odom RE-USE Company has about 25 different wheeled devices in the store. They also have a paved parking lot and take full advantage of it. What they lack in outdoor storage, they compensate for by rolling out eight or nine carts worth of inventory to the parking lot every morning.

Another essential piece of store equipment if the chainfall, a mechanical hoist mounted from the ceiling that uses pulley ratios to reduce the weight you lift. This equipment tries to make up for a forklift–and in some instances it does–but it requires an open trailer or truck to load into, which customers do not always have. A forklift requires lots of maneuvering room, so it is not always a good investment for a smaller store. There are a variety of other hydraulic lifting devices available; some are rolling platforms that could lift a cast-iron claw foot tub up to passenger van height. Others are constructed of overhead framework known as a Gantry Crane. Budget constraints and personal preference come into play in selecting the equipment best for each store.

The pickup truck with hydraulic tailgate and a stout lumber rack is the backbone of a small store fleet. Its versatility and economy are hard to beat. Paired up with a selection of two or three different size trailers, a salvage crew can go statewide and have a worthwhile trip if the job is too small for a semi. Semi-trucks are hard to beat for the big commercial/institutional salvage job, where volumes of materials are dealt with. They have the added benefit of secure dry storage if not unloaded right away. Some trucking companies rent a loaded trailer for a monthly fee lower than mini-warehouse rates if overflow space is needed and offer off-site parking at their lots.

MARKETING

Purchase a truck or equipment—adding your business name on the truck is a common marketing tool. Label the truck with pictures of what you do, lists of materials sold, and quantities of materials rescued from burial, and that's even more marketing.

Shortly after opening Odom RE-USE COMPANY contacted the local college art department and asked if they would help build the company RE-USE Moose sculpture in part using used building materials. The enthusiastic art instructor actually did the entire sculpture with used building materials. His class had a design competition, and the final design was built by the students for college credit. Upon dedication of the sculpture, Odom RE-USE Company received great media coverage and lots of positive comments, as well as having the most unique seven-foot tall landmark on the street.

Used building material customers are primarily homeowners, often do it yourselfers. Landlords, arts and crafts folk, and small business owner/operators are also regulars. Some stores that advertise use the classifieds in the daily paper as well as the weekly advertiser type paper for reaching these customers. Classified advertising is essential to a small size store not only to keep your business name in the public eye but also to help manage limited space. When the store is tight for space, increasing "short lead time" advertising, such as classifieds or radio, helps to make more space in the store.

Odom RE-USE Co. has had a lot of luck with plain talking live ads on the local talk radio station. They also provide uniforms to employees with the company logo, give out nice oversized coffee mugs to donors, and use big yard signs at all salvage and deconstruction sites. The H.B.A. home show is a good opportunity to show off goods and illustrate services to a new group of the public. Any giveaways handed out during the show should of course be re-usable and or have recycled content.

The sign in front of a store should be as large as legally possible and easy to read from a distance and at whatever speed the traffic travels down your street.

A smart business should also call the local newspaper photographer whenever there is an interesting picture of waste reduction—of course featuring your work. They appreciate the tips; it helps photographers do their job. Call them when you are working at a well-known landmark or if you have devised a special device such as a ramp to slide seven foot wardrobe cabinets out of the second story of a dormitory, safely to the ground.

PERSONNEL

Personnel are the single most consuming challenge many small businesses face.

A good staff will make the business; a bad staff can kill the business. In staffing a used building materials business, seek out like-minded individuals with green values if you can. In Traverse City, Odom RE-USE Company has attracted a large number of self-employed people for the field crew work because they go from very little fieldwork to needing five people at once several times a year. This works well for the self employed who do their own work in slack time.

Mr. Odom experiences total labor costs, including sub-contractor costs, running at or close to 50% of revenue with taxes, work comp. and benefits included. This includes fieldwork at about 30% of labor totals and without purchasing many cash items for resale. Purchases for resale of easy to sell material, like antique tubs or doors, would quickly skew this ratio. Monitoring this ratio is critical to profitability. Any month a small town store losses money will likely been one where this ratio exceeded 55%.

Staff will follow the lead of the owner(s) and manager. Write a company handbook and give it to every employee upon hiring, spelling out your procedures and policies. Try to be as consistent as possible. Don't expect perfection.

SUMMARY

To succeed, the used building material store needs at least one committed individual in it for the long run. This person needs either a strong background in either building materials or construction, as well as some business acumen.

There is no single reason why there cannot be a used building material yard in every community big enough for a box-store home improvement center. Where today there is approximately 200 full service used building materials stores in North America; there could be thousands, at least continent-wide if not wider, in the immediate future. Wherever building material waste is generated, used building material stores also need to exist.

ORGANIZATIONS

1 Used Building Materials Association. More information on the web: ubma.org

2 The **RE*S*tore**, a project of **RE*S*ources**, headquartered in Bellingham, WA.

TECHNICAL DEVELOPMENT FOR DECONSTRUCTION MANAGEMENT

Authors: Chunlu Liu and Sung Kin Pun (Deakin University, Geelong, Victoria, Australia)
Yoshito Itoh (Nagoya University, Nagoya, Aichi, Japan)

ABSTRACT

The Australian construction industry, particularly in the area of demolishing existing facilities, is responsible for up to 40% of the country's enormous solid waste streams, totalling about 14 million tonnes annually. The recently created concept of deconstruction, rather than destruction for demolishing a constructed facility, came about because of the rapidly increasing number of demolished buildings and changes in levels of environmental awareness. However, deconstruction processes are now seen as only an interesting concept for reducing waste through reuse and recycling, but they fail to achieve widespread understanding or acceptance. The challenges faced by deconstruction are significant and diverse. The maturity of deconstruction practice depends on not only on the development of deconstruction techniques and management, but also on the enhancement of deconstruction awareness by the owners, designers, and construction teams, as well as the development of environmental regulations. These practical limitations are interrelated and mutually promotional. The technical developments in deconstruction management resulting from this research will have direct effects on various aspects, including the development of design and construction for deconstruction, deconstruction technology, reused material certification, recycling technology, and a method by which to calculate environmental benefits so that deconstruction would be promoted from an interesting concept mainly in theory to wide acceptance in practice.

KEYWORDS: Deconstruction; Destruction; Deconstruction Management; Information System; Lifecycle Waste Minimisation

INTRODUCTION

Most industrialised countries, including Australia, have achieved high levels of consumption and correspondingly high levels of waste disposal. Australia has the second-highest domestic waste production per capita among all member nations of the Organisation for Economic Co-operation and Development [1]. Nearly one tonne of solid waste is sent to landfills, per person each year, as the total waste stream in Australia is about 14 million tonnes, of which somewhere between 16% and 40% is construction and demolition waste [2]. The demolition of building structures produces enormous amounts of materials that, in most countries, result in significant waste streams. The construction industry, particularly in the demolition of constructed facilities, is the top contributor among all industry sectors to these levels of waste.

The recently created concept of deconstruction, dismantling components of a constructed facility in a scheduled process, rather than destruction of a building came about because of the rapidly increasing number of demolished constructed facilities and changes in levels of environmental awareness [3]. Deconstruction is, at present, only an interesting concept for reducing the demolition waste landfill by enhancing reuse and recycling, but fails to achieve widespread understanding or implementation. The challenges faced by deconstruction are significant and diverse. More widespread implementation and practical use of deconstruction depends not only on the development of deconstruction techniques and management, but also on the enhancement of deconstruction awareness by the owners, designers, and construction teams, as well as the development of environmental regulations, and others. These practical limitations are interrelated and mutually promotional [4]. The technical developments in deconstruction management resulting from this research will have direct effects on the development of design and construction for deconstruction, deconstruction technology, reused material certification, recycling technology, and a method by which to calculate environmental benefits from replacing destruction with deconstruction.

Based on the current construction management and information technologies, methodologies for deconstruction management are proposed in this research for the purpose of reducing demolition waste. The main expected outcome is to draw interest from the construction industry, research institutions, and government departments for the implementation of deconstruction.

MINIMUM LIFECYCLE WASTE

Construction and Demolition Waste

Since the adoption of the National Strategy for Ecologically Sustainable Development by all levels of government in Australia in 1992, the pursuit of ecologically sustainable development has been increasingly incorporated into the policies and programs of various industries [5]. With the aim of developing best practices in waste minimisation from construction and demolition, an agreement between five leading construction companies and the Commonwealth Government, the WasteWise Construction Program was initiated in 1995 to pioneer best-practice waste reduction in the industry, and was expanded in 1998 with the membership of fourteen organizations [6]. Until this program concluded in 2001, there were no residential builders who formally practiced waste minimisation, despite their significant contribution of waste to landfills.

Due to community concerns over potential environmental impacts on developed areas, it is becoming difficult to simply set up more landfills. However, the siting of landfills in remote locations increases transport costs and energy use. In recent years, there have been various attempts to set up advanced recycling technologies for demolition waste, as well as at improving landfill disposal technology [4]. As further improvements in processing are technically limited, future efforts will have to concentrate on improving the methods of deconstruction. The conventional destruction of buildings often leads to the mixing of various materials and the cross-contamination of its components. A small fraction of the solid waste generated during the demolition of buildings contains chemicals hazardous to human health and the environment [7]. Research presents that the leachate from land filled by solid waste from construction and demolition activities poses a potential risk to groundwater quality [8]. In addition, the destruction might result in a large disaster. For example, the flying debris from demolishing the Royal Canberra Hospital building on 13 August 1997 killed a girl and sent at least nine others standing in a designated viewing area located 300 metres away to the hospital with serious injuries [9]. Although the idea of dismantling buildings into various parts during deconstruction evolved quickly in the construction industry, few successful approaches have been available. This subject needs long-term efforts in various aspects, including research to promote deconstruction in practice so as to decrease the rate of demolition waste to landfills, reusing more building components, and increasing the ease of recycling materials.

In present practice, the concept of deconstruction is hard to implement due to the low or negative economic benefit gained from systematically dismantling a building, rather than demolishing it. In addition, sub-contractors are not equipped with the necessary techniques and equipment that an efficient deconstruction process would require. A well-researched framework to develop the management of deconstruction could assist contractors and sub-contractors to decrease demolition waste in construction projects.

Lifecycle Analysis of Construction Materials

The idea of depicting the lifecycle of a particular construction material is to ascertain what the main events are in the cycle, from the extraction of raw materials to the final disposal to landfill. This gives an indication of how long certain materials or structural components can possibly be used to gain the maximum possible lifespan, thus reducing waste over time. To identify and evaluate opportunities for environmental improvement and to evaluate the environmental burdens affiliated with a product, materials used, wastes released, and the classification and quantification of energy must be assessed over a lifecycle. Figure 1 shows the degradation of a typical material in a cycle. Due to the variety of materials used in construction, some details in this cycle may differ from one to another.

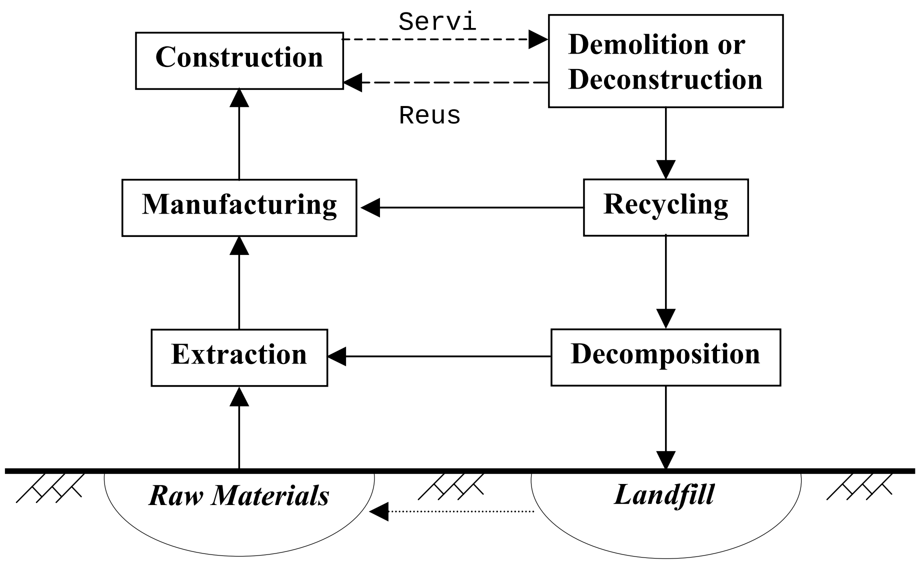


Figure 1 Lifecycle of construction materials

The process of the material lifecycle begins with the extraction of raw materials. For example, with aluminium, bauxite is extracted from the earth and then processed to make aluminium. The aluminium, which is now in bulk form, has to be manufactured to suit its application within the building design. It may be an extrusion that joins panels together, or it may be part of an electrical fitting. The processed item is then transported to a warehouse-like environment, from which it is used in construction. Finally, it is constructed as a part of a building, with maintenance undertaken on it. In the case of aluminium collected from deconstruction activity, it is more likely to be recycled by being melted down to form with extraction, and then manufactured again. Aluminium, which is, ideally, constantly recycled, will eventually end up in a landfill if it is unfit for recycling due to contamination or ineffective demolition. Other various materials fall into multiple streams of different categories depending on how many times they are reused, and other factors such as the location, the climate, and the usage applied.

When assessing reuse feasibility, technological, economical, and ecological aspects are important considerations [10]. Technology has to be improved to achieve efficient methods of deconstruction, so that the materials being salvaged are worth the effort economically. Some worth must also be given to the positive impact that the reuse or recycling process has on the local ecological environment. By giving thought to the steps in a construction material's lifecycle described above, an information management system built on databases could be developed to locate potential opportunities for direct reuse of materials from one project to another within a region. For example, a building may require large amounts of timber for a section of work. Significant economic and waste saving could be achieved if the particular sub-contractor were able to efficiently locate the equivalent amount of second-hand timber deconstructed from a site in the same vicinity. In the long term, the ideal situation would be to flood the market with second-hand construction materials and construction products.

Maximum Conservation of Construction Resources

The concept of waste management is a crucial element in determining how much waste material is sent to landfills, and in determining how waste can be reduced. As discussed above, landfill creation is an outcome that communities would aim to avoid, due to the huge planning and environmental issues involved. Waste reduction can be limited by reducing the supply from the construction and demolition industry. An ideal solution for a constructed facility that cannot be used as it is, from the structural or functional standpoint, is to renovate or relocate it. For example, in 2001, the Architectural Institute of Japan launched a design competition to extend the service life of a building to one hundred years, three times the existing design life of thirty years [11]. In this case, the life of the building is extended, and the majority of the building is retained. In addition, buildings that are optimally designed with environmentally sustainable materials and with deconstruction in mind are of extreme value when it comes to reducing waste. However, most buildings that are currently being refurbished or totally demolished are not of this nature. Through optimal material selection and with the necessary maintenance, buildings are in the position to exist for many years. When the clients' wants and needs change and the building is no longer suitable, the materials used for fit-out can be efficiently retained through deconstruction, and either reused or recycled. This should result in minimal waste to landfills, and thus achieve the goal at the outset. The main structure of the building can still exist through refurbishment. When the time comes for demolition, it can then be deconstructed to achieve maximum reuse. It forms a decision-making tree with the wastes at the bottom, meaning that they are the last choice. Figure 2 describes that there is a maximum conservation of resources by preventing waste at the outset, by optimally designing the building, and by extending the building's life.

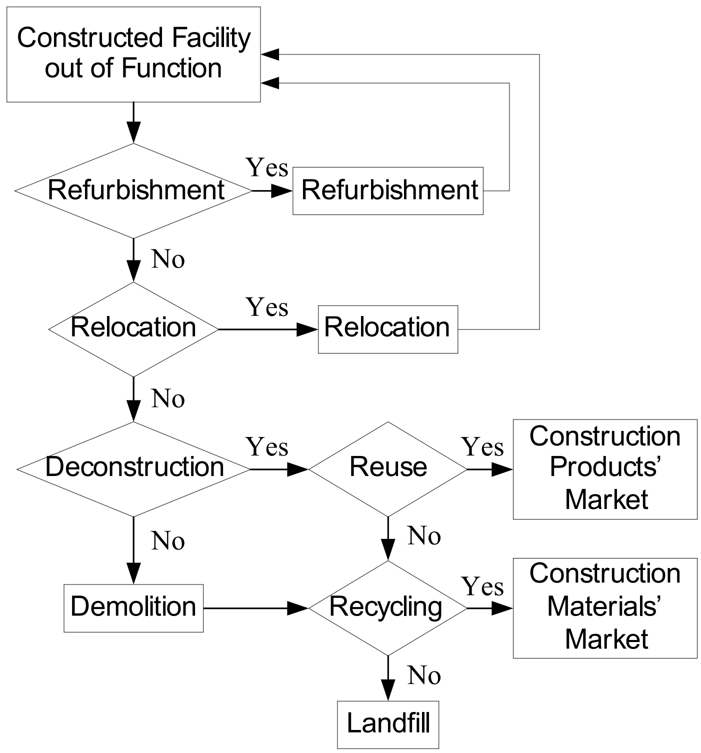


Figure 2 Maximum conservation of construction resources

Deconstructing the building and reusing its materials would provide the next best result, compared to refurbishment or relocation, in terms of waste minimization. Deconstruction resulting in recycling allows a majority of the material to be recycled and reprocessed into a building element. The last process in order of preference is the disposal of the demolished waste to landfill, which should only occur after all other options have been fully explored and investigated using deconstruction management approach. The current high incidence of waste material from demolition is a result of buildings being rigorously demolished to rubble, leaving no reusable materials. Recycling is also out of the question, due to the high labour content required and difficulty in sorting the different materials. Sub-contractors quickly complete the current typical demolition project prior to moving onto the next job. They are simply fulfilling their contract and getting paid accordingly. Due to cost factors, there is often no time in the current production-orientated system to be concerned with systematically sorting every bit of material that is demolished, unless it is specifically requested in the contract. The occurrence of this situation results from various factors as previously mentioned.

PROMOTION FROM DESTRUCTION TO DECONSTRUCTION

Destruction and Deconstruction

Deconstruction was hardly considered while most existing buildings or building components were designed, constructed, or repaired. In addition, neither the equipment nor the techniques have been especially developed for deconstruction. Under these conditions, deconstructing a commercial or industrial building or a body of infrastructure is very difficult for a demolition company to adopt, for the time being. For residential structures, particularly those made from timber and bricks, there may be fewer requirements for special tools or machines, and their main building components can be more easily reused or recycled. Furthermore, the enormous number and similar structural characteristics of residential buildings will also enable the deconstruction team to develop and apply the deconstruction technology and management approach more easily. This makes residential structures ideal locations to adopt experimental deconstruction.

It is obvious that the deconstruction of a building has many advantages over conventional destruction from the viewpoints of local and global environmental protection [12]. However, the low or negative economic benefit of deconstruction may influence the industry to consider not dismantling a building, but demolishing it. Cost, then, is a significant factor, and is usually the main factor that the industry as a whole applies when making decisions. Safety is also a significant factor to consider when opting for either method of dismantling. When using machines required for heavy demolition, there must be care taken to avoid injury to labourers and other personnel on site. There can be higher potential for injury when deconstructing materials such as glass and sharp steel, so care must be taken. Guidelines and effective procedures would have to be developed if deconstruction were to become more prevalent in the industry, so that issues such as safety would be adequately addressed.

Development of Deconstruction Implementation

The current level of deconstruction of structures is severely limited by numerous factors. The main obstacles can be categorised as environmental awareness in the construction industry, deconstruction techniques, deconstruction management, and legal regulations. So far, most buildings have been designed and constructed with no consideration of what will happen to them after the service life, and design for deconstruction or construction for dismantling has only been recognised for a few years by only some researchers. Environmental awareness has not yet been developed in the building owner, the designer, or the constructor. Research and development on deconstruction technology and management have not drawn much apparent interest from managers or engineers, and no authoritative governments or associations have published a "deconstruction code." Some current legal regulations do not promote deconstruction implementation. For instance, the disposal costs for demolition waste are rather low and the certification procedure for the quality of used components has not been well established or widely understood. In the Victorian landfills in Australia, the difference of disposal costs per tonne between municipal solid waste and construction and demolition waste is only one Australian dollar [13]. Figure 3 shows these subjects, to be developed for the implementation of deconstruction.

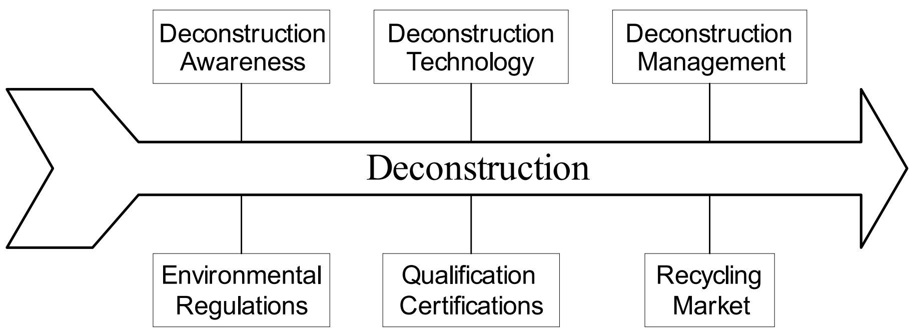


Figure 3 Development of deconstruction implementations

The implementation of deconstruction on a large scale is dependent upon the development of various subjects. They contain: the development of deconstruction techniques and management, the enhancement of deconstruction awareness with the owners, designers, and construction teams, the development of environmental regulations, quality certificates, and a market for reused materials and products. It can be forecasted that deconstruction will be highly beneficial to the current construction industry and the environment. The development of these practical subjects is interrelated and mutually promotional. For example, the technical developments in deconstruction management have direct effects on the development of other subjects.

Key Issues for Deconstruction Management

Similar to the resource requirements of a construction project, on a deconstruction project, a diverse group of people come together. Divergent materials or components change their shapes, functions, and positions, and specially developed machines act in three-dimensional space. The deconstruction activities also need to achieve requirements in time, cost, quality, and safety. Deconstruction also contains unique management contents, due to its strict environmental protection requirements, its newly emergent issues and uncertainty, and so on. The currently well-developed construction management methodologies can be modified to model the environmentally friendly dismantling and recycling of constructed facilities by integrating them with the latest information technologies. The following are several basic issues of the promotion of deconstruction management:

Modelling Dismantling Activities

Different dismantling activities may be defined according to a number of variables, including the type of building under consideration, the dismantling techniques available, and the objective of the dismantling effort. Different environmental constraints, like obligatory levels of separation, can also lead to different dismantling activities. After the dismantling activities are determined, the resources necessary and the duration of the activities need to be specified in detail. Usually, each dismantling activity can be processed using different dismantling techniques, which can be expressed by the use of different resources, and which will result in different processing times. For instance, the dismantling action of an outer wall of a residential house can be performed using pneumatic hammers, by a grabbing bucket, or with a hydraulic excavator. The different dismantling techniques result in different disposal costs, varying demolition time, and different environmental impacts during and after the dismantling activities.

Deconstruction Database Development

The deconstruction data and the general information of a project must be captured from several sources, including the building owner, estate agency, and the deconstruction engineering team. Similar to the construction of a building, the deconstruction of a building contains product data to represent the characteristics of each building component, such as the compositions of an outer wall, and processes this data to represent the necessary information related to a dismantling activity. The database is used as an information hub for the deconstruction project's scheduling and site planning. The national architectural design code system may be referenced to define the data item in the database, in order to represent each dismantling activity. The data related to each product to be deconstructed are input into the database, and these data may contain all the resource requirements including materials, machines, workforce, budget, time, and space. The resources needed for one dismantling activity can be classified as renewable resources, such as machines, and non-renewable resources, such as the financial budget. The renewable resources used for one dismantling activity are calculated on a period basis, but the non-renewable resources consumed in a dismantling activity are calculated over the entire duration of the project.

Deconstruction Scheduling

The planning of dismantling activities is undertaken on a project basis. Using scheduling principles, the scarce resources available for deconstruction can be allocated to these dependent or independent activities, over time and through the site, in the most efficient manner. A deconstruction schedule is, for each deconstruction process, an allocation of one or more time intervals to one or more deconstruction products. Deconstruction schedules may be deconstruction product-oriented or deconstruction process-oriented. The corresponding scheduling hurdle is finding a schedule to meet the various challenges in the most efficient way. The deconstruction schedule is first modelled and optimised using network analysis, and then represented in the bar chart so that it can be easily understood. The availability of deconstruction project scheduling relies heavily on the project participants' ability. Compared to construction, deconstruction planning of a building is more demanding in time, space, safety, and environmental regulation.

Visualisation Simulation

The visualisation approach of a deconstruction project may be developed in the Computer-Aided Design (CAD) environment. The recently developed Virtual Reality Modelling Language (VRML), with free downloaded software, may also be used for the visualisation processes. Complete data from the whole building are vital for the visualisation process. In most cases of existing buildings to be deconstructed, the CAD drawings are not produced in three dimensions (3D). As generating a very accurate and detailed CAD of a whole building requires a team of professional CAD drafters and a sound investment, a simple 3D CAD following the brief architectural code of building components may also be acceptable. The salvaged product resulting from deconstruction and its effect on the deconstruction site are strongly dependent on the deconstruction process and dismantling activities adopted. Therefore, three kinds of visualisation need to be developed. They are the deconstructed products (building components), the deconstruction processes (dismantling activities), and the deconstruction space (site location). Due to a lack of engineering experience and theoretical knowledge in deconstruction, rational deconstruction scheduling is more difficult to generate for a practical project, and therefore a better model is particularly necessary for the deconstruction process in practice. The development of a visualisation technique for deconstruction planning will make a substantial contribution towards achieving this target, and will also be conducive to the spreading of deconstruction in practice.

Economic and Environmental Contributions

The purpose of the modelling and visualization is to evaluate the improvements that could be achieved from deconstruction implementation. Computational results for a typical structure may be used to show the differences between destruction and deconstruction under various dismantling scenarios, so as to quantify both economic and environmental values of deconstruction. Each dismantling scenario, with different techniques and restrictions, may be defined in conjunction with the demolition or construction company. Furthermore, with the increased numbers and types of deconstruction projects, the development of deconstruction techniques, and the implementation of environmental protection regulations, deconstruction management may become an attractive teaching and research field, like present construction management.

DEVELOPMENT OF DEMOLITION MATERIAL MANAGEMENT SYSTEM

System Function Development

In recent years, with the increasing pressure of environmental requirements, second-hand material or product exchanges have been widespread in various fields. Approaches based on information technologies, particularly the Internet, are used for research and practice to promote such exchanges, and several management systems have developed for waste exchange [14]. However, either the information about construction and demolition waste or the number of contractors who want to buy second-hand materials or construction and demolition waste is very limited [15]. In order to develop a widely accepted, internet-based waste management system in the construction sector that will overcome the limitations of conventional waste-exchange systems, a couple of new features are added to the developed information system, Demolition Material Management System (DMMS).

Different from most conventional waste management systems, DMMS deals with both construction and demolition waste, particularly the latter, for the purpose of promoting deconstruction. Generally speaking, compared to demolition waste, construction waste is relatively easy to reuse or recycle, due to the singularity of waste materials. Instead of the conventional, second-hand construction material exchange, DMMS aims at the generation, exchange, and disposal of demolition materials. The providers of demolition materials may seek potential demanders of second-hand materials and construction projects before the implementation of demolition, so that the demanders may be involved in the demolition activities, and the demolition may be oriented to reuse or recycle demolition materials. In addition, DMMS supports the information exchange of demolition projects and construction projects for a long term, so that a demolition project may be scheduled in consideration of the construction projects which need demolition materials, and vice versa. As shown in Figure 4, for the purpose of information accuracy, membership is required before providing demolition supply or demand information. Besides the systems managers, general web visitors may also positively participate in the systems, navigating the education module, chatting on the visiting board, or browsing system information. The current URL for demonstrating DMMS is: http://www.deakin.edu.au/~skp/dmms/. The remainder of this section will briefly describe the system structure design and implementation.

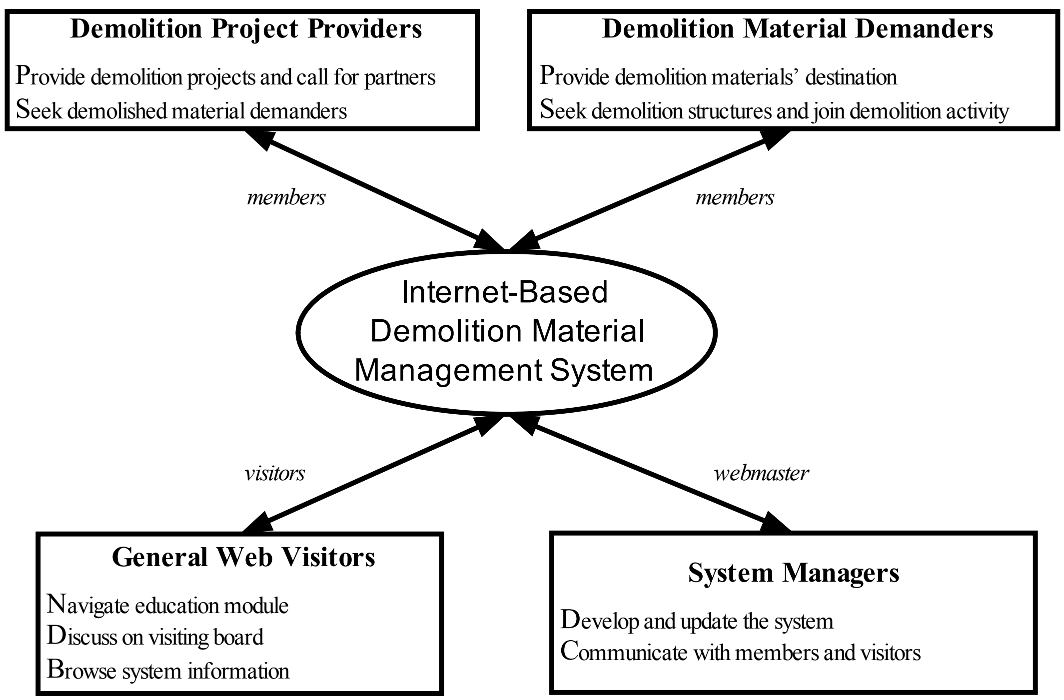


Figure 4 Roles of system participants

System Structure Design

The system uses three-tier client-server architecture. As shown in Figure 5, the Oracle database server manages the databases that describe projects, materials, and user profiles. The Web server acts as both client and server. The PHP (Hypertext Pre-processor) is a part of Web server, and gives the privileges of retrieval, modification, insertion and deletion of databases by the system program. On the other hand, it generates an HTML (HyperText Markup Language) code for the client side, according to the result from the database.

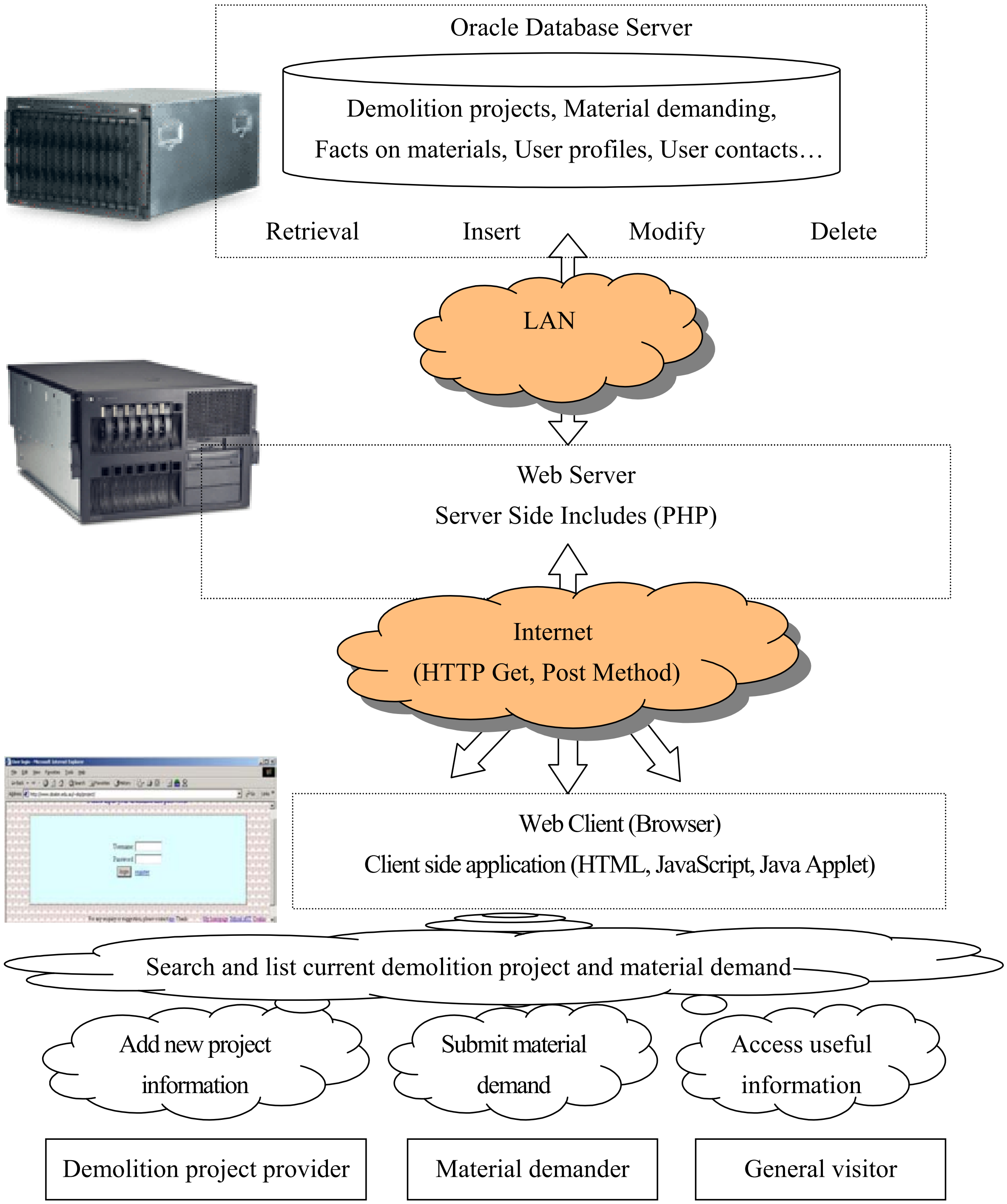


Figure 5 System structure

The client-side program runs inside the Web browser, the most available tool to access Internet. Its application entities include HTML, Java Script, and Java Applet. HTML gives the appearance and formation of the Web page, while Java Script helps in forming the Web page and validating the data inputted by the user. These two elements communicate to the server using get and post methods from HTTP protocol. They form the main application part of database access, including the demolition-project provider inserting a project into the database, the material demander inserting a material demand into the database, and all users retrieving project information from the database.

While HTML form is insufficient to describe the object to be submitted to the Web server, Java Applet performs this important part. It provides genuine graphical user interface to a user contrasting raw HTML form. It is also dynamic in one single Web page, without the need to refresh the page. More importantly, support of standard protocol allows Java Applet to retrieve information from the PHP program, and transmit information the user inputs on the client side back to the PHP program. This feature is extremely useful. The system needs a user to draw a simple shape of their building to be demolished. The characteristics of the drawing are sent to the server, and the whole drawing is saved in the server as an image file. This customer-drawing approach will help users to gain knowledge of the building that is retrieved from the database.

System Implementation

The Web page is divided into three frames. The upper frame does not carry any actual function. It displays the title banner to the page. The left-side frame is the main menu area. Content regarding a particular menu item appears in the right-side frame.

The first and default menu item is the “Notice Board.” It displays up-to-date information about the change of the Web page. The “Member Area” is the core of the system, and the main source of the database. If a user has not logged into the system, the login screen will be shown to authenticate members by username and password. The user also has the choice of registering as a member, and providing contact information. After logging into the system, submenu items are shown. “Changing Profile” and “Changing Password” allow a member to change his or her personal contact information and password.

“Adding Project” provides a wizard-style procedure to members, allowing them to add a project into the database step-by-step. The data needed for the process includes: the type of the project, the location of the project, the earliest and latest available start date, photos that help to describe the project, the dimensional and structural features of the project, and a user custom drawing tool, which allows the user to draw lines and shapes to further describe the project. Figure 6 shows the interfaces when a user provides information of a demolition or construction project into DMMS. After all necessary data is collected, potential materials produced or needed are categorized, quantified, and listed. The user is able to modify these numbers, if the user is able to gain more precise data through other mechanisms. The data is then stored into the database. The user is able to remove projects from his or her list, in case the exchange is completed and the materials are no longer available. The user can also modify the quantity of a particular item, or items, on the list.

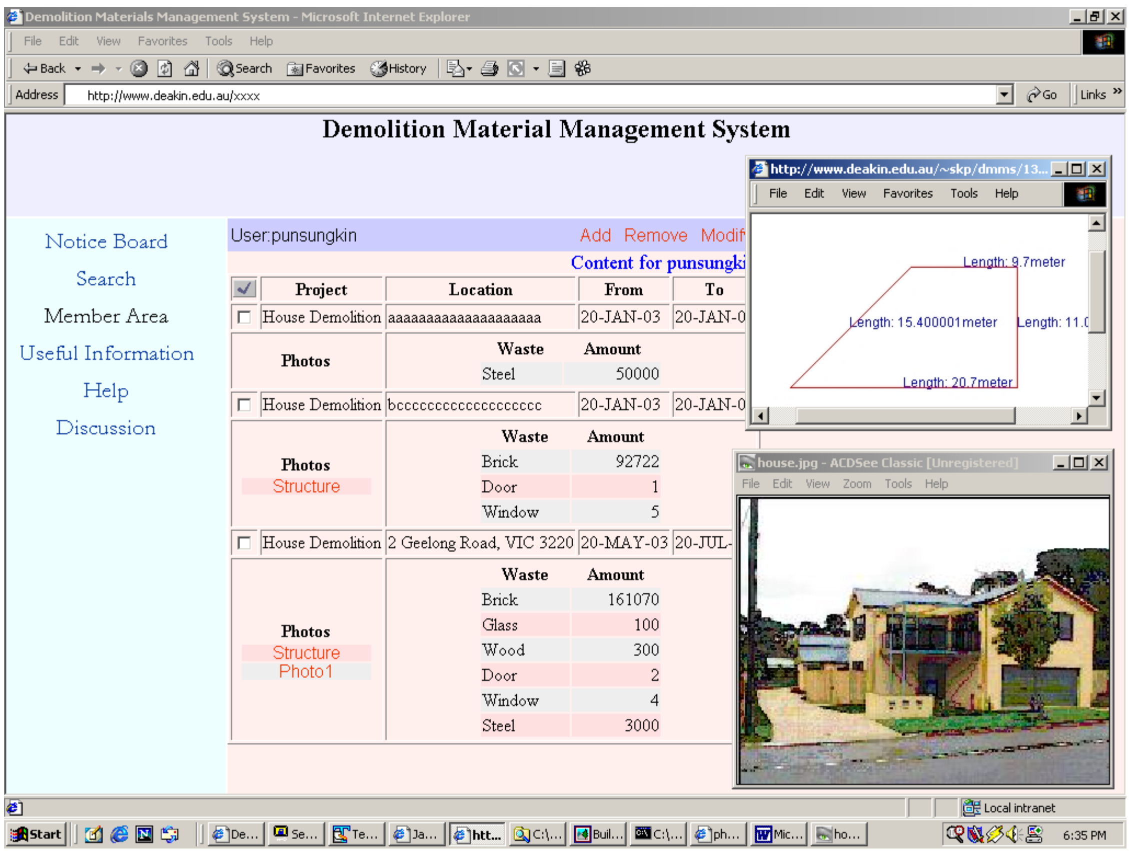


Figure 6 Interface of demolition project information acquisition

"Search" is also an important part of the system. Users can search the catalogue using single or combined criteria, including date, location, and the type and amount of materials. There are also pre-defined categories for quick access. While viewing listed search results, only a member who has logged into the system can see the contact information for every project. The "Useful Information" section gives users, both members and non-members, lessons on deconstruction and the environment. "Help" is also available, which shows the user how to use the Web page, and addresses possible problems and questions. Finally, a "Discussion Board" allows users to discuss issues of material reuse and recycling. It also provides a channel for the system manager to answer questions from users.

DISCUSSIONS AND CONCLUSIONS

In recent years, lifecycle management approaches have been broadly applied to constructed facilities from the viewpoints of function, economics, environment, and safety. Because of the lack of deep study into deconstruction, these approaches hardly achieve any actual lifecycle analyses. This research will promote the expansion of lifecycle management in engineering practice, as well as in academic education and research. Furthermore, it is envisaged that the deconstruction management developed from this research would have tremendous effects of salvaging demolition waste from landfills. To enable the demolished materials to be reusable or recyclable will not only prevent natural land from becoming a possible landfill, but will also avoid the excessive extraction of raw materials from the earth. There is no doubt that deconstruction represents the future of demolition, and will eventually create a new industry sector. Despite its delay in gaining wide understanding and practical implementation, the continuing efforts to promote deconstruction over destruction, and the practicable deconstruction management techniques developed in this research, will accelerate deconstruction progress. All demolition clients, demolition firms, and demanders of reused or recycled materials will benefit from the broad adoption of deconstruction. In addition, this research will lead to a better understanding of deconstruction and deconstruction management, will speed up the development of relative aspects such as the enhancement of deconstruction awareness, the establishment of environmental regulations, the recycling market, and qualification certifications of reused or recycled construction materials and products.

The main conclusions generated form this research can be stated as follows: (1) The needs of deconstruction are emphasised so as to draw interest from the construction industry, research institutions, and government departments for the widespread implementation of deconstruction. (2) Based on the lifecycle of construction materials, the maximum conservation progress of construction resources is put forward for the purpose of waste minimisation of construction materials. (3) The advantages and disadvantages of deconstruction are compared with those of demolition. The basic requirements for implementing deconstruction are also discussed. (4) In order to promote the application of deconstruction, a model and a demonstration site of an internet-based demolition material management system are developed for the generation, exchange, and disposal of demolition materials and construction waste.

REFERENCES

1 **New South Wales Environment Protection Authority:** *Human Settlement*, http://www.epa.nsw.gov.au/soe/soe2000/ch/, accessed on 15/01/2003.

2 **Reddrop, A. and Ryan, C.** *Housing Construction Waste: A Research Study by the National Key Centre for Design*, Australian Government Publication Service, Canberra, 1997.

3 **Itoh, Y. and Liu, C.** Introduction: Sustainable Civil Infrastructure Systems, *Journal of Computer-Aided Civil and Infrastructure Engineering*, Vol. 17, No. 3, 2002.

4 **Chini, A. R.** *Design for Deconstruction and Materials Reuse*, CIB Publication 272, International Council for Research and Innovation in Building Construction, 2002.

5 **Australian Ecologically Sustainable Development Steering Committee.** *National Strategy for Ecologically Sustainable Development*, Australian Governments Publication Service, Canberra, 1992.

6 **WasteWise Construction Program.** *Major Achievements of WasteWise – Phase II (2001)*, http://www.ea.gov.au/industry/waste/construction/wastewise/, accessed on 15/01/2003.

7 **Sheridan, S. K., Townsend, T. G., Price, J. L., and Connell, J. T.** Policy Options for Hazardous-Building-Component Removal before Demolition, *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, ASCE*, Vol. 4, No. 3, 2000, pp. 111-117.

8 **Weber, W. J., Jang, Y. C., Townsend, T. G., and Laux, S.** Leachate from Land Disposed Residential Construction Waste, *Journal of Environmental Engineering, ASCE*, Vol. 128, No. 3, 2002, pp. 237-245.

9 **Tabloid News Service**, *Rain of Horror Pounds Aussies*,

http://www.tabloid.net/97/07/14/B1.html, accessed on 15/01/2003.

10 **Hendriks, C. and Dorsthorst, B.** Reuse of Constructions at Difference Levels: Construction, Element or Material. CIB *World Building Congress*, Wellington, 2001.

11 **Architectural Institute of Japan.** *Architectural Design for Reduction of 30% LCCO2 and Extension of three Times of Service Life (100 Years)*. http://www.aij.or.jp/aijhome.htm (in Japanese), accessed on 15/01/2003.

12 **Kibert, C. J. and Chini, A. R.** *Overview of Deconstruction in Selected Countries*, CIB Publication 252, International Councill for Research and Innovation in Building Construction, 2000.

13 **Industry Research and Strategy Report**: *Understanding the Waste Stream, Statistical Overview*, EcoRecycle Victoria, Melbourne, Australia, 2000.

14 **Global Presence.** Resource Exchange Information System for Regional Exchange Operators, http://www.globalpresence.com.au/exchange/, accessed on 15/01/2003.

15 **Chen, Z., Li, H., and Wong, C.** Webfill before Landfill: An E-Commerce Model for Waste Exchange in Hong Kong, *Construction Innovation*, (in press) 2003.

EVALUATING A DECONSTRUCTION BUSINESS MODEL

Authors: George C. Penn (Global Energy Options); Steve Knudsen (Global Energy Options); Ingo Bensch (Energy Center of Wisconsin)

ABSTRACT

This paper discusses the accomplishments and challenges of a new business in Milwaukee, Wisconsin that was started to deconstruct houses with the intent of building new houses. This business also seeks to provide other social benefits to the community such as training of inner-city youth and development of affordable, energy-efficient housing in declining inner-city areas. The evaluation project looked at the construction of the business' first home which has been used as a Model Home and recommendations for dealing with the challenges faced with the business model.

The Energy Center of Wisconsin (ECW) was interested in evaluating several issues related to the operations of this new business. These issues included:

- Energy Use and Emissions Impacts
- Recoverability of Materials from Deconstructed Homes & Landfill Impacts
- Amount of Recovered Materials Used in Construction of the Model Home
- Business Model Challenges
- Transferability of this Business Model in Other Parts of Wisconsin

This paper will briefly discuss the research approach and the results of our findings. We recommended changes for consideration for anyone interested in this type of business model including creating a non-profit business form and ensuring that recovered materials not immediately useful to present home construction are sold to improve cash flows.

KEYWORDS: Deconstruction; Environment; Embodied; Energy; Landfill; Business

INTRODUCTION

This paper discusses the results of an evaluation conducted to review a business model being tested under a project funded by several organizations in Wisconsin interested in deconstruction tied to new home construction. The Energy Center of Wisconsin was one of the funding organizations and sponsored the evaluation of the effort. Before this discussion we provide some insights into the deconstruction industry.

Deconstruction, the systematic disassembly of a building to recover materials for reuse, is a new term to describe an old process that was commonplace prior to 1950. Since that time mechanical demolition has become the dominant means by which buildings are taken down. The primary advantage of mechanical demolition is that buildings can often be taken down more quickly at less cost than they can be using deconstruction. However, rising landfill costs and diminishing landfill capacity, increased interest in recovering quality building materials, and growing awareness of the environmental effects of demolition have led many to reconsider deconstruction.

Previously Reported Benefits of Deconstruction
One direct benefit of deconstruction is that it reduces the amount of materials that are disposed of in landfills. Estimates of the total amount of construction and demolition (C&D) debris generated annually in the U.S. vary between a fifth and a third of the nation's solid waste stream. The Environmental Protection Agency reported in 1996 that the U.S. produced an estimated 136 million tons of building-related C&D debris and estimated that only 20 to 30 percent of this debris was recovered for reuse or recycling.[1] In 1999, WasteCap Wisconsin estimated that Wisconsin is expected to have generated nearly one million tons of C&D debris in that year.[2] It is claimed that a significant portion of building materials that become debris could be reclaimed by deconstructing buildings instead of demolishing them. Other reported environmental benefits of recovering materials include conserving timber resources and saving the energy needed to manufacture new building materials, which, in turn reduces air emissions, water pollution, and land use impacts.

Deconstruction and the resale of recovered materials may also provide business and employment opportunities in local communities, especially those that are candidates for neighborhood revitalization. According to one source,

> "Deconstruction is optimal for rebuilding local economies. Deconstruction can promote the recycling of dollars spent in a local economy by providing local salaries, channeling salvaged materials through local building material reuse stores, and by supplying material to local re-manufacturing operations and local housing renovation projects." [3]

The National Association of Home Builders (NAHB) concludes that deconstruction is especially suited for training youth and low-skill workers with an aptitude and an interest in the building trades.[4] Also, the Institute of Local Self Reliance suggests that other professional career opportunities offered by employment in deconstruction include historic restoration, land reclamation, re-manufacturing, brown-fields remediation, and lead hazard remediation. [5]

In the past, conventional business experience suggested that deconstruction was more costly than demolition, and that it would be difficult for deconstruction businesses to compete with their demolition counterparts. However, the revived interest in deconstruction has spurred research that more carefully investigates the economic impacts of deconstruction, including its cost-effectiveness.

Three Studies Relevant to This Work
Our literature review included a variety of works. Three studies we reviewed provide significant insights related to our findings.

A study conducted by the University of Florida's Center for Construction and Environment involved deconstructing six houses during 1999-2000 to examine the cost-effectiveness of deconstruction and salvage when compared to traditional demolition. The study concluded that “deconstruction can be more cost-effective than demolition when considering the reduction in landfill disposal costs and the revenues from salvage.” [6]

Another study by the NAHB Research Center examined the disassembly of a 2,000 square foot residential building in Maryland. The study documented the amounts and types of material recovered, labor costs, time spent on disassembling the building and processing the recovered materials, and the salvage value of the recovered materials. The study found that 70% by volume of all materials from the building were either salvaged or recycled. Also, the total cost for deconstruction, including maximum salvage and recycling, was estimated to be between $4.50 to $5.40 per square foot, while standard demolition was estimated to be between $3.50 and $5.00 per square foot.[7]

The results of these two studies suggest that deconstruction could be cost-competitive with demolition *provided that a high material recovery rate is achieved and that a significant portion of the recovered materials can be sold*.

Despite the barriers, efforts have been made to incorporate recovered building materials into new construction. For example, we reviewed a third effort by GreenHOME which built a single family home using recovered materials. These materials included flooring, brick, interior doors, flagstones, kitchen cabinets, and framing lumber. Like GreenHOME, a major goal of the REEHouse project is to use recovered building materials to construct affordable housing in Milwaukee. (GreenHOME is a non-profit organization that promotes sustainable homebuilding for low- and middle-income residents in Washington D.C.).

The REEHouse Project

The REEHouse project discussed here recovered materials by deconstructing buildings and used them to construct a demonstration single-family home in a Milwaukee neighborhood. REEHouse, Inc. (REEHouse) also sought to provide job opportunities for the community, training opportunities for inner-city youth, and affordable housing for low- and middle-income homebuyers in the city. The entrepreneur developed business model to be for-profit while partnering with local non-governmental agencies providing social services consistent with this goals.

In order to start this business, the owner sought out funding from governmental and non-governmental organizations for start-up grants and in-kind services. The first step was to get funding to develop a business plan. With this funding in hand he worked with a professor at the University of Wisconsin in Milwaukee in the Architecture Department to develop a plan. Using this plan he was able to get startup funding from several state agencies and other organizations. These agencies and organizations included the Wisconsin Department of Natural Resources (Solid Waste Reduction and Recycling Demonstration Project), ECW, Wisconsin Recycling Market Development Board, Wisconsin Conservation Corp., Harambee Ombudsman Project, Northside Community Development Corporation, and the Milwaukee Urban League.

Each of these organizations contributed either financial or in-kind services toward the startup and test of this for-profit business. For example, the Department of Natural Resources, ECW, Recycling Market Development Board, and Urban League contributed funds as grants. The

Wisconsin Conservation Corp contributed labor costs for the youths trained by the project and the Northside Community Development Corporation contributed in-kind space in a business development facility. And the Harambee Project sponsored a construction loan for the Model Home.

The project was funded for two years, after which it was expected that the business should run on its own cash flows.

The Evaluation
The evaluation that is the basis of this paper investigates the deconstruction and construction processes used by the REEHouse business. The objectives of the evaluation included determining the material, energy, environmental, and affordable housing impacts of the project, and the degree to which these impacts are beneficial to the business, the community, and to society at large. Research methods used in the evaluation include data collection and analysis, home construction site visits, interviews with REEHouse staff and other stakeholders, and literature and on-line searches. The full 139 page report is available through the Energy Center of Wisconsin by calling on of the authors.

Milwaukee is a city that is rich in deconstruction material resources from condemned houses of two types. There are both Inner-city under-maintained houses in lower income areas and houses in flood plane zones that have been targeted for removal by the city. This suggests that Milwaukee is potentially a good place for a deconstruction business.

On attribute of the REEHouse business model that is unique compared to the few similar efforts around the country is that REEHouse seeks to operate as a for-profit business. This unique characteristic is in part what drove the interest in evaluating the business model.

WHAT THE EVALUATION HOPED TO SHOW

The evaluation was interested in investigating the material, energy, environmental, and economic impacts of the REEHouse project by examining the project's deconstruction and Model Home (the Home) construction efforts. The evaluation hoped to determine the amount of materials that were recovered by deconstruction and subsequently used to construct the Home, and whether using recovered materials reduced the Home's construction costs. Comparison of the Home's construction costs with similar-sized single-family homes in Milwaukee that used standard construction methods was of particular interest.

The evaluation was interested in learning about the energy and environmental impacts of deconstruction and Home construction, especially as they related to savings in embodied energy and avoided disposal of materials in landfills. Since the Home was also designed to be energy efficient, the evaluation also was interested in determining how much operating energy the Home would save compared to standard, similar single-family homes.

Further, the evaluation was interested in finding out whether deconstruction was cost-effective. REEHouse's goal of training youths in the building trades through deconstruction and how this training affected deconstruction and the Home construction operations were also of interest. Further, the barriers encountered by the REEHouse project and the project's impacts on the community were of interest.

Finally, the evaluation wanted to learn what the potential for deconstruction was for other parts of Wisconsin, and whether the REEHouse project could be replicated in other Wisconsin communities.

Approaches

A number of approaches were used to evaluate the impacts of the REEHouse project. The approaches centered on three research methods:

- Data collection and analysis
- Interviews
- Literature and on-line searches

The research methods reflect the particular needs of the type of research being conducted for each of the key research topics. One or more of the three methods listed above may be used to investigate each key research topic.

Key Research Topics

Evaluation of the REEHouse project is centered on several key research topic areas including:

- REEHouse Model Home Material and Cost Analyses
- Energy Impacts
- Environmental Impacts
- Economic Impacts
- Replicability of the REEHouse Project

We provide a short summary of how these impacts were developed here. There is a much more robust discussion of the methods used to develop the results reported in the full report.

The Home's material and cost analyses were accomplished by a robust accounting of the materials used in the construction of the home. The amount and types of materials used to construction were itemized from the design drawings and verified by numerous visits during the construction of the home. The construction costs were then developed using local supply company costs for the materials used.

There are two types of energy impact analyses conducted for the evaluation. The operating energy savings (electric and gas use) for the home was determined by modeling the Home and three standard home designs in REMRate. This tool is used for the home performance programs in place in Wisconsin. The embodied energy savings were determined by assigning embodied energy values for each of the materials both recovered through deconstruction and used in construction of the Home. Embodied energy savings related to not demolishing and transporting the recovered materials to the landfill were also quantified.

Environmental impacts that are discussed are both qualitative and quantitative. The quantitative impacts include emissions reductions, landfill deferral, logging requirements reductions and others. There are emissions reductions from both reduced operating energy and from reduced embodied energy requirements. Previous studies conducted by Global Energy Options have determined the emissions for electric and gas use in the state. For example, the pounds of CO2, SO2, NOx, Hg and particulates emissions emitted for each kWh delivered to a home are known and applied to the electricity used by the Home and the standard homes to determine reductions (savings). For a frame of reference, we follow with two tables from the report.

Table 3
Air Emissions Factors:
Embodied Energy Savings –
Industrial and Transportation Components

Air Pollutant	Industrial: Coal (lbs/MMBtu)	Industrial: Natural Gas (lbs/MMBtu)	Industrial: Petroleum (lbs/MMBtu)	Transportation: Petroleum (lbs/MMBtu)
Carbon Dioxide (CO_2)	218	117	159	162
Carbon Monoxide (CO)	- - - - -	- - - - -	- - - - -	1.26
Sulfur Dioxide (SO_2)	1.094	0.0006	0.5071	- - - - -
Nitrogen Oxides (NO_X)	0.566	0.1000	0.1429	1.03
Hydrocarbons	- - - - -	- - - - -	- - - - -	0.27
Particulates	0.020	0.0070	0.0143	- - - - -
Mercury (Hg)	0.000016	0.00000026	0.0000008	- - - - -

Table 4
Air Emissions Factors: Operating Energy –
REEHouse Model Home

Air Pollutant	Electricity (lbs / kWh)	Natural Gas (lbs/Therm)
Carbon Dioxide (CO_2)	2.23	11.7
Sulfur Dioxide (SO_2)	0.0112	0.00006
Nitrogen Oxides (NO_X)	0.0058	0.01
Particulates	0.0012	0.0007
Mercury (Hg)	0.00000016	0.000000026

Also, determining the amount of materials that are diverted from the landfill through deconstruction and recovery is accomplished through accounting of the deconstruction efforts. And wood used in the Home that was recovered through deconstruction is used to determine the number of acres of forest that do not have to be mined, from data provided by the Forest Products Lab in Madison Wisconsin.

Looking at labor requirements and the cost of materials that are used in the Home that are both new and recovered allowed a non-robust review of the economic impacts of the project.

The rest of this paper presents our findings from this research.

FINDINGS - RESOURCE AND LANDFILL SAVINGS

Materials Recovered Through Deconstruction

During this project REEHouse deconstructed six buildings, of which five yielded usable quantities of recovered materials. Recovered materials used in Model Home construction consisted mainly of recovered lumber obtained from deconstructing the five useful buildings. Of the five buildings, the most successful deconstruction operation was for a house located on North 49th Street (49th St.) in Milwaukee. Three of the houses deconstructed were acquired through the contract with the City but one of these did not produce useable materials. An arrangement with one of the local demolition companies yielded two homes for deconstruction and the sixth building was a warehouse from which REEHouse recovered some nice large timber framing wood that was not used in the Model Home.

REEHouse staff estimated that 80% of the material found in the 49th St. house was recoverable, and that 80% of these materials were recovered, resulting in a 64% recovery rate for the house. Time constraints limited the amount of materials they could recover. A total of 28.7 cubic yards (775 cubic feet) of lumber were recovered from this deconstruction rather than going to the landfill. Estimated rates of material recovery were much lower for the other buildings, ranging from 0% to about 12%. Barriers to recovery include the condition of the house, time available to deconstruct, and business logistics challenges. The following table shows the recovery success for each of the properties.

Table 14
Buildings Deconstructed by REEHouse, Inc.

Building Address	Building Type	Approximate Building Size (ft^2)	Building Provider
4755 N. 49th Street	Single Family House	1,170	City of Milwaukee
1824 W. Vine Street	Duplex	1,600	City of Milwaukee
2463 N. Teutonia Street	Single Family House	1,600	City of Milwaukee
2619 W. Auer Avenue	Large Duplex	2,600	Barrett Demolition
9320 N. Lakeshore Drive	SF Ranch House	2,500 – 3,000	Barrett Demolition
4880 N. Lydell Street	Warehouse	10,000	Barrett Demolition

Looking at the recovered materials used in the Model Home, we estimate that this resulted in reductions of materials to the landfill of about 20.4 cubic yards (8.8 tons), which saved about $317 in disposal costs. The 28.7 cubic yards (13.4 tons) diverted from area landfills from the 49th St. deconstruction resulted in savings of $482 in disposal costs. Reducing disposal costs does not directly benefit REEHouse but may benefit demolition contractors who would otherwise have to pay to dispose the demolition rubble. Reducing disposal costs may encourage demolition companies to work with deconstruction businesses such as REEHouse.

As an aside, we also estimate that using recovered materials to construct the Model Home resulted in timber resource savings of one acre of timber.

Materials Used in Model Home
The greatest amounts of reused lumber were used in the first and second floor exterior walls, the first and second floor joists, and the fascia and soffit framing. Ninety five percent or more of the lumber used in these sections was recovered rather than new. The total volume of reused lumber in the Home was about 550 cubic feet (20.4 cubic yards), which constituted about 43% of the total volume of lumber used to construct the Home. A following table from the full report showing more detail about how this ~43% is calculated.

Table 13
Reused and New Lumber used in
REEHouse Model Home Construction

Type and Location of Lumber	Volume of Reused Lumber (ft^3)	Volume of New Lumber (ft^3) (*=estimate)	Total Volume of New+Reused Lumber (ft^3)	Percent Reused of Total Lumber (*=estimated %)
Roof Trusses	3.56	131.90	135.46	2.6%
Exterior Sheathing	0.00	260.36	260.36	0.0%
1st and 2nd Floor Subflooring	0.00	82.63	82.63	0.0%
1st Floor Exterior Walls	170.33	8.96*	179.29	95.0%*
1st Floor Interior Walls	7.20	136.78*	143.98	5.0%*
2nd Floor Exterior Walls	110.05	18.89*	128.94	85.0%*
2nd Floor Interior Walls	3.02	57.42*	60.44	5.0%*
Interior Stairs (see text)	1.67	31.71*	33.38	5.0%*
Fascia and Soffit Framing	25.33	0.00	25.33	100.0%
1st floor Joists	140.80	3.47	144.27	97.6%
2nd Floor Joists	87.57	7.61*	95.18	92.0%*
TOTAL	549.53	739.74	1289.27	42.62%

REEHouse plans to install about 1,150 square feet of recovered hardwood flooring on the first and second floors of the Home at a later date. Doing so would increase the total volume of reused lumber in the Home to 621.4 cubic feet; about 46% of the total volume of lumber used.

FINDINGS - ENERGY AND EMISSIONS SAVINGS

The deconstruction and the construction of the Model Home using recovered resources resulted in savings in energy use. Also, the home was constructed to be more efficient than homes that meet the minimum Wisconsin residential building code.

Embodied Energy
Embodied energy is the energy to create a product and deliver it to the construction site. We estimated the embodied energy savings for the materials in the demonstration home that were recovered.

The recovered materials in this home save nearly 52 million Btu in embodied energy, which is equivalent to saving 373 gallons of diesel fuel or 2.4 tons of coal. Viewing this parameter from the deconstruction side, we estimate that embodied energy savings for the 775 cubic feet of lumber that was recovered from the 49^{th} St. site is 74.4 million Btu.

The following table is an example of where part of the embodied energy savings comes from.

Table 27
Embodied Energy Savings due to Using Recovered
Building Materials to Construct the REEHouse Model Home

Building Material	Embodied Energy Savings (Btu)	Percent of Total Embodied Energy Savings
Framing Lumber	48.529,540	93.8%
Plywood	3,207,360	6.2%
TOTAL	51,736,900	100.0%

Operating Energy
Operating energy is the energy used to heat and cool the home. These savings are not inherent in the deconstruction goals but are the result of the goal of building an energy-efficient home.

Based on its energy-efficient design and construction, the 1,797 Model Home would use about 27.8 mmBtu/year less heating and cooling energy than the average for the three control houses. Most of the energy savings would be in the form of natural gas for space heating – with about 226 therms/year savings. This is a saving of about 14.2% of the total energy requirements for the Model Home if it were constructed by the same standards as the control houses.

About 153 kWh/year of electricity for space cooling would also be saved if air conditioning is installed. This is not a large fraction of the cost of the electricity for the home because the air conditioning requirements in northern states like Wisconsin are not high.

While these energy savings are of value to the homeowner, they also result in savings to society in the form of emissions reductions as discussed earlier. The following table provides more insights into the components of energy use by each of the home modeled.

Table 28
Comparison of Operating Energy Use:
REEHouse Model Home vs. Control Houses

	REEHouse Model Home	House 1	House 2	House 3	Base Average of Control Houses	Units
Space Heating	66.1	100.7	88.1	130.1	106.3	MMBtu/year
Space Cooling	2.4	3.3	3.3	3.9	3.5	mmBtu/year
Water Heating	26.2	27.2	26.4	31.5	28.4	mmBtu/year
Lights & Appliances	20	20.1	20	24.4	21.5	mmBtu/year
TOTAL	114.7	151.3	137.8	189.9	159.7	mmBtu/year
Conditioned Area	2,744	3.102	2,750	4,013	3,288	ft^2
Intensity	41,800	48,775	50,109	47,321	48,735	Btu/ ft^2/year.
Heating Degree Days	7,400	7,400	7,400	7,400	7,400	HDD
Home Heating Index (HHI)	3.3	4.4	4.3	4.4	4.4	Btu/ft^2/HDD/ year
	Energy Savings for Heating and Cooling				27.8	mmBtu/year
	Percent Savings of Total Energy Use				14.2%	

Emissions Reductions
There are reductions in atmospheric emissions from both deconstruction/construction operations (embodied energy) and from reduced energy use by the efficient home (operating energy).

Reductions in embodied energy requirement for constructing the home result in reductions in emissions from not using that energy. We estimate that using recovered materials to construct the Model Home resulted in air emissions reductions of 7,502 pounds (3.75 tons) of carbon dioxide.

Further emissions savings are attributable to the reduced operating energy use of this home compared to similar homes built in the Milwaukee. Carbon dioxide emissions would be reduced by one and a half tons per year for this Model Home. As with the energy savings, this reduction in emissions is not inherent to deconstruction activities but is a result of constructing an efficient house.

FINDINGS - BUSINESS MODEL CHALLENGES

Resources
To ensure that enough material resources are available for the construction of the Model Home, it was necessary to deconstruct several homes. The total materials available from deconstruction of homes will be more than the materials needed to construct the Model Home because not all of the materials recovered would be useful in this one home. Before starting the project to deconstruct and construct the home, REEHouse worked out a deal with the City of Milwaukee whereby the City would make 15 houses available to REEHouse for this business startup project.

Unfortunately, a change in city personnel and unexpected requirements for access to buildings resulted in the City providing only three houses to REEHouse. This required much extra work on the part of the business to acquire other sources of their resource materials (houses to deconstruct). This type of challenge results in a higher cost of doing business.

Cash Flow
The REEHouse model had two limiting components that resulted in cash flow problems. First the model was not set up to sell any of the materials recovered from deconstruction. So, while it was doing the deconstruction and construction it had no incoming cash other than the grants provided by the sponsors.

In addition, the business was set up based on getting houses from the City of Milwaukee whereby the City would pay about $5,000 for the deconstruction and cleanup of the property. Because fewer houses were available from the City than expected, one of the sources of income identified in the business plan was reduced.

Employment
REEHouse also was working with a local non-governmental organization that helps inner-city youth gain job skills and improve their lives. This organization provided youth to help with the deconstruction and the construction of the Home. The effort did provide training to a number of unemployed persons in the area.

The reduced number of houses available from the City of Milwaukee made it difficult to keep the youth busy. The original plan was based on deconstructing about 15 homes. Because the City provided only a few houses and the business had to hunt for more houses to deconstruct, there were not enough houses available at any one time to keep the youths busy. This strained the relationship between REEHouse, Inc. and the social organization providing the youth labor.

Further, because the youths proved to be unreliable and/or their workplace skills were poorly developed this caused problems for the business. This added another level of complexity and strain to this start-up business. While this is business component is not inherent to starting a deconstruction business, it is one of the goals of the REEHouse business.

Cost of Construction
One of the goals was to build affordable housing for residents in the inner city. However, it is generally true that the cost of deconstruction of a building is greater than the cost of construction. Also, adding other social value such as youth training adds cost. However, the cost of the youth training was covered by another local organization and is not included in the cost of construction of the Model Home.

The original business plan was based on the City providing 15 homes for which it would pay REEHouse the same rate it would pay demolition contractors to remove a condemned home. This is in the order of $5,000 per home average. This would have provided the business with income to lower the cost of doing business. However, since REEHouse had to find other sources of income while they were not receiving homes from the City, the cost of the home was increased. Further, because many of the materials acquired from the deconstructions were not immediately useful to the construction of the Model Home, the unit cost of the materials used tends to be higher.

Our estimated construction costs of the Model Home compare reasonably to construction costs for standard single-family affordable homes built in Milwaukee. Based on a 1,797 square foot living area, the estimated construction cost per square foot of the Model Home ranges from $\$62.14/ft^2$ with large cost savings from reusing materials in construction to $\$76.95/ft^2$ for no cost savings from reusing materials. This range is slightly higher than construction costs per square foot, for three baseline standard single-family Milwaukee affordable houses, that range from $\$56.23/ft^2$ to $\$70.82/ft^2$. This comparison suggests that designing and energy-efficient single family home and building it using recovered materials can be competitive with similar standard built single-family homes while providing societal benefits with support from other organizations that provide social services.

An example table showing part of our analysis of cost of construction follows.

Table 17
Estimated REEHouse Model Home Construction Costs
Listed in the Business Plan

Cost Item	Amount ($)
Materials	$46,102.00
Subcontractor Costs	$72,665.00
Survey and Permit	$1,700.00
Total Job Labor	$17,814.00
TOTAL	$138,281.00
Less Reused Lumber Cost Savings	– $26,620.00
TOTAL Estimated Cost	$111,661.00

FINDINGS - TRANSFERABILITY

We also looked at the potential for this type of model to work in two other cities in Wisconsin – Madison and Wausau. Madison is the capital city and has a higher average income than the inner-city area where the home was built in Milwaukee. Wausau is a more rural city in the northern part of Wisconsin with a lower average income than in Madison but somewhat higher than the inner-city area in Milwaukee. Thus, there is less demand for social components of interest in the REEHouse business model.

Both of these other cities have less “available resources” in the form of condemned housing. Neither city has dilapidated housing on the same scale as Milwaukee or flood plane areas designated for rezoning as does Milwaukee. Thus, unlike Milwaukee, there are not enough recoverable materials to meet the demands for affordable housing in these cities. So identifying deconstruction opportunities and scheduling employees would be more challenging.

In Wausau, we found only one business that is involved in recovering materials and it is interested in only high value materials like special plumbing fixtures and large-beam, quality framing wood. Also, there are established businesses in Madison that ultimately compete for the scarce resources, though in a demolition dominated atmosphere. In Madison there are stores that sell used building materials and there is a company that does deconstructions when they are convenient and profitable. While Milwaukee also has several businesses that sell reused materials, the resource stock in Milwaukee is large enough to allow another entry into the market.

Thus, it appears that Milwaukee is the most fertile ground in Wisconsin for the REEHouse, Inc. business model.

RECOMMENDATIONS

We have several recommendations for a business interested in deconstruction for the purposes of reusing the materials recovered in construction of affordable housing:

- Establish the business as a non-profit entity. Doing so would allow it to receive grant money and in-kind donations of labor, equipment, and services. Non-profit status would also allow for tax deductible donations of recovered building materials.
- Develop a side of the business that sells recovered materials that are not needed for an impending house construction. This will improve cash flows and help schedule deconstruction crews when there is not enough deconstruction work. And, consider being in only one side of the business – either deconstruction, or construction using recovered materials, depending on local market conditions and infrastructures.
- If there is a personal imperative to provide social value such as training to youth in need of skills, try to get financial support from government and non-governmental organizations. This will help to keep labor costs for deconstruction down. And, ensure that the partners have provided training to develop work relationship skills and education to youths they will send.
- Build networks with other organizations in the area needing removal of buildings for future construction projects. Depending on a single source of homes to deconstruct is inherently risky. While capitalizing on the needs of the City to remove houses is useful, the business should continuously look for private sources of resource materials.
- Ensure there are adequate resources and understand the competition in the area. This business model requires strong access to houses that can be deconstructed. If there are businesses actively pursuing deconstruction that are selling the materials through established venues, determine how this business will meet an unmet market need.

REFERENCES

1. **Livingston, Dennis and Jackson, Mark.** *Building a Deconstruction Company – A Training Manual for Facilitators and Entrepreneurs*. Washington, DC: Institute for Local Self-Reliance, 2001.

2. **WasteCap Wisconsin.** *Construction and Demolition Debris – Briefing Paper: Reducing, Reusing, and Recycling*. Milwaukee, WI: WasteCap Wisconsin, 1999.

3. **Livingston, Dennis and Jackson, Mark.** *Building a Deconstruction Company – A Training Manual for Facilitators and Entrepreneurs*. Washington, DC: Institute for Local Self-Reliance, 2001.

4. **National Association of Home Builders Research Center, Inc.** *Deconstruction – Building Disassembly and Material Salvage: The Riverdale Case Study*. (CX 8244809). Upper Marlboro, MD: National Association of Home Builders Research Center, Inc, 1997.

5. **Livingston, Dennis and Jackson, Mark.** *Building a Deconstruction Company – A Training Manual for Facilitators and Entrepreneurs*. Washington, DC: Institute for Local Self-Reliance, 2001.

6. **Center for Construction and Environment.** *Building Deconstruction: Reuse and Recycling of Building Materials*. Gainesville, FL: University of Florida, Center for Construction and Environment, 2000.

7. **National Association of Home Builders Research Center, Inc.** *Deconstruction – Building Disassembly and Material Salvage: The Riverdale Case Study*. (CX 8244809). Upper Marlboro, MD: National Association of Home Builders Research Center, Inc, 1997.

8. **National Association of Home Builders Research Center, Inc.** *Deconstruction – Building Disassembly and Material Salvage: The Riverdale Case Study*. (CX 8244809). Upper Marlboro, MD: National Association of Home Builders Research Center, Inc, 1997.

THE URBAN EXPLORER CAPSULE – IMPROVEMENT OF REUSABLE BUILDING STRUCTURES MANAGEMENT

Author: Leszek Świątek (Technical University of Szczecin, Poland)

ABSTRACT

In Poland, a large part of 3 million dwellings have not been properly maintained for the last 50 years, and they now require comprehensive and extensive renovation. Work done in a traditional way is a source of a large amount of heterogenic building waste.

We should focus on existing objects that can be reused for housing needs. Carefully collected inventory data should be used to create a second-hand building materials market, and to improve building maintenance and management procedures. For ergonomics of organisation we need **the Urban Explorer Capsule (UrEC)** – a kind of smart, reusable mobile stand, collecting data and providing information about material circulation and reuse possibilities in the neighbourhood. Knowledge on reuse potential will help to run the Reused Building Materials Neighbourhood Centre, which will be a part of the pilot project to train unemployed people in Szczecin area.

INTRODUCTION

According to state sustainable development policies, Poland, like other Central and East European (CEE) countries with their economy in transition, has not created real and stable mechanisms to promote rules, techniques, and technologies of sustainable building. In the housing sector, many environmentally friendly technologies are still too expensive in the CEE region, and generally are used as pilot or demonstration projects on a small scale. Relatively low ecological awareness of society, and a lack of information distribution on advantages of sustainable technologies usage are two reasons for the symbolic level of sustainable building.

The housing sector makes up about 20% of fixed assets in the structure of the Polish economy. There is a considerable surplus of potential in our economy, which allows for housing development in the coming years without big capital expenditures. It refers to both the manpower used (big unemployment may be reduced by building sector) and to the industrial potential. In the structure of housing costs, direct expenditures for building materials and their transport to building sites considerably exceed 60% (up to 70%) of total building costs.

In Poland, a large part of 3 million dwellings have not been properly maintained for the last 50 years, and they now require comprehensive and extensive renovation. Renovation works and demolition done in a traditional way are a source of a large amount of heterogenic building waste, which is sent to waste dumps (especially so-called "wild dumps").

PRESENT SITUATION

We have to realize that today, at the beginning of the twenty-first century, 90% of housing resources are old and still exist. They will have to be adjusted to meet the new requirements, including function, health, the human factor, and environmental standards. Aspects such as tenants' mentality, management procedures, and building maintenance will influence building life span, materials and products circulation, and energy and water consumption. Improper maintenance practices, lack of building repairs, and no renovation works are typical for post-socialist, existing housing stock and will reduce a building's technical life span. Shorter building vitality will generate huge waste, old building materials, and used products flow and rotation, with a strong environmental impact.

Today in Poland, administrative methods of house keeping and maintenance are passive. The group of private homeowners is still weak, compared to state or communal properties, to execute avoidance of building devastation or improper maintenance. In that case, as soon as possible, we should find easy methods of good, effective, and smart maintenance, respecting rules of sustainability, which are not expensive compared to new investment costs. It is necessary to stress that effective usage of sustainable technologies and building materials depends on end-users' understanding and acceptance level. Describing environmentally-friendly technologies (P.V. panels, solar collectors, and small-scale waste-water treatments) and whole building structures as a kind of hardware, we have to focus on organising a process of using them as a kind of "environmentally-friendly" and "end-user-friendly" software. Lack of smart maintenance (part of that software) will create tenants' disintegration, and increase economical, social and environmental costs of property.

The housing situation in Szczecin does not greatly differ from that in the other twenty cities in the country with populations over 200,000 inhabitants, in terms of the synthetic indicator illustrating the housing situation. The Szczecin ratio is 319.4 apartments per 1000 inhabitants. The average area of an apartment is around 56 m2 (the average for Polish cities being 55 m2), and there is an area of 18.5 m2 per person. On the other hand, the shortage of apartments (estimated at around 13,000 apartments) and the increasing so-called replacement seems to be an important social problem in the city.[1]

The principal part of the Inner-City Area in Szczecin is formed by a well-planned compact housing development of high architectural quality, built in historic eclectic style in the last quarter of the nineteenth century. The buildings stand along numerous circuses, squares, and boulevards that, in several cases, follow the star pattern. An area of 56 street blocks is, at the same time, the most important concentration of retailing and services in the whole region, being also a principal housing ward for about 60,000 inhabitants.

Renovation of Szczecin's Inner-City Area, which is seen as a basic material element of the city's identity, is a priority project for the City of Szczecin as a whole. Renovation of the Inner-City Area, apart from general goals of rehabilitation, will reinforce the function of the citywide shopping center as a mixed-use urban structure. An important goal of renovation is also to change and balance the social composition of the inhabitants of the Inner City.
In 1993, the Polish Cities' Association awarded the Szczecin Renovation Strategy the first prize in a competition, "Innovations in Cities." The strategy gives priority to comprehensive renovation of whole blocks of the inner-city area, instead of the previous practice of haphazard repairs of individual buildings.[2]

The housing conditions in the Inner-City Area are particularly unfavorable because of the poor technical condition of the tenement blocks, the poor standard of apartments (stove heating, absence of bathrooms and toilets), the sharing of apartments by several families, problems with parking vehicles, problems caused by the social structure of the residents, and the small number of green areas. There are different standards of using and finishing flats in the existing housing stock. It is a cross-section through all historical periods, in which buildings of different standards of technical or sanitary equipment were built. Often, improper exploitation of the building, lack of current modernisation, and lack of maintenance reduce the possibility of effective operation of and durability of buildings.

The Inner-City renovation process (which is continued) allows us to make some conclusions and reflections. The technical part of the project is important, but we have to remember the end-user. Concentration on the appropriate design, including maintenance for the future, and the relationship between tenants and living space, is very important as a long life process. The material form of the building and technical regimes are not the most important aspects. The main part of the building's life span is an occupational period. Therefore, maintenance methods should be revised. Ergonomic mechanisms and tools for implementation of housing stock management organization should improve old housing buildings, and raise the quality of living and working at the revitalized houses.

4R – ARCHITECTURE OF RESOURCES MANAGEMENT

Environmental space, Factor Four, Factor Ten, and eco-efficiency are all different methods used to focus on the long-term and global perspectives of resource consumption. The conclusions from work on environmental space reveal a continued need to develop strategies and methods to define sustainable development and achieve sustainable patterns of production and consumption. Work on these aforementioned issues reveals a need for an overall, holistic approach to the economic, social, and environmental dimension of sustainable development.

What does it mean for our consumption pattern, that future generations must be able to fulfill their needs?

The waste management method, defined as the "3R formula" (reduce, reuse, and recycle), seems insufficient to achieve the aforementioned Factor Four and Factor Ten assumptions in the economy of developed countries. This is due mostly to the style of consumption, deeply materialized culture, and short-perspective policy reflected in short-perspective design. A revision of the formula should be considered, necessitating new approaches to resource depletion and waste minimization.

One proposal could be a new "**4R formula"** implying "**RETHINK**, REDUCE, REUSE, RECYCLE". To execute the "3R formula" successfully, we have to add a first step to the gradation: **RETHINK** in the waste management sector and in sustainable architecture, as well as in urban design and city management. Our attitude towards resources, and especially towards waste as a part of resources, should be changed. Then, we can discover new, creative possibilities for **"waste free" architecture**, based on renewable energy, natural, biodegradable building materials, recycled building structures, and the active participation of future users.[3] We should create a new paradigm: think about existing building structures and ongoing cycles. Expanded Producers' Responsibility (EPR) or product stewardship requires designers as marketing experts to build up a new aesthetic of re-circulation economy using existing resources (as much as possible) efficiently. Architecture is a part of that conservative culture.

Generally, besides a conservative designers group, we should call for a conservative society. Therefore, contemporary design should focus on the creation of a dynamic process of living structures, with the involvement of local society harnessing their positive human energy in the right direction to show and renovate large, existing, urban spaces into high-quality areas, with good living conditions for our next generations.

Improvement of the housing situation in Szczecin will depend on activities in the field of organization and construction, such as the creation of new, non-profit organizations to build rental apartments, rational management of housing resources in the public sector (ownership transformation, exchange of apartments), and major renovation of particular buildings, raising the standard of apartments. These renovation activities create obvious opportunities to salvage building materials and everyday household products from the housing stock, and to develop an alternative sustainable market based on reused building-material distribution centers.

To prolong not only technical, but also moral or social building life span, we should think about effective and holistic maintenance organisation. We should think about **ergonomics of housing-stock management organisation,**[4] to involve tenants in pro-ecological attitudes and environmentally friendly practices and activities (positive human-energy involvement). That interactive approach to houses' maintenance is important, in case of changes in the housing market, with a diversity of consumers, lifestyles, and needs for good living conditions and good neighbourhoods.[5] Ergonomics of housing-stock management should simplify relationships between all actors in the housing property scene. It should help to organise good quality for living in nice environment, and organise tenants' engagement to guard the state of property for a long life, and create new initiatives, including environmentally-friendly technologies adaptation, materials recovery, reuse and recycling, or products dematerialization.

Focusing on housing-stock maintenance, ordinary building examination has to be done every five years by registered inspectors, according to the state building code. Such examination has to be specified in an obligatory building code. An ordinary examination report includes basic and general data about building structure, all installations and their technical state, without details of materials specification and possibilities of their reuse or recycling.

For the abovementioned ergonomics of organisation, we need the Urban Explorer Capsule (UrEC), a smart, reusable mobile stand, collecting data and providing information about materials circulation and their reuse possibilities in the neighbourhood. Unified questionnaires and checklists procedures as activities in addition to ordinary building inventory and examination will be used to collect information about the potential for building materials' salvation. Therefore, short training for examining inspectors to focus on reusability or recycling potential will be organised in field of the UrEC activities. Building examination results and knowledge about the building's material recovery potential will be presented to tenants at the neighbourhood meetings. Therefore, the UrEC can be used as a good tool to start an ergonomic system of housing management. Full involvement of tenants is the main rule of the aforementioned systems. Tenants' activity leads to inhabitants' care of buildings and their surrounding state and value, helps to educate and integrate more neighbours, motivates information exchange, creates local social and psychological ties, and improves emotional values of interacting partners. Knowledge on reuse potential collected with the capsule will help run The Reused Buildings Materials Neighbourhood Centre, which will be a part of a pilot project to train unemployed people in the Szczecin area.

GOALS OF THE PROJECT

The Pilot UrEC Project, supported by STBS (Szczecin Society of Communal Building) and Municipal Job Centre, was set up to serve two main purposes:

l. On a local scale, it ought to provide enough verifiable data to make it possible to formulate a local sustainable maintenance policy and The Reused Buildings Materials Neighbourhood Centre, with a training program for unemployed tenants, applicable within the framework of the long-term programme of renovation of the inner-city area.

2. Thanks to adequate provisions for the transfer of knowledge in the Project, it should allow dissemination of the practical results on a national scale, to other local authorities in Poland.

The UrEC project was supposed to achieve the following goals:

- Proper maintenance of existing building structures and their technical and moral life-cycle prolongation.
- Promotion of sustainable renovation, with emphasis on energy, water saving, and waste reduction (including building materials’ reuse or recycling).
- Dematerialization process, as selected products are replaced by new, efficient services.
- Residents’ involvement and awareness built up to community integration by advisory points, training programs, and renovation and revitalisation projects.
- Evaluation of building materials’ reuse and recycling potential, with a recognition map of future resources and urban exploration areas.
- Collection and analysis of inventory data on reusable building materials and products located in the area.
- Online computer database operation on local reusable building materials and products.
- Promotion of additional cooperation and information exchange among interested parties.

PLANNED ACTIVITIES

Different types of presentations, education, consultation, and networking are planned as sample activities realized in the frame of UrEC, to effectuate involvement of tenants and to build up a salvaged-materials market infrastructure.

A main task of the Urban Explorer Capsule is improvement of building structure management. After design-stage approval, the Szczecin Society of Communal Building, as institutional operator of the capsule, will initiate the constructing and operating stages of the project. The schedule of the UrEC activities will be planned according to the existing building examination plan and renovation programme in the Inner-City area. The UrEC will be a part of the housing administration office situated closer to tenants. Therefore, this is the strongest profit motive to run the capsule.

The Municipal Job Centre will organise training about building deconstruction and materials salvation for a group of unemployed people. Part of the group will help to run the capsule, and another part will start the Reused Buildings Materials Neighbourhood Centre. Technical University and NGO (Green Federation) will participate in the project for technical and organisational support. Most necessary building inventories and examinations will be filtered through Urban Explorer Capsule, with emphasis on prevention methods of maintenance and reusable and recycled materials' potential description in housing stock.

Another part of the activities is the promotion of commercial "green" products, with a focus on energy efficiency, water saving measures, and environmentally friendly building materials and technologies. This should bring some financial support for running the capsule activities. Use of the ESCO (Energy Service Company) mechanisms or the establishment of LETSystem can be an additional offer to make a local community more active in field of eco-efficiency, and might refund capsule occupancy.

Tenants' mentality, and probably their passive attitudes, could pose problems in capsule realisation and operation. Therefore, the choice of the capsule prototype's first location should be made carefully, with good sociological recognition. Description of the capsule formula and its activity should be disseminated in advance among tenants of chosen houses. Their active involvement in the UrEC project is the basic factor to achieve the objectives of better, effective, and reusable building structure management.

THE URBAN EXPLORER CAPSULE FACILITIES

The Urban Explorer Capsule idea is a familiar one throughout history: people wandering from place to place, from country to country, offering their wares for sale. Their market stalls, and indeed their homes, go with them. They can be put up quickly, and quickly taken down again.

The UrEC program is starting with a preliminary design process in the appropriate form of a mobile, interactive object, which should operate the same way as the aforementioned market stalls of history.

The UrEC should be a compact-size trailer, which allows for going through narrow gates from the street to a building's yard.

Then, the capsule in the building yard should spread its facilities and areas around the core part for the operating period. As a reusable stand, it should survive a number of appearances, and should present the ability to start transformations. Flexibility of the capsule's structure will reduce operating costs, and should allow for a long life of that object.[6]

The core part of the capsule should consist of a computer multimedia workstation with internet access, and a small exhibition room with promoted energy and water-saving measures.

A private part should be designed for one person (the operator), arranged as a small sleeping area with a separate dry toilet and kitchen annex. Anyway, volunteers' engagement will be necessary to run the capsule.

A reusable meeting tent used outside the capsule should play different functions such as showroom and performance area (live music, body language theatre, play room, exhibition area).

Another part of the UrEC should be a changeable storage module with toolboxes, necessary for simple repairs, disassembly, or deconstruction. Sample salvaged materials and products could be separated and collected in a storage area to present their embodied reuse potential.

THE UrEC ACTION PLAN

Sample, possible activities realised in the UrEC project located in the Inner-City Area in Szczecin are planned as follows:

- Preparation process and advertisement by local posters campaign, posting, or local media involvement; the UrEC program goals presentation,
- The capsule arrival and location in a building yard, inside of an urban block,
- The “Neighbourhood Fest” celebration, with live music performances and the UrEC program presentation,
- The “green” products promotions, lectures on ESCO system, and LETSystem introduction,
- Visual inspections of condemned properties,
- Start of inventory data collection, energy, and water consumption audits, building materials audits, and structure expertise,
- Registration of everyday products and building materials to local exchange,
- The computer database of tenants’ demands and offers as a part of LETSystem stewardship, and
- Consultation and meetings with individuals, advice on proper maintenance methods, architecture advocacy within building modernisation or renovation procedures (i.e., simple design of heating-system improvement or old windows replacement with necessary building-permit service).

CONCLUSIONS

We should focus on existing objects, existing housing stock, or other functional buildings that can be adapted for housing needs. We can follow an idea of Hundertwasser, a painter and architect from Vienna, to imagine the activity of the architecture doctor who heals sick buildings.[7] To succeed in that kind of therapy, carefully collected inventory data should be used to help to make a good design for building maintenance or effective exploration of existing resources. While designing and then maintaining, we should think about dynamic processes, and not only about static objects.

The dematerialization process offered by the Urban Explorer Capsule will be easier to implement when rules of ergonomics are used in building-maintenance organization and management, and as products are replaced by new services and information exchange. It will also help to improve relationships between tenants, important in the context of human loneliness growth in an information-society era, to build up the sustainable future, and to maintain existing houses as national resources that last for generations. Tenants’ self-engagement for better environmental quality will allow implementation of environmentally-friendly technologies, including reuse and recycling in the housing sector on a wider scale, and leading to improvement of reusable building structures. Rules of ergonomics in housing sector management should set up new mechanisms for easier and interactive communication between all parties responsible for a healthy home and an at- home labour environment, which could be the first step to sustainable-development-conscious evaluation in local communities.

REFERENCES

[1] *Szczecin. The City Development Strategy*. Szczecin City Council, 2002

[2] *Ecological Renovation Demonstration Project in Turzyn Area in Szczecin.* Project report, Woon – Energie, Gouda, Municipal Renovation Team, Szczecin, 1995, pp. 21-22

[3] **Świątek, L.** „Don`t Waste" Architecture, *Proceedings of XXI World Architecture Congress,* UIA Berlin 2002.

[4] **Charytonowicz, J.** Ergonomia zarządzania zasobami mieszkaniowymi in *Zastosowania ergonomii,* 4/99, 1999, pp. 115.

[5] **Middelbeek, M.** Company Policy – Patrimonium 2000, *Proceedings of seminar System strategicznego zarządzania w wieloletnim planowaniu utrzymania technicznego budynków*, Szczecin, 2000, pp.11.

[6] **Reinhard, E.** *Nomadic Architecture. Exhibition Design.* Lars Muller Publishers, Baden, 1998

[7] *For a more human architecture in harmony with nature, Hundertwasser architecture.* Benedikt Taschen Verlag GmbH, Cologne, 1997s

HOW DO YOU IDENTIFY THE BEST PRACTICABLE ENVIRONMENTAL OPTION FOR CONSTRUCTION AND DEMOLITION WASTE?

Authors: Katherine Tebbatt Adams (Centre for Resource Management, Building Research Establishment, UK)

ABSTRACT

It has recently been estimated that 72 million tonnes of Construction and Demolition (C&D) waste arose in 1999 in England and Wales accounting for approximately 20% of total waste arisings. Of this 35% is estimated to be recycled. Improving the efficiency of the construction and demolition industry is a key objective for the UK Government, with the publication of a strategy for more sustainable construction. Much of the current attention is focused on waste arisings through the construction and demolition processes, with little focus on deconstruction and materials reuse.

The Best Practicable Environmental Option (BPEO) is a tool advocated by the UK Government for making waste management decisions emphasising that the waste hierarchy of reduce, reuse, recycle, recovery and finally disposal cannot be applied without taking into consideration, environmental, economic and social impacts. This paper concentrates on a theoretical BPEO model that has been developed for C&D waste. Data has been obtained on waste arisings and causes from BRE's waste auditing software, for a range of construction and demolition projects including housing, offices, retail, restaurants and the leisure sector. This data, when combined with other relevant data and surveys forms the baseline scenarios for determining the BPEO for the C&D waste stream. The evaluation of potential waste management routes for the identified 10 key C&D waste groups (concrete, inert, packaging, timber, ceramics, plastics, plaster and cement, metals, insulation and miscellaneous) is currently being undertaken. Life Cycle Assessment will be a key tool in identifying the impacts and a number of criteria including the ability to provide on-site solutions, improve resource recovery, reduce environmental and social impacts, improve productivity and reduce costs will be used.

KEYWORDS: Construction and Demolition Waste; Best Practicable Environmental Option; Waste Management Options; Criteria; Decision making tool

INTRODUCTION

Waste management in the UK is undergoing a period of rapid transition with a large number of EU and UK legislative drivers (e.g. The Landfill Directive, Packaging Legislation and the Landfill Tax) aimed at producers of waste. The construction, demolition and refurbishment industries will have to play an important part in increasing their resource efficiency, reducing environmental impacts and meeting legislative targets. In order for the construction and demolition industries to improve their current waste management practices, the Government has funded a study to provide clear, authoritative guidance on construction, demolition and refurbishment waste management to determine the Best Practicable Environmental Option (BPEO). This is to be achieved by:

1. Researching current waste types, amounts and waste disposal routes.

2. Analysing potential waste management routes.
3. Identifying, and where possible quantifying, impacts relating to cost, legislation, global and local environment.
4. Providing the tools and guidance to help waste producers to identify their BPEO.

The BPEO will be undertaken by identifying and analysing factors for the management of these wastes. Key variables include the environmental impact, cost, compliance and technical viability arising from the different types of waste management methods identified. These variables and other key factors will be modelled and used as a basis for testing waste management scenarios in order to identify the BPEO. By providing a decision making tool for the key players based on environmental, economic and implementation factors it is anticipated that this will reduce overall resource consumption and associated environmental impacts, increase productivity and reduce costs.

CONSTRUCTION & DEMOLITION WASTE IN THE UK

The construction industry is one of the largest industrial sectors in the UK. It employs 1.5 million people in 180,000 companies with a turnover accounting for about 10% of Gross Domestic Product (GDP). The sector is characterised by approximately 25 major companies (forming the Major Contractors Group), 200 medium sized companies and a large number of small companies. Many of these are linked in larger construction projects as contractors and specialist sub-contractors. For a building that stands for 50 years or more, the impact of C&D waste over its lifetime can be assessed by adding together three factors:

1) the C&D waste generated during initial construction
2) the C&D waste generated by subsequent renovations, and
3) the C&D waste from final demolition.

Although C&D waste and its environmental impacts at the end of a building's life may be substantial, over the building's lifetime they account for a relatively small portion of total costs and impacts. For this reason, it can often be difficult to obtain a strong commitment from developers to prevent C&D waste and the end-of-life consequences of demolition.

A total of 424 million tonnes of waste was produced in the UK in 2000 (1). C&D waste is 17% of the total amount of waste generated the third largest waste stream after the mining and quarrying and agriculture waste streams. C&D waste is the largest proportion of controlled waste at 33%.

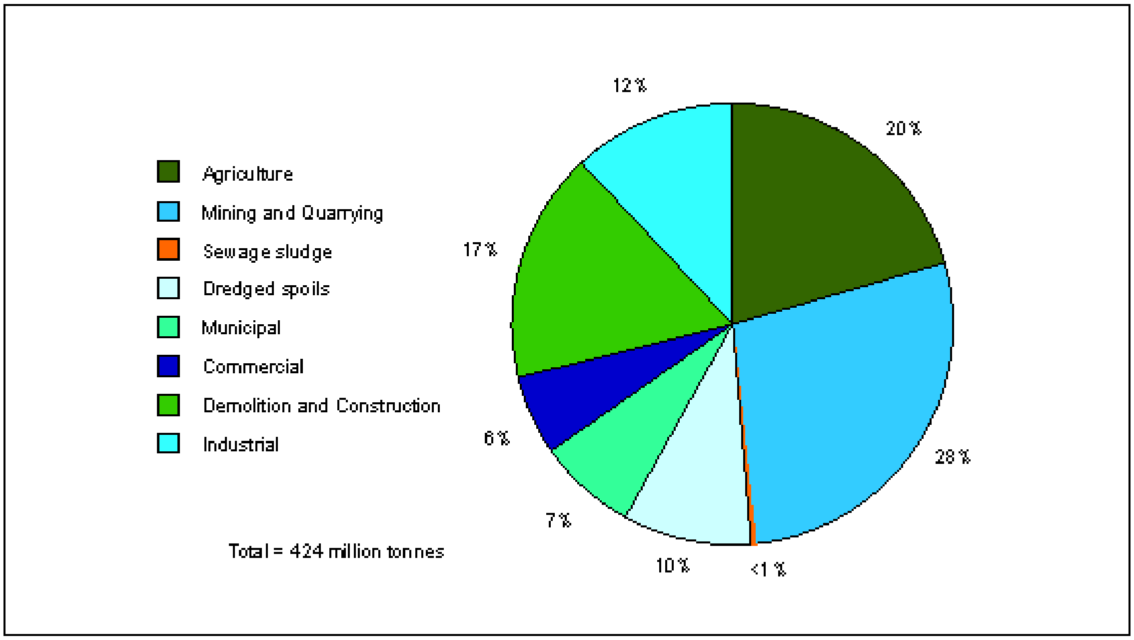


Figure 1: UK Waste Generation by Sector

The exact nature and amount of C&D waste arisings in the UK is largely unknown. The Environment Agency (EA), supported by the then Department of Environment, Transport and Regions (DETR) and the National Assembly of Wales commissioned the Symonds Group to undertake a major survey to provide consistent figures of the amounts of C&D waste produced, recycled and disposed of (2). One of the key criticisms been levelled at the Government and industry in recent years is the lack of accurate waste arisings data. Without the data it is hard for the waste industry to plan future requirements for waste management, or for the construction industry to improve its performance.

Symonds estimated that the production of C&D waste and excavated soils in England and Wales in 1999 is 72.5 million tonnes (69.2 million tonnes in England) which excludes road planings and materials reused onsite (range of +/- 35% at 95% confidence level). The survey did not cover wood, plastics or architectural salvage and reclamation, which account for the majority of waste from the construction process, excluding core C&D waste.

This 72.5 million tonnes comprises of:

- 33.8 million tonnes (46%) of C&D waste (mainly hard demolition waste such as concrete and bricks)

- 23.7 million tonnes (33%) of soil (mainly from excavation)

- 15 million tonnes (21%) of mixed C&D waste, soil, minor amounts of inert

Future surveys of C&D waste other than 'core' materials need to be undertaken. It is essential to understand where and what composition the C&D waste is. Surveys on the actual waste arising from construction sites need to be incorporated into the national surveys as well as C&D waste from other sectors such as industrial, commercial and municipal.

Demolition waste is thought to be approximately 30 million tonnes per year and is taken to include waste from the demolition of structures and parts of structures and include recycled/reclaimed materials where appropriate. However, there is much variation between estimates of how much waste is generated, most reports use figures from previous work, which are often based on estimation or informed guesswork. Of the 72.5 million tonnes of C&D waste identified:

- 25.1 million tonnes (35%) (24.4 million tonnes in England) were recycled (by screening and/or crushing);
- 9.5 million tonnes (13%) (9.1 million tonnes in England) were re-used on licensed landfills for site engineering (including daily cover) and restoration;
- 20.3 million tonnes (28%) (19.0 million tonnes in England) were spread on sites registered as exempt from waste management licensing under specific exemptions and
- 17.5 million tonnes (24%) (16.7 million tonnes in England) were disposed of to landfill.

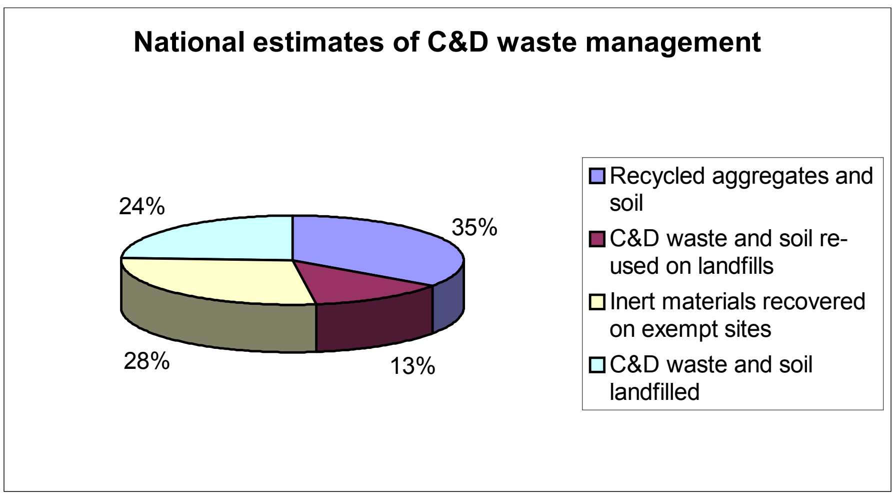


Figure 2: National estimates of C&D waste management

Inert and C&D waste has been traditionally disposed to landfill, often sites specifically licensed for this waste stream. However, it is worth noting that inert waste is often referred to as 'core' C&D waste that only includes concrete, bricks and blocks, but excludes clays, soils, asphalt and 'other materials'. The introduction of the landfill tax has resulted in an increasing proportion of inert C&D waste going to sites exempt from licensing or it is being treated in screening and crushing plants prior to re-use or as an aggregate or fill. The changes in waste management practices have led to some difficulty in quantifying the amount of C&D waste produced.

SMARTWaste™

SMARTWaste™ is a waste-auditing tool designed by BRE for C&D waste, and has been in operation for 2 years on construction, demolition, refurbishment and manufacturing sites. The following product groups for waste have been derived as:

- Timber
- Concrete
- Inert
- Ceramic
- Insulation
- Plastic
- Packaging
- Metal
- Plaster and Cement
- Miscellaneous
- Furniture
- Electrical equipment

These 12 waste groups form the basis of the BPEO model. These are similar to other waste classification systems as they are based on material groups. Within these material groups are individual products. Material groups help identify the recycling potential and products within those groups. These enables waste management strategies on sites to be more effective as actual product wastes can be addressed. They were also introduced for ease of use on a construction site as the European Waste Classification System can be problematic to use on a site level.

From the SMARTWaste^{TM} tool it can be seen that packaging at 25.9% represents the greatest amount of waste from construction sites followed by timber at 12.3% and plaster and cement at 11.5% and miscellaneous (office, canteen waste etc) at 9.6%. When packaging timber is included in the timber figure it is increased to 26%. Plastic stands at 3% but if plastic packaging is included these rises to 8%. This is based on a limited number of case studies of different sizes and types but the data is believed to be the most accurate and reliable data available for construction and demolition sites. Further implementation of SMARTWaste^{TM} on various sites is expected to provide a more accurate picture.

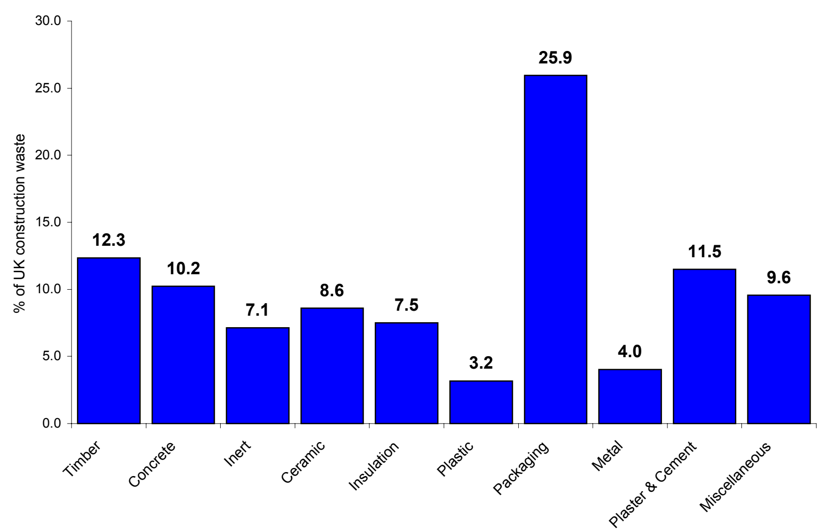


Figure 3: Composition of on site construction waste by SMARTWaste^{TM} data

BEST PRACTICABLE ENVIRONMENTAL OPTION

In order to develop Best Practicable Environmental Option (BPEO) guidance it is necessary to address the waste management activities involved and gain an appreciation of the range of waste streams and the processes generating these wastes. The England and Wales Waste Strategy emphasises that it is unlikely that one approach will represent the BPEO for all elements of the waste stream. C&D waste is a complex mixture of different materials, in differing proportions originating in differing locations. BPEO is defined in the 12th Report of the Royal Commission on Environmental Pollution as:

'the outcome of a systematic and consultative decision-making procedure which emphasises the protection and conversation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term' (3).

The concept of BPEO means that local environmental, social and economic preferences will be important in any decision. The BPEO may be different for the same type of waste originating from differing locations. Decisions will have to be made with regard to international obligations (e.g. Landfill Directive), national policy framework (such as the Waste Hierarchy) and policy guidance at regional and local levels (e.g. Waste Local Plans). For some waste streams, and in some circumstances, options nearer the bottom of the waste hierarchy may be the best and most practical BPEO. The assessment of BPEO for C&D waste is not straightforward with many factors to consider with an inherent lack of data and is evolving through ongoing research. Within a planning context, guidance advises that the BPEO should be site specific.

PROPOSED BPEO MODEL

For each waste management option the environmental impacts, including transport, need to be identified in broad terms. Legal constraints might rule out some options whilst technical and economic constraints make others less acceptable. An initial scoping matrix identifies those options, which are worth further consideration and more detailed work. After the scoping exercise has been carried out, detailed appraisal of the remaining options will be undertaken. At each stage the reasons for rejection or further consideration of each option will be set out. The outcome of the process might identify more than one option as being appropriate. The overall BPEO for a waste stream is likely to be a mix of different waste management options as different options will be environmentally beneficial and economically affordable

Baseline Information

Baseline information on waste types and characteristics is essential to determine the BPEO. A series of questions will be asked dependant upon the classification of the waste. Therefore the BPEO will be dependent upon the data that is entered regarding the waste in question. For example painted timber waste will most likely have a different BPEO then unpainted timber. The BPEO is dependent upon the initial classification of the timber waste. Examples of questions will include:

- Amount of waste?

- Is the waste clean?
- Is the waste preserved?
- Is the waste mixed?
- Can it be segregated on site?
- What is the waste mixed with?
- Is the waste an off-cut?
- Is the waste treated?
- Is the waste softwood?
- Is it a standard size?
- Is it damaged?
- Does it have any metal fixings?

Criteria

Criteria are an essential part in the BPEO assessment and include:

- Technical: new echnologies, current and future management routes, innovation, specifications
- Environmental: transportation, impacts on water, air, lands, global and local
- Social: health, community, employment, transport
- Legislative: landfill tax, landfill directive, packaging regulations, European waste catalogue, etc
- Economic: markets, supply, financial cost, environmental cost, viability, proximity

Information for these criteria will have to be available for the BPEO assessment. Verification of the information will be undertaken where possible. A key issue is how these criteria will interact with each other and if necessary how the criteria will be weighted. Weighting will only occur if a consensus of opinion can be obtained from the waste processors, users, producers and other interested parties. At this stage, the user of the guidance will weight the decision using cost and environmental impact data.

DATABASES

The databases lie behind the BPEO assessment. Databases have been created for the legislative, technical, economic and social criteria. These are divided into the type of process, which can be generic i.e. 'recycling' or material specific such as the recycling of 'plasterboard', inert etc. Re-use, recycling, recovery (including combustion) and landfill have data attached. Data sources are clearly indicated on the database and these form the basis of the scenarios. Quantitative data has been applied for the economic criteria (e.g. capital cost, gate fee, haulage cost, collection cost, revenue for recyclate, aggregates tax, landfill tax, Packaging Recovery Note etc) and also for environmental criteria based on the waste management options. Various sources have now been identified that provide data for the environmental impacts including global warming potential (CO_2), acidification (SO_X), transportation (NO_X), particulate emission (PM10), dioxins, VOCs/odours, resource displacement, euthrophication (N). These have been established from the WISARD model for municipal solid waste management (MSW) produced by the Environment Agency (EA) (4) and the IWM2 model, also for MSW produced by Procter and Gamble (5). This data is limited in use for the purposes of construction and demolition waste as the waste stream is generally more mixed and organic but is adequate for this study.

There is a separate database for legislative criteria as this criterion is applied at the scoping stage of the BPEO model and not at the assessment level. A waste management route is therefore discounted early on, if it does not meet legislative requirements. There is also a separate database for transportation impacts from transporting the waste by road, rail and water. This is of course dependant upon the type of waste being hauled, aggregates will vary considerably in price compared to packaging for instance. Data is also available for potential casualties from the mode of transport, noise, structural damage, road congestion, fuel consumption (litres/km), cost and employment for road transport. These databases from the basis of each scenario and the scenario data-entry form.

2 questionnaires have been designed, one for construction and demolition waste managers and the other for construction and demolition waste producers. The main reason for this is due to the inherent lack of data for the BPEO assessment levels, including 'threshold' values, e.g. minimum tonnage, cost, maximum distance etc. The questionnaire is being combined with a construction timber waste management and production questionnaire and has been sent out to over 1500 companies. Press releases will also be sent to appropriate magazines and journals. It is anticipated that detailed information for waste producers will be on:

- Distribution of size of companies generating the waste
- Regional variation and distribution of waste producers
- Types of businesses
- Overall volume/cubic metres of C&D waste produced
- Cost of waste disposal
- Percentage composition of waste
- Percentage segregation of waste
- Amount of waste reprocessed
- Percentage composition of types of C&D waste
- Opportunities for increased sustainable waste management
- Barriers for increased sustainable waste management

For waste managers detailed information will be on:

- Distribution of size of companies generating the waste
- Regional variation and distribution of waste producers
- Types of businesses
- Total volume of waste
- Percentage managed by different waste management methods
- Markets for the recyclate and also for reuse
- Percentage composition of types of C&D waste
- Opportunities for increased sustainable waste management
- Barriers for increased sustainable waste management

METHODOLOGY

The BPEO methodology is currently under development. It will be based on scenarios (e.g. urban/rural) developed from case studies in a flow chart basis. The BPEO methodology is summarised in Figure 4.

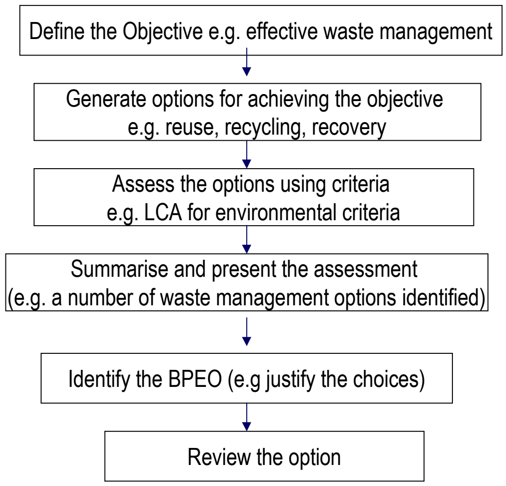


Figure 4 - BPEO methodology

Examples of the BPEO in practice

The following scenarios are being analysed:

Construction: New build	Deconstruction, demolition and refurbishment
Housing: timber frame; brick and block	Traditional methods: e.g. by hand, pulling Explosive e.g. charges Newer methods e.g. heating
Offices	Selective demolition e.g. deconstruction
Retail	Refurbishment e.g. internal fit-out
Roads/Civil Engineering	

The 12 SMARTWaste product groups are being tested for each of these scenarios and where applicable the scenario will be presented as rural and urban. It is important to relate the waste product back to the waste production process as this will affect the level of contamination, quality, size, amount etc of the waste product in question. At this stage a number of baseline questions are asked to help the user to distinguish what type of waste they are dealing with and this will then determine the BPEO for their waste. As the data can only be established for waste management options in general terms, the level of questions to determine the characteristics of the waste are limited. The rural and urban scenarios are based on the proximity of waste management facilities. Mixed waste will also be analysed coming off site by analysing component percentages of inert waste. As the waste coming off site is mixed the analysis will take place as the waste transfer station stage. A number of waste transfer stations are providing information on the economic and environmental impacts of their waste management procedures and have been visited as case studies.

It must be emphasised that the BPEO system is still under review. It is anticipated that this will continue to develop as the project advances over the coming year and application of the system to the real world through case studies, site visits and questionnaires. Figure's 5 and 6 provides an example of how the BPEO will be undertaken. All scenarios will go through an initial scoping matrix which will identify which waste management options need analysing in further detail. Options are ranked in terms on environmental impacts and cost in three categories: low significance, medium significance and high significance. Options, which are of high significance in terms of cost and environmental impacts, will be discounted at this stage with reasons attributed to this. As the waste product groups have been matched to the European Waste Catalogue, the scoping matrix will eliminate options that do not meet the legislative criteria. Figure 7 shows the level of information required for each scenario.

BARRIERS

Barriers include a lack of reliable and accurate data for the criteria to enable the BPEO to be identified and a lack of case studies whereby the scenarios for the BPEO can be generated from all relevant waste management sectors. The ownership and uptake of the guidance is key if the BPEO is to make any difference to waste management practices in the future. Translating the BPEO into practice could be difficult if the choices are unsuitable for the producer and the end-user; therefore the BPEO will generate a range of choices to minimise this risk.

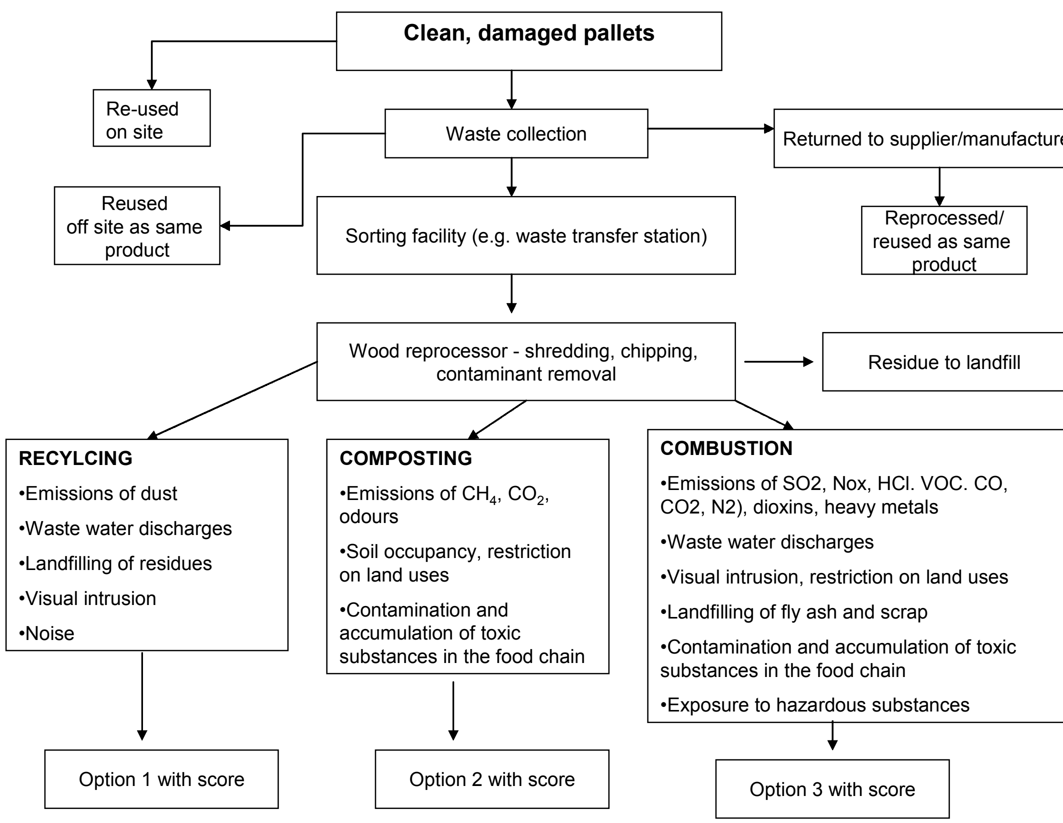


Figure 5: Scenario using the BPEO Methodology

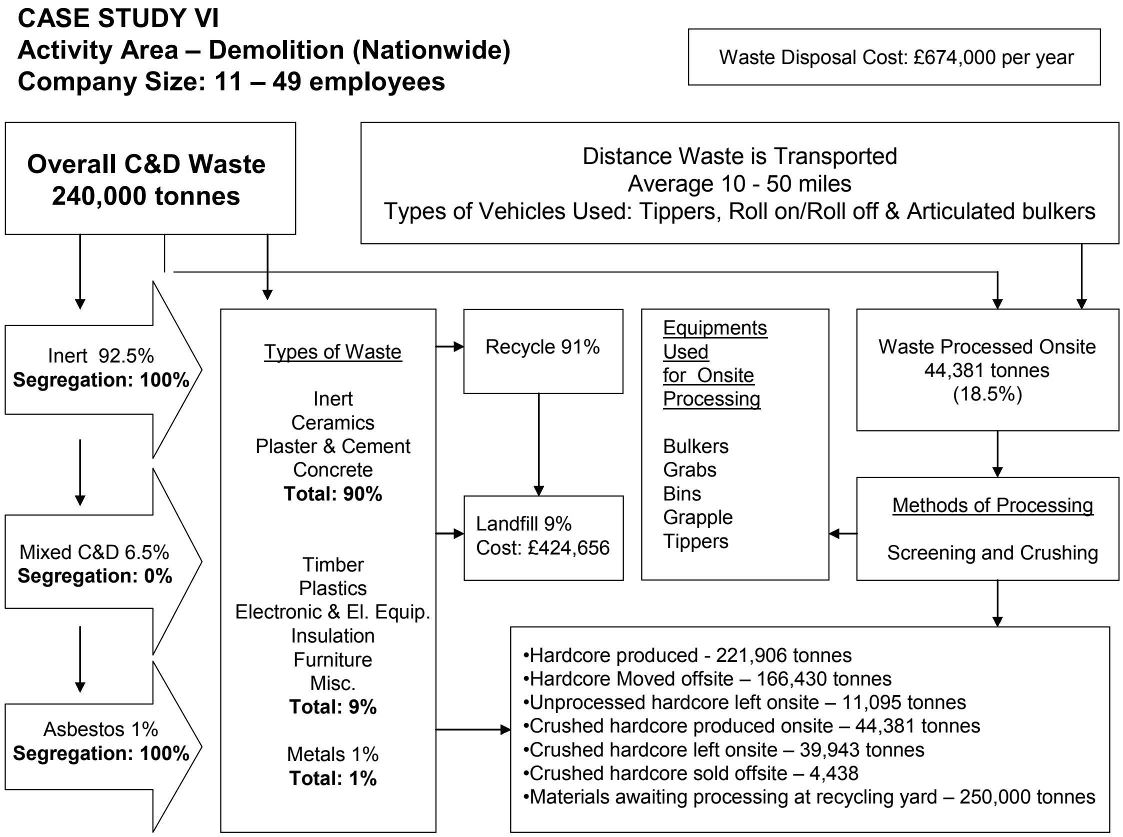


Figure 6: Scenario for a Demolition Company

THE FUTURE

It is anticipated that the BPEO tool will eventually become a web-based application, which will be linked into a Geographical Information System (GIS). This will have spatial datasets on waste facilities, waste producers and other relevant information. This would allow the BPEO to be a location specific tool whereby decisions could be made on the entering of a postcode, still using the same criteria. Other approaches could be effectively combined with the BPEO including cost benefit analysis, multi-criteria analysis and social impact analysis to enhance the tools application.

The project has so far identified a number of policy implications for local, regional and national bodies to consider. Firstly that there is little information actually available with regard to the type, composition, waste management routes and associated impacts for C&D wastes. The main body of information is for the inert fraction, though studies have shown that increasingly non-traditional C&D wastes are becoming more commonplace e.g. packaging, especially with the rise of prefabrication. By undertaking site visits and a questionnaire study, some of the missing data will be obtained but there is a great need for a formalised system to gather data, as to the allow the industry to plan for the high grade recovery of the waste materials.

The main findings emerging that when it is economically viable to re-use, recycle and recover C&D waste, it is already occurring. However, contamination levels are a key barrier to the reprocessing of some types of waste e.g. softwood timber mixed with chipboard. When the volumes produced are low which is apparent for the majority of the construction industry with over 90% being small and medium sized enterprises or the production of the waste is slow then the majority of the waste will be placed into skips, usually mixed ones and only the hardcore fraction will be separated out at waste transfer stations for recovery, usually for low-grade applications e.g. fill, sub-base materials. The barriers include contamination, commercially viable thresholds, financial investment, geographical location, commodity price and the volume of waste. It is therefore becoming increasingly important to identify all construction and demolition waste producers so that high quality C&D waste can be separated earlier on or easier within the process to make better use of these wastes.

BRE Scenario Data Sheet- Inert Waste from Demolition of Housing

				Notes/ Data Source
Description	Specification Details	Name		Name and description
		Description		
	Process	Process		Briefly descibe the waste generation process
		Location		Identify Location
		Location details		Describe the location needs, how much space is needed
BPEO Information				
Baseline Assessment	Type of waste			General information on the raw material used - cullet, colour, flat glass and the generation of the raw material waste
	Quantity of waste			For each process, per year (tonnes)
	Quality of waste			Requirements for quailty and contamination levels of cullet
	Source of waste	Geographical source		Source of glass - local, regional, national
		Transportation impacts		Mode and distance of transportation
Scoping Exercise	Current technology for waste management	Type of technology		Scoping matrix
		Cost		Scoping matrix
		Feasibility		Scoping matrix
		Location		Scoping matrix

Figure 7: Data entry sheet for each scenario produced

REFERENCES

(1) Department of Environment, Transport and Regions, 'Waste Strategy 2000 for England and Wales', HMSO, London, 2000

(2) Symonds, 'Construction and Demolition Waste Survey for England and Wales 1999', Environment Agency, Bristol, 2000

(3) Royal Commission on Environmental Pollution, '12th Report on the Best Practicable Environmental Option', RCEP, London, 1988

(4) Ecobalance UK, 'WISARD 1995-1999' Environment Agency, Bristol. 2000

(5) McDougall F., White P., Franke M., & Hindle P., 'Integrated Solid Waste Management: a Life Cycle Inventory' Blackwell Science, Oxford, 2001

ACKNOWLEDGEMENTS

This work has been carried out by funding from the Department of Trade and Industry, UK

BARRIERS IN MINIMISING CONSTRUCTION WASTE

Author: Rubina Greenwood (Welsh School of Architecture, Cardiff University, UK)

ABSTRACT

By avoiding or reducing the production of waste, waste minimisation is an effective approach to solve the pollution problem in construction industry. The amount and type of the waste depends on the construction methods and stage of construction. The amount of waste can be reduced by adoption of waste minimisation practices, e.g. minimising the amount of raw materials used, as well as reusing and recycling materials.

This paper identifies the barriers to reuse and recycling of construction waste through analysis of case studies. These studies are part of an on going European Regional Development Fund and European Social Fund funded 'Construction Waste Minimisation' demonstration projects being carried out at Cardiff University, UK. This study has identified opportunities and barriers for waste minimisation through reuse and recycling, demonstrated via the involvement of live projects. However during the implementation of this study, the following constraints were identified:

- Management and building project team relationship
- Role of supply chain
- Transfer of information
- Market
- Role of waste management companies and funds
- Design consideration

KEY WORDS: Construction Waste Minimisation and Barriers

INTRODUCTION

The objective of this study was to minimise construction waste and to identify waste streams by collecting waste arising data and through counselling building project teams. A further aim of this study was to promote awareness in the building construction industry about environmental issues, best practice and use of recycled and reclaimed materials. It must be emphasised that a key concern was to promote actual on-site awareness and initiatives to minimise waste, and to this end various training tools and checklists of actions have been developed. Particular attention has been given to the following factors:

- Site management
- Design issues
- Contractual matters
- Partnerships between building project teams

Waste minimisation means reducing the amount of toxicity of the waste generated, which can be achieved by reducing the quantity of materials used (and therefore potential for wastage) or by reusing existing materials. Ideally, prevention of waste is the target, but once it has been created recycling is the method of managing the waste. Prevention of the waste means the effective use of natural resources, energy needed to manufacture new materials as well as reducing pollution (1).

More than thirty projects (Companies) were recruited and waste minimisation and prevention, efficient use of energy and water strategies were introduced to companies supported by an on going monitoring programme.

Prior to introducing waste management strategies, a baseline survey enabled the overall level of understanding of waste minimisation among contractors/project teams to be identified. This survey provided the baseline on which a plan of action for each company/project was set up. A monitoring model was developed to assess the implementation by companies of the proposed plans and the achievement of project targets.

Waste arising data was also collected and data used for three categories of analysis:

- Total weight of waste arising at different construction stages
- Type of waste streams on different construction stages
- Percentage of waste that went for recycling

Study shows that waste can be minimised if waste minimisation is considered as part of the contract. On-site, segregation of waste and reusing of material were the most common adopted methods to minimise waste (2) (3) (4). However, many contractors were not aware of government initiatives to minimise waste or to improve the environmental performance of their business.

This study also shows that there is not a strong relationship between environmental certification such as ISO14001 and actual waste minimisation activities in small and medium companies. Environmental certification for small and medium companies is a very expensive step compared to taking waste minimisation initiatives on-site.

WASTE MINIMISATION INITIATIVES

To minimise waste two main stages of building project were identified as needing review:

- Contract and contractual agreement stages: Client, contractor and architect play important roles in reducing waste through incorporating waste minimisation activities during the contractual agreement stage.
- Construction stage: a structured methodology has been produced which can be incorporated at the construction stages to minimise waste.

Contract and Contractual Agreement

This study identified three main players in the construction supply chain that play an important role in reducing construction and demolition waste during the pre-construction process which:

Client - employer

It was observed much of waste could be minimised through contractual agreements from clients to contractors, and clients to designers and eventually through the whole supply chain.

Therefore it is important that waste management and minimisation should be incorporated during the each stage of the contractual agreement e.g. in the building.

The client can also have an influence on the design and construction methods, which can be incorporated to enable, ease of reuse of the facility after its design life and dismantle building elements, which, can be reused. However, this area of improvement needs a very comprehensive study to enable the building to be dismantled in practical way.

Architect and designer
In an environmental point of view it is desirable that, at the end of a facility's natural lifetime, as many of its components as possible are reclaimed or recycled for reuse in other construction applications. If this can be achieved then environmental impacts will be significantly reduced. However, future success depends on the following issues being addressed:

- Working closely with suppliers of construction products to minimise wastage, for example of non-standard panel sizes to avoid cutting standard panels.
- Making sure the design and specification of the building is appropriate to the requirements.
- Appropriate methods of the construction to support the structure's weight and is easy to dismantle.
- Use of recycled and reused materials in design
- Form of the building or facility
- A good balance between the overall design and safety factors
- Building designs that are adaptable for future conversion

Contractors and Project Managers
At this stage of the process, it is important that the contractor is involved. At the very least this should mean liasing with designers and clients as to their intentions and therefore what techniques and materials will be required. The contractor should have the opportunity to alter the plans if the requirements will not be appropriate. Further to this role, the contractor should also be involved at this stage in the site preparation, logistical needs, and installing site facilities. In terms of what this project is trying to promote, they should also attend induction courses to ensure that the techniques and materials they use are to a standard desired by the client, particularly in reference to waste minimisation.

Construction Process
To minimise waste, it is necessary to have a structured methodology that is flexible enough to provide guidelines of the effort to minimise waste on site. A structured methodology has been generated which is based on the Environmental Management System model.

Phase 1: Investigation of the current situation

- Evaluate the client's interest in minimising waste
- The type of contract
- Type of building facility going to be constructed
- Information about labour jobs
- Identifying the waste streams likely to be produced
- Identifying the possible causes of waste arising

- Site layout and temporary facilities
- Study of materials and handling procedures on site.

Phase 2: Analysing and evaluating the waste minimisation opportunities
Once the waste streams and causes of waste generation have been identified, the second phase is to identify the cost – effective opportunities to minimise waste through setting up methods/techniques that are flexible enough to adapt to the nature of the project. This activity can be performed using teamwork and brain storming with the members of team. At this phase the aim is basically to draft the route mapping for waste and prepare strategies.

Phase 3: Implementation of waste minimisation strategies
The most important aspect of the implementation of the strategies is to overcome the barriers presented by the personnel. It is also important that implementation plans understood and accepted by all the people that will be affected by the changes. Some of the typical activities considered in implementation plans are:

- Training the staff for the change
- Communicating the plan in an effective way and suitable time
- Changing documentation
- Obtaining commitment from staff

Phase 4: Monitoring
This is the phase that determines how successful the waste strategies being implemented actually are. This phase also determines whether the targets that were set are adequate enough and whether these targets need to be adjusted. Decisions should be made at this stage based on results obtained and the analysis of the implementation process. Some of these decisions will involve applying corrective actions to the implementation process, as part of a feedback system to review the improvement of the methodology.

Phase 5: readjusting the changes
The two main purposes of this phase are:

- Making sure the changes proposed after monitoring are being adopted.
- Making sure that all levels of staff are being informed of the changes and improvements and if necessary that training is provided to assist in implementing new changes.

This methodology can also be used with modification at pre construction stages. This methodology is a systematic approach to organise the implementation of performance improvement processes in construction project situations.

BARRIERS IN MINIMISING WASTE

The main barrier to implementing waste minimisation on site level is lack of infrastructure to manage waste in an environmentally sound manner. However, during the implementation of this project, the team encountered various constraints to improvement of waste minimisation on and off site. These constraints are divided into the following sectors:

- Management and building project team relationship

- Role of the supply chain
- Transfer of information
- Market
- Skip hire companies and Funds
- Design considerations

Management and Building Project Team Relationship

Managers see waste as an avoidable 'whole Life' problem of building activity. Approaches to waste management are both pragmatic and impeded by perception of a lack of managerial commitment. The ability of operatives to minimise waste on site is mainly influenced by the managers. Although individuals saw the relevance and importance of the waste minimisation, their attempts to do so were constrained by time and cost pressures on projects, and by work processes that were not designed to facilitate waste reduction strategies. Further to this, managers were seen as the main source of responsibility for waste minimisation efforts. Therefore without managerial input, it is difficult for the other site staff to take waste minimisation issues seriously.

However, in this section the project team have highlighted the following factors, considered the key reasons for all the proposal plan of actions in terms of waste minimisation not being implemented:

Uncertainty of the site staff

During the project in many 'on board' projects, it is common for either the site manager or other site level staff to leave half way through the project. This means that all the proposed initiatives or any other plans need to be repeated or may not even be considered by the new personnel. New personnel arriving mid project tend to be more concerned about the completion of the project and are unwilling to undertake other initiatives which are not part of the tender. In many cases even sub contractors leave the job due to the casual structure of business or financial competitiveness in construction industry, particularly towards SMEs.

Role of the site manager

Waste minimisation is not a required role of the site manager in many cases; therefore he/she does not concern themselves with handling waste in an environmentally sound way. S/he does normally pay attention to site tidiness and maybe the handling of materials but not to deciding the appropriate final destination of waste. On the other hand on some projects he/she has been seen as in charge of waste management. The role of site manager and foreman therefore needs to be reviewed in terms of their scope of the jobs, in order to try and reach uniformity.

Role of supply chain

The word partnership in sustainable construction is a very broad term, however in the context of this project can be taken to mean co-operation between the various segments of the building project teams. During this project it was noted that a company agreeing on the segregation of waste materials would not necessarily mean the subcontractor co-operated in segregation on site. In some cases the suppliers would not take back their packaging despite it being segregated on site. It was determined that this could be a result of Health & Safety Laws, which for example now require one tonne sand carrier bags to be tested for strength after each use, and therefore supplier companies feel that reusing these bags is not worth the expense. Lack of co-operation was frequently observed between various segments of the site teams.

Transfer of Information
In this study transfer of information meant three types of information:

Transfer of information from top to bottom of the supply chain
One of the main constraints faced by the project team was the transfer of information from management to all other levels of the team. In many cases the company decided at management level to implement a waste management plan but did not relay the information to employees at site level, meaning site staff did not receive an induction into their waste management initiatives. Obviously if site staff are not inducted they would not be ready to accept any practices that they have no experience in or have been forced on them from managerial level. Not only do company's initiatives towards waste management not usually go through all levels of staff, but awareness programmes concerning new developments in industry or new technological needs of the industry take a long time to filter through to all members of the workforce.

Transfer of information from R &D bodies to the industry stakeholders
Many initiatives that were proposed by the project team were very new concepts to the companies. It was observed from the baseline survey that many companies were not aware of many initiatives undertaken by government agencies or research bodies. It was realised that many government initiatives were actually directed towards big companies where the understanding of business methodology is quite different than in SMEs.

Reviewing the training of the supply chain.
One of the most important obstacles faced by project team during project implementation was lack of training in environmental issues. Many units of the building project teams did not have any training or course work towards improving environmental performance. Particular focus should be on the intense need for training at site level on site environmental issues.

Market
This study identified that even if contractors or building project teams agree to recycle materials, recycling opportunities are very limited in the South Wales, UK area. During the project a directory of recyclers in the South Wales, UK area was produced with the assistance of Groundwork Directory for Recyclers. If a company does have recycling opportunities then these companies struggle to find a Market. It is important to promote solutions based on market strategies and that there should be incentives for companies to be involved in waste reduction.

Skip hire companies and sector development
During the project implementation it was observed that if a skip hire company (especially small and medium sized firms) decides to establish a recycling opportunity at their transfer station then it seems to be difficult to gain investment funding, which, if available, then tends to go big waste management companies.

Design considerations
It would be appropriate to mention here that market promotion of recycled materials can be achieved once attention is paid to the design stages of the project, where, through client or other pressures, the architect or designer can incorporate recycled materials in their specification or design.

Design consideration is one of the most prominent factors influencing waste production on site, especially where the design requirements are not compatible with the market specification of the materials. For example, plasterboard is always supplied in a different size to the architect's specified size in the buildings and as a result the plasterboard is cut down to the required size and rest goes into the skip as waste. Various aspects in design consideration can be identified as effecting waste production. Implementing building methods that will ensure that when future modification or decommissioning occurs, building elements and the entire structure can be taken apart and reused with ease and minimal wastage. (1)
This will involve outlining strategies such as building room widths and heights to dimensions that enable contractors to use whole standard sized materials such as structural timber, plaster board, bricks etc to reduce off cut waste. Other strategies for consideration here include construction companies using their buying power to have materials suppliers manufacture elements in sizes, which allow better efficiency of material use for a particular building design. (5) Especially in projects, which are design-to-built, it would be possible to integrate the design of the building with the dimensions of the materials supplied, or the supplier could supply materials that comply with the design such as, concrete blocks and plaster boards etc.

DISCUSSION

A particular hindrance to waste minimisation initiatives is the present state of recycling opportunities. Materials sent for recycling was totally dependent on the regional recycling facilities. It was found that South Wales, UK has very limited opportunities for recycling, in particular for building glass, wrapping plastic (packaging) and building polystyrene. There were no recycling facilities for insulation material and plasterboard. However, specific research needs to be done to identify the opportunities for recycling insulation material and plasterboard, and how recycling can better relate to waste streams produced by specific project types.

During the project it was observed that most contractors play a very significant role in improving the environmental performance of the building process and operations. It should be noted that architects and designers have as important a role as contractors. However the nature of their role differs as contractors are more concerned with site operations particularly in reference to Small and Medium Enterprises, as the contractors are the people who actually run the construction operations on the site, and architects and designers impacts are more related to the life cycle of the building.

There was generally a positive response towards developing environmental policies for their companies. However there was very low interest towards the official accreditation schemes such as ISO 14001. The lack of interest in big accreditation schemes is because while companies recognise the value and importance of these schemes, they simply cannot afford to train the staff or implement the standards or even go through the certification process due to financial reasons.

It was also observed during the project implementation that there wasn't the infrastructure to implement complete environmentally sound programmes or activities in South Wales. It was confirmed by various visits made by the project team to some sites of big companies' who are certified with ISO 14001 but were not actually involved in any waste minimisation activities.

Overall most of the on board companies implemented or incorporated many of proposed activities to minimise waste. However segregation of waste, material handling and storage can be improved on sites. In many cases even if company agrees on segregation policies, skip hire companies do not seem to be providing either the facilities or reduced rates to the segregation schemes. This provides a major problem for persuading companies to undertake segregation, because they often do so on the understanding and incentive that their costs will be reduced. However this doesn't work in practice because some skip hire companies charge the same rates even though they themselves make money by sending material for recycling and not for landfill.

Furthermore, minimising waste is considered as an ad hoc activity not part of the core activity of the construction. During implementation of the project it was found that all available human expertise is not usually utilised efficiently towards the goal of encouraging building project teams to minimise waste on site.

It was observed there was quite an obvious reluctance towards sending materials for recycling and reclaiming because of the lack of market flow for recycled material. Finally to minimise waste from construction industry we need to make business case for it, which incorporates the promoting market for recycled and reclaimed materials.

ACKNOWLEGEMENT

European Regional Development Fund
Mandix Design and Management Consultants, UK
CIRIA – Construction Industry Research and Information Association

REFERENCES

(Books)
1. Addis, B., and Talbot, R., Sustainable Construction Procurement: A guide to delivering environmentally responsible projects, CIRIA, London, UK, 2001.

2. Chadwick, L., Materials Management, Profitability and the Construction Industry' in: Building Technology and Management, Chartered Institute of Building, Ascot, February 1982.

3. Skoyles, E.R., and Skoyles, J.R., Waste Prevention on Site. Mitchell: London, 1987.

4. Skoyles, E.R., Management Role in Waste Control: Materials Management in the Construction Industry, NCMHC, Sterling Publication Ltd, 1983.

(Reports)
5. Greenwood, R and Jones, P., Construction Waste Minimisation through Counselling Building Project Teams and Collecting Waste Arising Data, European Regional Development Funded Project – REF. 51303, CRiBE, Welsh School of Architecture, Cardiff University, UK, 2001.

(Papers)
6. The Secure Site – An impossible Dream? Chartered Institute of Building Occasional Paper44, 1991.

(Proceedings)
7. All Winkle, S.J. and Stambridge, D.W., An Analysis of the Barriers to the Reuse and Recycling of Building Materials. In: Proceedings of CIB first International Conference: Buildings and Environment, Building Research Establishment (Garston), UK, 1994.

8. Atkinson, C., and Collins, R. J. and West, J., Use of Waste Materials in Building Products. In: Proceedings of CIB First international Conference: Buildings and the Environment, Building Research Establishment, Garston, UK, 1994.

THE CONDITIONS AND CONSTRAINTS FOR USING REUSED MATERIALS IN BUILDING PROJECTS

Authors: Mats Eklund (Linköping University, Linköping, Sweden); Svante Dahlgren (TP Property Consultant, Norrköping, Sweden); Agnetha Dagersten (Stångåstaden Housing Company, Linköping, Sweden); Gunnar Sundbaum (Sundbaums AB, Linköping, Sweden)

ABSTRACT

Examining two Swedish case studies of buildings that were built with a large share of reused materials, such as concrete frames, we analyzed the conditions that made these pilot projects possible. We also examined the constraints of the projects. The analysis is structured around four central themes: the project organization, the participating actors, the financial issues, and the technical issues. The authors played different role in the projects, and we arranged a semi-structured discussion and interviews with the actors involved in one of the projects. The paper suggests that there were no significant structural driving forces behind the realization of the projects; however, individual commitment from some key actors made these reuse projects realized. This study outlines some aspects that would be useful to consider in new projects.

KEYWORDS: Actors; Building; Concrete; Conditions; Constraints; Deconstruction; Financial; Organization; Reuse and Technical

INTRODUCTION

In industrial countries such as Sweden, people are moving from industrial towns and smaller communities to cities and suburban areas often associated with universities, to find work in the service sector and in high-tech industry. This development results in empty buildings in some places, and housing shortages in other places (1). Because empty apartments are expensive to heat and maintain, they are often demolished long before the building's technical-life expectancy is reached. Reusing the materials from such buildings in areas in need of housing makes sense; however, this is not a common practice. Generally, buildings are demolished and virgin raw materials are used for new buildings. Such building practices do not maintain the quality of the materials and waste natural resources and energy.

Wood, steel, and concrete are the Swedish building sector's most important materials, when you combine their embodied energy and mass (2). Improved recycling practices that use reused materials instead of virgin materials would significantly improve the environmental performance of the building sector. However, concrete is typically recycled as aggregate used for landscaping or road construction. In such applications, concrete mainly substitutes crushed rock that is an abundant material in many countries. Furthermore, the energy used to produce crushed rock is less than 10% of the energy used to produce concrete. If reused concrete instead substitutes concrete produced from virgin raw materials, the environmental performance of the reuse practice would be significantly improved.

In two cases in southern Sweden, concrete and other materials have, after deconstruction, been reused in new buildings. This article analyzes the conditions for reuse in these two cases and discusses them in a more general context. Furthermore, there are many constraints for reusing materials in building projects. We examine the constraints of reusing materials in these two building projects.

METHOD

The authors have been involved in different roles in the projects. In 1996, the idea for the first project (Udden) was formed by Gunnar Sundbaum. The second project (Nya Udden) was completed in 2002. The authors come from the company owning the new property (Stångåstaden), the project management company (Sundbaums AB), and Linköping University, who evaluated the environmental performance of the projects. In 1999, the Udden project was evaluated in a Swedish report (4), focusing mainly on the technical and environmental aspects of the project. During a meeting in 2002, the authors identified the conditions they believed were necessary for the realization of these projects. We met with many of the actors that had been involved in the completion of the projects. This approach was modeled on the focus group approach (5), which can add a new dimension and generate new information, compared to traditional interview methods. Before the interview, the participants were asked to complete a survey that addressed conditions and constraints according to these categories: organization, actors, technical aspects, and financial aspects. During the meeting, the participants were asked to prioritize conditions and constraints for the projects. Finally, the participants were asked to discuss the optimal conditions and organization for future projects involving reusing materials.

THE PILOT PROJECTS

The Udden Project

The Udden project was started in 1996, when Gunnar Sundbaum was exploring ways to deal with empty buildings in Finspång, Sweden. This town has a long industrial tradition, but improved productivity in industry has decreased the need for labor. In Finspång, multi-family units are owned mainly by a municipally-controlled company that faced a difficult financial challenge for the first time. In 1996, 325 of the 2400 apartments were empty, costing the company a great deal of money. The company's earlier strategy to meet such problems was to improve the housing; but this was no longer sufficient since the causes of the problem of empty apartments was related to the economy and the location of the apartments (cf. 6). It became obvious that the buildings had to be demolished to decrease the number of apartments and to simultaneously try to improve the quality of living in those areas by creating more space between the remaining buildings. It was decided that five buildings containing more than 100 apartments would be demolished. They were built in the 1960s, but they were renovated several times since then and were in good condition.

Figure 1. *This is one of the apartment buildings in Finspång, Sweden that was torn down and functioned as a material source for a new building in Linköping, Sweden.*

Gunnar Sundbaum suggested that the “apartments should be moved” to Linköping to address a housing shortage there (especially a housing shortage for students). That is, the materials that could be reused should be moved to another site to be reused in the construction of new apartments. This would require the building to be deconstructed carefully so the materials could be reused. This suggestion was made to the managing directors of the housing company in Finspång and to the largest housing company in Linköping. In 1997, they decided to develop the project and requested bids from three large contractors.

In order to make use of as much of the materials and products as possible, the general contractor carefully deconstructed two of the buildings in Finspång. The buildings were constructed mainly out of concrete and beams cast in-place. To reuse these materials, they were cut with a diamond saw. The deconstruction was predicated on what the new building could use. Materials and products from about 50 larger apartments in the two buildings that were deconstructed were used to construct a building containing 22 smaller apartments (totaling 1070 m^2). In the Udden project, reuse was not restricted to concrete walls and beams (Table 1), although this is the most conspicuous feature of this building (Figure 2).

Table 1. *Selected products and materials reused in the Udden project. Data refers to number of items unless specified.*

Concrete wall elements	73	Kitchen sinks	12
Concrete beams	41	Water taps	39
Concrete foundation	30 m^2	Sanitary ware	46
Doors	45	Radiators	63 m^2
Windows	89	Clay bricks	220 m^2
Wood flooring	600 m^2	Window ledges	26
Kitchen cupboards	92	Mineral insulation wool	236 m^3
Wardrobes	78	Mineral insulation	636 m^2

Figure 2. *Concrete elements cut from cast in-place concrete walls delivered to the building site in Linköping under the supervision of the county governor, Björn Eriksson.*

The environmental performance of the Udden project was evaluated; for the impact categories studied, it turned out to be a better option than using conventional building techniques and materials. If the elements would have been transported a distance longer than 140 km, the emissions of nitrogen oxides would be higher for the reuse project due to the truck transport (1).

The Nya Udden Project

The Nya Udden project, a student housing project, was completed in November 2001 . However, there are many significant differences from the Udden project. First, the material source was an area in Norrköping where the buildings were built with pre-cast concrete elements, which meant that time-consuming cutting of elements was not needed. The organization of the deconstruction and building process also differed substantially. In this project, there were different actors responsible for the deconstruction and the building processes. The building process was not coordinated by a general contractor. Instead, a project management firm that hired several subcontractors performed the coordination of the building process.

In 1999, the property owner in Norrköping, Hyresbostäder initiated a 100 million euro refurbishment project involving 1600 apartments in the district of Ringdansen, Norrköping. The area was built from 1968 through 1972, and was the home of about 5000 people. However, the area had gained a bad reputation and was not considered attractive. The refurbishment project aims at an attractive district with about 1000 apartments. This is accomplished mainly by removing upper floors on many of the buildings, which means that a careful deconstruction was needed.

The new building had 54 new small apartments, but the original idea was that 500 new apartments would be built using the concrete elements from Norrköping. Because the careful deconstruction turned out to be more expensive than deconstruction that aimed at crushing concrete, the agreement between the material supplier and the user of the material was terminated. This led to the conclusion that most of the new 500 flats had to be built with conventional technique and using materials and products of virgin origin.

Reuse in the Nya Udden project focused on the concrete elements more than the Udden project did (Table 2) (Figures 3 and 4).

Table 2. *Reused materials and products in the Nya Udden project, Linköping, Sweden.*

Reused materials	**Number**	**Tons**
Concrete partition walls	138	524
Concrete outer wall elements	72	208
Concrete beams	224	684
Concrete stair-cases	8	16
Iron banisters	16	
Windows	34	
Window ledges	100	

Figure 3. *The concrete elements from the refurbishment project arrived at the building site in Linköping, Sweden.*

Figure 4. *Frame construction in Nya Udden. Additional steel supports were used to further reinforce the building.*

ORGANIZATION AND ACTORS

To realize building projects like these that involve deconstruction and construction, a number of actors have been involved in the organization of the project. In the Udden project, resulting in 22 small student apartments, twelve actors have been identified - the four most important are listed in Table 3. These twelve actors are involved directly in the deconstruction and construction of the project. Furthermore, regional and national agencies have granted money for the projects, and the projects have gone through a conventional planning process by the local government. These two processes were crucial for the accomplishment of reuse building projects. The issue of governmental grants is discussed below under financial aspects; but regarding the spatial planning process in the local authority it is worth noting that a reuse building project differs from a conventional building project. First, the timing of deconstruction and construction of a new building is difficult to manage by itself. Such a project needs to go through a spatial planning process that could complicate the issue of timing. However, this was only a slight problem in these projects. On the other hand, building with reused concrete elements demanded more flexibility in the spatial planning process, because the builders were much more tied to the building size and design than in a conventional building project.

Table 3. *Main actors of the integrated deconstruction/construction projects (Udden and Nya Udden) involving deconstruction in Finspång and Norrköping and construction in Linköping. Several smaller companies were responsible for heating, sanitation, electricity, etc.*

	Udden	Nya Udden
Owner of the new property	AB Stångåstaden	AB Stångåstaden
Project management	Sundbaum Bygg och Miljö AB	Sundbaum Bygg och Miljö AB
Main contractors	NCC AB	Idébyggarna (concrete frame) and Åhlin and Ekroth
Reused building materials supplier	Vallonbygden AB	Hyresbostäder AB

In the Nya Udden project, the responsibility for the deconstruction and the frame assembly was not in the same organization. The refurbishment project was done without proper coordination with the building process in Linköping.

Owner of The New Property

The owner of the new buildings, Stångåstaden, is a municipally-controlled company in Linköping, Sweden, and is a key actor in the two projects. This section describes some of the features of the company that potentially could have influenced the decisions to build apartment buildings with reused materials. The first issue is public ownership. Have the owners influenced the company to take these initiatives? The informants working for Stångåstaden state that the politically-appointed owners did not interfere with these decisions, and the ownership involves only management on a strategic level, emphasizing the importance of a high environmental profile of the company in general. This ambition was further manifested in the two projects by recruiting an environmental manager.

Instead of ownership, the informants at Stångåstaden stressed the size and financial power of the company as a condition that made these projects possible. Its turnover in 2002 was about 115 Meuro, and its return exceeded 12 MEuro. Such conditions make it possible to take an increased risk and to take on pilot projects such as these. In both these projects, no decisions about any grants were made before the projects started. It was possible for Stångåstaden to go ahead with the building process because of their financial stability.

However, our informants also emphasized that the managing director was committed and liked the ideas very much. He also saw the opportunity to strengthen the environmental profile of the company through these projects. The two projects described here were securely anchored and driven by the top management of the company, rather than by individual employees in the organization.

Project Manager

Gunnar Sundbaum at Sundbaum Building Consultants came up with the idea of solving the two problems of empty dwellings in one town with housing shortage in another with an integrated deconstruction and building project. Previously, he worked in property management and refurbishment of unattractive housing areas, with the aim of improving their quality. His company was responsible for the project management of the Udden project and the Nya Udden project. Gunnar Sundbaum was the main innovator behind the project. His experience with surplus and shortage problems made him an integral designer of the project. He acted as a catalyst for both projects by presenting the idea to the key actors: the managing directors of the housing companies that experienced both surplus and shortage problems. Through his efforts, the concept became firmly anchored within a purchaser organization with sufficient financial stability to engage such projects. He also employed skilled people to act as project leaders, and provided the project buyer with an organization to tackle all the practical problems that would arise.

Reused Building Materials Suppliers

The owners of the buildings that could potentially be deconstructed and their motives are, of course, crucial if deconstruction of buildings will be chosen over demolition of buildings.

Vallonbygden (the municipally-controlled housing company in the Udden case) was ambivalent about the project. It was difficult for them to communicate a positive message regarding a project that included deconstruction of their property. From the view of the local authority that indirectly influenced the company’s decisions, it was difficult to accept that buildings needed to be removed. This is partly because of a psychological effect associated with admitting that the town was in an economical recession (4). The unpleasant but necessary decision became easier, thanks to the idea of a deconstruction approach. The company management believed that it was better to be associated with a project where new buildings were constructed using materials from deconstructed buildings, than to simply demolish their empty buildings. Therefore, their role in realizing the project was not as a main force, but they were still a positive project partner.

Hyresbostäder, who managed the large refurbishment project in Norrköping, was the material supplier for the Nya Udden project. Their refurbishment project has an overt environmental profile. Because of this, the government granted 26 million euro to the project. One of the environmental aims of the project was a high degree of recycling of the materials that the deconstruction would generate. This goal was also a condition for the governmental grant. During the deconstruction work, careful handling was needed when the elements were to be reused in a new building, making this process more expensive than expected (cf. 3). The agreement regarding concrete element deliveries to the building projects was broken after the Nya Udden project. Instead, after deconstruction of the top floors, the concrete was crushed and mainly used for local landscaping. At present, it is not clear whether the governmental grant will be affected by this practice. One can conclude that this material supplier focused on its own refurbishment project and did not become involved in the process of building new apartment houses.

The Main Contractors for Deconstruction and Building

The Udden project had general contractor responsibility for both the deconstruction and construction of the new apartment building. This made it possible for the contractor to use the same staff for the deconstruction as for the building process. Depending on progress in the project development, staff could be used in a flexible manner, either at the deconstruction site or at the building site. The incentives for the workers responsible for the deconstruction to be careful with the concrete elements and the other products were obvious. Any problems related to the reused materials and products would become their own headaches later.

The company Idébyggarna was responsible for the transport of the elements and the erection of the concrete frames in the Nya Udden project. They had to solve several problems in the process (see below in Technical aspects). The main problems regarded coordination with the deconstructors about how the elements should be handled and stored. Because the storage site was not planned, the handling and loading of the elements was inefficient. The informant from this company stated that they have learned a lot from participating in this project, and they would be happy to make use of their experience in similar projects.

Åhlin & Ekroth was the company responsible for the main part of the Nya Udden except the concrete frame. Their representative in the focus group stressed that it was not very different or more difficult than a conventional building project. However, the reuse practice still influenced all the other building contractors. The demand for coordination and cooperation between the different builders was greater than in an ordinary project. In this project, it actually contributed to the creation of a cooperative atmosphere at the building site. Being involved in the Nya Udden project led to an increased commitment to environmental issues among the employees. In all the projects Å&E has been involved in since then, there has been an improvement of waste management at the building sites, resulting in lower costs for the company. According to our contact, this organizational improvement can be attributed to their participation in the Nya Udden project.

TECHNICAL ASPECTS

The contractors in the focus groups stressed that they have not met any serious, immediate technical problems in building with reused materials. The technical problems encountered are related to the organizational and financial aspects more than any other aspects. The focus groups noted that timing was a serious issue that needed to be addressed in future projects. In the Nya Udden project, there was significant time pressure at both the deconstruction site and at the building site that made the preparatory planning process too short. Furthermore, different actors were responsible for the deconstruction and the construction. This made the temporary storage sites at both locations inefficient, and it caused many problems because there were no immediate incentives for the people deconstructing the buildings to handle the elements carefully. They were not aware of the problems caused by storing the elements. Wall elements were stored and transported standing, which did not cause any problems, while beams were stored lying down. Four beams were stored on top of each other, and if this was not done properly, cracks could arise. When this problem occurred, concrete beams had to be discarded.

To make sure that the construction at Nya Udden would suffice in terms of pressure failure, some tests were performed on the beams. It was no problem to satisfy standards in this respect, but to ensure safety over-dimensioning of supports was also applied.

Building standards have changed in many respects since the buildings were constructed. In both the projects, noise reduction standards were not met using the old elements. In the Udden project, a new concrete layer was added on the beams; in the Nya Udden project, this was solved by using insulation materials and gypsum board. Extra insulation and surfacing of the outer walls had to be added to meet insulation standards in both projects.

Comparing the two projects, partial deconstruction of element buildings seems better than having to saw cast in-place concrete walls and beams. However, to some extent, the technical problems in the Nya Udden project were easier to solve and were outweighed by the organizational problems regarding the different incentives of the deconstruction team and the builders.

FINANCIAL ASPECTS

For both projects, using a large degree of reused concrete elements cost roughly 10% to 15% more than building with conventional building practice. This additional cost has been compensated for by governmental grants for “green building practices,” so that the cost for the property owner roughly equals that of a conventional building. However, in both cases, the grants were awarded at the time the decision to build was made. The property owner, Stångåstaden, thereby took a risk of starting two building projects without knowing the financial outcome. This uncertainty was also 10% to 15% of the total project cost. The focus groups urged a rapid and flexible process for awarding grants for building projects. The informants believed that such a practice would facilitate decision-making significantly, and would lead to more reuse building projects in Sweden.

The additional cost for reuse should be viewed in the context of the pilot character of these projects. No contractor had any experience with projects such as these, and their response in the focus group was that a 10% to 15% cost reduction could be easily accomplished in future projects. These projects were performed on a relatively small scale. Because only 26 and 54 small apartments were built, the projects do not make it possible to make significant large-scale profits. The participants in the focus group concluded that projects such as these could be profitable if the scale is increased and if the contractors benefit from earlier experience and knowledge.

In the Udden project, the total cost for the concrete frame was 80% higher than if virgin materials would have been used. This increase can be attributed to cost for labor that is doubled in this reuse project, compared to a conventional building project. On the other hand, the materials cost was only 20% higher than projects using virgin raw materials.

It is worth noting that the customers, the tenants, would not be prepared to pay extra for the benefit of living in a building made of reused materials. Rather, it has been noted that the quality demands from the tenants are higher in the reuse buildings, while the quality demands raised by the property owner are slightly lower than in a conventional building project.

CONCLUSIONS

Generally, environmental initiatives like the use of environmental management systems or environmental investments in companies often have their origin in either market demands or changes in legislation. However, some authors also refer to the simple explanation that committed and influential individuals often want to do something they believe is good. The latter explanation is largely applicable in the cases described in this article. However, some conditions of a more structural kind–for example, financial aspects–also have to be met if reuse projects are to be realized. As for policy implications from this finding, the focus should be placed on creating favorable conditions for the committed individuals, rather than exclusively stressing the importance of the structural conditions.

There are several aspects that should be considered for future building projects with reused materials to address the constraints experienced in the these two pilot projects.

The informants emphasized that a large-scale use of reused materials in the Swedish building sector will not take place unless it is possible for actors to profit financially from this practice. In this context, three conditions for further development were identified as crucial.

(i) The size of the individual projects. Projects the size of 20 to 50 small apartments do not make it possible to use technical improvements and techniques to produce a significant financial return.

(ii) Benefit to the contractors. The building contractors need to know that there will be more projects of the same kind if they develop technology and building techniques for use with reused materials.

(iii) The endurance of governmental bodies that influence the financial boundary conditions through grants or subsidies. The two pilot projects that this article deals with were decided under uncertainty about whether any subsidies would be granted in a process that was difficult to manage and predict the outcome.

In the Nya Udden project, the governmental grants required deconstructed materials to be recycled. It still seems, however, that no quality demands regarding the kind of recycling were raised, which made it possible to break the agreement and instead crush the concrete elements to save some money. In the future, such refurbishment grants could be more explicit about grant requirements. This would create more favorable conditions for reuse projects.

According to our informants, the realization of a new project of this kind should be predicated on the manager of the building project controlling the building/s that should be deconstructed. This would help cope with the timing problem and would mean that the builders will not have to depend on actors who are not involved in and committed to the building project.

The two pilot projects described in this paper involve significant changes to the layout of the apartments. The material source buildings contained two to four-room apartments, and the new buildings are smaller one or two-room apartments for students. In a new project, the material source building and the planned building should be as similar as possible. The focus should be on deconstructing a building so that as much source material as possible can be reused in the new building.

REFERENCES

1) Roth L and Eklund M (2001). Environmental analysis of reuse of cast-in-situ concrete in the building sector. In: Shanableh A and Chang WP (eds.) Towards sustainability in the built environment. Brisbane.

2) Roth L, Eklund M and Simonsson A (2002). Assessing the building sector’s most important materials from an energy and material resources perspective. In: Proc Sustainable Building 2002, September 23-25 Oslo, Norway.

3) te Dorsthorst BJH and Kowalczyk T (2001) Re-use of apartment buildings: a case study. In: Chini A. (2001) Deconstruction and materials reuse: Technology, Economic and Policy. Proc of the CIB Task group 39. CIB publication 266.

4) Sundbaums, Linköping University and NCC Technology (1999) Rapport Profilen-Ryd. A pilot project reusing concrete frames. (In Swedish).

5) Wibeck V (2000) Fokusgrupper: om fokuserade gruppintervjuer som undersökningsmetod. Lund (In Swedish).

6) Bowes H and Golton B (2001) Obsolescence and demolition of local authority dwellings in the UK- a case study. In: Chini A. (2001) Deconstruction and materials reuse: Technology, Economic and Policy. Proc of the CIB Task group 39. CIB publication 266.

RECYCLING GYPSUM DRYWALL RECOVERED FROM DECONSTRUCTION PROJECTS: A TECHNOLOGY AND MARKET OVERVIEW

Authors: Timothy G. Townsend (University of Florida, Gainesville, Florida, United States)
Kimberly Cochran (R.W. Beck, Orlando, Florida, United States)

ABSTRACT

A major component of modern buildings is gypsum drywall, also referred to as wallboard or sheet rock. Drywall is composed of 90% gypsum ($CaSO_4$-$2H_2O$) and 10% paper. Several successful drywall recycling operations exist in North America. Major markets include manufacture of new drywall, portland cement production, and agricultural amendment. Most successful recycling operations utilize post manufacturer scrap drywall or scrap from construction projects. Those interested in recycling of gypsum wallboard from deconstruction projects face additional challenges. This paper presents an overview of the existing technologies used to recycle gypsum drywall, the primary markets, and the hurdles to wide-scale implementation of drywall recycling. Issues surrounding recycling of drywall from deconstruction projects are discussed, including environmental issues such as lead-based paint and asbestos.

KEYWORDS: Gypsum Drywall; Recycling; Wallboard; Sheetrock

INTRODUCTION

Gypsum drywall is a major component of most modern buildings, yet it often is one of the least likely components of the waste stream produced from building construction, demolition or deconstruction to be recycled. Several gypsum wallboard recycling facilities successfully operate in North America at the current time, but in some areas (Florida for example) drywall recycling is relatively nonexistent. This paper provides an overview of the current state of gypsum drywall recycling in North America and includes a discussion of issues such as markets and processing techniques. In addition, most of the drywall recycled at the present time is post-manufacturer waste or scrap from new construction activities. Those interested in recycling drywall recovered as a part of deconstruction activities must also consider several environmental issues such as asbestos and lead-based paint. These issues are also discussed. Much of the background information for this paper, including a complete set of references, can be found in Townsend et al. (2001) and Cochran (2002).

DRYWALL BASICS

The mineral gypsum possesses many attributes that make it an attractive construction material. Calcined gypsum can be wetted to form a paste that can be directly applied to a structure's surface or that can be molded into a desired shape; the gypsum hardens upon drying. Gypsum is naturally fire resistant. Gypsum drywall, often referred to as gypsum wallboard or sheet rock, replaced gypsum plaster as the major material used for interior wall surfaces because of its ease of installation. Gypsum drywall consists of approximately 90% gypsum and 10% paper facing and backing. Gypsum is composed of calcium sulfate ($CaSO_4$) and water (H_2O). Also referred to as hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$), gypsum is mined from deposits formed by ancient seabeds as a raw material for many different manufacturing, industrial, and agricultural uses. Over 80% of the gypsum mined is used in manufactured products such as drywall.

Drywall is manufactured by first calcining the gypsum, a process that heats the mineral to remove part of the water (resulting in $CaSO_4 \cdot 1/2H_2O$). The stucco that is formed is then rehydrated by mixing with water, and the slurry created is spread onto a moving continuous sheet of paper and sandwiched between another layer of paper. This continuous sheet of wallboard is allowed to harden for several minutes, cut into panels and sent to a kiln for final drying. It is trimmed to the dimensions required, bundled, and is then ready for shipment. Drywall comes in many different types and sizes to meet specific construction needs. Several specialty products are manufactured including moisture resistant drywall (greenboard) and Type X drywall. Type X drywall contains small glass fibers designed to increase the board's ability to withstand high temperatures from fires for a longer period of time and thus, would be used in projects that would require higher heat resistance than regular drywall would provide.

Drywall enters the solid waste stream in several different locations. These include the manufacturing facility, new construction sites, renovation activities and when a building is demolished or deconstructed. Debris from construction sites is typically encountered as large pieces that can be somewhat easily removed from the other debris components. Because of its friable nature, gypsum wallboard is very difficult to recover from mixed debris resulting from standard demolition practices. It can, however, be recovered through deconstruction using the appropriate removal techniques. Renovation debris is generally a mix of construction and demolition debris.

The amount of waste drywall produced during a deconstruction project varies as a function of the structure. Composition studies on construction debris find that gypsum wallboard makes up 5% to 25% of the waste stream (Cochran, 2001). A typical rule of thumb for drywall generation from construction activities is one pound of drywall per square foot of construction (Yost, 1993). When the National Association of Homebuilders (NAHB, 1997) deconstructed of a multi-family residential home in Baltimore County, Maryland, they tracked the mass of materials removed. Plaster over gypsum lathe boards accounted for 17% of the weight of materials removed (21.6 tons; see Figure 1). Tansel et al. (1994) examined the components of residential houses in South Florida and estimated drywall to be present at 6 lb per ft^2.

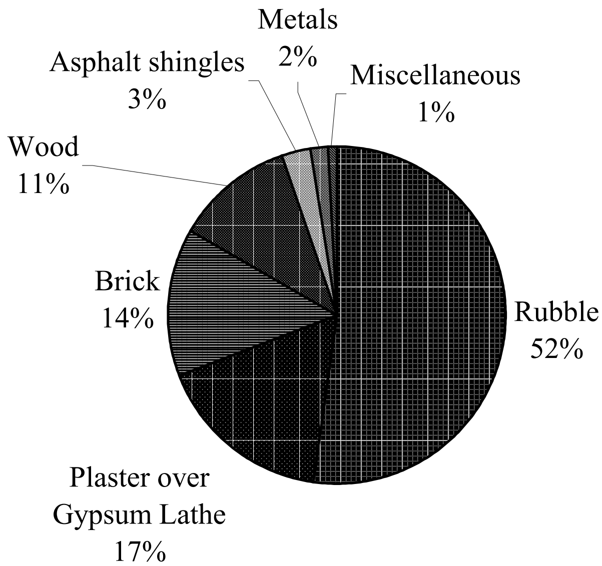


Figure 1. Composition of Materials (by weight) from a Building Deconstruction in Maryland [NAHB 1997]

RECYCLING MARKETS

Several different markets have been proposed for recycling gypsum drywall. These are summarized in Table 1. The primary markets that are reviewed here are the ones most commonly practiced in North America: use in the manufacture of new drywall, an ingredient in portland cement manufacture, soil amendment, and an additive to compost. Drywall programs have been most successful in recycling scrap drywall from new construction activities because of the ease of separation and the lack of contamination with other materials. While it is certainly feasible to recycle wallboard from deconstruction activities, quality issues must be addressed.

New Drywall Manufacture

Gypsum from waste drywall can be recycled back into new drywall. Many wallboard manufacturers currently recycle their own post-manufacturer scrap material at their facilities.

Table 1. Summary of Major Markets for Recovered Gypsum Wallboard

Market	Use
Manufacturing Processes	Manufacture of new drywall Manufacture of portland cement Manufacture of new construction materials (blocks)
Land Application Markets	Plant nutrients (calcium and sulfur) Improving soil structure (aids drainage in clayey soils) Reclamation of sodic soils Correction of subsoil acidity Plant disease prevention Reducing phosphorous leaching from manure-loaded soils
Other	Animal bedding Compost Bulking and drying agent Settlement of dirt and clay particles in turbid water Absorbent for greases A material for road base construction An ingredient in flea powder and similar products

While a small amount of paper is acceptable, the majority must be removed. Recycled gypsum will typically represent as much as 10% to 20% of some manufacturers' gypsum feedstock. Recycling of scrap post-consumer gypsum wallboard at drywall manufacturing facilities is currently being practiced in several areas of North America, most notably by the New West Gypsum Company in the Northwest US and Southwest Canada. As a result of regulations banning the disposal of drywall in landfills in some parts of Southwest Canada[1], New West Gypsum has been able to provide the needed end-market for discarded drywall, and this has spread into Washington and Oregon.

It is worth noting that in some areas of North America, new wallboard is being manufactured with synthetic gypsum. Several industries produce synthetic gypsum as a by-product of their manufacturing processes. The most common is the by-product of air pollution control technology at coal-fired power plants used to remove sulfur from the gas stream. The gypsum industry is moving toward the use of synthetic by-product gypsum as a source of the raw mineral. This, along with the recycling of post-manufacturer scrap, may limit the ability (or desire) of some plants to recycle post-consumer scrap drywall.

Portland Cement Manufacture

Gypsum is an ingredient in the manufacture of portland cement. Gypsum is added to the cement to control the setting time of the concrete. Gypsum, along with the cement clinker (coming from the cement kiln), is processed in a ball mill, grinding the mixture to a very fine powder. Typical

[1] The presence of gypsum drywall in landfills has been linked to the production of hydrogen sulfide (H_2S). H_2S is a malodorous gas that has caused numerous complaints at landfills around North America. While drywall is not currently banned from landfill disposal by any state in the US, several locations are considering placing restrictions on the amount of drywall that may be land disposed.

gypsum contents in portland cement range from 5 to 10%. The gypsum used at a typical cement kiln is mined gypsum, a very different physical form than that resulting from processed drywall. The materials feed system at the plant may therefore require some adjustment. Paper should be removed. The purity of gypsum in the wallboard is a major concern. The gypsum purity in typical wallboard should be high; care should be taken during the collection of the wallboard to minimize the amount of impurities such as soil that are introduced. In addition, processing the wallboard should take care in removing the paper backing, as there is not much tolerance in this end market for paper contamination.

Application to Soil

Gypsum is a common soil amendment, and is used for several different purposes. Gypsum provides a source of calcium and sulfur for plants. Gypsum is commonly applied to peanut crops in the Southeast US as a source of calcium. A typical application rate for gypsum applied to peanut crops is 600 to 800 pounds per acre. Applications rates for other crops have been reported as much higher. Many vegetables, including potatoes and corn, have been shown to benefit from gypsum application. Unlike lime, gypsum does raise the pH of soils and it is therefore preferred for crops that require calcium but where the soils are already alkaline (and cannot accommodate pH adjustment). Gypsum has been found useful for reclaiming very salty soils; the calcium in the gypsum substitutes for the sodium in the soils, allowing the sodium to leach away. The application of gypsum has thus been found to benefit road-side soils that have been contaminated as a resulting of deicing salt. Gypsum has the ability to flocculate clayey soils and to promote drainage where problems such as “hard-pan” occur.

The processing requirements for gypsum drywall that is applied to soil may differ somewhat from those required in the industrial processes such as portland cement or new drywall manufacture. While foreign materials such as nails and corner beads should be removed during processing, agricultural uses can tolerate some ground paper and soil in the mixture. The presence of trace components (such as lead from lead based paint) might be of greater concern when land applied (relative to the industrial uses) because of the potential for human contact and soil or groundwater contamination. Thus, wallboard from sources such as renovation, demolition, or deconstruction activities should be monitored and may be limited for this market. The method of mechanical gypsum application to the soil will dictate the size of the material and the degree of processing needed. With some application techniques, larger pieces of drywall may cause damage to plants as the gypsum is “thrown” from the spreader at high velocities. If the drywall is being tilled into the soil, large sizes may be permissible as size reduction will also occur during the application process and plant damage from application is not a concern.

Use in Compost

Gypsum drywall has been proposed as an amendment in composting systems in a number of locations. The paper fraction of the drywall should certainly biodegrade along with the other degradable organic matter in the compost feed stream. The gypsum itself, however, will not biodegrade to any major extent; it will instead be incorporated into the final compost product. The result is a calcium- and sulfur-rich compost, which may have a benefit for some crops (as described above). Gypsum also offers the potential to bind up odors associated with ammonia. On the other hand, if the composting system is not kept aerobic, anaerobic microorganisms can result in the production of H_2S. The key is to keep the compost pile aerobic. The application of gypsum wall board to mechanically agitated compost systems (e.g. a windrow turner) tends to work better than static systems (e.g. a forced air static pile) because the mixing and physical breakup of the gypsum that occurs. Ground drywall placed in static piles along with yard trash and food waste has been observed to be relatively intact at the end of the composting process.

PROCESSING SYSTEMS

Several different processing methods have been utilized for preparing gypsum drywall for recycling. As discussed above, the type of processing required will be dictated by the source of the wallboard and the required quality of the end-market. The major objectives of processing are separation of the wallboard from other components of the waste stream, separation of the gypsum from the paper, and the size reduction of the gypsum. Separation of drywall from other waste stream components can be achieved by manual sorting, but for the most part, the key is to recover the gypsum wallboard when it is produced. In most construction and deconstruction activities, the majority of the drywall will be produced over a short time frame. If the recovery system is designed appropriately, relatively contaminant-free loads of drywall can be obtained. However, some degree of inspection and manual clean-up may always be required.

A big issue associated with drywall processing is dust. Dust is either addressed by containing as much of the processing system as possible (enclosing the processing equipment in a container or a building) or by providing water in the form of a mist to minimize emissions. Drywall processing systems will, in many cases, require an air permit (appropriate regulatory authorities should be contacted). Several vendors market self-contained drywall processing equipment. Many of these operate using some type of grinder followed by a screening system and a dust collection system is typically included. Standard size reduction devices found at many waste processing sites (e.g. tub grinders, horizontal mills) can be used to process drywall. Dust issues may need to be addressed and screening will normally be necessary. Trommel screens are frequently used screening devices. Trommel screens have, in fact, been used as stand-alone operations were drywall is both separated from the paper and size reduced. The gypsum recovery efficiency is not as high as can be obtained by a combination of grinding and screening, but recoveries greater 60% are certainly possible. A preliminary size reduction step using a loader or compactor has been found useful for obtaining better efficiency in trommel-only systems.

A recent development worth noting is the use of small grinders directly at the construction site. These grinders are portable and small enough to bring directly to the construction site to grind the drywall (as well as other components such as wood and brick). The drywall can then be land applied if the soil demonstrates the agronomic need. The contractor saves in terms of container and hauling costs. While this technology has not yet been applied to deconstruction projects, it is certainly possible that it could be in the future.

ENVIRONMENTAL CONSIDERATIONS

As with the recycling of most construction materials, environmental and human safety issues must be addressed. The biggest environmental issue that most people in the waste management industry are familiar with regarding gypsum drywall is the production of odors in landfills. This should not be a great concern for those recycling gypsum drywall, with the possible exception of gypsum's use in composting systems (see previous discussion). It is noted that the authors have heard drywall processors comment that large piles of stock-piled gypsum drywall have been found to have some odor problems when stored out of doors for a long period of time. This has not been a major issue, however.

When dealing with drywall from deconstruction or demolition projects, several other potential environmental issues must be explored. The presence of paint, particularly lead-based paint, could limit the recycling of wallboard, especially for soil application purposes. Since most paints that contained a large amount of lead were used on doors, window sills, and on exterior walls, most drywall should not be heavily coated with lead. Lead might be more of a concern for markets such as land application and compost. Samples of suspect drywall should be tested for lead content and compared to appropriate risk-based clean soil concentrations. For example, in Florida, the soil cleanup target level for lead (for residential exposure settings) is 400 mg/kg. Mercury has been reported to have been used as a fungicide by some wallboard manufacturers in the past. Thus for markets such as land application, analysis of mercury might be needed. Asbestos, an issue that is always of concern when dealing with the renovation, demolition or deconstruction of buildings, was not widely used for the manufacture of gypsum drywall in the past. Asbestos may, however, be encountered in the joint compound associated with the wallboard installation. Requirements for the identification and management of asbestos containing materials are outlined in the Clean Air Act regulations. While these issues do certainly require added attention, with proper care and testing (with the final market in mind), drywall removed from deconstruction projects should be able to be recycled.

As a final note, questions have been raised concerning the glass fibers found in Type X drywall. Wisconsin researchers have reported that Type X drywall was not harmful to soil organisms (earthworms). Concerns have also been raised about the possible impact of the glass fibers on the human respiratory system. The drywall industry asserts that the size of the fibers is too large to have an impact to those cutting type X drywall; the impact of grinding operations has not been examined. Research is currently underway to examine this issue.

BARRIERS

The recycling of gypsum drywall is technologically feasible. This is certainly true for scrap drywall from new construction activities (where asbestos and trace metal contaminants are not an issue). And with proper care, testing, and market selection, recycling of drywall from deconstruction and demolition activities should also be feasible in many situations. Several barriers, however, may limit drywall recycling and are thus worth discussing briefly. First and foremost is the economic viability, an issue familiar to those in the deconstruction industry. In many cases, the cost of landfilling is so small that the cost of separating the drywall from the rest of the waste stream and its subsequent processing is more expensive. This is true in many locations for construction and demolition (C&D) debris as a whole. In Florida, US, for example, C&D debris can still be disposed in unlined landfills with very low tipping fees. While a dramatic policy decision such as a landfill ban on drywall would open up recycling markets, the lack of existing markets dampens enthusiasm for this approach. An innovative solution that some jurisdictions in California, US, have implemented is the requirement of a deposit by contractors when retrieving a permit. The deposit is only returned if the waste produced by the project is recycled.

Another barrier encountered with the implementation of drywall recycling program is the necessity to change the status quo. The contractors who produce the waste stream and those that manage the waste stream have a system in place that has historically worked, and requiring changes such as separation of drywall from the rest of the waste stream, even if it does not result in any additional cost or labor, can be hard to accomplish. Education and dialogue are required. Even many of the potential end users (e.g. cement plants, farmers) are reluctant to use recycled gypsum. Again, education and demonstration projects are needed.

SUMMARY

Gypsum drywall is a construction material that has recycling markets that are technologically feasible. The primary markets are use in new drywall manufacture, portland cement manufacture and as a soil amendment. Minor markets include use as a compost amendment and for animal bedding. Though drywall from deconstruction projects can be recycled in many of the same manners as drywall from new construction projects, this material must be evaluated more closely because of the possible presence of trace contaminants. In addition to those environmental considerations, recycling program implementation barriers must be addressed. Continued education and demonstration of drywall recycling is needed; in many cases policy and regulatory changes may be required before gypsum drywall recycling reaches its full potential.

REFERENCES

Cochran, K. 2002. "Estimation of the Generation and Composition of Construction and Demolition Debris in Florida." Master of Engineering Thesis, University of Florida, Gainesville, Florida.

NAHB Research Center, Inc. June 1997. "Deconstruction – Building Disassembly and Material Salvage: The Riverdale Case Study." USEPA Assistance Agreement Number CX 82444809: 48.

Tansel, B., Whelan, M. P., and Barrera, S. 1994. "Building Performance and Structural Waste Generation by Hurricane Andrew." International Journal for Housing Science and Its Applications 18 (2): 69-77.

Townsend, T., Barnes, A., Cochran, K., Carlson, J. January 31, 2001. "Recycling of Discarded Gypsum Drywall in Florida." University of Florida, Gainesville, FL. Prepared for the Florida Department of Environmental Protection.

Yost, P. A. 1993. "A Feasibility Study and Cost Analysis of Recycling Construction Site Gypsum Wallboard Waste." Master of Science Thesis, University of New Hampshire, Durham, New Hampshire.

OVERCOMING THE BARRIERS TO DECONSTRUCTION AND MATERIALS REUSE IN NEW ZEALAND

Authors: John B. Storey and Maibritt Pedersen (Centre for Building Performance Research, Victoria University of Wellington, Wellington, New Zealand)

ABSTRACT

The New Zealand Government has recently published a strategy document which sets the nation a target of reducing construction and demolition waste going to landfills by 50% of the 2005 figure by 2008. Half of the Territorial Authorities in New Zealand have set themselves the even more ambitious target of zero waste by 2015.

This paper discusses the ways in which deconstruction and materials reuse could contribute to achieving these targets, outlines the general and New Zealand specific barriers to realising such targets and discusses ways in which these barriers might by overcome in the New Zealand context.

KEYWORDS: Deconstruction; Barriers; Solutions; New Zealand

INTRODUCTION

New Zealand is a country of four million people, living in an area of 268,021 square kilometres, which is roughly equivalent on both counts to the state of Oregon in the USA. It consists of two main islands, is 1600 kilometres (1000miles) in length and is located some 1300 kilometres (800 miles) east of Australia. Auckland is the only conurbation of more than one million people, although there are two other conurbations with populations of more than 350,000 and a further three with populations in excess of 100,000 people. These centres are distributed along the entire length of New Zealand, although three-quarters of the population lives on the slightly smaller north island. Away from the generally quite small central business districts (CBDs), urban settlement is dispersed and consists mainly of one or two storey light timber frame construction. Construction within CBDs employs the full range of building materials and construction systems utilised internationally. Population is dispersed and travel distances between centres can be quite large.

Figure 1 Main Population Centres in New Zealand

The research for this paper was conducted as part of extensive research into the current state of deconstruction in New Zealand, with the intention that this information would be correlated into a national report on deconstruction in New Zealand as part of the authors' participation in the CIB Task Group 39 on international deconstruction activity. The research was undertaken by a thorough review of existing published material related to the topic, a review of the legislative framework within which deconstruction exists in New Zealand, and a series of interviews to establish industry or local council opinion where information was lacking or out of date in published form.

The NZ government, in their recently released policy document *The New Zealand Waste Strategy – Towards Zero Waste and a Sustainable New Zealand 2002*[1], requires a 50% reduction by weight in construction and demolition waste going to landfills by 2008, but this strategy document has as yet has no legal standing and offers no construction and demolition (C&D) waste specific ways to accomplish this objective. The Ministry for the Environment who prepared and promulgated the document states: *"The strategy acknowledges the limits of the information on which the targets are based. It indicates that the targets should be considered as "goal statements rather than mandatory requirements". The targets are to be reviewed by December 2003. In the meantime councils are encouraged to set their own targets in line with those in the strategy. This request recognises that it may be impractical for local targets to be the exact equivalent of the provisional national targets".*[2] The Ministry for the Environment expects to produce a consultative regulatory document sometime in 2004 and may enact legislation on this topic thereafter. However, further action by the Ministry for the Environment on C&D waste minimisation remains unclear at this time.

The implementation of waste minimisation policies is the responsibility of local Territorial Authorities in New Zealand rather than the direct responsibility of Central Government. Over half of the Territorial Authorities (TAs) in New Zealand have declared that they will aim to have zero waste by 2015. This self-imposed target goes well beyond government expectations and is an encouraging sign for the future. The zero waste goal continues to receive the encouragement of Central Government but very little financial or legislative support.

Although the often-quoted figure for construction and demolition waste in New Zealand is 17%[3] of municipal solid waste generation, this figure does not include C&D waste taken to privately owned 'cleanfill' dumps or illegal dumping of C&D waste. Neither does it include figures from all Territorial Authorities. Dumping charges vary widely, with some being free for hardfill and in other situations over $NZ 100 per load. Often cleanfill dump rates are very much cheaper than municipal landfill rates[4]. Therefore, although there are currently no accurate figures for C&D waste, it is certainly considerably higher than the 17% of total waste figure.

Currently the government's main motivation for reducing C&D waste is to reduce pressure on landfills. The concept that it would be possible to concurrently reduce waste generation and resource depletion, and maximise the utilisation of our existing material investments, does not seem to be part of government thinking at this point in time. Nevertheless it obviously makes good sense to do this from a national perspective, both economically and environmentally. In general the signs are positive with regard to waste minimisation in New Zealand but the linkages to deconstruction and the opportunities for resource conservation through material and component recovery, which are implicit in deconstruction strategies, are not currently widely recognised.

Deconstruction of existing buildings is more labour intensive than demolition and provides increased employment opportunities, which also supports government policies. But again this fact is not widely understood.

In addition to the general lack of awareness of the overall benefits of deconstruction there are significant barriers to the widespread adoption of deconstruction strategies in New Zealand, although none are insurmountable given the current governmental and local authority interest and support for waste minimisation in general.

If widely adopted deconstruction could provide a significant way to enable the New Zealand Government to realise its stated intentions with regard to C&D waste.

LEGISLATION

Existing legislation related to construction and demolition waste minimisation is spread throughout a number of acts, policies and targets in NZ. A helpful way for people to be made aware of their existing responsibilities and the inherent opportunities might be the creation of a comprehensive document encompassing all environmental policies related to the construction industry. Such a document would make existing legislation much more accessible and understandable and therefore more usable.

The lack of performance specifications and testing regimes for reused components is linked to current difficulties in acquiring council approval for building consents and this situation is cited by some demolition contractors as a barrier to the incorporation of pre-used materials and components into new development[5]. Often local councils will not approve[6] the use of recycled components especially in relation to structural and energy conservation use because of the lack of certainty connected such items. Achieving New Zealand Building Code compliance with reused materials and components needs to be researched and systems put in place to remove this barrier for people wanting to reuse materials and salvaged components. The development of nationally accepted standard specifications and certification for reused components and materials would save time and confusion during the approval process.

The actual amount of C&D waste is currently unclear and there is an urgent need to establish an accurate database. Central government is encouraging this. The target date for completion of this phase of the work is 2005 but there is as yet no legislation to back up this request. Local authorities are currently being left to devise their own measurement criteria and this will undoubtedly lead to a considerable number of compatibility problems in the future and a waste of resources and time their eventual integration into the necessary national database. It is therefore important that the Ministry for the Environment establish as a matter of urgency clear guidelines concerning the statistical criteria required as the basis of future waste minimisation action.

The Ministry for the Environment is currently evaluating which areas of waste reduction are priority targets for incorporation into legislation in the next 12 to 18 months. With regard to construction and demolition waste, the Ministry has stated that:
"This target is one of the secondary stream of targets in the Strategy, in that reduction is not expected to be achievable immediately. The Ministry has initiated a Waste Management Planning project that will provide a base for this work to proceed in the near future."[7]

The Ministry acknowledges that no action has yet been undertaken in this area.[8] It is unclear why the Ministry regards C&D waste as a second priority issue although it may be in part due to the misconception that we are only dealing with about 17% of the waste stream and the notion that C&D waste is rather more environmentally benign than many other waste sectors.

To ensure success, the waste strategy needs to be reinforced by mandatory requirements, and followed up by additional transitional support and funding. In the absence of common national guidelines, technical backup and a legislative base from which to operate, each local authority establishes and implements waste minimisation and management strategies within its own local area. These schemes vary widely in terms of their effectiveness, and can and are changed at the political whim of both elected officers and non-elected officials. However the publication of the national waste strategy has at least indicated central government thinking on the issues and initiated considerable and widespread debate concerning C&D waste amongst some local authorities.

Currently C&D waste has only been addressed seriously by a few of the councils, in particular those of the larger centres such as Auckland, Hamilton and Christchurch.[9] Some smaller councils have also made attempts to address construction and demolition waste by working in close collaboration with neighbouring councils, primarily to establish a larger market for recovered materials and components[10]. These councils tend to be in higher density areas or in areas which are adjacent to the main centres. For some areas, particularly in the smaller, more isolated areas of the country, or where little development is occurring, construction and demolition waste is less of a percentage of the total waste stream and therefore is regarded as less of a priority to target for action.[11]

MARKETS

Unless there is a market for recovered materials there is very little point to deconstruction. Any barriers therefore, to establishing, maintaining and developing markets are fundamental to the development of deconstruction practices in NZ.

There are two distinct market sectors related to resource recovery, each with their own characteristics and issues. Markets for low volume, high value, rare, unique or antique architectural components appear to be well established or developing, and are largely self-supporting economically. This sort of recycling occurs nationally almost irrespective of the size and financial circumstances of the locality. Many of these recyclers are small, essentially connected to the domestic market and will pass customers on to other similar organisations if they do not have the items the client requires. Native timber and bricks are also often held in the salvage yards of demolition contractors. The market for such items is flourishing and it is often difficult to meet demand. Specialist equipment and machinery is sometimes recovered from buildings and often pre-sold before removal[12].

Some other recovered materials are high volume, low value, such as concrete. The market for such materials in New Zealand is currently restricted and is mainly in Auckland where there is a shortage of readily accessible, local aggregate. For more geographically isolated areas with low or dispersed populations it is more difficult for the salvaged goods market to grow due to the scale of economy and the inherent physical and economic feasibility of creating usable products and finding local markets or transporting heavy and bulky items to larger centers. [13] Growth in these areas would require subsidies which would have the effect of distorting the market and would be unlikely to find favour in the current political climate.

It may be possible for interested local authorities to cooperate on a regional basis to increase the volume of materials being recovered, and make it financially viable to purchase more efficient recovery equipment. Such equipment could travel around the region as necessary to building sites or temporary holding dumps and the recovered materials might be used in council projects. The obvious advantage in this approach is that transportation of the heavy unprocessed C&D waste is kept to a minimum, and in more isolated areas premiums for storage may be less than in the major cities.

Direct sales of the processed material from the site of processing will mean transportation is minimised and this practice should be encouraged. TAs might also provide free or very low cost dumping of separated clean C&D waste which would facilitate future recovery once volumes or market conditions permitted this[14].

Grants from central government might be necessary to encourage the smallest or most remote local authorities to initiate and maintain a waste minimisation programme as a service to the community even if it is not financially viable.

Another possible solution to this problem of small spread out communities and markets is to encourage innovation. One of the problems identified by some of the councils, particularly those involved with the Zero Waste programme is that the collection, sorting and treatment of waste is less of an issue that finding uses for it afterward.[15] If new and diverse, localised uses for waste C&D material can be identified and developed this may help to solve the problem of how to deal with waste in smaller communities. Some councils have hired consultants for local market opportunity research,[16] and some are currently in the process of looking into opportunities in their own regions. The authors are involved in teaching a university course in which one of the assignments is to invent and develop new materials or products using waste. Achieving secure and economically viable volumes of waste/recycled materials in remains one of the most intransient problems in rural areas.

The current government in New Zealand has already made a commitment to further innovation and scientific research through the 'Science and Innovation policy of 2002'[17]. It asserts that: 'A key goal of this policy is to actively promote economic transformation. It also aims to further our understanding of our environment, and effectively contribute to solving the social challenges we face.'[18] This is a potential starting point for researchers or innovators to secure funding.

There would appear to be some resistance amongst the general public, designers and amongst many builders to use pre-used materials. This is a worldwide problem and is of course not a single problem but a series of interlinked issues. The collective effect is to inhibit the use of pre-used materials and components and make their use the exception rather than the rule, at least in new buildings.

With the public there seem to be two contradictory influences at work. New Zealand has in general terms the same consumerist attitudes and perceptions as the rest of the westernised world. The notion that pre-used is inferior and that wear makes items undesirable and unfashionable seems pervasive and is perhaps the inevitable result of years of advertising which has consistently lauded the new, fashionable and unblemished.

This is counteracted to a certain extent in New Zealand by the perception that many new building materials are not as durable as older materials. This is particularly true when comparisons are being made with items such as native hardwood which extremely durable but is now difficult and expensive to source new in any but recycled form. Recycled timber is therefore much sought after and commands high prices. There seems to be little resistance to the use of pre-used items in alterations to existing buildings where there is a need to match what is already there. However the market for pre-used items in new buildings remains small. This may however be more a result of what owners think of as being appropriate in a design rather than a resistance to the reuse of materials. There is no known research concerning whether people living in older houses have a different attitude to the reuse of materials compared with those living in new houses in New Zealand. Such research could be very important in establishing a wider market for pre-used materials, as education could then be targeted into addressing misapprehensions amongst the public at large.

Amongst designers the imperatives appear to be somewhat different. Certainly designers are very fashion conscious and may well be resistant to the employment of obviously pre-used materials and components visible in the finished work, unless they, as designers, are making a deliberate design statement. A growing number of designers are in fact using pre-used materials in this way, but this constitutes a tiny fraction of the materials used in new buildings.

When materials are not seen in the final work the issue is generally one of liability. Most specifications while not specifying 'new' materials do call up the notion of them being 'the best of their kind and in compliance with the performance and durability requirements of the New Zealand Building Code'. If new materials are used and have been assessed as being code compliant and they fail, designers and structural engineers generally feel confident that they will not be held liable. However with reused materials the situation is not nearly so straightforward. Many designers feel that they are taking an increased personal risk and few are willing to do this in the absence of any pre-used materials testing or certification schemes in New Zealand.

Clients too may feel the need for the reassurance that certification brings to the employment of pre-used materials. There is a need for a grading and certification scheme at least for recycled timber in New Zealand if markets in this area are to expand. This would also help to still the concerns of building inspectors who are often rather dubious about the employment of 'second-hand' materials and components, especially when used in structural or drainage/plumbing situations. Certification of pre-used materials could either be organised through industry groups or the Building Industry Authority which promulgates building controls in New Zealand. Research into pre-used materials and recycled/ virgin mixes would add certainty. Some of this might initially need to be from public good research funds but once a market is established commercial organisations would probably fund research in their own market sector.

For builders the main issue is the extra time and effort it takes to access and prepare pre-used materials in sufficient quantity, sizes and quality. It is obviously far easier and more convenient for them to ring up a single builder's merchant, than to access materials from a whole series of smaller outlets. The answer might be for builder's merchants to stock pre-used materials and components but this is unlikely to happen in the foreseeable future as the two main chains of builder's merchants in New Zealand are owned by large, diversified companies who produce or import many new building materials and so have a vested interest in selling new product, preferably their own.

As can be readily appreciated, clients and designers need to be quite determined to use pre-used materials and components in new buildings as the principal benefit is resource conservation rather than cost saving. The extra time, effort and risk involved to the designer is rarely recognised in fee payments. Yet unless the demand is there the market will not grow and deconstruction will remain the exception rather than the rule.

As central government and many local authorities are committed to general waste reduction, which is synonymous with resource conservation, they need to help the market to grow. If they insisted that a proportion of pre-used materials were used in all public works then market conditions would change overnight, the exception would become the rule and would lead to a more stable and stronger market for the C&D salvage market.[19] If the market demand was there, many of the other problems and issues either fall away or there would be enough commercial interest to solve them.

It is unlikely in the New Zealand context that legislation would be enacted that would require private sector buildings to incorporate pre-used materials. So persuasion and education is required, to explain the benefits to the community and the individual of resource conservation, to address misapprehensions concerning the long-term viability of pre-used materials and to turn around the public's negative impressions concerning 'second hand' materials.

One of the strategy programmes of the 'information and communication measures and actions' contained in the *NZ Waste Strategy*, is to *"develop and implement programmes for public information and education"*[20]. It is perceived that there is a lack of resources to effectively deal with waste and waste minimisation education. Environmental education that does occur is usually localised and many councils and community groups would like to see more direct central government leadership in this area with the provision for and encouragement of standardised national environmental education in the primary, secondary, tertiary and continuing professional development areas. [21]

There is a perceived lack of New Zealand specific information and case study examples concerned with implementing deconstruction. The government could fund the production of such documentation and demonstration projects as part of its information and education strategy under the NZ Waste Strategy.

THE CONSTRUCTION AND DEMOLITION INDUSTRY

The demolition industry in New Zealand is largely unregulated at present, although there is an 'Approved Code of Practice for Demolition'[22], which emanates from the Department of Labour's Occupational Safety and Health service (OSH) and deals with safe practice. Despite this people who demolishing buildings in New Zealand are not required to have any professional qualifications. The unregulated nature of the industry is beginning to be addressed through the NZ Demolition Contractors Association's push for nationally recognised qualifications and the development of a standard code of ethics.[23] However, the NZDCA is sometimes perceived as an Auckland based organisation rather than a nationally representative organisation by some demolition contractors outside of the North Island[24].

There is a general lack of networking within the industry which may be a result of the contractors operating in a very competitive market, the localised nature of most demolition contracting organisations and great disparities in the skill levels across the industry.[25] Survival is the prime motivator for most demolition contractors and issues such as waste minimisation and environmental responsibility are generally not seen as a priority.[26] The building industry as a whole is very fragmented and hierarchical,[27] with little meaningful dialogue on broader environmental issues between architects, designers, builders and demolition contractors. Increased cooperation and networking may facilitate greater understanding of life cycle issues in design and construction and help to engender a greater level of collective environmental responsibility by the industry particularly in relationship to achieving a greater understanding of the direct impact design has on demolition. However unless economic benefits can be clearly identified and information on how such benefits accrue to the various parties involved disseminated, such voluntary action is likely to involve only a small minority of the industry organisations.

Several demolition contractors contacted have stated that if buildings and internal components were easier to disassemble, there would be greater materials salvage and possible reuse[28]. This call for increased design for disassembly is an issue that designers, and tertiary architecture and design teaching establishments need to take on board. Currently however there is little discussion of these issues in tertiary institutions or within continuing professional development (CPD) environments. Very little research is currently being carried out concerning suitable designs and construction practices in regards to life cycle considerations or deconstruction. It is probably true to say that the design professions and most tertiary educators in New Zealand remain largely ignorant of life-cycle resource conservation and deconstruction and demonstrate little inclination to take these issues onboard.

In the absence of leadership from either the professions or tertiary providers on this issue it may be that regulation or incentives may be required to ensure progress. However there are some individuals and organisations who have demonstrated an interest and one step forward may be to simply provide a vehicle for cross industry dialogue to occur, perhaps leading to the development of a pan industry organisation to address the whole issue of waste minimisation and resource recovery. It is known that a number of research proposals are currently being considered by central government in this regard.

ECONOMIC FACTORS

In the last few years there has been an increased interest in salvage within the demolition industry. The primary driver for this observable increase has been in all cases economic rather than environmental[29]. The main barrier to further development in this area is also however economic. There is considerable variation from region to region concerning the economics of resource recovery.[30]

In some of the larger centers such as Auckland and Christchurch where an increase in salvage has been noted among demolition contractors[31], one of the main sources of profit is in the on-selling of the salvaged materials and the avoidance of high tipping fees. This is particularly relevant in Auckland where salvage rates of up to 95% have been achieved by the larger companies such as Ward Demolition in some situations.[32] In the existing highly competitive market, tenders are sometimes offered at a price lower than the cost of demolition with profit coming from the salvage sold.[33]

In centres such as Wellington however, the lower cost of raw materials means a less stable and profitable salvage market. This, combined with the increased health, safety and operational requirements and low landfill charges makes comprehensive resource recovery less viable in most commercial situations. Salvage in these circumstances is restricted to only the highest value materials such as native timber, metals, lime-mortared brickwork and some easily removed fixtures and fittings.[34]

Strengthening the salvage market through some of the options already discussed, such as recycled component quotas would help to turn this situation around but often the real problem in the commercial sector is the unwillingness of developers to allow sufficient time for deconstruction to occur. In many cases developers are working with borrowed money, at high interest rates and endeavour by every method possible, to shorten their loan period and so maximise their profits.

Demolition requires a resource consent in New Zealand and some local authorities are considering the introduction of the requirement for mandatory waste minimisation plans to be lodged and adhered to as a condition for granting resource consent. Target two of the waste minimisation targets in the New Zealand Waste Strategy states:
'By December 2005, all regional councils will ensure that new or renewed industrial resource consents include a recognised waste minimisation and management programme…'.[35] However this target is not yet part of the C&D waste part of the Strategy. Even if it were such a procedure will only be meaningful in terms of the salvage of components and materials from construction and demolition activity however, if markets are available for the recovered materials. The notion of a percentage of the materials from the demolished building being reused in the new building which replaces the pre-existing one has only been considered by a few of the most forward thinking local bodies[36] as yet and none yet have a requirement that a proportion of recycled materials be incorporated in their infrastructure or building work nor do they require new buildings be designed to facilitate disassembly.

Many of the larger demolition companies have a large workyard and storage of recovered materials prior to sale does not appear too much of an issue. However in small communities it may be that local authorities rather than demolition contractors will need to be proactive in the provision of sorting stations, storage facilities, and perhaps organise the processing and on-sale of recovered materials. Moratoria on or relief from local taxes can also be an effective way of ensuring the economic viability of a recycling organization, particularly at startup.

Another option which is common in other countries but is currently relatively rare in New Zealand is for demolition jobs to be advertised, ahead of time with salvagers, community groups and the public being allowed to take as much as they wish, using their own time and labour, paying as they leave with their acquired wares. This is a form of on-site selling which is successful in a variety of different forms. There are however health and safety issues involved and with the strict regulation of these matters in New Zealand this is not seen as a preferred option in most circumstances. However prior notice would allow individuals and organisations to identify the salvaged items they wish to purchase for removal by professionals. One major organisation in Auckland, Nikau Deconstruction Engineers Limited, has a sales manager who secures sales for large, specialised or unusual equipment before the demolition begins, so that goods can be transported straight from the site to their new owners, thus avoiding additional transportation and storage costs. Sometimes these sales will go offshore to places like Malaysia.[37]

TECHNICAL ISSUES

Often lack of detailed information on the actual materials and construction systems employed in a building adds to the uncertainty of deconstruction. This may affect both its technical and economic feasibility. While the original contract drawings are usually available and will give much valuable information, substitution of materials noted in the specification is common, as are unrecorded changes which occur during the life of the building. There seems to be no easy, workable answer to this problem except to stress the need for a careful and thorough pre-demolition survey by skilled staff. Currently all buildings require a pre-demolition survey as part of the resource consent process, to establish whether or not there are any hazardous materials incorporated into the works. This could be easily extended into a condition survey which would verify or reveal variances between the archived documentation and the reality in terms of materials and construction.

There has been some discussion concerning the possibility of applying the notion of extended producer responsibility (EPR) to building products. This would mean that the original manufacturer would be responsible for recycling 'their' products at demolition and the national waste management strategy document sees this as a long-term possibility. Superficially this is an attractive notion, however unlike cars and other consumer products building products often have an extended lifespan and manufacturers may well go out of business long before their building products come to the end of their lives. Often the components or systems used where EPR might be most sensibly employed are manufactured in other countries which would make enforcement difficult if not impossible. There are however some possibilities in relation to items with a short lifespan such as proprietary equipment. This might be a particularly effective solution if these items were leased rather than bought, which is an increasingly common way of dealing with interior fit out elements and could easily be extended to services installations, and kitchen and bathroom equipment.

Quite a number of new materials coming into New Zealand from overseas are given subsidies in their country of origin and this makes it difficult for recovered materials and products to compete. This is particularly difficult for a country like New Zealand to deal with as New Zealand seeks to avoid both subsidies and tariffs.

The use of composite materials chemical bonding and other non-reversible building techniques continues to expand. All such methodologies make deconstruction of buildings more difficult. This is a fundamental problem which could be addressed by insisting that all manufacturers of such systems develop a safe, cost effective method of disassembly before they are allowed to market their product. Such a law is unlikely to be initiated in New Zealand but may be attractive to the European Union.

CONCLUSION

Deconstruction as a concept is currently little understood in New Zealand. However central government has declared its strong support for the notion of reducing construction and demolition waste in New Zealand by 50% of the 2005 figure by 2008. The widespread adoption of deconstruction practices in New Zealand could make a major contribution to the realisation of this target.

Lip service to waste minimisation strategies has occurred in the past with very little action being forthcoming. Therefore, although it is very encouraging that the current government seems to be taking the matter rather more seriously than previous governments, little action is occurring at present and C&D waste has been given a low priority for action and presumably funding. The government has however proved itself to be fairly flexible in its response to changing information and if presented with an action plan which would enable it to reach its desired goals at minimal cost, it would be likely to listen.

Developing the market for pre-used building materials and components is perceived as the key action in this respect in New Zealand. If central and local government would be prepared to set minimum quotas for the use of pre-used materials in their own building and infrastructure work, this would change the entire nature of the market at little or no cost to itself. Such action is seen as the most positive step government could take in relation to reducing C&D waste taken to landfills in New Zealand. This action would create a strong and stable market and encourage all parties to invest in equipment and training. It would also provide demonstration projects which would encourage emulation by the private sector. Central government must be seen to lead this initiative otherwise few Territorial Authorities are likely to see their own individual actions as being significant enough to change the market place and with it the economic viability of deconstruction practices.

Deconstruction is very much in its infancy in New Zealand and education and research is needed to raise its profile and to provide usable information and actively promote deconstruction as a worthwhile and viable option to make a real and significant contribution to achieving the government’s resource recovery targets. Several research programme proposals are being prepared currently and there are a number of government agencies to which applications for funding can be made with some hope of success.

There is a need for all the involved parties to get together and start to listen to and understand each other’s points of view, issues and problems. Only then can common ground be found and consensual solutions established. A starting point for such a process may be the organisation of a C&D focused conference for all interested parties.

The outlook for the development and adoption of deconstruction practices in New Zealand is quite positive even though there is still a long way to go. There is a need to learn from successful international efforts in this area, but New Zealand can move very rapidly to pick up worthwhile ideas and adapt them to its own circumstances. The political and social climate is right for this to happen with respect to deconstruction in New Zealand at this time.

Universal Barriers to Deconstruction

Barrier	How this relates to NZ	Solutions
1 Legislation:		
Current standard specifications	Standards give the impression that new materials must be specified.	Development of standard specifications etc, which incorporate reused/recycled components Document and publish examples of the successful use of reused and recycled components Government and local council as examples in new development.
2 Markets:		
The high cost of transport and storage of recycled components and materials.	Small, dispersed population.	Market networking. Direct sales from site.
Uses for some salvaged materials are undeveloped.	Finding uses for some recycled or salvaged materials is difficult	Increased research focusing on problem materials.
Designer/public/builder attitude: 'new is better' and new buildings are permanent.	The majority of building materials specified and used in NZ are new. Design for deconstruction uncommon	Education for architects in life cycle considerations and holistic design principles. General education of public, designers and builders. Easy to use guides in the use of salvaged materials/design for deconstruction. Publishing and compilation of research into quality aspects of reused goods.
The lack of a grading system for reused components	Native timbers and bricks are generally used in non structural situations.	Development of a grading system Training in the grading of reused materials. Liability issue addressed
Guaranteed quality/quantities of reused materials are difficult.	Smaller areas of NZ are more geographically isolated. The scale of economy is not large enough to sustain a large salvage market.	Increased networking of salvage businesses/builder's merchants. Increased deconstruction *NZ:* See NZ specific barriers section
Lack of information and tools to implement deconstruction.	There is a lack of NZ specific documents or information kits for the implementation of deconstruction, specific feasibility studies or clear NZ example cases.	Compilation of guides, development of implementation ideas. Clear ways to implement NZ Waste Strategy targets are needed. Increased pilot studies and test cases Strategic planning to address barriers.
3 C + D Industry:		
Lack of communication and networking in the C&D industry	Unregulated, and largely uncooperative, hierarchical C&D industry in NZ.	Greater communication, networking and collaboration. Increased conferences, email discussion groups, networking, professional articles publications etc.
lack of design for deconstruction	International research is not always applicable to NZ. There is a lack of example cases built in NZ. Design for deconstruction is not taught at architecture schools	Education of architects and designers through CPD / competitions / conferences / exhibitions / case studies etc. Education at architecture schools. Development and sharing of teaching resources and case study examples. *NZ:* Republication of the NZIA life cycle environmental impact charts on the internet
Difficulty in securing funding for research	The Ministry for the Environment. The Science and Innovation Policy	Governments and funding agencies need to make waste minimisation a priority.
4 Economics Factors:		

The tightening up of Health and Safety legislation	Increased OSH regulations may effectively prevent the hands on nature of deconstruction through time delays and additional safety equipment costs.	*NZ:* Cooperation between OSH and environmental architecture advocates ensuring maximum safety and environmental practice. Subsidies for implementation of OSH requirements in deconstruction.
The benefits of deconstruction are long term and collective	Current climate of first cost only economic development.	Enforceable legislation and increased requirements in building consent approvals Government set measurable and monitored targets Increased education on environmental building impacts for developers.
Lack of financial incentive for deconstruction		Implementation of economic incentives and deterrents to encourage deconstruction.
Market pressures - the current climate of 'as fast as possible'	Limited time to salvage maximum materials in the demolition stage. Deconstruction takes longer.	Subsidies to demolition contractors – transitional only Salvage operations to work along side but independently of demolition contractors. Transferal of environmental responsibility to developers.
It is difficult to access or apply economic assessment tools for de-construction or LCA in some cases.	There are no NZ specific deconstruction evaluation tools or national feasibility studies.	Collection of existing tools in one place. Possibly website. Development of non region-specific tools or more flexible parameters. *NZ:* The development or adaptation of deconstruction economic viability tools for NZ A deconstruction economic viability feasibility study for NZ
Deconstruction needs a more skilled workforce than demolition	Unregulated demolition industry Lack of case jobs to train on.	Increased opportunities for training and transition from traditional demolition to deconstruction. Cooperation between the construction and demolition sectors.
5 Technical Issues:		
Lack of documentation	Records of materials used in construction are not kept.	Better recording of materials used Storage of records in the actual building
Increased use of insitu technology, chemical bonds and plastic sealants etc.	Commonly used in new buildings in NZ. Most concrete structures have insitu components.	Research viable alternatives to these techniques. Development of ways to separate these bonds
Most existing buildings are not designed to be deconstructed.	This is true in NZ.	Research and development to find ways to effectively deconstruct these buildings. Implementation of design for deconstruction techniques into learning establishments a priority.

NZ specific barriers

Barrier	Solutions
1. Legislation:	
Confusion as to what Government / NZIA etc legislation is, relating to environmental responsibility	Compilation of all NZ environmental policy/targets etc related to construction Clarification of The NZ Waste Strategy targets
Inconsistent units of measurement in local waste data, no national data.	Clear, standardised units to be developed to make a national database
Waste management is a local council responsibility. This means there is no enforced national direction.	Increased central government financial and legislative support and direction

C&D waste minimisation is not a priority for some local councils / central government	Support given to councils to move towards greater waste minimisation (zero waste) Education seminars. lobbying of central government to change the priority waste rankings Reports to identify barriers to increased C&D waste minimisation and market opportunities.
2. Markets:	
NZ's small, dispersed population and geographic isolation.	Cooperation between smaller areas to increase markets. Mobile recycling / processing plants Identification of local market opportunities.
3. Economic Factors:	
Low tipping rates (including cleanfill).	Tipping rates need to come into line with the true cost of disposal. Use of the Ministry for the Environment 'Landfill full cost accounting guide' Many local governments have already introduced 'user pays' waste schemes and increased tipping fees.
4. Technical Issues:	
Some new materials are cheap	NZ has no control over foreign systems or subsidies. True cost research to establish taxes for imported materials either at import or retail stage. Central and local governments to specify materials which do not undercut the salvage market.
NZ is in a high seismic activity region.	Research into systems that work in seismic areas.

[1] Ministry for the Environment *The New Zealand Waste Strategy, Towards Zero Waste and a Sustainable New Zealand.* Ministry for the Environment, Wellington, New Zealand, 2002.
[2] Ministry for the Environment, *National Targets for Priority Waste Areas,* http://www.mfe.govt.nz/issues/waste/content.php?id=97
[3] Ministry for the Environment, *National Waste Data Report, May 1997,* Ministry for the Environment, Wellington, New Zealand, 1997
[4] For example in the Tauranga District, tipping rates are approximately $98 per tonne at landfill and approximately $10 per tonne at the cleanfill.
Kliskey, Murry, Solid Waste, Senior engineering Officer, Tauranga District Council, *personal phone conversation,* 31/01/03.
[5] Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
[6] New building and renovation requires a building consent, which is approved by local authorities in NZ in accordance with the non prescriptive *NZ Building Code*.
[7] Ministry for the Environment, *National Targets for Priority Waste Areas,* http://www.mfe.govt.nz/issues/waste/content.php?id=97
[8] Ministry for the Environment, *National Targets for Priority Waste Areas,* http://www.mfe.govt.nz/issues/waste/content.php?id=97
[9] Christchurch City Council has set up 'Target Zero'. This is a resource efficiency/waste minimisation initiative working with Christchurch businesses to save money and reduce environmental impacts. They have set up a construction waste minimisation directory, conducted construction waste reduction case studies, and commissioned reports into the C&D waste stream and recommendations from consultants.
Phillips, Laine, Resource Efficiency Advisor, Christchurch City Council, *personal phone conversation,* 22/01/03.
Christchurch City Council, *Target Zero*, http://www.ccc.govt.nz/TargetZero/
REBRI – Resource Efficiency in the Building and Related Industries is an initiative jointly funded by the Auckland Regional Council, Auckland City Council, BRANZ and the Ministry for the Environment.
Auckland Regional Council, *REBRI,* http://www.arc.govt.nz/arc/environment/waste-&-recycling/rebri.cfm
Christchurch City Council, *Target Zero*, http://www.ccc.govt.nz/TargetZero/
[10] The Auckland region councils work for example together in various ways, meeting, sharing information and supporting each others', or collaborative projects. Some of these councils are large city based councils such as the North Shore City Council. Others like the Rodney District Council are smaller without a large city based population.
Harris, Julie, Zero Waste Officer, Rodney District Council, *personal telephone conversation,* 22/01/03

[11] David Reece, Engineer/Services Manager, Opotiki District Council, *personal correspondence,* 22/01/03
[12] Carter, Helina, Service Manager, Nikau Deconstruction Engineers, Auckland *personal correspondence,* 23/01/03
[13]Bradshaw, Deborah, Policy Planner, Nelson City Council *personal correspondence*, 22/01/03
Kearney, Matt, Refuge Consultant, Far North District Council, *personal correspondence,* 22/01/03
Longworth, Mike, Resource Engineer, Masterton District Council, *personal correspondence*, 22/01/03
Reece, David, Engineer/Services Manager, Opotiki District Council, *personal correspondence,* 22/01/03
[14] This issue was sited as a major barrier by representatives from the Nelson City Council, Far North District Council, Masterton District Council, and Opotiki District Council. All of these councils are relatively small in the NZ context.
Bradshaw, Deborah, Policy Planner, Nelson City Council *personal correspondence*, 22/01/03
Kearney, Matt, Refuge Consultant, Far North District Council, *personal correspondence,* 22/01/03
Longworth, Mike, Resource Engineer, Masterton District Council, *personal correspondence*, 22/01/03
Reece, David, Engineer/Services Manager, Opotiki District Council, *personal correspondence,* 22/01/03
[15] Reece, David, Engineer/Services Manager, Opotiki District Council, *personal correspondence,* 22/01/03
Schafer, Helen, Zero Waste Coordinator, Porirua District Council, *personal correspondence,* 22/01/03
[16] Phillips, Laine, Resource Efficiency Advisor, Christchurch City Council, *personal phone conversation,* 22/01/03.
[17] Labour Party New Zealand, *Science and Innovation Policy 2002,*
http://www.labour.org.nz/fb.asp?url=http://www.liveupdater.com/labourparty/LABOURpol-economy.asp
[18] Labour Party New Zealand, *Science and Innovation Policy 2002,*
http://www.labour.org.nz/fb.asp?url=http://www.liveupdater.com/labourparty/LABOURpol-economy.asp
[19] Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
[20] Ministry for the Environment *The New Zealand Waste Strategy, Towards zero waste and a sustainable New Zealand.* Ministry for the Environment, Wellington, New Zealand, 2002, pp 30
[21] Schafer, Helen, Zero Waste Coordinator, Porirua District Council, *personal correspondence,* 22/01/03
[22] Minister of Labour, *Approved Code of Practice for Demolition*, Occupational Safety and Health Service, Department of Labour, Wellington, New Zealand, 1994.
[23] Carter, Helina, Service Manager, New Zealand Demolition Contractor's Association, *personal correspondence,* 22/01/03
[24] Allan, Director, Southern Demolition, Christchurch *personal correspondence,* 22/01/03
[25] Kendrick, Terry, Director, Harbour City Demolition, Wellington *personal correspondence,* 22/01/03
Edge, Allan, Director, Southern Demolition, Christchurch *personal correspondence,* 22/01/03
Ross, Steve, Manager, Nash and Ross Contractors Ltd, Dunedin, *personal correspondence,* 22/01/03
[26] Kendrick, Terry, Director, Harbour City Demolition, Wellington *correspondence,* 22/01/03
[27] Dalloz, A, *The Contribution of New Zealand Local Authorities to the Promotion of Cleaner Production: Are rules appropriate instruments? The example of the building industry in the Auckland region*, Department of Planning, University of Auckland. 1997
[28] Kendrick, Terry, Director, Harbour City Demolition, Wellington *correspondence,* 22/01/03
[29] Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
Edge, Allan, Director, Southern Demolition, Christchurch *personal correspondence,* 22/01/03
Ross, Steve, Manager, Nash and Ross Contractors Ltd, Dunedin, *personal correspondence,* 22/01/03
[30] Kendrick, Terry, Director, Harbour City Demolition, Wellington *correspondence,* 22/01/03
Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
[31] Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
Edge, Allan, Director, Southern Demolition, Christchurch *personal correspondence,* 22/01/03
[32] Owles, Randel, General Manager, Ward Demolition, Auckland *personal correspondence,* 22/01/03
[33] Carter, Helina, Service Manager, New Zealand Demolition Contractor's Association, *personal correspondence,* 23/01/03
[34] Kendrick, Terry, Director, Harbour City Demolition, Wellington *personal correspondence,* 22/01/03
[35] Ministry for the Environment *The New Zealand Waste Strategy, Towards zero waste and a sustainable New Zealand.* Ministry for the Environment, Wellington, New Zealand, 2002. pp 23
[36] Currently one of the Timaru District council buildings is being refurbished, deconstructed and demolished. The façade is being retained and it is planned that most of the material that is salvaged will be reused in a new second hand resource recovery centre that the council is building.
Woodnorth, Briony, Zero Waste Advisor, Timaru District Council *personal correspondence,* 28/01/03
[37] Carter, Helina, Service Manager, Nikau Deconstruction Engineers, Auckland, *personal correspondence,* 23/01/03

LIFE CYCLE COORDINATION OF MATERIALS AND THEIR FUNCTIONS AT CONNECTIONS DESIGN FOR TOTAL SERVICE LIFE OF BUILDINGS AND ITS MATERIALS

Author: E. Durmisevic*, T.M.van Iersel**

Delft University of Technology, Department of Building Technology, The Netherlands
e-mail: e.durmisevic@bk.tudelft.nl *; t.vaniersel@bouwenmetkarton.nl **

ABSTRACT

This paper will explore the aspects of service-life planning of structures. The focus will be on optimization of use and service life of every building component, by means of systematization and design for assembly/disassembly.

Buildings are constructed of elements and components, which have different functional and technical life cycles. This can result in three life cycle coordination scenarios.

(i) Use life cycle of the component < technical life (service life) cycle of the component.
Such components should be reusable or recyclable.
(ii) Use life cycle > technical life cycle (service life) of the components.
Such components should be replaceable and recyclable.
(iii) Use life cycle = technical durability (service life). Such components should be recyclable.
[Durmisevic 02]

Service-life planning seeks to identify long-term requirements for a building, and to ensure that the design is optimized for the required service life. In this way, structures can be better designed to meet client needs, resources are more efficiently used, and environmental impacts are controlled. As a result of service-life planning, the lifecycle coordination matrices can be developed, which indicates the disassembly-sensitive components.

The assumption in this paper is that the life cycle coordination matrix, based on the scenario planning for buildings and their components, is an important aspect of sustainable construction. This assumption will be elaborated through one case study, which is based on the above mentioned scenario (iii), use life cycle =technical durability.

KEYWORDS: Design for Assembly/Disassembly; Design for Deconstruction; Life Cycle Coordination; Service Life Planning; Use Life / Technical Life Cycle

INTRODUCTION

Generally, economic prosperity of modern society is based on an industrial system that consumes a huge amount of materials and energy on a flow-through basis. Accordingly, it is obvious that it will be increasingly difficult to sustain the quality of life if serious efforts are not made to effectively use the earth's limited resources and to reduce waste production. Having this in mind, we have to adopt the dynamic circular systems approach for future sustainability.

Therefore, rather than destroying structures and systems while adapting the building to fit new requirements, it should be possible to transform the building by disassembling sections back into components, and then reassembling them in the new combination. This articulates the concern for designing a building configuration that deals with the arrangement of building elements and components by defining the relationships between them.

DESIGN FOR DECONSTRUCTION

Dependence between building components is very often the reason for demolition and costly renovation of buildings. Most projects are focused on the assembly view, in order to make them faster and easier. Once the building is there, it starts its life through different phases in use, which require maintenance (finished assembly is being removed for service reasons), modifications (functional assembly is being removed for adaptation reasons), and disassembly (total assembly is being dismantled). These aspects are usually not taken as a design criteria of buildings. Rather, all building components are being put together in a manner that will reduce construction costs and time without taking into account what happens after they are built. With the move toward more sustainable development, there is a need for this short-term approach to be expanded to encompass the entire service life of the structure.

This means that a design protocol should be established to cover the whole life of the building, from initiative to production, assembly, and finally, disassembly of the finished assembly.

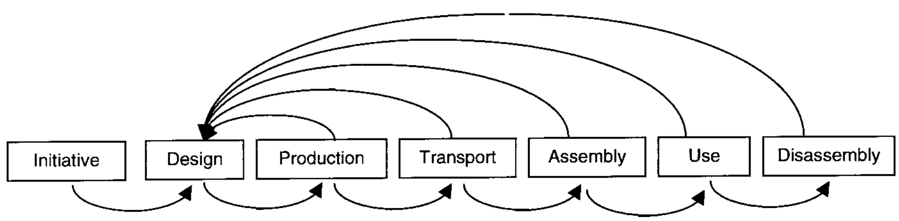


Figure 1: Life cycle phases (1)

During the design phase (one of the first phases), the greatest potential exists to influence the building's properties in all life cycle phases. Such a concept provides a framework for the multidisciplinary teamwork that can influence the building design for cost-effective and high performance buildings.

In order to truly close the life cycle loop of a building and its materials, the design should be focused on the development of disassemblable structural configurations. Deconstruction seeks to maintain the highest possible value of materials in existing buildings by dismantling buildings in a manner that will allow reuse or efficient recycling of materials that comprises structures. At the same time, through design for disassembly, spatial systems of the building also become more transformable.

Considering the life cycle phases of the building (Figure 1), design criteria of design for deconstruction will have an impact on each life cycle phase of the building. Table 1, below, gives a specification of design principles for deconstruction per design phase.

	design phases	design principles
1	feasability phase	strategy planning outline scenario planning
2	conceptual design	scenario planning functional decomposition systematization outline assembly dissasembly planning design of open configuartion
3	definitief design	finalize systematization finalize configuration specificationof base elements assembly/dissasesmbly planning finalize the connections outline the manual for maintanance and hendeling of structures
4	preparation for connstructon	specification of reusable and recyclable elements
5	construction phase	outline of user menuel for building systems and components
6	exploatation phase	
7	transformation phase	assesment of suitability of the structure for specifieq transformation scenario specification of reusable systems; development of operational building model user menuel
8	dissasembly phase	development of optional plan for reusable components

Table (1) Design principles for deconstruction per design phase.

The enactment of design for deconstruction in Table (1) is based on nine key principles: 1) short-term and long-term strategy planning, 2) scenarios planning, 3) functional decomposition, 4) life cycle coordination of materials and their functions, 5) systematization according to the functions and life cycle, 6) design of open configuration, 7) planning of base elements, 8) assembly/ disassembly planning, and 9) specification of demountable connections. More detailed description of these principles can be found in the proceedings of TG 39 Conference 2002 (paper “Design Aspects of Decomposable Building Structures”, by E.Durmisevic). (6)

In the initiative phase of the building, the short and long-term strategy has to be sought out. This will result in development of different scenarios for the use of the structure. Accordingly, a hierarchy of technical systems can be worked out.

The essential element of the conceptual design phase is provision for open building configuration, whose systematization is based on the principle of clear separation of materials and components with different functions, different use life cycles, and different technical life cycles.

Furthermore, when finalizing design for disassembly, aspects such as an open hierarchical structure, specification of the base element, provision of assembly/disassembly plan, and design of demountable connections will ensure that the structure is 100 % deconstructable.

SHORT TERM AND LONG TERM STRATEGY

Service Life Planning

Service life planning sets the boundary conditions for design for deconstruction. Further on, the design process should optimise the structure for its total life cycle. Service life planning is a design process that seeks to ensure, as far as possible, that the service life of a building will equal or exceed its design life, while taking into account (and preferably optimizing) the life cycle costs of the building. (3) The design scenario where the technical durability of a structure is equal to its use durability will have minimum environmental impact. Such structures need no maintenance. Conventional structures create a negative impact throughout the whole life cycle (manufacturing, transport, construction, maintenance, demolition, transport, reuse, recycling, landfill). The only negative impact that above-mentioned type of structures produce is related to the production of components, transport of components, and recycling of components. One pilot project will be presented in this paper where the principles of technical life cycle equaling use life cycle has been used as a design strategy. Further more this paper will:

- specify general principles needed to forecast service lives,
- define a method for estimation of the service life of components or assemblies for use in specific building projects.

As the length of the service life cannot be precisely known in advance, the objective becomes to make an appropriately reliable forecast of the service life using available data. The purpose for most clients will be to ensure that the most advantageous combination of capital, maintenance, and operational costs is achieved over the life of the building. The output of service life planning will be a series of predicted service lives of components, and a projection of maintenance and replacement needs and timing. (3)

Buildings are constructed of elements and components that have different technical and use life cycles. Design that does not seriously take this aspect into consideration produces fixed structures that cannot be easily reconfigured during the operational phase of the building, and which are difficult and expensive to maintain.

Generally (taking into account difference in use and technical life), all buildings could be classified into three groups:(2)

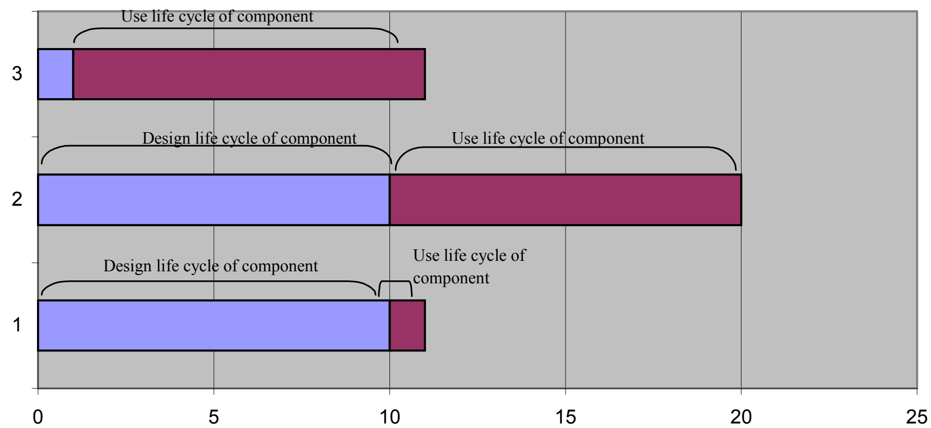


Figure 2: Three scenarios for life cycle coordination

1. Use life cycle of component < technical life cycle of components

For example, the expected use life cycle of one switch in a wall is 2 years, while its designed technical life is 30 years. Or, the expected use life cycle of one partitioning wall is 5 years, while its designed technical life is 75 years. This means that the wall has a reuse potential of 15 times. Accordingly, 15 times reuse of one wall, compared to 15 times demolition and construction of the new wall, results in a material reduction of 96.6% if the wall would be replaceable in 75 years.

The components belonging to this category should be assembled as totally independent parts of the structure, in order to ensure their easy disassembly and reusability.
Important deconstruction aspects for this category are: functional separation, life cycle coordination, systematization, open hierarchy, base element specification, assembly/ disassembly planning, geometry of connections, and method of connections.

2. Use life cycle > technical life cycle

This is very often the case with installation systems and facade systems in a building since they have a shorter life cycle than the expected use life cycle of the building. Components in this category should be designed for replaceability and recycling.

Important deconstruction aspects for this category are: functional separation, functional independence, life cycle coordination, systematization, open hierarchy, base element specification, assembly/ disassembly planning, geometry of connections, size, and method of connections.

3. Use life cycle = technical life cycle

These are buildings whose component's design life cycle has been optimized to their technical life cycle. That means that after the end of the use life cycle, all components will be recycled. Such buildings produce minimal environmental stress, since there is no waste production at the end of the building's life. The idea behind this scenario is to use materials that will stay in perfect condition for 19.5 years, and after that will rapidly deteriorate.

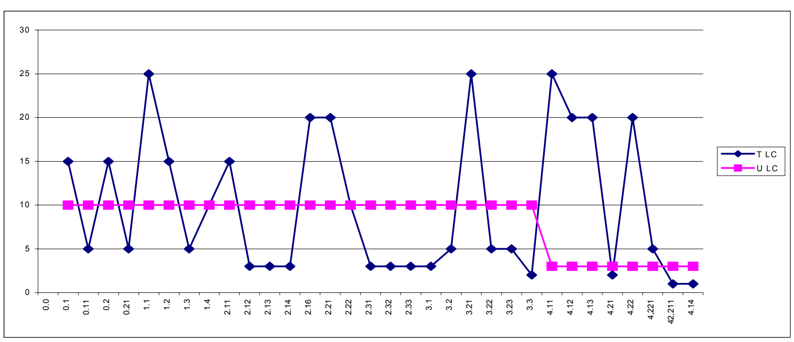
If the design is focused on the strategy to replace the building or to move some of its parts to other locations, then deconstruction aspects for this category would be the same as for other two groups. However, if the strategy of design is focused purely on one use and then recycling, important deconstruction aspects for this category would be: open hierarchy, base element specification, assembly/ disassembly planning, geometry of connections, and method of connections.

The life cycle design of a pavilion which belongs to Group 3 will be presented here as a case study.

CASE STUDY AND DESIGN STRATEGY

Service life planning of the pavilion
The pavilion was designed with the idea of being used for exhibition at one location, and then replaced in other locations, with a total lifetime of 10 years. Keeping in mind that the pavilion would have a rather short life cycle, we decided to try to find materials whose durability would not go over the desired use life cycle.

Strategy:	Short-term	Exhibition space for 30 days
	Long-term	Movable exhibition space for 10 years



<u>Materials not consistent ULC</u>

TLC > ULC
1.1, 3.21, 4.11: Honeycomb core
4.12, 4.12: Transparent foil

TLC < ULC
2.11: Spool

Figure 3. Life cycle coordination illustrating the difference between technical life cycle (TLC) and use life cycle (ULC)

The lifecycle coordination matrix (Table 2 and Figure 3) shows that the service life of most of the components is optimised for a short use life. There are few components whose life cycle is longer than the desired service life. The technical lifetime of the transparent façades (ETFE-foil), for example, largely exceeds the use life. This foil was chosen because it can meet the terms of fire regulations.

The technical life span of cardboard (specified in above figure as 0.12 and 3.22) in buildings is difficult to estimate. First, cardboard in its present applications has a life span of days up to weeks. No direct knowledge is available concerning life spans over a longer period of time.

Second, there are hardly any cardboard buildings with a permanent function. One of the rare examples of cardboard buildings that is still in function are buildings designed by S.Ban (1957) in Nagoya. (4)

The exceeding technical life span of all connection materials (bolts, screws, rings, etc. 2.21, 2.31) can be subscribed to the quality of the standard products available in the shops. All of these metal products are standard galvanized, extending their technical life span.
The technical life span of the cardboard honeycomb core (specified in above figure as 4.1) in the wall- and roof-panels is 25 years. Thanks to the top layer of solid board, this core is protected (compare: interior door).

The used spools in the pavilion have a significant shorter TLC than the ULC. This spool consists of reused wood chips, which are collected from the waste stream of the wood industry, reducing the total environmental impact.

To satisfy the need of the third group (service life = technical life) the building material has to be recyclable. Ninety percent of the chosen building materials were cardboard, produced by the Dutch paper and board industry.

Structuring of pavilion's configuration
All cardboard used was standard products and was recyclable. As such, the final scenario, aimed at the recycling of materials at the end of their technical life cycle, could be achieved.

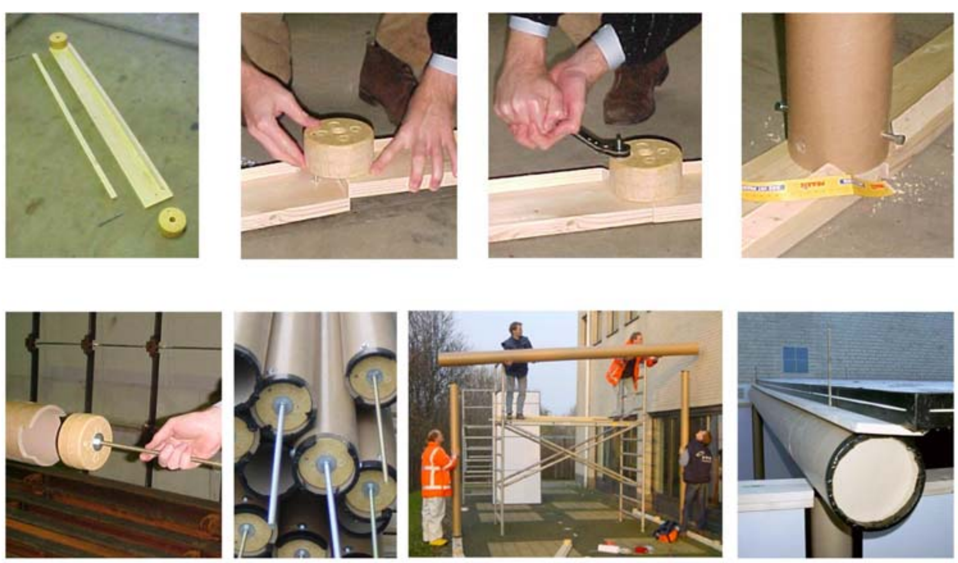


Figure 4. Pilot project - assembly sequences of intermediaries, columns, and beams

In order to satisfy the reuse scenario that promotes replaceability and reuse of components whose life cycle is longer than their technical life cycle, the design of the building configuration has a crucial role.

After specification of service life planning for the durability performance of building components, deconstruction of sensitive parts of the structure has been accentuated. Further focus of design for deconstruction is on independence and exchangeability of building components, through specification of configuration, assembly sequences, and connections.

The building structure is defined as the hierarchical arrangement of the elements, and relations that the building consists of. It represents how parts are arranged into groups of parts (components), and how groups of parts are arranged in the whole building. A key characteristic of disassemblable configuration is a minimal number of direct relations between building components.

Conventional buildings are characterised by complex relational diagrams, representing maximal integration of all building elements into one dependent structure. The number of relations can be reduced by the specification of the base (key) element of the structure. Such an element should have the longest technical and use life cycle. All subassemblies should have relations only with the base element. Another possibility in reducing the dependence through relations is by the use of an intermediary between two components, which was the case in this pilot project (Figure 5).

The relational diagram in Figure 5 indicates the problem in structuring this configuration in the first part of assembly, where a great level of dependence is created between different levels of assembly (Figure 5). Such configuration caused no environmental problem for the short-term use, after which, the pavilion was disassembled and replaced in another location. However, if some parts should be replaced before total disassembly, complex disassembly operations would take place, resulting in damaging of some components with longer reuse potential.

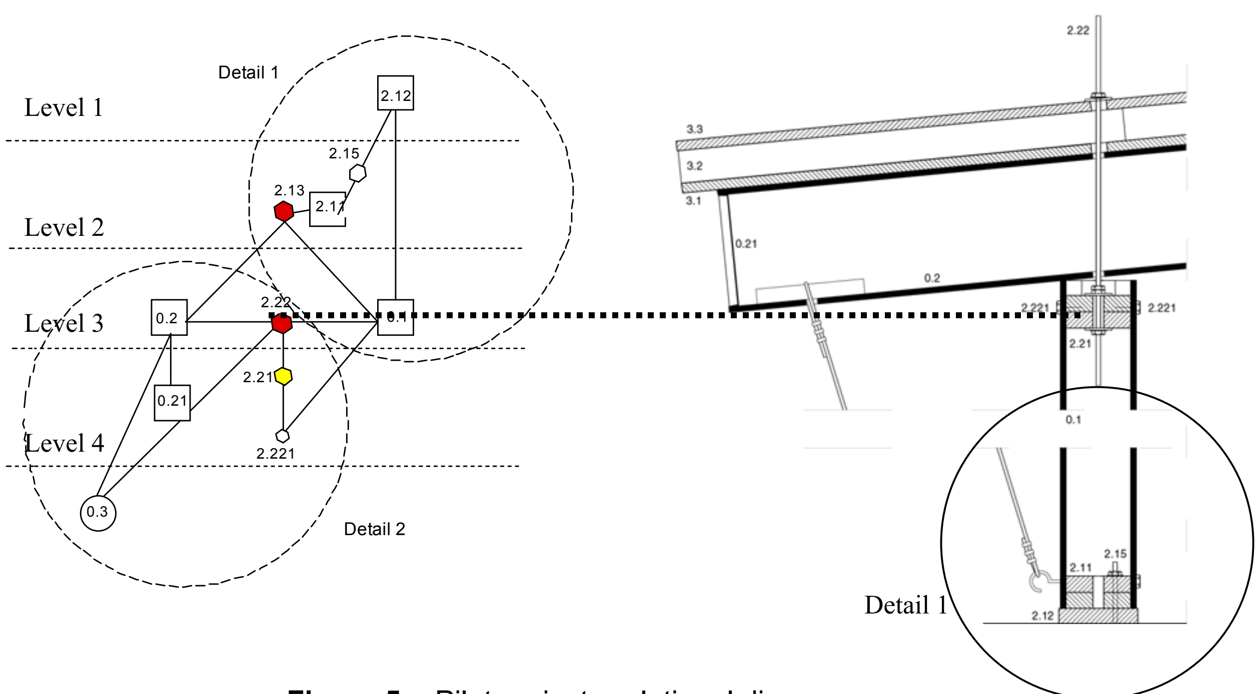


Figure 5a: Pilot project - relational diagram

Reconfiguration of the structure can be done in a way that will provide an open hierarchy. By the reduction of the number of relations between the components, the number of independent and exchangeable components can be increased. For example, the alternative to the relational diagram of Detail 1, which is presented below, will provide greater independence of the column. (01)

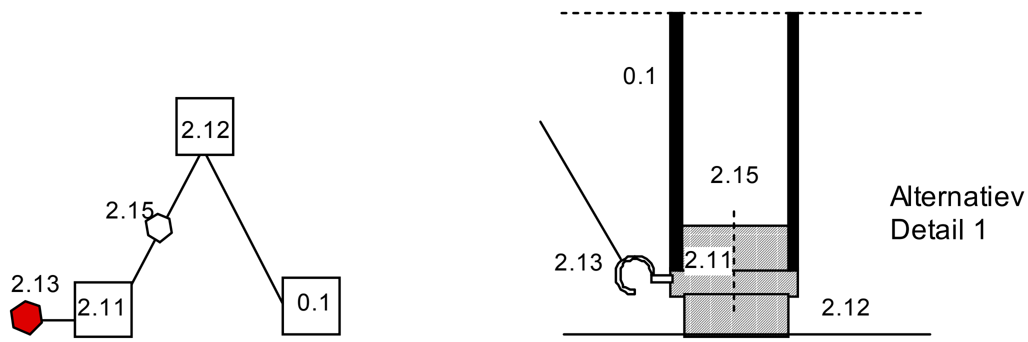


Figure 5b: Pilot project - relational diagram alternative configuration of detail 1

Figure 6: Pilot project – final assembly

CONCLUSIONS

The way we assemble the building reflects its disassembly potential, while the decisions made regarding materials will affect the recycling potential of materials. Therefore, the design decisions regarding materials and assembly principles made at the beginning of the design process, can have consequences for the entire service life of the building and its materials.

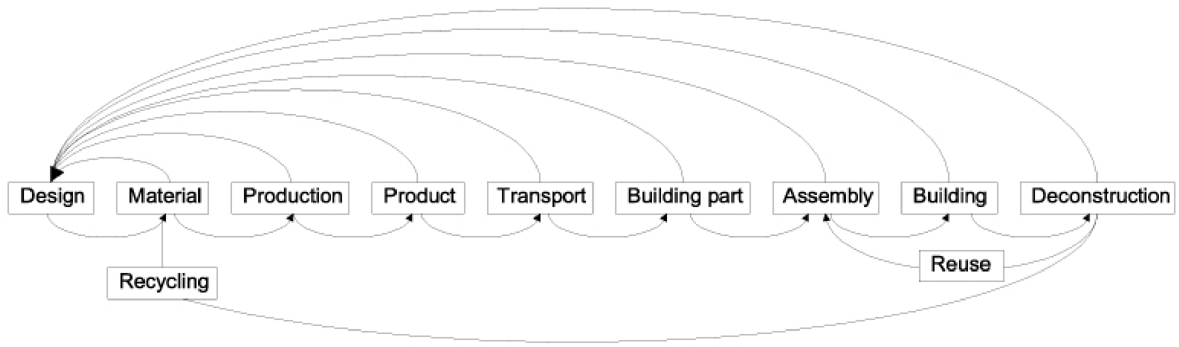


Figure 7: Pilot project – life cycle phases of the building and its materials

Design for deconstruction should take into account long and short-term strategies for the use of buildings and materials. The long-term strategy should rely on reuse of buildings and building components, while the short-term strategy should take into consideration the recycling potential of materials. These strategies will set boundary conditions for service life planning in each design phase (Table 2).

REFERENCES

(1) E.Durmisevic, J.Brouwer; Building with systems, Conference proceedings Beyond Sustainability, TU Eindhoven 2001

(2) E.Durmisevic, B.J.H. te Dorsthorst; Building's transformation capacity as the indicator of Sustainability, A way to measure the environmental impact of flexible housing, Conference proceedings Open Building Mexico 2002

(3) ISO/FDIS15686-1-Draft international standard

(4) GG Portfolio, Gill 1997, Barcelona

(5) Levensduur van Bouwproducten, Praktijkwaarden. SBR, Rotterdam December 1998

(6) E.Durmisevic *Design Aspects of Decomposable Building Structures*, Conference proceedings of TG 39 conference 2002, Germany

KNOWLEDGE MODEL FOR ASSESSING DISASSEMBLY POTENTIAL OF STRUCTURES

Authors: E. Durmisevic, Ő. Ciftcioglu*, and C. J. Anumba**

*Delft University of Technology, Faculty of Architecture, Department of Building Technology
**Center for Innovative Construction Engineering (CICE), Loughborough University

ABSTRACT

The most important issue regarding a building today is increasing its environmental efficiency, which can be achieved by creating the potential for closed-loop material recycling of building products. One way to achieve this is through the design of demountable structures whose components can be reused in another combination, or recycled. A conceptual-knowledge model for assessing the disassembly capacity of buildings/systems is described in this paper. Disassembly capacity is defined as a single parameter. Since this parameter is a function of a number of factors, such as material levels, structuring, and connections, standard linear latent-variable models are not adequate in this case. Besides the limitation due to linearity, the fuzzy nature of the variables also heavily limits the validity of conventional models.

To deal with the complexity and vagueness of the variables, an intelligent knowledge modeling approach is considered. The model is essentially an artificial neural network with appropriate neurons as information processors, and it is subject to machine learning to establish the model parameters. Each neuron represents a cluster center in the relevant multidimensional space, and the cluster centers are determined in advance, according to the requirement specifications at hand. In this paper, the role of disassembly capacity in sustainable building technology is highlighted. Further an associated knowledge model formulation with underlying intelligent decision-making capability is described. This approach emphasizes the novel application of information technology to building technology.

The aim of the research is to develop a model that will assess the disassembly capacity of buildings and provide support for design for disassembly.

INTRODUCTION

As the problem of environmental degradation increases, designers will come under increasing pressure to provide solutions to reduce energy and material consumption. Design for disassembly is one possible solution, in which the building can be truly deconstructed by a reversal of construction sequences. Disassembly potential is defined as the ability of a building’s structure to be selectively taken apart with the intention of reusing and up-cycling some (or all) of its constituent parts. The discussion in this paper is based on the assumption that greater disassembly potential means greater flexibility and environmental efficiency, and therefore, greater sustainability. Two key indicators of deconstruction are independence and exchangeability of building components. Independence is defined as the ability of building parts to be recognized as separate parts of the structure, in terms of functional and material independence. This can be achieved by the separation of functions, systematization of materials into independent clusters, and the design of open hierarchical configurations. Exchangeability is defined as the potential of a component to be dismantled. This can be achieved by the design of simple geometry of component edges, parallel assembly sequences, and use of demountable connection methods. According to the level of independence and exchangeability of building components, all building structures can be grouped into three categories (Figure 1):

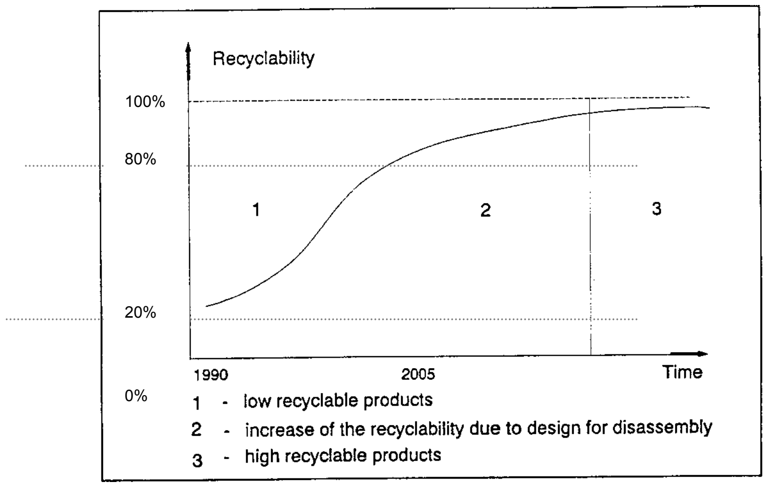


Figure 1: *Three categories of structures [3]*

Category 1
The first category has low disassembly potential where both indicators have less than 30% of their best values. This can be recognized as a standard waste stream in construction. Accordingly, more than 80% of construction waste will be produced during deconstruction. Those are, for example, structures with monolith connections, or structures with complex relational diagrams, where replaceability of one component will influence a number of related components. In this category, building components are being down-cycled, incinerated, and landfilled after deconstruction.

Category 2
The second category has medium disassembly potential, with both indicators having between 30% and 70 % of their best value. Accordingly, between 20% and 80% of construction waste will be produced during deconstruction. These are partially deconstructable structures. For example, about 35% of offices in the Netherlands are constructed out of concrete panels (with integrated facade and load bearing structures) creating a fixed shell. Such fixed shell is filled with flexible installation and partitioning systems. In this category, building components are being recycled after deconstruction.

Category 3
The third category of transformation has high disassembly potential, where both indicators of transformation (independence and exchangeability) have more than 70% of their best values. Accordingly, less than 25% of construction waste will be produced during deconstruction. Such structures are called deconstructable structures. Deconstructable structures define a method of construction in which use is made of integrated structural, mechanical, electrical, envelope, and

partitioning systems in a way that will stimulate their independence and exchangeability in different phases of the building's life cycle. The systematization is derived from the fact that different parts of the building have different life cycle and functional expectance, and therefore, should have a status of independent parts within the structure. In this category, building components can be reconfigured or reused after deconstruction.

Sustainable design and construction should aim at promoting Category 3. This paper discusses the development of a knowledge model that can assess the disassembly potential of building structures. Such assessments can be used in two ways:

1. As an indicator of the environmental impact of the building.
2. As decision support for design for disassembly.

FRAMEWORK FOR THE DEVELOPMENT OF THE KNOWLEDGE MODEL

In order to develop the knowledge model, indicators and aspects of deconstruction are defined. A dismantleable building can be defined as a building that is made of pre-made components assembled in a systematic way that is suitable for maintenance and replaceability of single parts. When designing a building that should meet such conditions, the overall relationship between building components should be of primary importance.

This brings us back to the essence of making that is true for any building assembly and material combination and deals with:

1. Natural order within the building that moves from high to low (expressing the load path through a structure);
2. Separate elements, which respond differently to changing conditions (The elements have different life spans, which lead to differential movement, differential durability, or incompatible materials);
3. Interfaces which ensure continuity of functions from one component to another.

These are, at the same time, the three main components of every configuration, namely: hierarchy, material specification, and connections. The two indicators of deconstruction (independence and exchangeability) rely on the specification of these components. Key disassembly aspects that will influence the suitability of a hierarchy for deconstruction are the relational pattern of the structure and the design of the base elements of the structure. Key disassembly aspects that will influence suitability of product specification for deconstruction are: functional decomposition, material levels, and life cycle coordination of material levels. Key disassembly aspects that will influence the suitability of connections for deconstruction are: assembly, geometry of product edge, type of connection, and morphology of connection. Each of these aspects has sub-aspects. In order to define the framework for the assessment model, aspects and sub-aspects are divided into dependent and independent variables.

The Model

The project aims to assess the disassembly capacity of buildings from a knowledge model. The knowledge model is developed by way of information acquired from the building concerned. A simplified basic model is shown below (Figure 2). The model is in a multi-level form with respect to the nodes, which are ranged. In that respect, the relationship between the nodes is in a feed-forward structure, so that causality among various dependencies is maintained. That means that any node in the model can affect only the nodes of higher ranks. The knowledge model has four levels of abstraction.

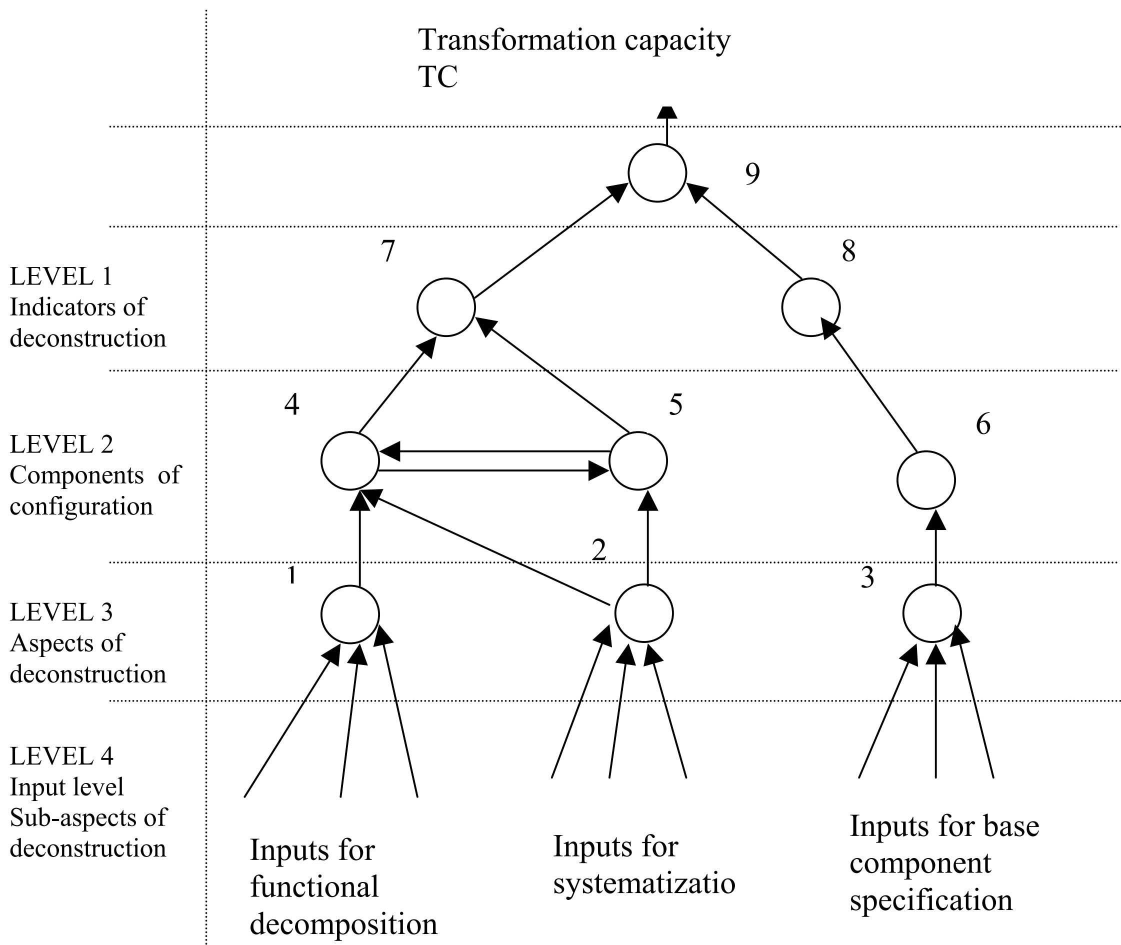


Figure 2: *Simplified knowledge model for the assessment of disassembly potential and transformation capacity TC*

Fourth level

The fourth level is the input level, which consists of sub-aspects (sub-components) and a specification of their impact on the main aspects. This is achieved by the weighting of each relation between a sub-aspect and a main aspect of deconstruction.

The table below represents Fuzzy variables that were used as the input to the knowledge model. Grading is done from zero to one. Zero represents the worst impact, and one represents the best impact on disassembly.

aspects	subaspects		grading
FD FUNCTIONAL DECOMPOSITION	functional separation	separation of functions	1
		integration of functions with same lc* into one element	0.6
		integration of functions with different lc* into one element	0.1
		(fs(n) + n(f)) / n =	….
	functional dependence	modular zoning	1
		Planed interpenetrating for different solutions (overcapacity)	0.8
		Planed interpenetrating for one solution	0.4
		Unplanned interpenetrating	0.2
		total dependence	0.1
		(fdp(n) + n(fdp)) / n =	….
LCC LIFECYCLE CO-ORDINATION	use life cycle/ coordination	long (1) / long (2) or short (1) / short (2)	1
		long (1) / short (2)	0.8
		medium (1) / long (2)	0.5
		short (1) / medium (2)	0.3
		short (1) / long (2)	0.1
		(fdp(n) + n(fdp)) / n =	
	technical life cycle/ coordination	long (1) / long (2) or short (1) / short (2) or long (1) short (2)	1
		medium (1) / long (2)	0.5
		short (1) / medium (2)	0.3
		short (1) / long (2)	0.1
		(fdp(n) + n(fdp)) / n =	
	use lifecycle / size	big (small) element / long L.C.	1
		small element / short L.C. or medium comp./short L.C.	1
		big component / short L.C.	0.4
		big component / long L.C.	1
		material / long L.C.	0.2
		big element / short L.C. or material / short life cycle	0.1
		(fdp(n) + n(fdp)) / n =	
RP RELATIONAL PATTERN	position and type of relations	vertical	1
		horizontal in lower zone	0.6
		horizontal between upper and lower zone	0.4
		horizontal in upper zone	0.1
	base element specification	base element- intermediary between systems /components	1
		base element- on two levels	0.6
		element with two functions (be. and one building function)	0.4
		no base element	0.1

aspects	subaspects		
SYS SYSTEMATISATION	structure and material levels	components	**1**
		elements / components	**0.8**
		elements	**0.6**
		material / element / component	**0.4**
		material / element	**0.2**
		material	**0.1**
	clustering	clustering according to the functionality	**1**
		clustering according to the material life cycle	**0.6**
		clustering for fast assembly	**0.3**
		no clustering	**0.1**
A ASSEMBLY	assembly direction	parallel	**1**
		stuck assembly	**0.6**
		base el.in stuck assembly	**0.4**
		sequential seq.base el	**0.1**
	assembly sequences	component (1) / component (2)	**1**
		component (1) / element (2)	**0.8**
		element (1) / component (2)	**0.6**
		element (1) / element (2)	**0.5**
		material (1) / component (2) or material (1) / component (2)	**0.3**
		component (1)/material (2) or element (1) / material (2)	**0.2**
		material (1) / material (2)	**0.1**
G GEOMETRY	geometry of product edge	open linear	**1**
		symmetrical overlapping	**0.8**
		overlapping on one side	**0.7**
		unsymmetrical overlapping	**0.4**
		insert on one sides	**0.2**
		insert on two sides	**0.1**
	standardisation of product edge	pre-made geometry	**1**
		half standardised geometry	**0.5**
		geometry made on the construction site	**0.1**
C CONNECTIONS	type of connection	accessory external connection or connection system	**1**
		direct connection with additional fixing devices	**0.8**
		direct integral connection with inserts (pin)	**0.6**
		direct integral connection	**0.5**
		accessory internal connection	**0.4**
		filled soft chemical connection	**0.2**
		filled hard chemical connection	**0.1**
		direct chemical connection	**0.1**
	accessibility to fixings and intermediary	accessible	**1**
		accessible with additional oper. which couses no damage	**0.8**
		accessible with additional oper. which reparable damage	**0.6**
		accessible with additional operation which couses damage	**0.4**
		not accessible - total damage of bought elements	**0.1**
	tolerance	high tolerance	**1**
		minimum tolerance	**0.5**
		no tolerance	**0.1**
	morphology of joint	knot (3D connections)	**1**
		point	**0.8**
		linear (1D connections)	**0.6**
		service (2D connection)	**0.1**

Third level:
The input on the third level is a specification of the impact that main-aspect components have on three components of the building configuration [performance based specification of product (material levels), hierarchy, and interface]. The weights simultaneously define the hierarchy of importance of each aspect.

Second level:
Input on the second level is a specification of the impact that components of the building configuration have on the indicators of transformation, independence, and exchangeability.

First level:
Input on the first level is a specification of the impact that indicators of transformation have on the disassembly potential, which represents the transformation capacity of a structure.

The input data for the model are collected based on expert assessment of the different criteria, which have an impact on the disassembly potential of structures. The information on the building design properties is concisely represented in the form of a matrix, called the knowledge matrix. In the model, each factor is represented with a node, and the knowledge matrix represents the relation/dependence among the nodes. Thus, nodes represent components, which play a role in the transformation capacity (TC). Each component is described by a fuzzy rule so that the node output is the firing strength of that rule. The inputs to each node are sub-components of the model, which are designed as associated fuzzy variables. Since each sub-component is a fuzzy variable, the imprecision made in its assessment is taken care of. This is accomplished by means of fuzzy logic, which is briefly described below.

Fuzzy Logic
Fuzzy logic explicitly aims to model the imprecise form of human reasoning and decision-making. It is based on the concepts of fuzzy sets [2,3]. A fuzzy set is a generalization of a conventional set, in that the memberships are assigned between zero and one, compared to being purely boolean. The fundamental concept of fuzzy logic is known as a *linguistic variable*. A linguistic variable is a variable that takes values from spoken language. It can be described by:

- qualitatively using an expression involving linguistic terms; and
- quantitatively using a corresponding membership function.

A linguistic term is useful for communicating concepts and knowledge with humans. A membership function is useful for processing numeric input data. Consider x as some variable over some domain of discourse, U, called the universe of discourse. X is a fuzzy set over U. The expression $\mu_X(x)$ is defined as the degree of membership of x in X. The function $\mu_X = f(x)$ is referred to as a membership function, and it represents the degree of association of the variable x with the fuzzy set X. Given a domain of discourse, U, fuzzy sets over U can be identified with a set of names of linguistic variables. Typical fuzzy sets of the speed of a car are shown in Figure 1(a).

Considering the example of driving a car, such a speed variable can be described as *high*, *low*, or *medium*. Although these values do not have precise meaning, a certain distribution between zero and one can be defined and associated with the values. This distribution is represented by a membership function. The membership functions are the fuzzy attributes or semantic labels of the quantity of concern. They are the basic elements of fuzzy computation. Fuzzy logic can be used in various ways. Some examples are the *rule base* in an expert system, *control* in engineering systems, *information modeling* in a knowledge base, and *semantic labeling* in a database. The essential machinery of fuzzy logic is the production of an output (consequent), based on given premises (antecedents), where reasoning plays the major role. This is accomplished by means of statements, which are referred to as *rules*. The general expression for a set of fuzzy rules is:

$$R^i : IF\ x_1\ is\ A_1^i\ and\ x_2\ is\ A_2^i\ \ldots\ and\ x_n\ is\ A_m^i\ THEN\ y^i\ is\ B^i$$

where R^i (i=1,2,…,l) denotes the i-th fuzzy rule. A basic example is illustrated in Figure 1(b) where two properties related to two items in a construction process are considered. The item may be considered as a building, the associated properties being width and height. The fuzzy attribute values are represented by the associated membership functions. Figure 1(b) shows a fuzzy partition of the height × width space with fuzzy sets. Each division is represented by a similar fuzzy partition scheme, where each triangle represents a fuzzy set. The shaded regions represent the overlapping areas of the fuzzy sets, where each fuzzy variable, i.e. height and width, is represented by two fuzzy sets. The universe of discourse is two-dimensional, and it can be represented by four rules.

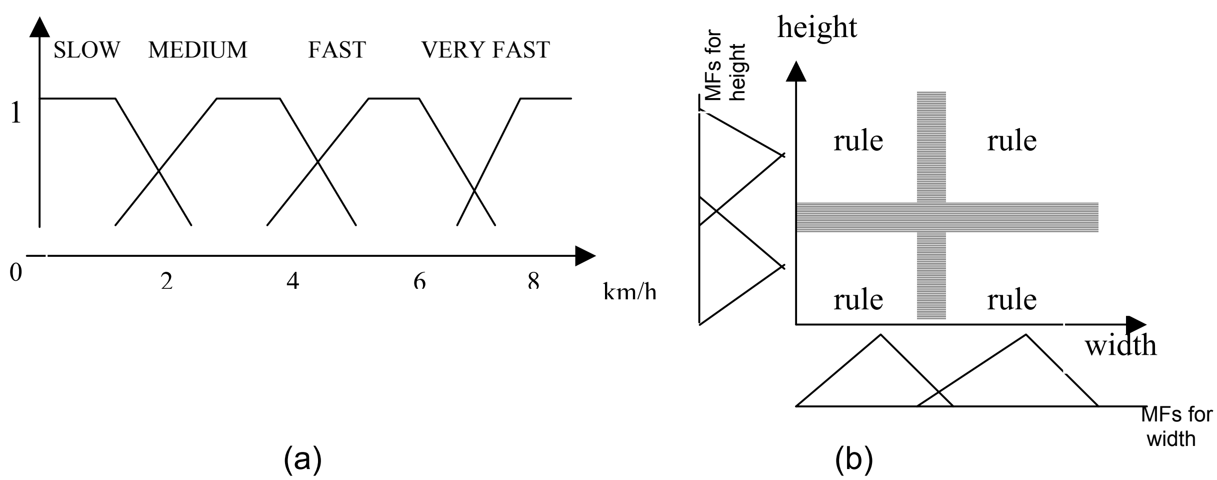


***Figure 3**: Typical fuzzy sets of speed (a) and fuzzy memberhip functions for height and width (b)*

DESCRIPTION OF THE KNOWLEDGE MODEL

In the sample basic model in Figure 2, there are nine main components playing a role in the determination of TC. Each node has sub-components, represented by incoming arrows. In the model, each node corresponds to a rule, and with the combination of nine nodes, the transformation capacity is determined. The relationships among main components are represented by relevant weight factors. Each weight is between zero and one, representing the strength of the relation. This is an estimated value with its associated imprecision. Therefore, it is conveniently represented as a fuzzy variable characterized by a membership function. The membership functions used in this work are in the form of Gaussian functions. Thus, a membership function μ is given by:

$$\mu(x_p) = \exp(-(x_p - w_{ij})^2 / 2\sigma^2 ,$$

where w_{ij} and σ are the mean and variance of the Gaussian function, respectively. A fuzzy "AND" is performed by arithmetic multiplication. The mean of each gaussian is characterized by the weight factors of the knowledge model. For $x_p=w_{ij}$, we obtain $\mu(x_p)=1$, so that the knowledge model verifies the transformation capacity for the standard inputs forming the model. In this case, the membership functions take the maximum values, indicating that the values of the components have their best representational values. Consequently, the representative knowledge model is formed.

The model can be used for the assessment of TC for the different inputs seen in Figure 2. For these inputs, the membership functions take their respective values and determine the associated TC. Since the knowledge model has a well-defined transformation capacity, TC_s, for the standard inputs, any deviation from these values, i.e., for test inputs, will, to some extent, diminish TC with respect to TC_s.

All inputs and specified weights are calculated by the use of fuzzy logic producing, at the end, an index representing the disassembly potential of the analyzed structure. The test model is optimized for the best value of disassembly potential. Each new case is calculated by a relationship-equation, and is compared with the best values.

CASE STUDY

For the experimental investigation of the model, the Project XX was chosen as a case study. Project XX is an experimental office building designed at the outset for sustainability. The main objective of the project was to develop a building for an expected functional life span of twenty years. After twenty years, all components should be reused or recycled. In the case study, the disassembly potential of the XX building has been calculated for two scenarios:

- Scenario 1: Long term strategy of total disassembly after twenty years.
- Scenario 2: Replace-ability of façade panels in case of placement of an additional entrance and window openings, or replacement of existing entrances.

Disassembly potential of XX building / Scenario 1

The structure of the "Office XX" in Delft is characterized by such systematization where load bearing frame, façade, floor panels, and roof panels were pre-made and independently assembled on the site (Figure 4). The XX building was designed for a short-use life cycle. After twenty years, the building should be deconstructed, and its elements reused in another combination or recycled.

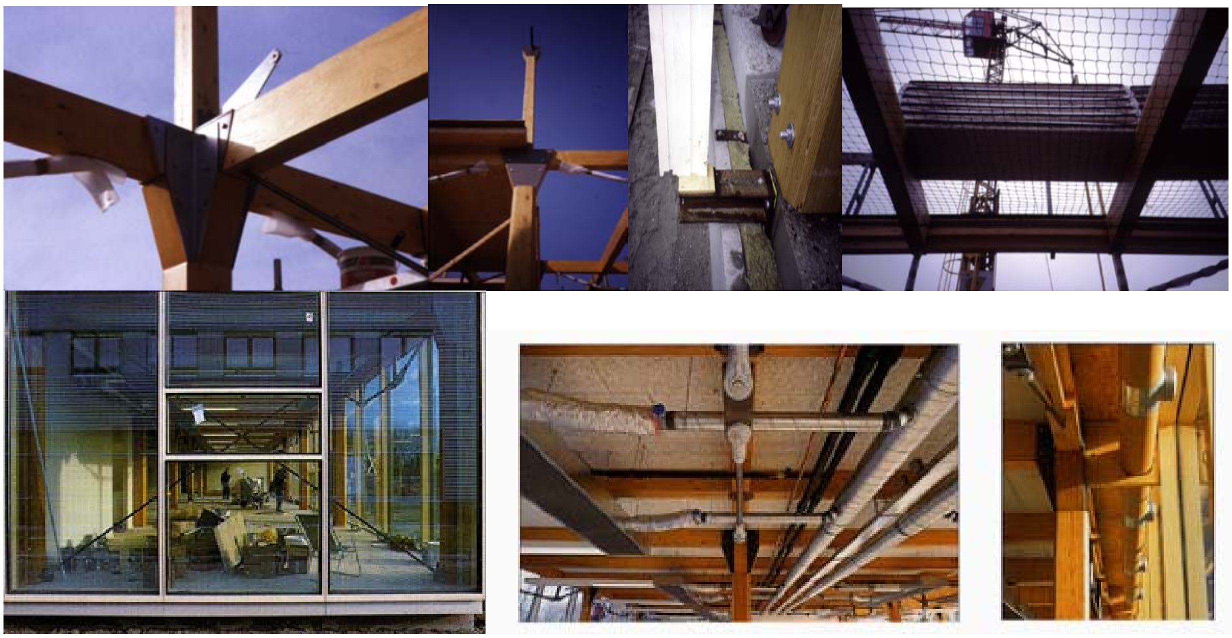


Figure 4: *Assembly sequences of XX Office Building in Delft, The Netherlands [1]*

Structural Frame
Structural frame of the building is made of laminated “Swedlam LVL” timber, with columns of 30x30x350 cm on the ground floor and 20x20x350 cm on the first floor, and beams reinforced with stand-off steel bar lower chords. The frame is stiffened by wind bracing on the ground floor, the first floor, and the roof. The method used to make wooden construction saved 25% of raw material.

Floor on the Ground
Floor on the ground is made of concrete, with 20% recycled aggregate. It is separated from thermal isolation with thin foil so that it could be easily replaced and recycled in the future.

Floor
Floor on the first level is made of wooden sandwich panels (600x500 cm) filled with sand. The panels have an assembly tolerance of 2 cm.

Roof Construction
Roof construction is made of “wood fibre concrete” and recyclable covering. Bitumen is only partly fixed to the layer of thermal isolation.

Building Envelop
Building envelope is made of triple-glass segments. The glass segments are placed in the wooden frame. All connections are kit-lose. Aluminum lintel, which is affixing the glass panels, is affixed with screws to the wooden frame.

Installations
All air ducts are made of carton and attached to the “T” profiles on the ceiling. The canal for the electrical installations and the holes for the water pipes are pre-made in the floor panels.

The diagram above presents the relationships between the main sub-systems in the XX Building and their hierarchical dependencies. The elements of the load-bearing frame are assembled in the first three sequences. They have further relationships with base elements belonging to different subsystems, which were assembled in fourth sequence. The most dependent elements in the XX structure are the load-bearing elements, because of their early assembly and great number of relationships with other parts of the structure. On the other hand, those elements would be the last ones to be disassembled, due to their functionality and long life cycle. Other sub-assemblies of the building have a high level of independence, since they are independent from each other and are only connected to the main structural frame.

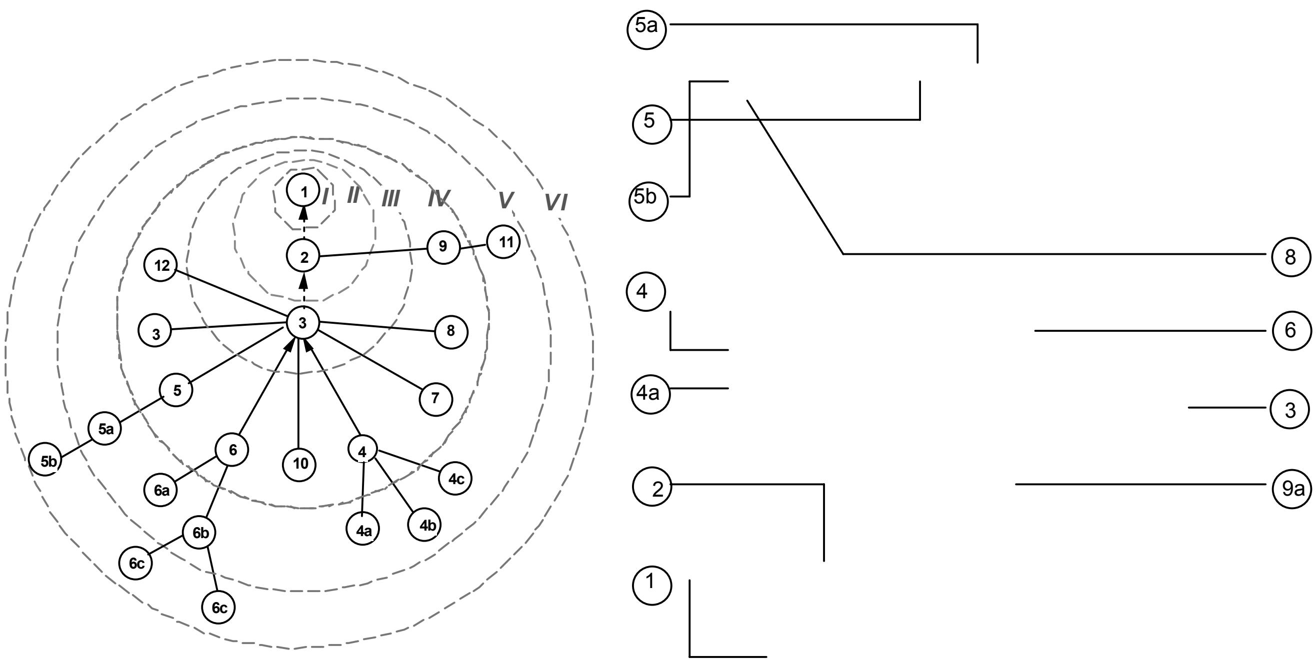


***Figure 5**: relational diagram of components figure 5b total assembly*

The open hierarchical relational diagram and the systematization of elements into independent clusters indicate that two components of configuration, namely hierarchy and material levels, are configured for disassembly. This means, for example, that parallel disassembly sequences of clustered units can be applied, which will save a significant amount of time. Furthermore, separation of functions provides more options for reuse of clusters, and makes it easier to modify them for new use.

However, the design of interfaces, which is also an important element of deconstruction, can be improved for more efficient disassembly. For example, the connection between primary and secondary beams can be characterized as “internal accessory connection,” wherein 30-cm long pins are inserted to connect two beams. Removal of the pins will cause damage to the beams. The material connection is provided between the concrete floor, which makes no room for disassembly. The same is true of the wall finishing.

For that reason, when calculating disassembly potential for the first scenario (total disassembly after twenty years), the suitability of detailing the XX Building for disassembly (which is a function of: type of the connection, geometry of product edge, assembly direction, morphology of connection, and tolerance) is Int = 0.753, or 75%.

The suitability of material systematization (which is a function of functional decomposition and level of systematization) is SYS=0.89, or 89%.

The suitability of hierarchy (which is a function of base element specification, life-cycle coordination, and relational pattern) is H=9.31 or 93%. Accordingly, the total Disassembly Potential (which is a function of independence and exchangeability resulting from the above-calculated parameters) of the XX Building is D =0.912, or 91%.

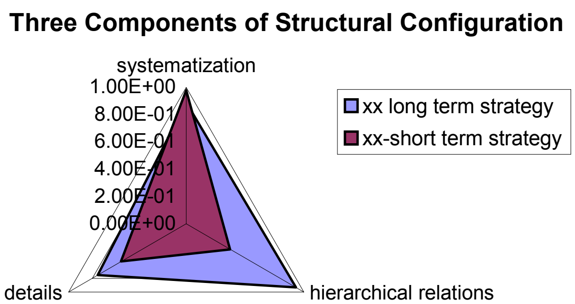


Figure 6: *Disassembly characteristics of components of configuration*

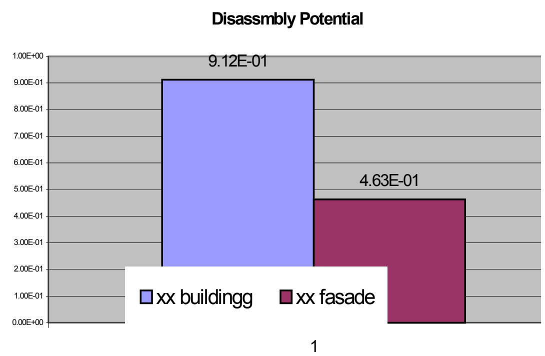


Figure 7: *Disassembly potential of XX structure*

Disassembly potential of XX façade system / Scenario 2

Type of connections
The disassembly potential calculated for Scenario 2, the short-term strategy (suitability of the structure for replaceability of façade panels), is much less than the disassembly potential of the first scenario (Figure 7). Detailing (Figures 6 and 7) is not suitable for exchangeability of façade panels, which accounts for this difference. To obtain more efficient disassembly potential, the following aspects should be improved: assembly direction, geometry of component edge, and type and morphology of connection (Figure 8).

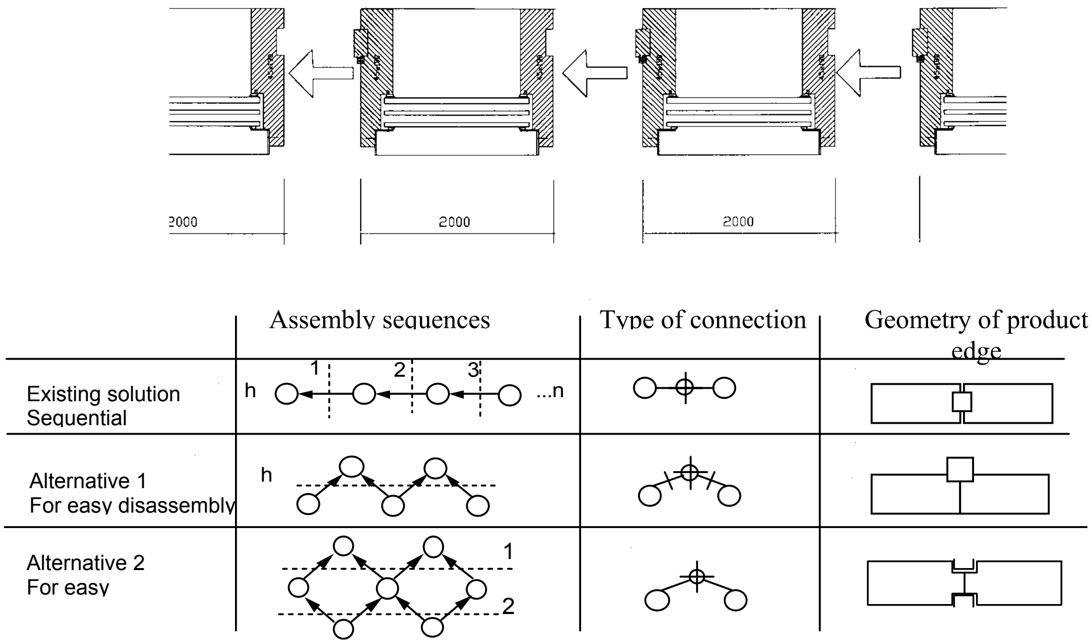


Figure 8: *XX façade system –type of connection and assembly sequences (existing situation on the top and alternatives)*

A linear sequence in assembly of the façade components, in combination with the connection type, results in demolition of at least sixteen façade components in the disassembly of a total structure. However, if one or two façade panels should be replaced, as suggested in the short-term scenario, the façade panels will have to be demolished (no reuse of façade frame can take place).

Hierarchy

Besides the above-mentioned aspects, which determine the type of physical relations within one configuration, other aspects of configuration should also be improved for greater disassembly potential of the second scenario. Hierarchical relational diagrams (Figure 9, right) and disassembly sequences (Figure 9, left) indicate closed and static configuration. This can be recognized through a high level of dependence between the façade and other components, and a lack of base element.

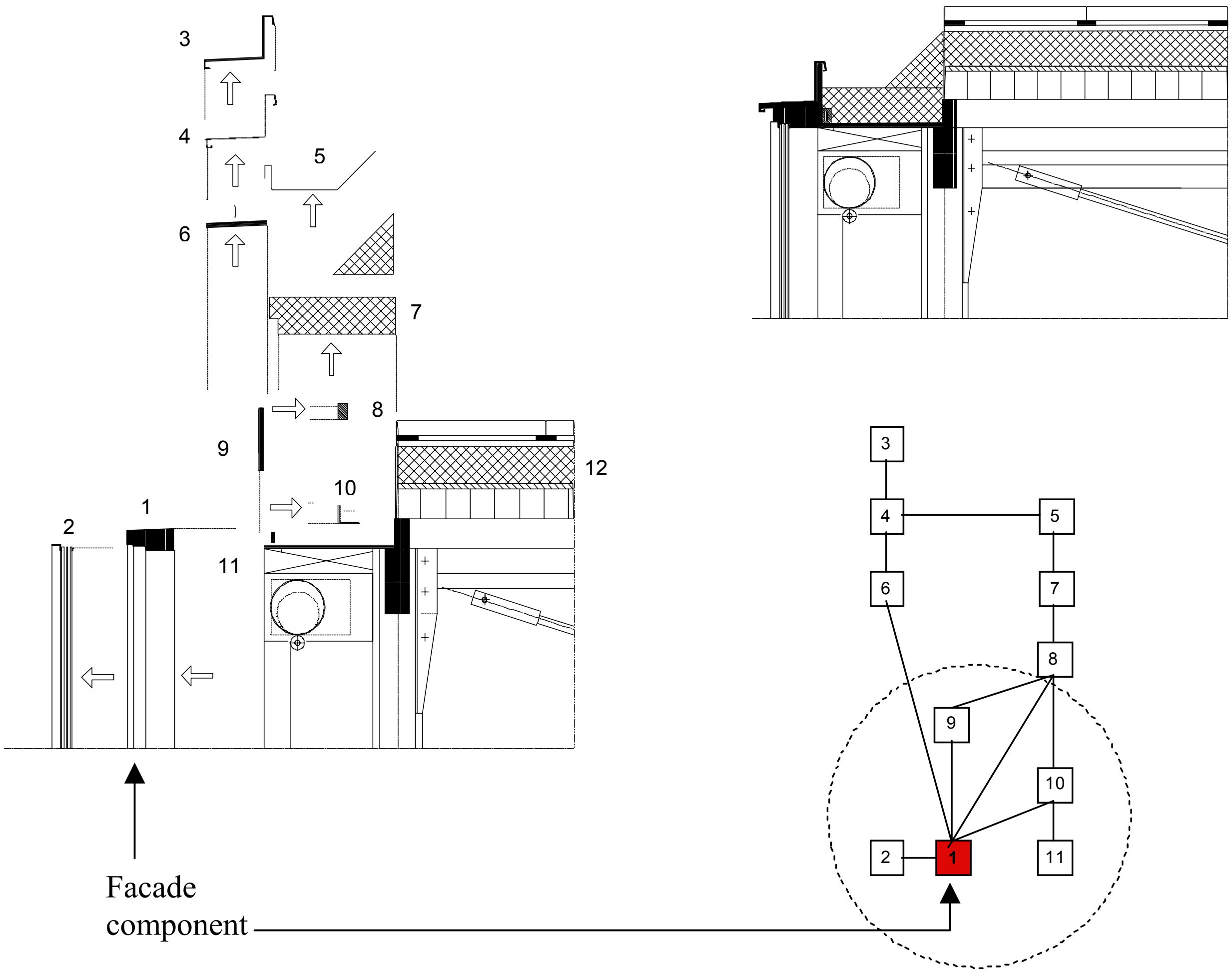


Figure 9: Disassembly sequence 9b Relational diagram

In order to achieve transformable configuration, the relational diagram should be transformed into an open one, with a clearly specified base element (Figure 10). Keeping in mind the above-mentioned disassembly potential of the façade panel, which is calculated as a function of type of connections, hierarchy, and systematization, D= 0.4, which is low. (Figures 6 and 7) This means that the configuration is mainly suitable for recycling, and not for reuse and reconfiguration, if the short-term scenario is applied.

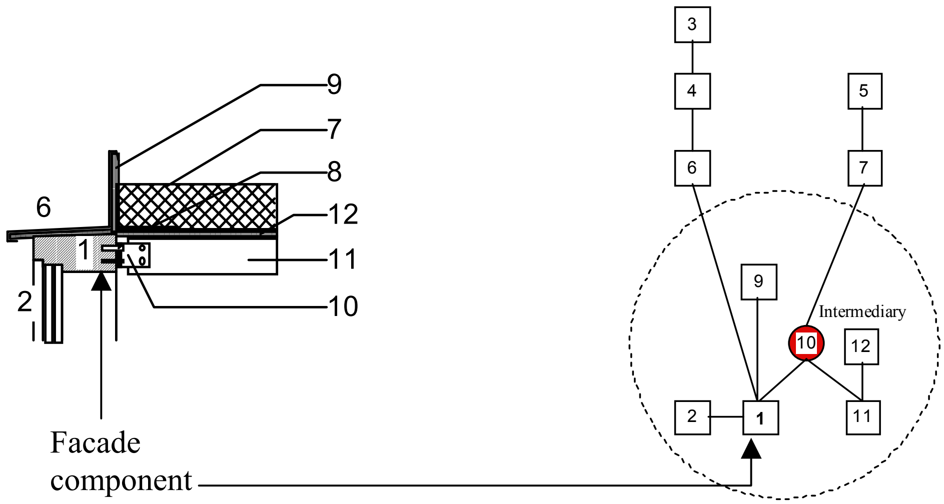


Figure 10: *Alternative solution for better disassembly potential*

CONCLUSION

Disassembly potential indicates the transformation capacity of structures and informs us as to whether specified material systematization, structuring, and detailing (of building or system configuration) are suitable for expected use scenarios. The knowledge model for assessment of the disassembly potential of structures can be used as an indicator of the environmental impact of the building, and as decision support for design for disassembly.

The model is generic in the sense that it can be used to assess the disassembly characteristics of any structure (building, system, or component structure). It gives an indication of the flexibility of a structure's configuration and its potential environmental impact. The model can be used for more accurate life-cycle assessment of structures, since it contains information about assembly methods and morphology of configurations.

REFERENCES

1 E.Durmisevic, J.Brouwer; Building with systems, Conference proceedings Beyond Sustainability, TU Eindhoven 2001

2 K.Penev (1996), Design of Disassembly systems, Theses Technical Universiteit Eindhoven, the Netherlands

3 Zadeh L.(1965), Fuzzy Sets. Information and Control 8 pp.338-353

4 Zadeh L.(1973) An Outline of a New Approach to the Analyses of Complex Systems and Decision Processes, IEEE Trans. System Man and Cybernetics, SMC, pp.29-44

OPTIMIZING DECONSTRUCTION OF LIGHTWOOD FRAMED CONSTRUCTION

Authors: Abdol R. Chini and Hai T. Nguyen (University of Florida, Gainesville, Florida, USA)

ABSTRACT

Deconstruction is the removal of a structure in reverse of the order in which it was constructed. It aims to preserve the invested embodied energy of materials, which is the total amount of energy required to transform raw material into a product and subsequently disposing it. Deconstruction also plays a vital role in waste management to "close the loop" of material cycle. The report looks at several case studies that have examined and explored the feasibility of deconstruction. These studies focus on the cost-effectiveness of deconstruction verses demolition on buildings of various sizes and shapes. Wastes from traditional demolition typically pass directly to salvage yards or landfills. With deconstruction, the materials intended for the landfill can be reused or recycled, thus extending the useful life of the material. The case studies establish the feasibility of deconstruction, in terms of costs, but briefly address replicating the recovery rate of material or the amount of materials diverted from landfill. The diversion rates range from 28% to 82%, with lumber and wood finishes being the bulk of that figure. A feasible rate of recovery can be determined from these case studies. Component quality and amount of hazardous material had the most effect on recovery rates. In order to optimize deconstruction of wood-frame construction, a set of recommendations have been suggested that allow future deconstruction projects to recover the maximum amount of material for reuse and recycling.

KEYWORDS: Demolition; Deconstruction; Landfill, Wood Framed Construction; Rate of Recovery; Hazardous Material; Material Reuse

INTRODUCTION

Deconstruction offers one solution to reduce the amount of construction waste and the demand on natural resources. Unlike demolition, the concept utilizes both reuse and recycle approaches so that materials can be diverted from landfills as waste. Deconstruction involves the removal of a structure by disassembling its components in the reverse order of its construction. In order words, the last thing to be installed is usually the first to be removed. The process can apply manual and mechanical means to deconstruct. The main idea is to salvage as much material as possible for reuse and/or recycle. In this case, materials that can be reused are preferable to materials that can only be recycled.

However, deconstruction is still in its infancy. The construction industry has not widely adopted this practice because of inadequate support, feasibility issues, not enough research, or the reluctance to change. First, not all building regulatory agencies support deconstruction nor have the necessary jurisdiction and guidance to facilitate the process. The problem is that there are very few standards on deconstruction, if any. So far, the rules for demolition apply to deconstruction. Second, there are a limited number of feasibility studies on deconstruction. The foremost concern is the costs associated with deconstruction. Many interested participants are concerned with whether deconstruction can be profitable or how to even generate revenue. Other feasibility issues include the costs of demolition compared to costs of deconstruction, and the market for deconstruction products. Third, research on deconstruction of different construction types and methods of deconstruction are limited. Most research focuses on light-framed construction, government sponsored projects and cost-effectiveness of deconstruction. Finally, the industry as a whole is reluctant to change. Demolition is a niche in itself. Many demolition contractors are comfortable with their schedule, pace, skill level, and responsibility. Changing their scope of work to or including deconstruction can affect a company dramatically. But more and more contractors are finding out that deconstruction can be beneficial to their company and community.

The benefits of deconstruction are significant, and when compared to demolition are advantageous. The main benefit comes from the fact that materials are being diverted from landfill and that natural resource is preserved. (Kibert and Chini, 2000) Other benefits include:

Social Benefits

- Provides a significant amount of employment opportunities
- Produces a flow of good quality, low-cost building materials into a community
- Generates other businesses to support deconstruction infrastructure

Economic Benefits

- Sale of salvaged materials will more than pay demolition costs
- Contains older buildings' craftsmanship quality materials
- Offer opportunity for existing demolition contractor to expand

Environmental Benefits

- Preserves space at landfills
- Decreasing site disturbance
- Saving energy by reusing materials

The objective of this report is to determine a feasible rate of recovery from deconstruction and make recommendations to optimize deconstruction of light-wood framed construction. The recommendations will result in a higher rate than the feasible rate, recovered from the structure (materials diverted from the landfill). The recovery rate of materials is the determining factor to whether deconstruction will accomplish optimum environmental benefits**.** This paper focuses on deconstruction efforts that involve building constructed predominantly of wood. The need to focus on wood construction is due to the fact that there are tens of thousands aging residential and other similar buildings in the United States alone that require demolition. A very high percentage of them were constructed using wood as structural and non-structural components. The data for this paper were taken from various pilot projects. These projects are case studies sponsored by various government agencies and programs.

CASE STUDIES

This paper reviewed three case studies to determine the feasible rate of recovery from deconstruction. The case studies represent different geographical regions throughout the United States. Group I consisted of buildings on the west coast of California, located within the former Fort Ord military base. Group II represented six buildings used in a study by the Powell Center for Construction and Environment (PCCE) at the University of Florida, Gainesville, Florida. Finally, Group III consisted of one building, which represented 25 similar buildings, within the Riverdale Village Community, in Baltimore, Maryland. The study at Riverdale was done by the National Association of Home Builders (NAHB) Research Center in 1997. (Lund and Yost, 1997) While the Group I study was a research effort spearheaded by the Fort Ord Reuse Authority (FORA) Pilot Deconstruction Project in 1997. (Cook, 1997) The PCCE conducted their study in Alachua County from August 1999 to May 2000. (Guy and McLendon, 2001)

Building's characteristics were important factors to analyze in order to identify and understand the conditions that affected recovery rate. The report examined the date of original construction, relative condition and quality of the components, building size, and number of story. Table 1 shows that most of the buildings were constructed prior to 1950, using high quality lumber with some composites, such as vinyl floor tile and plywood. The salvaged lumber held the most value and had the greatest potential for reuse. Each piece of recovered lumber went through some kind of visual grading by certified inspectors to determine their reuse potential. Group I graded 1009 total lumber pieces for reuse. While Group II graded 521 pieces once and re-graded 172 of the pieces after trimming off damaged ends. Group III recovered 603 lumber pieces, but did not attempt to grade them. The recovered lumber made up a substantial portion of the total recovered amount.

The relative condition of the buildings was good overall. Meaning, most components had little to no damage and/or could still perform the function they had intended for. Good condition related directly to the diversion rate. Buildings in good condition had a rate of 76 percent or better. While building (711), which was in poor condition yielded a little more than 28 percent. There were many factors contributing to the poor condition. They included water and termite damage, general molecular degradation, and human usage over time.

Table 1 - Summary of Case Studies

Bldg. No. Group	1807 I	2143 I	21 I	2252 I	7954 I	14 II	2812 II	2930 II	901 II	711 II	3650 II	4-plex
Function	office	MF	dental	shop	MF	res	res	res	res	res	res	MF
Built	1940	1940	1941	1941	1952	1900	1900	1915	1920s	1945	1950	1948
Level	1	2	1	1	1	2	1	1	1	2	1	2
Size (SF)	1125	4800	2220	2820	1313	2059	1238	2014	992	1436	1118	2000
Structure	wd.	wd.	wd.	wd.	mas.	wd.	wd.	wd.	wd.	wd.	wd.	mas.
Addition	1	1	0	2	0	1	2	3	3	1	1	0
Condition	good	good	good	good	good	good	poor	good	good	poor	fair	good
TTD (mo.)	2.5	4	2.5	2.3	0.4	2	2.3	2.8	1.1	0.8	1.5	0.5
RR (%)	82	66	65	82	n/a	53	n/a	77	n/a	28	n/a	76

Legend

mas: Masonry MF: Multi-Family Res: Residential,
RR: Recovery Rate wd: Wood TTD: Time to Deconstruct

Hazardous materials contributed to lower diversion rate. Asbestos containing material (ACM) and lead based paint (LBP) were the two culprits that plagued deconstruction. Most of the buildings had some form of ACM and/or LBP, which required professional abatement before deconstruction could began. Hazardous material abatement applied to demolition as well when jurisdiction called for. As a result, diversion rates were affected by discovery of ACM and/or LBP. Building 14 in Group II recovered only 53 percent because large amount of ACM were either removed or disposed of. In fact, all the buildings in Group II had asbestos and lead abatement.

The building size and number of story had no effect on the diversion rate. Table 1 reveals that two-story buildings (except for the 4-plex) actually had lower diversion rate, which ranged from 28% to 66%. The table also indicates the amount of time spent to remove each building. It is safe to say that more time does not equate to increased diversion rate. Both Building 21 and 1807 took 2.5 months to deconstruct, but the diversion rates were 65% and 82%, respectively.

Site conditions decreased productivity and diversion rate at some buildings. Adverse conditions included small size of the lot, vegetation, and proximity of other structures. Building 711 (28%) had an extremely confined lot. Access to the project was through an adjoining lot. Building 14 (53%) also had a constraining and congested lot, as well as Building 2143 (66%). It was found that workers had to spend time clearing areas for proper layout. In contrast, a large obstacle-free site improved maneuverability, thus increasing recovery rate. Larger site allowed workers to position processing areas closer to their immediate work area. This freed up time it would take to transport the removed components to a single or off-site processing area. The diversion rate from Building 2930 (77%) supported the assumption.

Deconstruction efforts had to address parameters set by regulatory agencies and the industry. These included permitting procedures, labor compensation and job safety, environmental assessment, hazardous material abatement, and time frame. Some of the parameters were already mentioned above, while the rest were addressed in the same manner as those that governed demolition practices. For instance, all projects had to perform hazardous material abatement before deconstruction permits were issued. And that job safety must abide by OSHA standards.

DISCUSSION

All of the contributing factors mentioned above represent variables that influence the results of deconstruction. No one factor will guarantee higher or lower diversion rate. It is the combination of factors that can establish an ideal condition for an optimum rate of recovery or diversion. However, the chances for an ideal condition to occur in every deconstruction project are unrealistic. The set of variables or parameters is unique for each project, unless it involves deconstructing the same group of structures by different parties. Even so, the results can still vary. The diversion rate from the case studies ranged from 28 percent to 82 percent. That is extremely inconsistent and unreliable, even though these buildings were constructed with relatively similar materials. The inconsistencies can be attributed to the different organizations and contractors who participated in the three case studies. Their varying methods of deconstruction contributed to the varying rate of recovery.

The structural components were made of light wood frame (from 2x4, 2x8, 4x6, etc.) and shared similar dimensioned lumber pieces. Finish materials, such as tongue & groove floor and siding, were similar across the board. In addition, the buildings were mostly constructed prior to 1950 and after 1900, using similar construction process. The preliminary diversion rate should show similar results or range should be much closer. That is where the variables come in. They represent the constraints that limit the diversion rate, as well as the facilitators that extend it.

There are some variables that are actually constants for deconstruction process. They include permit attainment, environmental assessment, hazardous material abatement, construction issues and public involvement. Addressing these standard issues requires time, money and experience. Since, deconstruction involves manual removal it takes considerably more time than demolition. The labor costs are usually more than demolition as well. It is feasible to spend more time on the initial stage (pre-deconstruction) than the removal itself. For instance, the time spent to assess and remove asbestos containing materials will negate unforeseen problems so that the recovery process can run more smoothly.

The deconstruction process will run into further obstacles even after addressing all required items. These are project specific constraints, which some are outside the control of participating parties, that will limit recovery rate. They include:

- **Labor constraints** - insufficient number of workers will reduce productivity or the amount of material recovered in a given time. High labor cost is one reason for lower number of workers. Lack of experience will also lower productivity, but will improve over time. Lack of experience can also increase damage while removing components.

- **Site constraints** - small site hinders maneuverability, thus lowering productivity, limit amount of on site storage and processing (sorting and de-nailing) spaces. Proximity of other structures will also restrict workspace and maneuverability. This condition is expected for urban sites.

- **Project funds** - small deconstruction budget, unless publicly funded, will limit number of workers, equipment and tools. The budget can also trim profit margin, since most salvaged materials are not resold right away. Most deconstruction projects will lose money before gaining back from resale.

- **Hazardous material constraints** - any hazardous material must be removed, leaving less material to be recovered. Some hazardous materials are disposed of when the cost of abatement does not justify cleaning or that the components that contained it does not have a reuse potential.

- **Weather constraints** - adverse weather conditions (rain or heat) can lower productivity and also damage exposed materials.

The building itself can impose certain constraints on deconstruction, which limits the rate of recovery. Material quality is the primary constraint. Relatively good quality materials will definitely increase recovery rate. In contrast, poor quality or degraded materials will have the opposite effect. Another major building constraint is the degree of connections, which is the extent of permanently fixing a component to another. The difficulty of separating can either limit removal or damage the material during removal, thus lowering the recovery rate.

All the constraints or a combination of them can drastically reduce the diversion rate. Table 2 shows the feasible rate of recovery with their set of constraints. The constraints or limiting factors are separated into two types. Standard constraints are those imposed on deconstruction and demolition, and project specific constraints occur at each particular project. Some constraints are more critical than others, like damage of materials during removal, and poor material quality.

Table 2 Feasible Rate of Recovery per Constraints

Rate	Standard Constraints	Project Specific Constraints
82%	Public involvement Regulatory enforcement	Number of workers
76%	Regulatory enforcement Hazardous material abatement	Multiple layer of finishes Number of workers Weather condition
55%	Regulatory enforcement Hazardous material abatement	Site restriction High hazardous material content Material damage during removal Crew experience
28%	Regulatory enforcement Hazardous material abatement	Poor material quality Site restriction Contained hazardous material Hand demolition

The case studies involved buildings that were built prior to 1950s. These buildings had some degree of asbestos and lead in or on finishes. There will definitely be changes done to the structure over time, which means multiple layers of finishes or haphazard repairs. Future deconstruction project will likely involve small deconstruction contractors with few crews. However, the market for salvaged lumber and wood novelty is expanding so that demands for recovered product will offset deconstruction cost. The rate of recovery and subsequently the rate of diverting materials from landfills, is feasible at 75% of total materials available in a building; given that the building is constructed of light-wood framing and the quality of materials is relatively good.

RECOMMENDATIONS FOR OPTIMUM DECONSTRUCTION

The case studies addressed many issues that contributed to the effectiveness of deconstruction. An ideal deconstruction project will divert a high percentage of materials from disposal. The recovered materials have to be reused or recycled. The cost-effectiveness of deconstruction versus demolition depends on the value of recovered or salvaged materials. More diverted materials mean more value and income to offset costs associated with deconstruction. However, the value of recovered materials can only be determined be the market. Nevertheless, the focus of this paper is to assess a feasible diversion rate for future projects and then make suggestions that could improve that rate.

The following recommendations are based on the case studies reviewed on deconstruction. They are separated into three sections. The first section focuses on recommendations for the industry and regulatory agencies to facilitate deconstruction process. The second section focuses on recommendations for selecting buildings for deconstruction and the third sections provides recommendations for maximizing recovery rate during operation.

For the industry and regulatory agencies

- Promote the use of salvaged materials in the design and construction of new buildings - Industry and regulatory agencies can create a market (demand) for salvaged building materials in the local community. This would in turn help keep salvaged material value up and offset deconstruction costs. In addition, it helps create more jobs and entrepreneurial opportunities. Design new buildings that specify use of a percentage of salvaged or recycled materials. Finally, construction process can utilize salvaged lumber for support structures and formworks.

- Cooperation between land use jurisdictions and regulatory agencies to ensure efficient building removal process - Actively involving local enforcement agencies will provide guidance before the removal begins, discuss respective needs, and prevent regulatory gaps. (Cook 1997)

- Use demolition standards for handling lead-based paint (LBP) and asbestos containing material (ACM) - Deconstruction is a form of building removal. Many regulatory agencies require hazardous material assessment and abatement for any building that require removal. Demolition standards could address many common issues concerning proper procedures and practices, such as the safest way to manually disassemble components that contain low levels of hazardous material (beneath the threshold level that classifies the material as hazardous), or how much air exchange per hour is required.

- Enforcement of hazardous materials regulations - Asbestos surveying and handling, as well as lead surveying and handling are required for both demolition and deconstruction. This enforcement creates an equal starting point for both forms of building removal.

- Deconstruction permit - Typical demolition permit contains a waiting period before new construction. Deconstruction permit would extend that period to accommodate manual labor. Permit fees should be based on the projected volume of wastes. "Fees can then be rebated based upon proof of diversion of the materials to an accepted recycling or reuse end use." (Guy and McLendon, 2001) The permit should be a one-stop for deconstruction, which can save contractors time and the land use jurisdictions indirect costs. (Cook 1997)

- Deconstruction project be handled by professional - Licensed contractors who specialize in demolition are encouraged to incorporate deconstruction into their services. The combined experiences of their crew(s) will provide necessary skills to disassemble buildings efficiently and cost effectively. Training programs will aid in effective recovering of materials.

- Contractors should provide proper insurance - Any contractors licensed for demolition (deconstruction is considered demolition for permit purposes) should provide general liability insurance, workers compensation insurance, bonds and other forms of surety. Contractors would also file Liens and Liens releases.

For building selection

- Location - The site's location must be considered to assess proximity to public view. Market demand is the biggest motivator for deconstruction because it provides opportunities for contractors to participate. Marketability also increases the salvage value of materials in order to offset the costs of deconstruction and make it profitable. If the site is near a main vehicular route or a dense center, the chances for public interest are greater than a rural site. This does not mean that deconstruction of a building on a rural site will divert less materials than an urban site. However, the redistribution of salvaged materials increases, as well as the resale rate.

- Site conditions - The area around the building can facilitate the pace of operation. Like construction projects, deconstruction operation requires careful planning of the area for logistical reasons. A typical operation requires space for processing of materials, which include a de-nailing station and disassembly area for large sections of the building. Other required spaces include storage areas for processed materials and container areas for recyclable materials. An ideal site consists of the following:

    1. Few trees with moderate brushes
    2. Slight to no slope
    3. Adjacent structure, if any, not closer than 15 feet on both sides
    4. A minimum of 30 feet clearance on any two adjacent sides

  If a site does not meet all criteria, adequate measure must be taken to provide necessary spaces. Meaning, additional time have to be taken into account for site preparation. In contrast, a confined site will hinder the pace of operation and reduce the waiting period before new construction. Contractors have to provide off site warehouse if there are no room on site for storage. In addition, time is also wasted for transporting materials off site.

- Construction type - The case studies in this paper indicated that wood-frame construction is an ideal type to deconstruct. Wood is still a commodity for most construction types. Both salvaged dimensional lumber and wood finishes are attractive to post market consumers. The market demand will motivate deconstruction to supply salvaged wood products. Wood framing had the highest recovery rate than most of the other material in the buildings. Materials recovered for reuse take less energy to process than recycled materials. In addition, individual wood components are lighter to manually handle and easier to separate.

- Building's integrity - The condition of the building's structure is a strong indication to the amount of materials that can be recovered, but not necessarily the rate of diversion. If the building is relatively in good condition, the crew will feel safer to remove components faster without worrying about structural failures. Good condition also includes little to no physical defects on structural components. Careful investigation of the structure is required to assess the condition before deciding whether to deconstruct or demolish. The investigation might involve studying the latest available construction documents, hiring a building inspector or a licensed structural engineer, hazardous material specialist, and any other demolition experts. However, when the conditions are poor or that the structure is run down, demolition might be the best solution to building removal. Demolition can be cost effective if heavy equipment is used in to clean up after selective deconstruction.

- Components' condition - This recommendation for selecting building is at a smaller scale than investigating the building's integrity. A contractor can utilize the same investigative methods as mentioned above. Investigating components' condition can occur simultaneously with building inventory assessment. The ideal condition of individual components include little to no defects or damages that can be remedied with little efforts. In addition, components such as wood framing must not have any signs of termite and water damage. Coring samples of walls, floors and roofs can determine the feasibility of deconstruction. Similar to the above recommendations, when the conditions are poor demolition might be the best solution to building removal.

- Scale of project - An important issue for contractor to consider before signing a contract is scale of the project. Meaning, the project must involve more than one building of similar construction type (for example, older residential development). To promote and make deconstruction more feasible, a contractor must select a project that includes removing more than one building. The more buildings deconstructed at one time equate to more potential materials for reuse in larger new projects. In addition, increased supply of similar components with a market can reduce cost of salvaged materials. Deconstruction project of larger scope like the Fort Ord Pilot Deconstruction Project offers greater opportunity for further research and exploration in deconstruction and creates more jobs for the community.

- Age of building - Research indicates that building constructed prior to 1960s has higher potential for material recovery. It is possible that the building(s) is relatively in good condition. The materials used prior to 1960s for construction are less likely to be composite. The quality of wood framing (cedar compared to pine) is relatively better.

For Operation

- Invasive inspection for hazardous materials - Provide wall and floor corings as part of investigating the content of materials and building material inventory. Discovery of hidden asbestos layer after work has begun can hinder progress dramatically.

- Building inventory assessment - This process occurs after a building have been selected for deconstruction and/or a contract was signed. Conducting a building inventory assessment allows the contractor to account for existing materials that can be salvaged. It also becomes an investigative tool for determining the condition of components and subsequently the structural integrity of the building. The value of material can be determined at this state. The assessment finds, quantifies and qualifies the materials in a structure before deconstruction begins. (Cook 1997) In addition, future research on deconstruction could use the inventory to compare the diversion rate and analyze which materials were more feasible to salvage.

- Processing and flow of materials - Recovered materials should be immediately sorted and segregated right after cleaning or de-nailing. Processing materials requires the most time in deconstruction operation. Controlling the flow of materials on the job site is critical to productivity. Moving de-nailing station(s) near the immediate area of work can reduce travel time. Locating containers and dumpster in a strategic areas, will not only create a safe job site, but also minimize walking time. The efficient handling of material will free up workers to disassemble more material in a given day or can increase the amount of reusable materials by carefully removing them.

- Disassemble sections as much as possible - The best way to disassemble components from greater height like roof is to transfer large sections to the ground. This method will require light crane or a pick-up truck. Disassembly labor is more efficient on the ground than at heights. It is also safer since workers will be pulling and knocking components free from each other on a flat surface. Using a light mobile crane to lower whole roof section to the ground may reduce labor costs as well as worker compensation insurance.

- Combine manual and mechanical deconstruction - Not all buildings are constructed entirely of wood frames. A lot of buildings have masonry components that require more than manual labor to remove. A combination of manual and mechanical approach is ideal for larger deconstruction projects, especially buildings containing brick veneer, concrete masonry units, and concrete foundation. Mechanical deconstruction can save time and money when there are not enough workers.

REFERENCES

Cook, Stan. "Fort Ord Reuse Authority Pilot Deconstruction Project," *Fort Ord Reuse Authority*. December, 1997.

Guy, Bradley and Mclendon, Sean. "Building Deconstruction: Reuse and Recycling of Building Materials." *Center for Construction and Environment*., 2001.

Kibert, Charles J. and Chini, Abdol R. "Deconstruction as an Essential Component of Sustainable Construction," *Overview of Deconstruction in Selected Countries*. CIB Publication 252, August, 2000.

Lund, Eric. and Yost, Peter. "Deconstruction-Building Disassembly and Material Salvage: The Riverdale Case Study," *NAHB Research Center, Inc.*, Upper Marlboro, Maryland, June, 1997.

PROGRAMMATIC FLUX, CAN YOU COPE?
A FIRST INTRODUCTION TO THE 'TIMESHIFTING-MODEL'

Authors: Klaas Nienhuis (Delft University of Technology, The Netherlands); Niels Woesthuis (Delft University of Technology, The Netherlands); Ir. Jean W. Frantzen (co-writer) (Delft University of Technology, The Netherlands)

ABSTRACT

Contemporary architecture is not designed for a high programmatic flux (frequent changes of use). Therefore, the service life of these buildings expires long before their technical lifespan does. The limited possibilities to disassemble buildings and their components result in large quantities of construction and demolition waste (CDW) and needless building activity. Prolongation of lifespan through transformation capacity is an efficient method to reduce the environmental impact of construction.

This case study focuses on the development of criteria that can be used for an architectural solution to increase the transformation capacity. Two architectural designs will be used to test these criteria on feasibility and usability.

KEYWORDS: Programmatic Flux; Disassembly; Lifespan; Transformation Capacity; Architecture

INTRODUCTION

Redouble the world's population, quintuple the world's level of prosperity, and still half of the world's environmental pressure. Is this a realistic scenario? Prof. Ir. Jon Kristinsson thinks it is a huge, but feasible, task that he refers to as "The New Necessity" (or in Dutch, "de Nieuwe Noodzakelijkheid")[1]. To reach this goal, however, in most cases a whole new approach of the design methodology is needed.

There are a lot of different ways to come closer to a solution. A few examples: reduction of used materials, the use of renewable raw materials, cleaner manufacturing processes, and the reuse of building materials. None of the above, however, can individually reach the described scenario. Factor 20 can only be seen as a realistic goal when a design makes use of a combination of interventions that are environmentally beneficial.

Factor 20

In the 70's a vision was developed by D. Commoner [2] that shows a connection between the environmental pressure (D), size of the population (B), global level of prosperity (W) and the environmental user impact (M). In the 90's, Ehrlich & Ehrlich en Speth have translated this relationship into a formula:

$$D = B \times W \times M$$

If, over the next 50 years, a target is to reduce the environmental pressure by 50%, the formula becomes:

$$0{,}5 = B \times W \times M$$

There are reasons to believe that the global population will double in the next 50 years, and specialists find it plausible to assume that the level of prosperity can even quintuple in the same period. With these assumptions the next formula emerges:

$$0{,}5 = 2 \times 5 \times M$$

This means that, when we want to reach the described target, the environmental user impact should be reduced by a factor 20!

$$0{,}5 = 2 \times 5 \times 1/20$$

A building's lifespan plays an important role in this discussion. Studies show that a redoubling of the lifespan results in an efficiency improvement of a factor 2. If compared to a 20 percent material reduction, this "only" leads to a factor 1.25. This implies major opportunities.

But lifespan does not only take part in future possibilities. In present society, it has a crucial influence on whether or not a project has a chance to succeed; for it is necessary to make frequent changes in the programmatic use of buildings. Unfortunately, a lot of contemporary architecture is not designed for such a high programmatic flux. Therefore, the service life of these buildings expires long before their technical lifespan does. The limited possibilities to disassemble buildings and their components result in large quantities of construction and demolition waste (CDW) and needless building activity.

For this reason, prolongation of lifespan through transformation capacity basically seems an efficient method to reduce the environmental impact of construction. But at the same time, this raises a number of questions. A building does not consist of just one part, but is an accumulation of individual products. Which of these products, then, should be prolonged, and for how long? At what point has the product obtained an optimal adaptability? Maybe it is not always wise to strive for a prolongation of lifespan. Is it, in some cases, not plausible to shorten, rather than prolong, the lifespan of the product, so that less environmentally-hazardous materials can fabricate it? In other words, the maximum lifespan of a certain product should not always be considered to be the optimal scenario, depending on the different goals of the design.

To form an opinion about the issue of lifespan, we should first take a look at the contents of the term "lifespan." It can be split up in two different aspects. First there is the technical lifespan that represents the period in which the product can physically be preserved. The economical lifespan is the time span in which there is a certain need for the product. Looking for an efficient way to reduce the environmental impact, it is important to realize that not only are the absolute figures of both lifespans significant, but also that the relationship between them is just as important. Any discrepancy between both aspects can produce valuable information about the product's (future) lifecycle. Subsequently, this information can be used to produce the product as durable or as sustainable as possible. Whether the product contains an urban plan or the production of a specific part of construction is not important. In both cases, the quotient of TL and EL produces information about the products need of adaptability and thus about the possibilities and limitations.

In this case study, we try to reduce the environmental impact not just by prolongation of lifespan, but also by shifting between two types of lifespan. To be able to do this, it is primarily important that from every product, clear targets have been made. If this has been done, a relatively significant reduction of environmental impact can be accomplished at any constructional scale just by balancing the time factor. We call this "Timeshifting."

The goal of the timeshifting model is to develop a set of criteria that help the user understand what the consequences and possibilities are, from choices based on lifespan and project targets.

The model can be used as a tool concerning various aspects, such as:

-managing lifespan related design issues.
-testing the design targets.
-supporting the process of designing with lifespans
-interacting and communicating with external specialist offices.

A central part of the timeshifting model consists of the formula:

TL / EL = TQ (Technical Lifespan / Economical Lifespan = Timeshifting Quotient)

In this formula, TQ represents the relation between TL and EL. By doing so, statements can be made of the different subjects that are relevant to the targets of the project. These subjects can diverge from the amount of environmental impact of the project, investment costs, and even the ability to reach a certain architectural quality. There is a fourth parameter, however, that has been mentioned before and plays an essential role within the model: the product. The timeshifting quotient of each product within the design can vary and depends on the chosen targets of the design. Moreover, these targets determine which products are being included in the model.

The outcome of every described parameter depends on different factors and can be interpreted in many different ways. Our interpretations are therefore essential for the outcome of the formula, and will be individually explained before exposing the actual model. The model itself will roughly be explained by text first, but clarified later with a visual example.

PRODUCT

A project is split up into several parts with comparable qualities. A project consists of a number of elements, which differ greatly. These elements are clearly separable and are called products.
These products vary from urban planning, infrastructure, and nature to material, ease of use, and fixing technique. Products do not need to be physical objects. A product is a focus point in a project, which has specific demands. When, for instance, the product infrastructure has been identified in a project, there are specific demands concerning economic and technical lifespan. These are described precisely. When reading the targets for a project, the products should be easily identified. There are also possibilities, later in the process of time shifting, to expand or refine a product.

ECONOMIC LIFESPAN (EL)

The economic lifespan of a certain product is the time span in which someone needs this product.

Who determines the EL?
Current users, or a client in the future (groups or individuals).

How is the EL determined?
Using the targets or through assumptions.

Of which is the EL determined?
Of a general need, or of a need for a specific product.

On which product does the EL focus?
The product has to be defined clearly to avoid confusion.

TECHNICAL LIFESPAN (TL)

The technical lifespan of a certain product is the time span in which this product complies with the demands concerning the functioning of this product.

Who determines the TL?
It is an objective comparison between the state of the product and a list of demands. Everybody can do this.

Of which is the TL determined?
The TL concerns precisely described products.

What are the demands?
The client determines these demands. He lists with which demands the product has to comply. These demands can cover several aspects of the product.

To avoid confusion, it is good to remember that EL concerns needs, and TL concerns functioning. An EL ends when the need for the product has diminished. This happens when targets are not met anymore with this product. It is good to know that it is very subjective whether or not targets are being met. The TL ends when the product no longer functions as it should. Physical products lose functionality by wear and tear, climate influences, or disasters. Non-physical products are not influenced by these factors, and thus have no finite technical lifespan. We believe that abstract products have an infinite TL.

Lifespan Case Study
The product is a printer. The target is: produce sharp b/w prints. At the moment of purchase of the printer, the user expects to fulfill his needs with this product for three years (EL=3). The estimated TL is five years.

1: After two years, the printer company offers a better printer. This printer makes color prints. This printer charms the user so much that he adjusts his target. His new target is to be able to make sharp color prints. The EL of his current printer has ended after two years.

2: After only one year, the printer breaks down (TL=1). The user still has a demand for his printer, and this demand has not been damaged by the fact that the printer has broken down. The user will repair his machine, buy this product again, buy another printer, or adjust his demands. This last option means also that the EL ends.

The EL differs depending on how precisely the product has been defined. When the product has been defined as "Canon bjc-4300 serial 32358620g9," the EL ends with the TL. When the product is "any b/w printer," the demand reaches further than this one printer, and can be met with several types of printers.

It appears to be very important to be aware of how the products and targets are defined. Do not confuse the end of an EL because of an altered target, and the end of an EL because of the end of a TL. The latter is actually never the case. The breaking down of your printer may be a strong stimulus to end the demand for this product, since it has broken down. But there is always a step between the alteration and the target. For example, the printer has broken down, let's consider if our targets are up-to-date and, if not, alter them. The EL has ended shortly after the TL.

QUOTIENT

The described parameters are combined in the model by the following formula:

TL / EL = TQ (Technical Lifespan / Economical Lifespan = Timeshifting Quotient)

This formula can be used for every product in the design. The outcome of the quotient can vary between zero and infinity. Within this area, there are three interesting situations that can be described as key points for the adaptability of the product:

1 TQ<1
2 TQ=1
3 TQ>1

First, the basic principles of these three situations will be explained. After that, a closer look will be taken at two of the three situations to cover the more complex and specific aspects.

TQ<1
This formula explains that the TL is shorter than the EL. This results in a need to reproduce the same product several times to keep meeting the demands. This situation can most often be recognized in disposable products, such as toothbrushes or light bulbs.

Figure 1 shows an example of a timetable from a product with a TQ = 0,2. This means that the product should be reproduced five times during the EL. Every TL begins with a production phase and ends with a demolition phase. The investment curve shows that these are the primary moments that require relatively large investments. These investments can be translated into costs, effort, environmental impact, or any other aspect that has a relation with the lifespan factor.

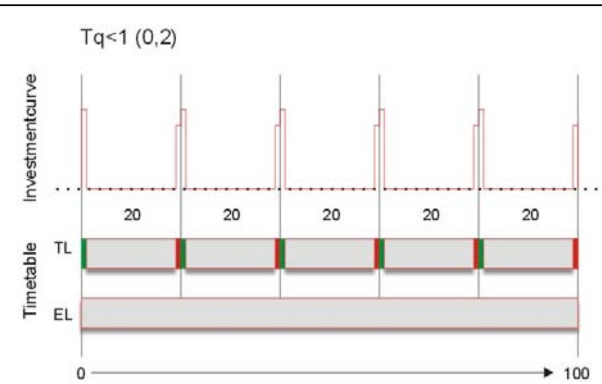


Figure 1 Timetable and investment curve.

TQ=1

In the second basic situation, the TL equals the EL. There is no need for large adjustments during the lifecycle of the product. This situation is typical of highly specialized, single-purpose products. This scenario is only realistic when both the TL and the EL are easy to forecast. An extreme example is a match.

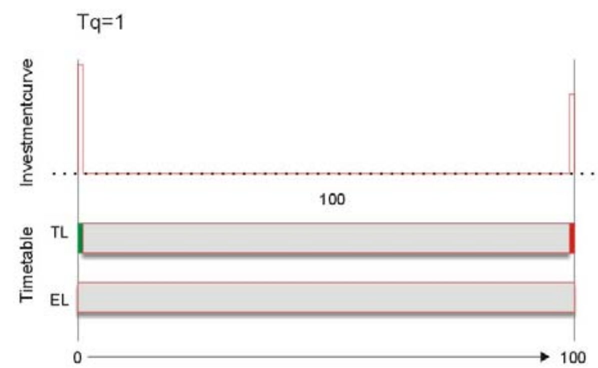


Figure 2 Timetable and investment curve.

Figure 2 shows an example of a timetable from a product with a TQ = 1. There are only two primary moments of investment: production and demolition of the product.

TQ>1

When the TQ>1, the TL is longer than the EL. This demands a certain adaptability from the product, for it should be able to transform to meet the changing demands.

In figure 3 the moments of necessary adaptation are visible as interruptions in the EL. The example has a TQ=4. This means that the product needs to adapt at three moments within its EL. These moments can, just as in the production and demolition phases, also be seen as primary moments of investment.

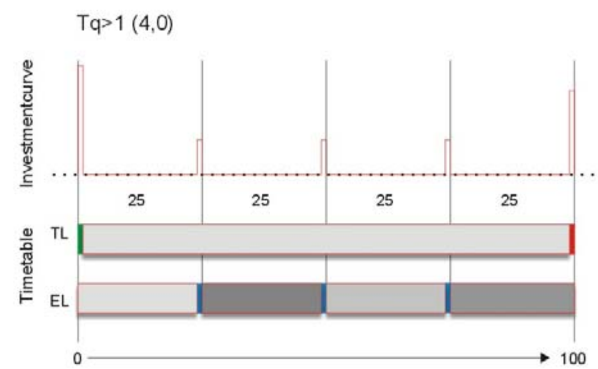


Figure 3 Timetable and investment curve.

The Cascade is a good example of such an approach within the practice of environmental technical construction. Every change of demands results in a new product by descending the Cascade. This repeats itself until the product can be destroyed.

One could conclude that products can be classified into three basic categories. TQ=1 represents specific products: TQ<1 describes disposable products, and TQ>1 describes products that are basically adaptable.

The situations described above form a base for a theoretical model. Using this model, statements can be made using the timeshifting quotient. However, in practice, several hard to forecast factors influence the eventual course of the scheme, especially when the TQ of a product does not equal one. These situations are easily visualized by elaborating the scheme. Two examples clarify this.

TQ<1

As an example we use a car. This is no typical disposable object, but depending on the targets, it can be used as such. So, again, it is clear that the correct TQ of a product depends on the targets issued to it by the user. This appears to be essential to the model.

It has already been mentioned that a product with a TQ<1 has to be produced several times to keep satisfying the demands. Practically speaking, no product has a TQ of a whole number (1,2,5,20) or its inverse, which would imply an EL that is an exact multiple of the TL or the other way around. There will always be a period in the end where the question arises of whether it is wise to produce the product again. If the choice is made to produce, the TL will outlive the EL, which would mean a product not satisfying a demand. We also could call this waste. If the choice is made not to produce, the demands are not satisfied at all. This is also not good. In the next scheme, a red X visualizes this period. The closer the TQ factor is to one or another inverted whole number, the bigger the influence of the choice described above.

An important characteristic of products with a low TQ is multiple-production phases. These phases are critical within the process. This is also the case with cars. There are two factors playing an important role at that moment. First, it is a phase where, generally speaking, extra investments are to be expected. Second, the user will have to choose in this phase. Even if the EL of this product has not ended, both previously described factors can add to a certain change of demands. Putting it differently, every time a user has to buy a new car because the TL of his original car has ended, the user might reconsider his demands and alter them. A smaller TQ might add to a less-stable economic lifespan.

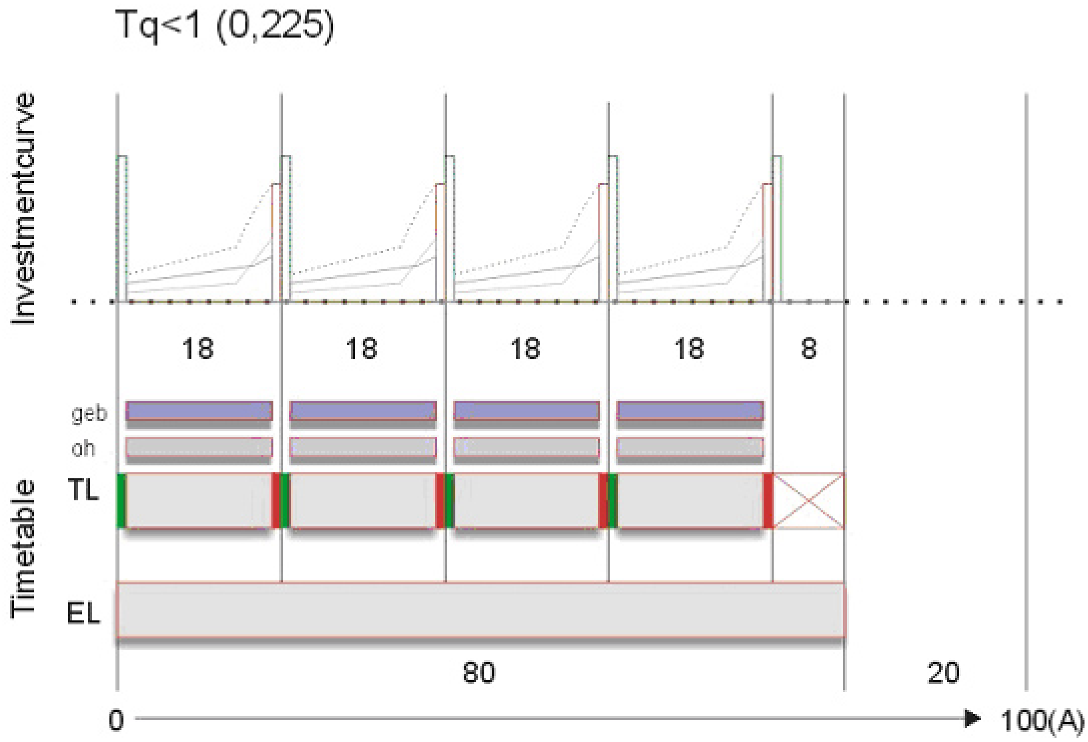


Figure 4 Timetable and investment curve.

The example shows the possibilities with more detailed information, by adding more timelines depending on TL or EL. In our example, we show maintenance (oh) and use (geb).

TQ>1
As an example of an adjustable product, we take a computer. At the time of purchase, we expect a TL of nine years. The EL is estimated at the time of purchase at 1.8 years. When planning in advance to forecast costs, our product has to be adjusted four times to be able to meet the demands. The next scheme shows an example where, in practice, the EL appears to be shorter (1.22 years). This results in more adjustments than planned. It is not always sure if the product can handle these adjustments. If not, this inability to change causes a period of waste. Nobody needs the computer. The scheme marks this period with a red X, which is a period of 2.9 years.

One of the possible reasons of this inability to be adjusted lies in the fact that the product has a narrow bandwidth. The bandwidth shows how many changing demands the product can take in, adjusting to these demands. The computer apparently reached its bandwidth after four adjustments.

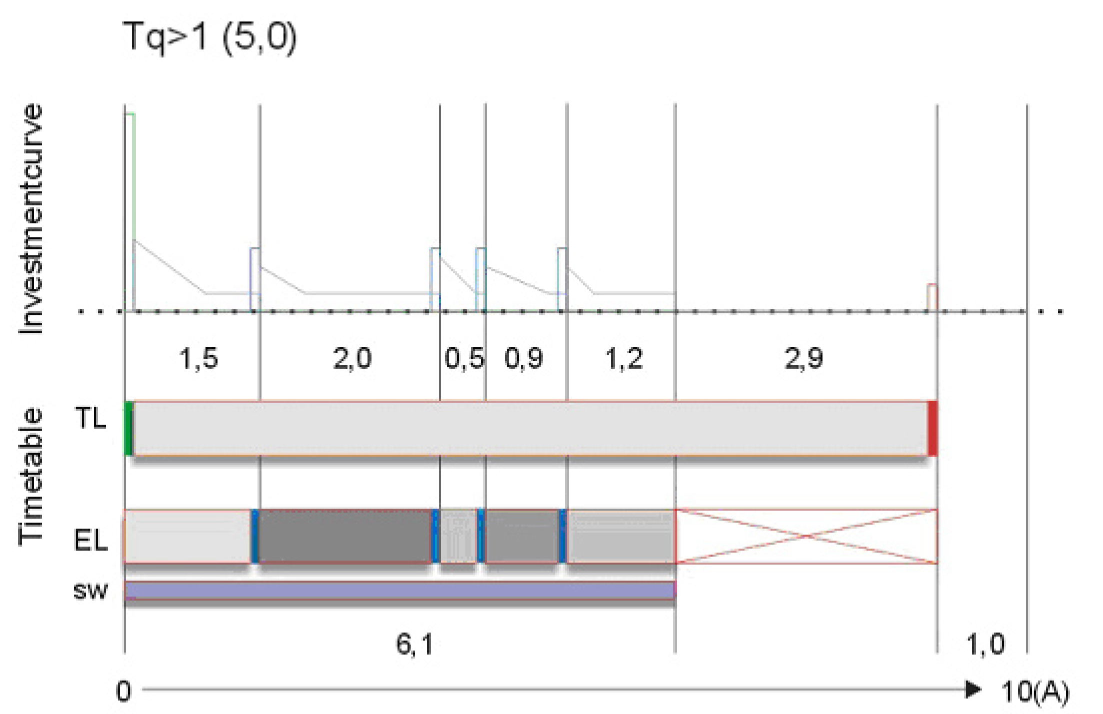


Figure 5 Timetable and investment curve.

The investment curve in this case shows the financial costs the user is confronted with during the life of his product. The extra timeline (sw) shows the costs of extra-purchased software. The curve shows that after every adjustment of the computer, costs rise temporarily. This is caused by the upgrading of the software to the new capacities of the computer.

According to the production phases of the car scheme, the moments of adjustment are critical points. Depending on the relation between adjustment investment and production investment, the user can decide to see the product as waste and purchase a new one. When these investments do not differ greatly, the product will rarely be adjusted.

HOW DOES IT WORK?

The timeshifting model has been developed in such a way that it can play a supporting role in either the initiation-phase of a project or during the design-phase. The model has primarily been designed as a tool for the initiating parties such as clients, architects and project developers. These parties, through the notion of lifespan, gain insight into consequences and possibilities in choosing products and targets.

The first step is to make a clear formulation of the problem for the project. From here phrasing and targets can be distilled. These targets stand at the base of this model and work in two directions. First, the model can be used more precisely if the targets are formulated sharply. Second, the model can help to improve the targets.

Every product that is to be researched needs targets. Therefore, it is important that product differentiation takes places at an early stage in the project and model. Of which products does the project consist? Another thing of equal importance: which product depends on which product? Only after knowing this can a product order be established. This product order is important because choices of one product influence the possible choices of the next dependent product. Choices for one product rule possibilities out for the next product. The model has to start with the least dependent product, also called the initiation product.

The model will be worked through in a fixed way. This has the advantage that not all targets from every product will have to be known at the beginning, which is also very unlikely. Targets can be written during the process of using the model, and can be adjusted using earlier choices.

The next step consists of translating the targets into a few product-specific focus points, to point out where priorities lie. Only when this has been done do we arrive at the central part of the model. All parts previously described come together at this stage. This stage must be repeated for every product, starting with the initiation product. The aim is to determine, per product, a so-called "voxel." A voxel is, essentially, a timeshifting quotient with an absolute value. Though the TQ offers us a lot of information about adjustability and lifecycle of the product, an absolute value is needed to comment on concrete solutions for products.

For each target of a product, the user looks at the EL, TL, TQ<1, TQ=1 and TQ>1. The goal is to generate theses on the influence of these aspects on the focus points. These theses contain mostly preferences or constraints for voxels, which are to be chosen, and which can then be visualized in graphs. After this has been done for every target, these graphs can be overlaid. This visualizes overlaps, and from these overlaps, voxels meeting all targets for this product can be chosen. Every voxel gives its own interpretation of the targets. Possibilities and restrictions are pointed out to the user. If too many possible voxels appear in the graphs, action should be taken to sharpen the targets.

Because the next product depends more or less on the previous one, the choice of a certain voxel projects an area of probability onto the next product. When drawing out this area, special knowledge is required about the product upon which this area of probability is projected. This is best done in cooperation with experts. This area of probability is used as an extra restricting filter when choosing a voxel for the next product.

Every time a step is taken towards the next product, the user should think about the amount of types issued of this product. This choice can be based upon targets formulated in an earlier stage. If multiple targets exist, and if these contradict one another, the model can be split into multiple parts. Chances are, the model will develop itself as a branching structure, with every branch having its own targets. It is possible to develop every branch separately. Partly because of this, a point can be reached when the amount of generated information grows too large for the model to handle efficiently. It may be wise to turn the model around. Instead of using it to forecast solutions, it can be used to test solutions. Parameters of a certain product can be transferred to a voxel. This voxel can be located and compared with the target(s) for this product.

The model results in a list containing the chosen voxels, with information about the focus points. To visualize this information, every voxel is given a timetable and an investment curve. This list of voxels can be fed back to the targets. If necessary, some voxels can be calibrated. The final list can be used as a basis for further research by specialized offices.

A Manual of the Timeshifting Model.
This manual describes a number of steps, which must be taken to use the model. This way of working offers insight into the choices of a project concerning lifespan. It also offers a format for certain steps to put generated data into perspective. This enables the user of the model to compare information quickly.

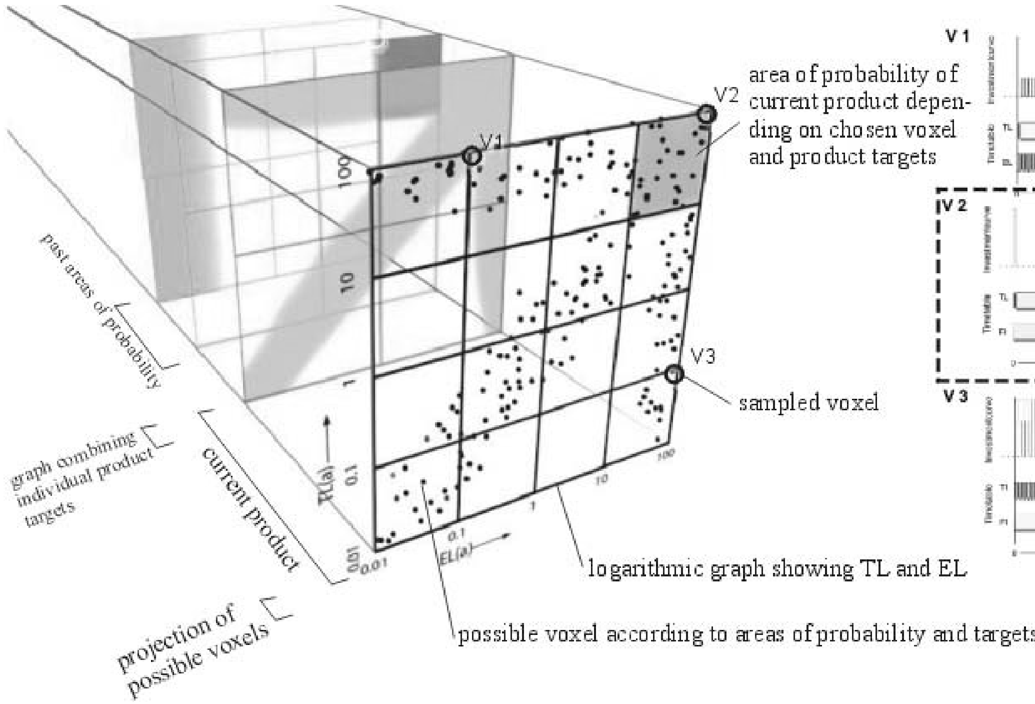
Manual Content

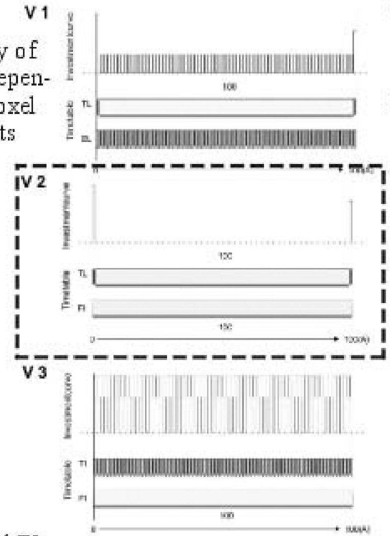
1 Formulation of a problem
2 Phrasing
3 Product differentiation of the project. Which products are identified, or which products are being researched?
4 Determination of dependence of the products and making of a product sequence, starting with the least dependent product.
5 Determination of targets. Targets are relevant for a few or even a single product. If not all products can be issued, or if there are one or more targets, one has to return to this point later in the process when targetless products are being treated.
6 Product criteria. Determination of focal points derived from the targets specific for a certain product.
7 Every target for the first product will be described using the five lifespan points: EL, TL, TQ<1, TQ=1 and TQ>1. Voxels are chosen and described.
8 The voxels of every target from product one are put together. An optimal voxel is chosen.
9 Drawing of an area of probability. This describes the range of probable voxels in the next product range. It constrains the amount of choices of voxels, and secures a clear line in the choices made.
10 Repeat steps 7,8 and 9 for every product. If the next product doesn't have any targets, new targets can be made using knowledge from the model and from design decisions. Go to step 5 if it is possible that a certain product has multiple variations.
11 Gather the optimal voxels for every product in text and image. This is the result of the model, a list with criteria for the products of the project.
12 Feedback to the targets. If not satisfied, voxels can be calibrated in step 8.

Manual Format

Steps 1 through 6 are formatted as plain text.
Steps 7,8 and 9 are put on one sheet per product. This is a rather complicated sheet, and is described on the next page. It shows a template with descriptions of all of the visual elements found on the sheet.
Step 10 does not have a format.
Step 11 is the actual result of the model and is formatted in a table.
Step 12 also comes in plain text.

TEMPLATE STEP 7.8.9

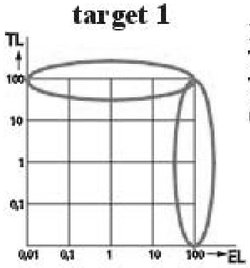




Timetables and investmentcurves of the sampled voxel. It shows EL, TL end TQ Per sampled voxel a small description is added.

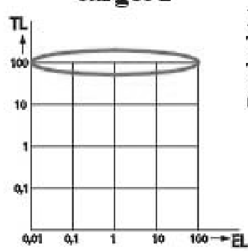
box highlightschosen voxel.

target 1



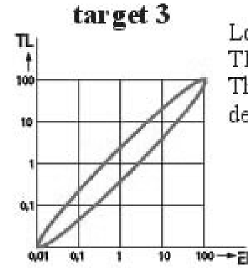
Logarithmic graph showing TL and EL. The red area shows the lifespan decisions for target 1.

target 2



Logarithmic graph showing TL and EL. The red area shows the lifespan decisions for target 2.

target 3



Logarithmic graph showing TL and EL. The red area shows the lifespan decisions for target 3.

CASE STUDY PROJECT

1 Formulation of a Problem
It is problematic that contemporary buildings cannot cope with a high programmatic flux. Therefore, the economic lifespan of a building expires long before its technical lifespan does. The inability to disassemble buildings and their components results in large quantities of construction and demolition waste (CDW) and needless building activity. Prolongation of lifespan through transformation capacity is an efficient method to reduce environmental impact.

2 Phrasing
Does a possibility exist to minimize the environmental effects resulting from changing trends? Which possibilities do exist to react on changing functions?

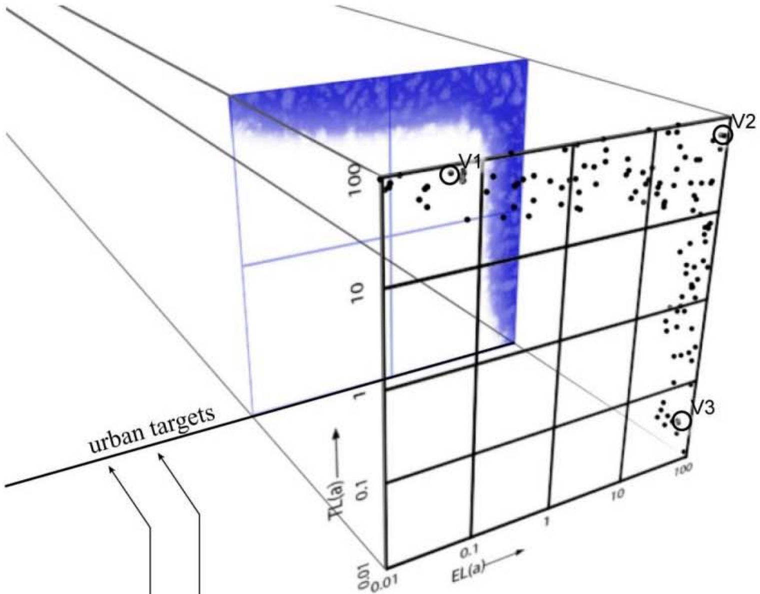
3 Products
Urban planning, function, building, building system, building element, and material.

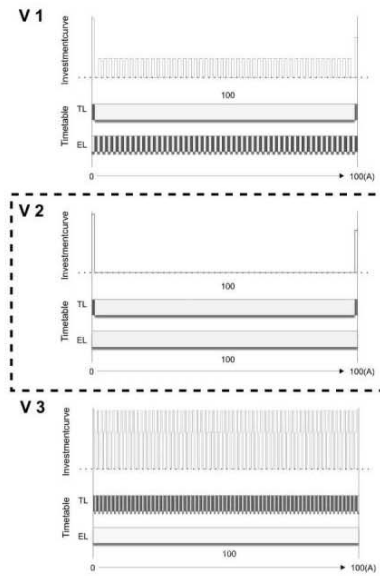
4 Dependence and Order
1. Urban planning
2. Function
3. Building
4. Building system
5. Building element
6. Material.

The urban planning product greatly influences the other products. Going down the list, influence diminishes.

5 Targets
1. To provide high-quality accommodation to a certain function (leisure or conference with a given bandwidth) with a long economic lifespan.
2. Through transformations to the building, other functions or the same function with altered demands, are accommodated for.
3. These transformations will be made with a minimal environmental impact.

6 Product Criteria
Urban planning: seeding power, architectural quality (AQ)
Function: position within bandwidth
Building: transformation capacity, AQ, building physics and constructional qualities (BPC)
Building system: spatial possibilities, bandwidth, BFC, AQ
Building element: mounting and demounting, BFC, AQ
Material: BFC, AQ

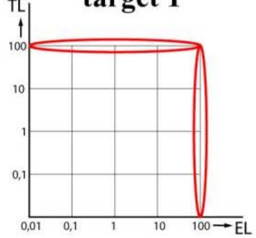




Voxel 1: TL=100, EL=0,5, TQ=200.
The possibilities to reach a great AQ are greatly limited because of a fluctuation in demands. When demands are so unclear, AQ is hard to acquire, because the urban plan has to be adjusted continuously. The long TL assures a good seeding power.
Voxel 2: TL=100, EL=100, TQ=1.
The potential for AQ is good and so is the seeding power.
Voxel 3: TL=0,5, EL=100, TQ=0,005.
The urban interventions are small and provisional. Continuouty does not exist so no seeding power exists. The need for AQ is great, so are the possibilities to reach it, though a short development period is available. Growing trees for instance is not possible. adjustmentcosts play a big role in the total EI

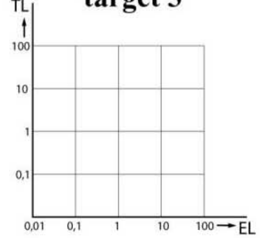
URBAN PLANNING STEP 7,8,9

target 1

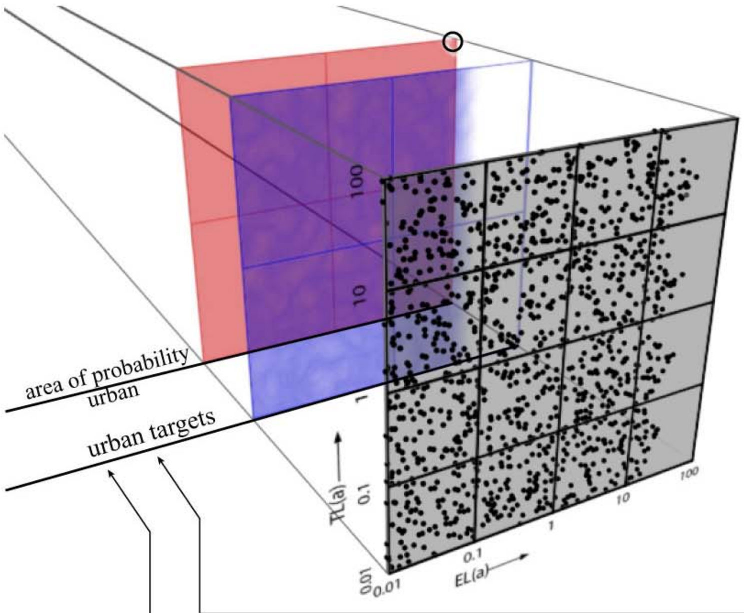


EL: this should be long to guarantee any action in the design area. The AQ depends on the amount of the demand. If the EL is longer, the technical possibilities for AQ grow bigger.
TL: the smaller the TL, the smaller the actions can be. Seeding power is best achieved using a long TL
TQ: there are too much parameters

target 3

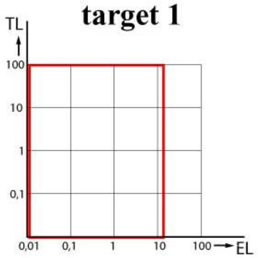


EL: if the EL is short, there are quick changes in demands. This results for instance in unpaved roads, "wild wonen" and no moving of large amounts of earth. When the EL rises, the building and demolition costs get less relevant, compared to the total environmental impact. The period of plain use should yield as little env. impact as possible.
TL: if the TL is short, quick urban solutions should be used. No large nature for instance.
TQ<1: the lower the TQ, the more important the building and demolition costs.
TQ=1: does not exclude anything.
TQ>1: building and demolition costs are relatively unimportant, the adjustments have a greater influence on the total env. impact.



Voxels do not appear clearly here. Only a field of voxels bordered by a maximum EL of 15 years. These functions are for instance: office, school, leisure, sports, conference, hotel, circus.

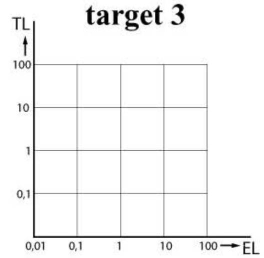
target 1



TL: does not apply
TQ: does not apply

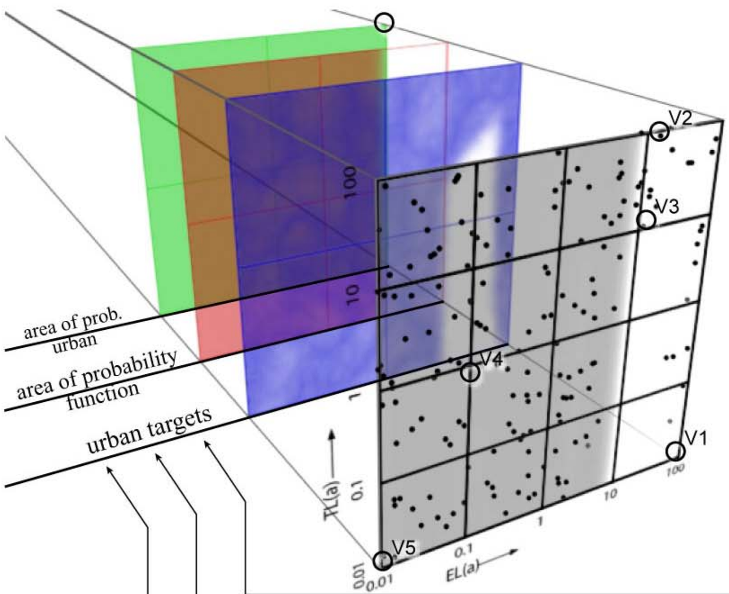
EL: a long EL implies cultural functions or monuments, trend-insensitive. High quality is promoted by a long EL, since there is a long development period available. Our targets imply certain function with an EL shorter than 15 years.

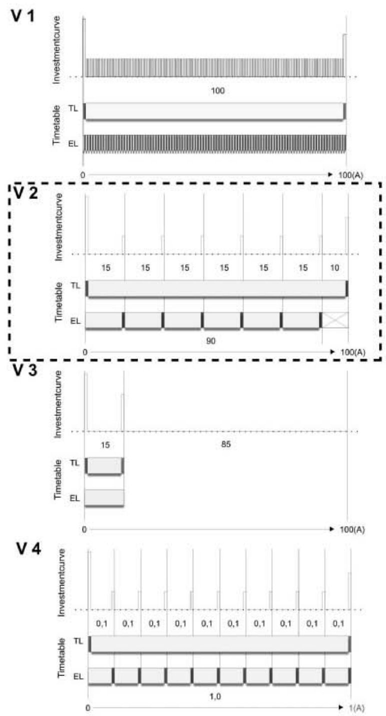
target 3



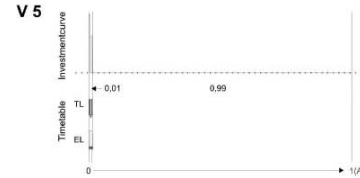
EL: to be able to see change, the EL should be relatively short.

FUNCTION STEP 7,8,9



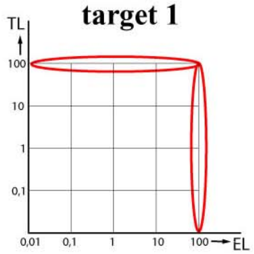


Voxel 1: EL=100, EL=0,01, TQ=10000
this building will be adjusted tenthousand times during one century to the frequent programmatic flux. For instance exhibition/fair buildings. These are adjusted about twice a week to cater for a new show. This results in quite a large environmental impact. Adjustments cannot be very large.
Voxel 2: TL=100, EL=15, TQ=6,7
this building stays for 100 years and probably has an office function. Adjustments can be more architectural.
Voxel 3: TL=15, EL=15, TQ=1
this one is highly improbable. An entire building that falls apart when it is not needed anymore.
Voxel 4: TL=1, EL=0,1, TQ=10
during the TL of one year, this building will be adjusted ten times. Very improbable.
Voxel 5: TL=0,01, EL=0,01, TQ=1
palmleaf hut, igloo in the desert.



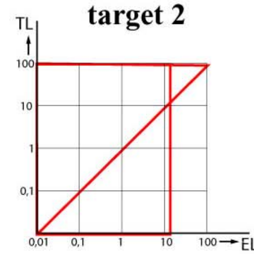
BUILDING STEP 7,8,9

target 1



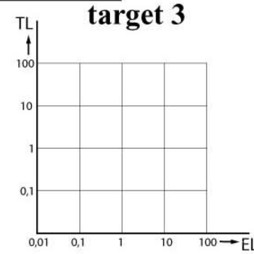
EL: this should be long in order to guarantee action in the design area. The AQ depends on the degree of demand. If the EL is long, the technical possibilities are greater.
TL: the lower the TL, the smaller and more provisional the interventions can be. A seeding function is best served with a long TL.
TQ<1: to achieve high AQ, the degenerationperiod should be short. Buildingperiods should be short to keep up the solution to the demand. This affects the AQ negatively. This sitiuation can cope better with changing demands.
TQ=1: "project XX", this situation is almost impossible to attain. This situation makes it possible to build very specificly for a single client. It is very risky to build TQ=1. When demands change over time, the building isn't adjustable.
TQ>1: adjustments have to be made. To guarantee AQ and BFC, there has to be a base quality. The building should not be totally transformable every time the EL ends because there is the risk of losing any present quality every time changes take place. The spatial structure should generally stay the same.

target 2



EL: the target implies a short EL (about 15 max.)
TL: the higher the TL, the more adjustments the building should be able to undergo.
TQ<1: no adjustments take place. The target doesn't agree.
TQ=1: idem
TQ>1: to calibrate the building to new demands, there should be adjusted.

target 3



EL: if the EL is long, few adjustments are needed. This doesn't neccesarily say anything about the environmental impact of these adjustments.
TL: This doesn't neccesarily say anything about the environmental impact of these adjustments.
TQ<1: no adjustment
TQ=1: idem
TQ>1: the more adjusments, the lower the environmental impact per adjustment is allowed.

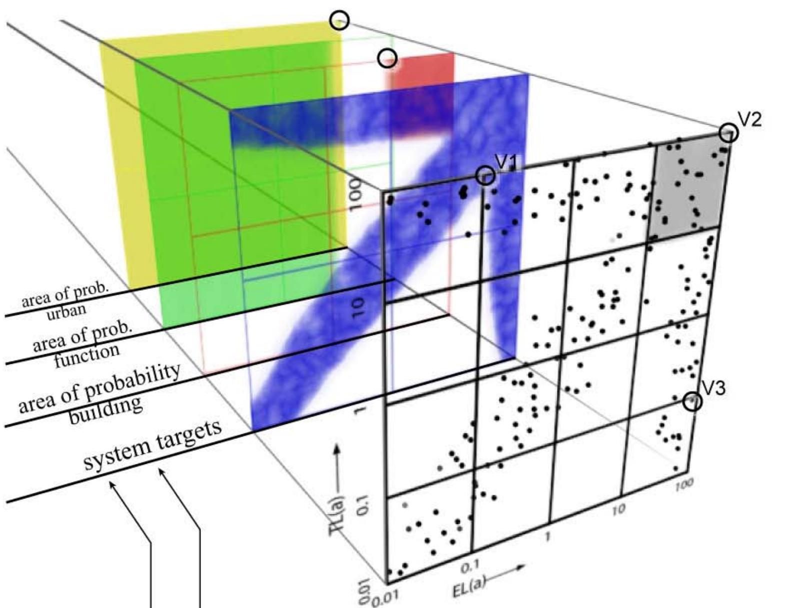
At this point, it is not possible to give relevant comments on the next product. This product is the "building system," and the current targets do not apply to this system. Therefore, a new set of targets must be made for the next product. Thus, we return to step five of the scheme. These targets can be made with knowledge gathered from the previous products, and with creative decisions. We decided, based upon these sources, to issue two building systems. These systems will be examined concurrently, but will receive different targets. This means the model will be split up into two parallel parts. These parts will be examined separately. We think this best fits our previous decisions.

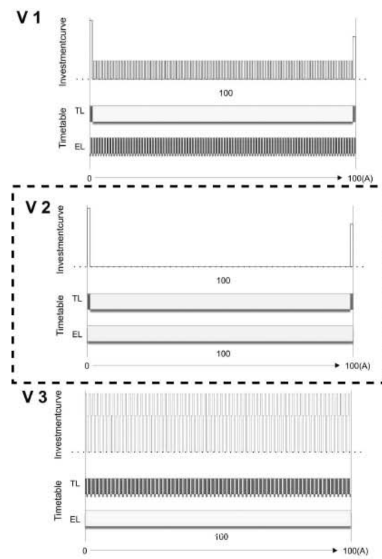
5 Target Building System
There must be two building systems. One should be fixed, and the other should be flexible.

Fixed Building System
1. The fixed system provides for a seeding function and a fixed AQ.
2. Both life spans should be long.

Flexible System
1. The flexible system is used to adjust the building.
2. Adjustments to the building using the flexible system should cause minimal environmental impact.
3. Both life spans should be long.

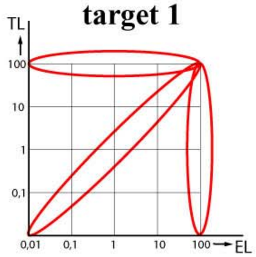
BUILDING SYSTEM FIXED STEP 7,8,9





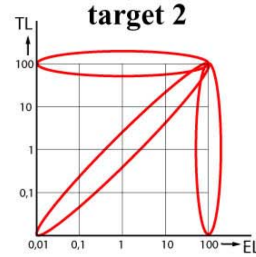
Voxel 1: TL=100, EL=0,1, TQ=1000
the system itself has to be adjusted regularly. this is very unhandy
Voxel 2: TL=100, EL=100, TQ=1
the system has long lifespans and needs no adjustments. this is optimal
Voxel 3: TL=0,1, EL=100, TQ=0,001
the demand for this system is great, allthough it breaks down every month. it doesn't work.

target 1



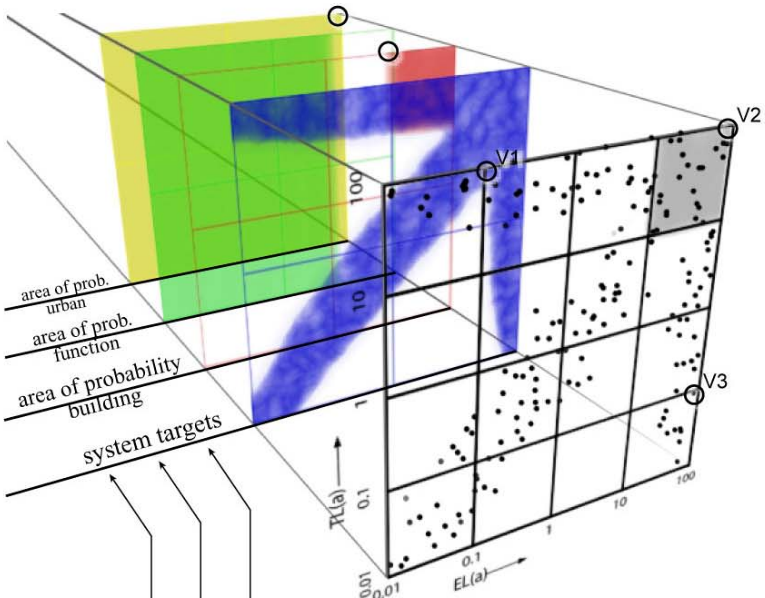
EL: a long EL offers more possibilities for the seedingfunction and a high AQ.
TL: it is a fixed building system, so it hes a long TL. This is good for seeding. A long TL makes the demand for a high AQ greater.
TQ<1: very bad for AQ and seeding.
TQ=1: no adjustments needed!
TQ>1: adjustments are needed, this doesn't comply with the target.

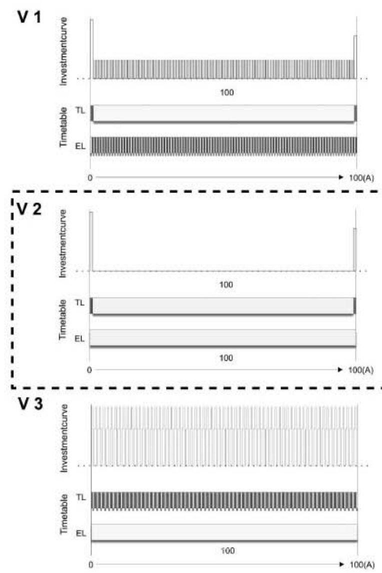
target 2



EL: long
TL: long
TQ: it is most probable a TQ+1 will be chosen.

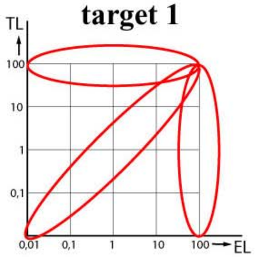
BUILDING SYSTEM FLEXIBLE STEP 7,8,9





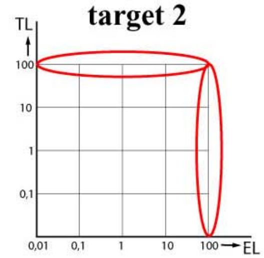
Voxel 1: TL=100, EL=0,1, TQ=1000
the system itself has to be adjusted regularly. this is very unhandy
Voxel 2: TL=100, EL=100, TQ=1
the system has long lifespans and needs no adjustments. this is optimal
Voxel 3: TL=0,1, EL=100, TQ=0,001
the demand for this system is great, allthough it breaks down every month. it doesn't work.

target 1



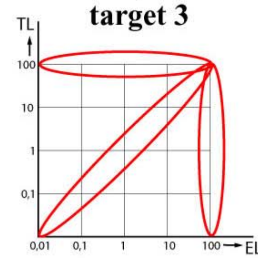
EL: if short, possibilities to adjust buildings with this system are small.
TL: idem
TQ<1: the smaller the TQ, the less influence the user has on when he wants to adjust the building with this system.
TQ=1: good choice
TQ>1: it is very hard to adjust a system.

target 2



EL: a long EL means more demand and thus more posibilities to reduce environmental impact.
TL: a low TL means that the system probably won't get to adjust the building.
TQ: these do not say a thing about this target.
target 3

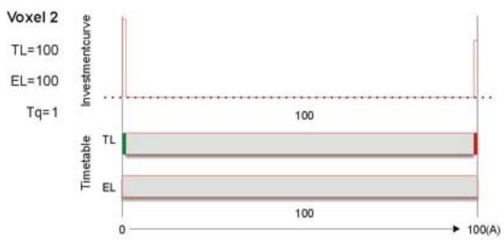
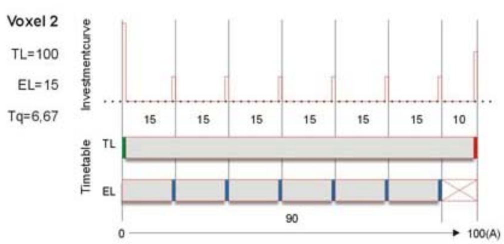
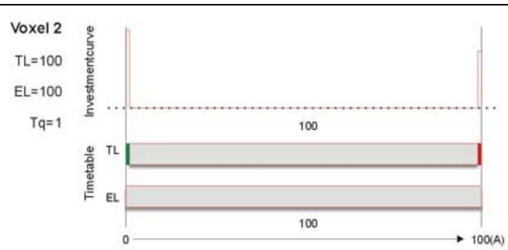
target 3

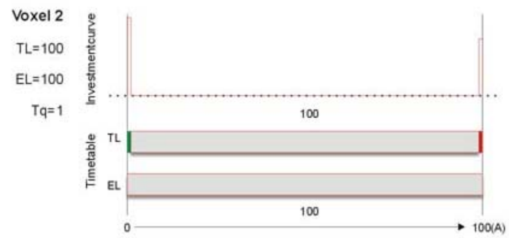


EL: long
TL: long
TQ: it is very probable a TQ=1 is chosen.

At this point, the current targets again fail to describe our next product, the "building element." So, it would be wise to also make these targets based upon previously gathered knowledge and new, creative decisions. We will not make these targets for two reasons. First, we think our model has been explained thoroughly enough to give a good image of how this model works. Second, we have arrived at a point previously described. At this point it will be almost impossible to use the model to forecast solutions. Any voxel chosen will generate such a large amount of building elements that, according to the voxel; we cannot control the amount of data. So, we should gather the data from the previous products, list them, and start designing with them. Then, when we arrive at the building element stage, the designer can test some elements in our model. Instead of forecasting, the model will be "back casting."

11 List of Gathered Voxeldata

Product	TQ	Timetable chosen voxel	Criteria
Urban Planning	1		The potential for AQ is good, and so is the seeding power. It offers the possibility to have a stable urban plan for 100 years, which is the best method to minimize environmental impact and offer seeding power.
Function	-		Voxels do not appear here, only a field bordered by a maximum EL of 15 years. These functions are: office, school, leisure, sports, conference, hotel, and circus. These functions best fit our target of flexibility and trend-sensitivity.
Building	6,7		This building stays for 100 years, and probably has multiple functions of the ones mentioned above. Adjustments can be more architectural. The main part of the building staying for a century is realistic, when looking at technical life spans of current building methods and materials. Another part of the building can change, and can keep up with changing needs and demands. This part assures that the entire building can be used during this century with minimal effort.
Building system fixed	1		The system has long life spans and needs no adjustments. This is optimal. For instance, cast-concrete constructions or welded steel constructions are able to last a long time, technically speaking, and to answer the demand for this product.

Building system flexible	1		The system has long life spans and needs no adjustments. This is optimal. Seemingly, we might confuse this building system with the fixed-building system. The big differences are the targets. With these in mind, we understand that the flexible-building system is best served with a long TL and EL. It is almost impossible to change a building system; for instance, changing from welded steel to wood. A building system is designed to last. Eventual parts of this system could have low life spans, but the system will stay. It will offer adjustability to the building during its entire lifespan.

12 Feedback
This would be the phase where the voxels from step 11 are compared to the targets from step 5. If these voxel do not exactly meet the demands, they can be calibrated. In this example, there is no need to carry out this final step.

CONCLUSION

Time is the most important factor within the timeshifting model. Time is an aspect essential for every product, and can be used to issue founded statements about various themes and products. The timeshifting model is used as a transformer of targets; it doesn't give clear-cut answers to design problems. These still have to be generated by a designer. The model offers better insight into the possibilities and restraints created by certain choices.

The formulated targets appear to have major importance. If these targets are just made up or formulated sloppily, it automatically appears in the model. The model also can be used to sharpen the design targets in an early stage of the project.

Specialists can use the large amounts of data that the model can generate, before or during the design, to study certain aspects, such as financial or environmental impact. Using the technique of visualizing, these data are clear and accessible.

REFERENCES

1 **prof . ir. Kristinsson, Jon** *Inleiding integraal ontwerpen.* Faculteit Bouwkunde, vakgroep bouwtechnologie, milieutechnisch ontwerpen. Delft, 1997

2 **ir. Dobbelsteen, Andy van den, ir. Alberts Kees** *Milieu-effecten van bouwmaterialen, duurzaam omgaan met grondstoffen* Publicatiebureau Bouwkunde. Delft, 2001

3 **Commoner, B.** *The poverty of power.* New York

4 **Speth, J.G.** *Can the world be saved?* Ecological economics, volume 1.

5 **Ehrlich, P., Erhlich, A.** *The population explosion* London, 1990.

A DECONSTRUCTABLE CARPARKING BUILDING IN AN ACTIVE SEISMIC ZONE

Authors: Morten Gjerde, John Storey and Maibritt Pedersen (Centre For Building Performance Research, Victoria University, Wellington, New Zealand)

ABSTRACT

This paper presents a case study of a reinforced concrete car parking building in Auckland, New Zealand which was designed to be disassembled and re-erected on a different site at a future date. One of the biggest challenges in the design of this building was to design a deconstructable building in an active earthquake zone. The lessons to be taken from the design are not only applicable to other reinforced concrete buildings in New Zealand, but are also significant for the design of reinforced concrete buildings in other seismically active zones around the world.

This paper describes and illustrates the design features of the building, discusses their significance and suggests directions for the design for deconstruction for future reinforced concrete buildings in seismically active and non-seismic zones based on the lessons from this project.

KEYWORDS: Precast Concrete; Deconstruction; Seismic Design

INTRODUCTION

In geological terms, the islands that comprise New Zealand are still very young. As New Zealand sits astride the 'Pacific Ring of Fire' seismic activity is a relatively frequent occurrence and buildings and other infrastructure must be designed to cope with tremendous dynamic movement. The New Zealand construction industry is highly conscious of this requirement.

Reinforced concrete is the most common structural material in medium to large scale buildings in New Zealand as the raw materials for its manufacture are readily available throughout the country. Iron ore, which is found mainly in the form of iron sand, is both limited in supply and difficult to process into steel, making steel buildings less common in New Zealand. The concrete industry is very well developed with design and manufacturing successes that are respected around the world. Precasting is the preferred method of concrete construction, allowing the structure to be formed in smaller, manageable pieces both on and off site. The use of precast concrete can reduce construction time frames and increase the quality of the result. To cope with the loads imposed by a seismic event, the common strategy is to 'knit' the individual pieces together so that they act as a whole, with structural connections commonly made using concrete cast-in-situ. In the case of flooring, individual precast units are generally joined by casting a reinforced concrete topping.

Although there have been a number of deconstructable reinforced concrete buildings built around the world, most have not been required to confront seismic conditions. In non-seismic zones 'stick' construction methods, where the necessary structural capacity can be achieved through bolted or screwed reversible connections between elements, generally allows better prospects for salvage and reuse of elements. However, in seismic zones the reinforced concrete structural frames are deliberately constructed as monolithic units to best withstand seismic forces. This approach tends to act as a barrier to designing a concrete building for deconstruction in this context. The unique quality of concrete being able to be formed into monolithic elements is, in effect, also the greatest barrier to its use in buildings designed to be deconstructed in New Zealand.

PROJECT DESCRIPTION

At the time the project was conceived, MacDow Properties Ltd. had acquired the land but did not have the confidence to proceed with full commercial development of the site. The New Zealand economy had not yet recovered from the devastating share market crash of 1987. In addition to economic uncertainty, there was uncertainty in the direction future growth and development of Auckland might take. Notwithstanding these adverse economic conditions the developers felt that they needed to realise some of the economic potential of the site and recognised an unfilled local demand for car parking which was being created by several publicly funded projects under way in the vicinity. In principle, the owners wished to commit to a development strategy that would not compromise their ability to maximise the development potential of the site when conditions were more favourable in the future. In this regard the development of a car parking building was ideal. The development costs could be kept to a minimum as car parking buildings can be simple, low cost structures but they can still generate substantial revenue. However they did not want to prejudice full commercial development of the site when economic circumstances changed in the future. The decision to develop the project based on a strategy of deconstruction was made by the developer as this strategy enabled the car park building to be designed so that it could be disassembled when no longer required on its original site and re-erected on a different, less costly site at minimal cost. This made good commercial sense to all those concerned with the project. In comparison with a standard design the cost of the project would be higher but in the end this difference was only marginal [1]. According to the structural engineer this investment would be paid back at the time of deconstruction when the large elements of the building could be recovered for about the same cost as for the total demolition and disposal of a conventional concrete structure [2]. The project was commissioned to proceed with the following objectives to be achieved:

> Maximise the parking efficiency, and maintain overall operation efficiency
> Provide a quality, low maintenance building at minimal cost.
> As the car park life was liable to be short or medium term, the construction should provide for maximum salvage upon termination of the site use as a strictly car parking building. [1]

A steel structural frame may have been considered for this project if it were to be built any where else. However, the designers chose to develop the design on the basis of concrete as structural steel was in poor supply at the time, their was a concurrent shortage of specialist operatives skilled in constructing a building of this scale in steel and it was determined that there would be an additional cost due to the need to protect the exposed steel frame from fire and corrosion in this context. In order to optimise on-site construction efficiency and quality, precast concrete elements were used wherever possible. 32 columns were precast off-site to their full height of approximately 11 metres. Refer to Figure 2. These columns were bolted to the cast-in-situ concrete foundations. The foundations were not specifically designed to be recoverable for reuse elsewhere but hopefully they might be incorporated into the structural design of a replacement building on the site. Corbels to take the mainly gravity loaded precast beams were integrally cast with the columns and the beam / corbel connections were welded in a manner that could easily be cut free for disassembly.

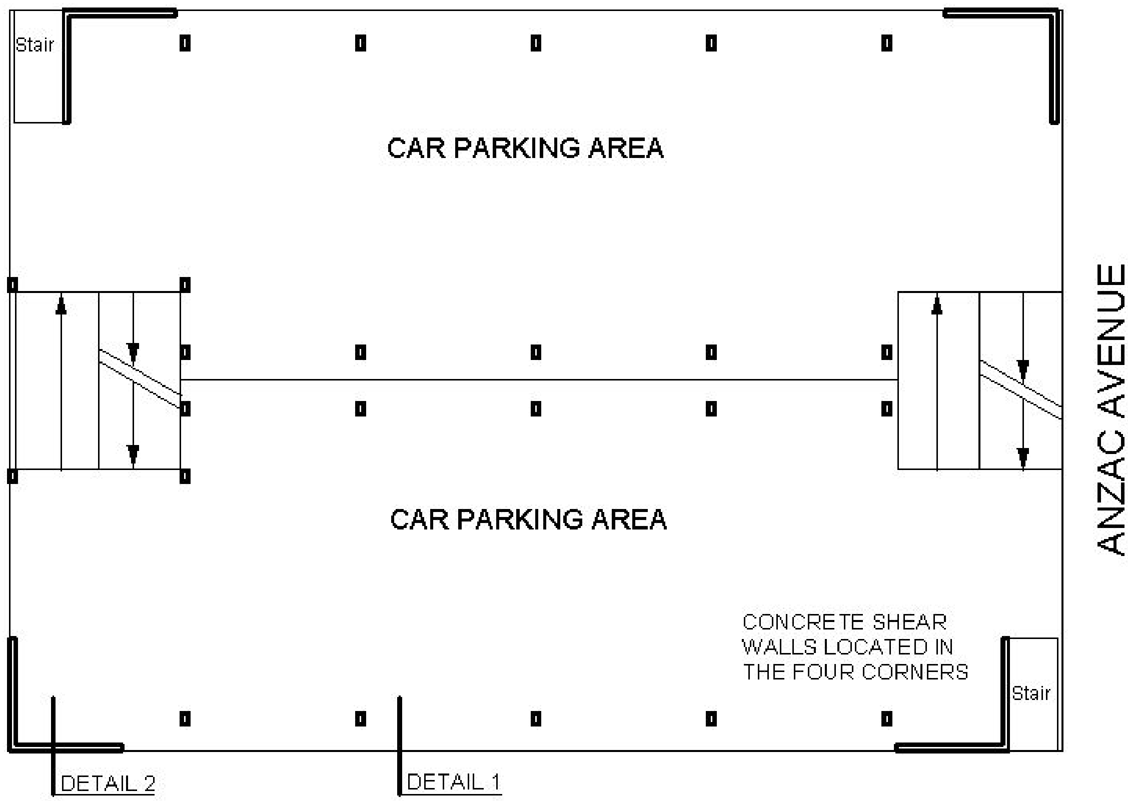
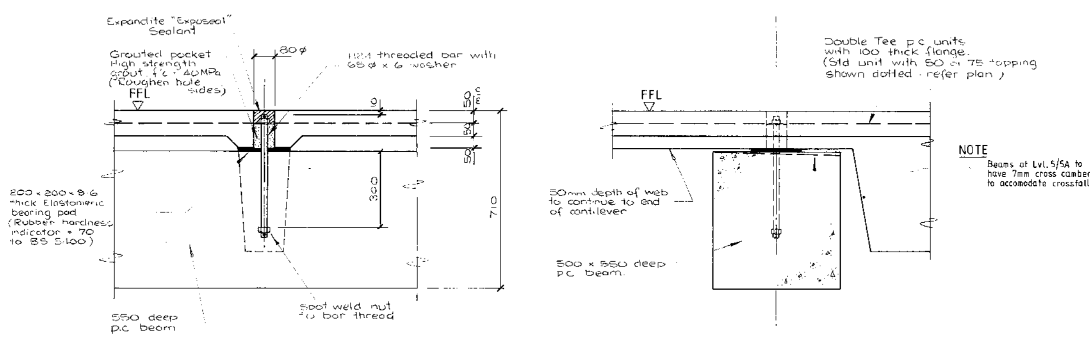
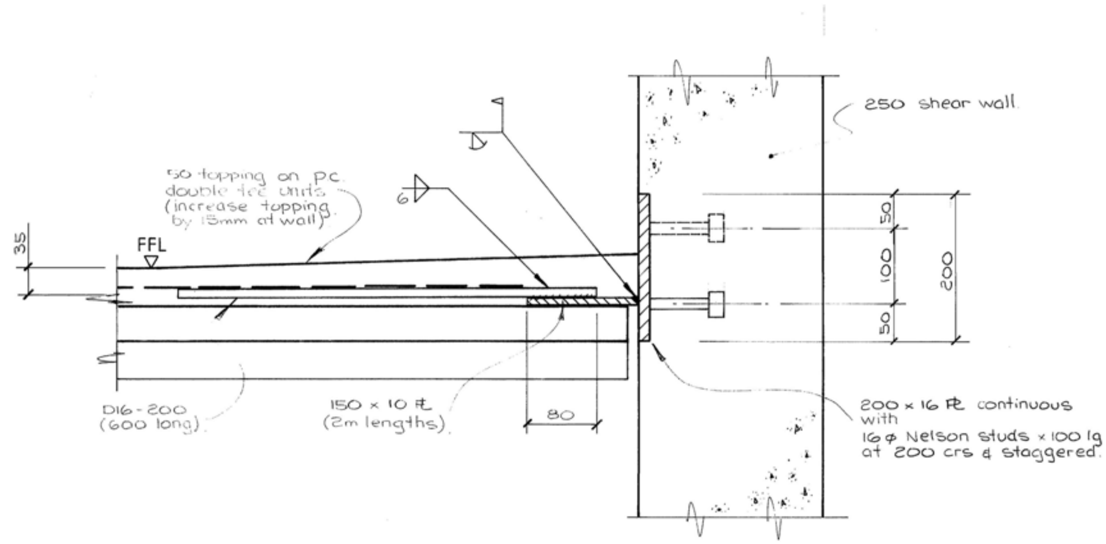


Figure 1: Plan showing the set out of cast-in-situ concrete shear walls in each of the four corners of the building. The plan steps 1/2 floor level at the split along the long axis with vehicle ramps connecting the levels at each end.



Detail 1: Showing the connection of flooring units to precast concrete beam. Threaded rods have been utilised to facilitate the disassembly process.



Detail 2: Showing the connection between cast-in-situ concrete shear wall and adjacent concrete flooring.

The flooring units are precast concrete double tees spanning 14 metres with a 1.5 cantilever over the supporting beam at each end. The units are pre-finished and do not require a concrete topping for surface or to create a structural diaphragm. Structural integrity is achieved by connecting the 100 mm thick flange of each to the adjoining unit by means of friction grip bolts. These bolts transfer the building lateral loads and are easily removable for recovery of the flooring units in the event of deconstruction. Connection between the flooring units and beams is achieved by the use of threaded rods, easily removed during disassembly. Such a connection in a typical concrete frame building would be made by casting a concrete junction around the flooring unit seated on the supporting beam. In this case however flooring units adjacent to the concrete shear walls were required to include a concrete topping cast on site to transfer the loads to the shear wall (refer to Detail 2). With the exception of these units all precast components are essentially pin jointed gravity units with no moment connections. This will allow easy and effective deconstruction with the recovery rate estimated to be in the order of 85% of the total structure.

As a car parking building, the structural layout and detailing was simpler than would have been the case in other building types. This helped keep the initial capital cost of the project low, even allowing for the incorporation of features to facilitate deconstruction. Examples of details which helped to keep the construction costs low include the floor level detail and the structural layout. The flooring units do not align precisely at the edges. An uneven floor is acceptable in parking building, and some industrial/storage buildings, but most uses require a more level floor. The structural layout optimises the spanning capacity of the concrete elements, allowing the deflection characteristics to be higher that would be normally allowed in other building types. The seismic resistant structural design strategy, driven by the objective of making the connections easily reversible, is to concentrate all the lateral resistance into four 'L' shaped shear walls. Consequently all beam / column connections are simple pinned joints, as are the floor to beam connections. In a typical building using a moment resistant frame the beam / column joint would be cast solid and be more difficult to deconstruct. The structural engineer estimates that the extra time required to design this building over and above the time required for a 'normal' building was no more than 10%.

Overall, a comparison between the building as constructed with a more conventional structure confirmed that the owner paid only a marginal cost premium.

In respect of lifecycle costing the structural engineer makes the following observations. When it is finally undertaken, deconstruction will be easily achieved – the precast concrete elements will be unbolted or cut free and removed as large units. This will probably be in the same order of cost as the complete demolition and disposal of a conventional reinforced concrete structure. The cost of the reassembly of the components will be similar to the original erection costs, which is considerably less than the cost of replacing the components and erection on-site. The reassembly costs will have to include the full cost of replacement of the cast–in-situ portions but even this is not likely to drive the cost up to nearly that of completely new construction. [2]

While the project goal was to create a car parking building that was able to be disassembled and reconstructed as a car parking building on another site, according to Ross Lee, the director in charge of the project on behalf of Stephenson & Turner Architects Ltd., the more likely scenario is that after deconstruction the elements would become part of a new building of a different shape to its current configuration. [4] As the project was designed for a central city site, the planning and design has been driven by issues such as site access, topography and boundary dimensions. It would be unlikely that such conditions could be repeated on another site and the temptation to reconfigure the building would be significant. While this would have little bearing on the viability of the project in terms of its technical deconstruction, reconfiguration should be anticipated by the prudent designer. The use of standard format and otherwise simple building elements, where possible, would facilitate the likelihood of reuse of the deconstructed items in future buildings.

Intrinsically an open car parking building requires very few different materials. In this case the use of concrete elements has further helped to rationalise the materials used in the structure. Precast and cast-in-situ concrete provides adequate structure, fire protection and durability in the exposed weather conditions. The choice of materials, in association with the design strategy, will contribute to the success of the project in fulfilling the objective of being relocated to another site. An example to illustrate this is a comparison of the chosen design with one that employs steel framing elements. In this case, the steel would more than likely be required to be encased in another material to provide the necessary fire resistance. It is unlikely that the fire protection materials could be easily removed and reused. Fire protection could add considerable cost to the project, based on an analysis of materials that are currently used to fire protect structures. A steel structure would also require protection from corrosion, which in turn would require maintenance, adding to the lifecycle cost of the project.

The design strategy is also notable in that it establishes precedent for further use in a number of other contexts. For example, as the project is designed for New Zealand environmental conditions, further development in the area of architectural finishes could facilitate other building types adopting the strategy. One of the obstacles to work through is the inherent unevenness between flooring units, as the concrete topping, typically used in other contexts not only to provide a structural diaphragm but to create a level floor surface, has been deleted. One way this problem could be overcome through the use of a raised floor system. Such systems are gaining favour in commercial office fitout to facilitate the reticulation of and modification to building services and, as they are robust and modular in nature can easily be incorporated into a deconstruction strategy. It is also of interest that by incorporating a raised floor system it would be possible to leave the soffits of the precast flooring units exposed in the space below, thereby reducing the capital cost and affording an excellent thermal mass to help moderate temperature swings. The Anzac Avenue Car Parking Building also establishes precedent for use of this strategy in seismic zones found elsewhere in the world. A qualification on this observation is that the use of precast concrete components is more common in developed countries. In developing regions, where the preference is for cast-in-situ concrete, further research would be necessary. The structural engineer has reported that the structural design and detailing concepts employed here could be used for any building.

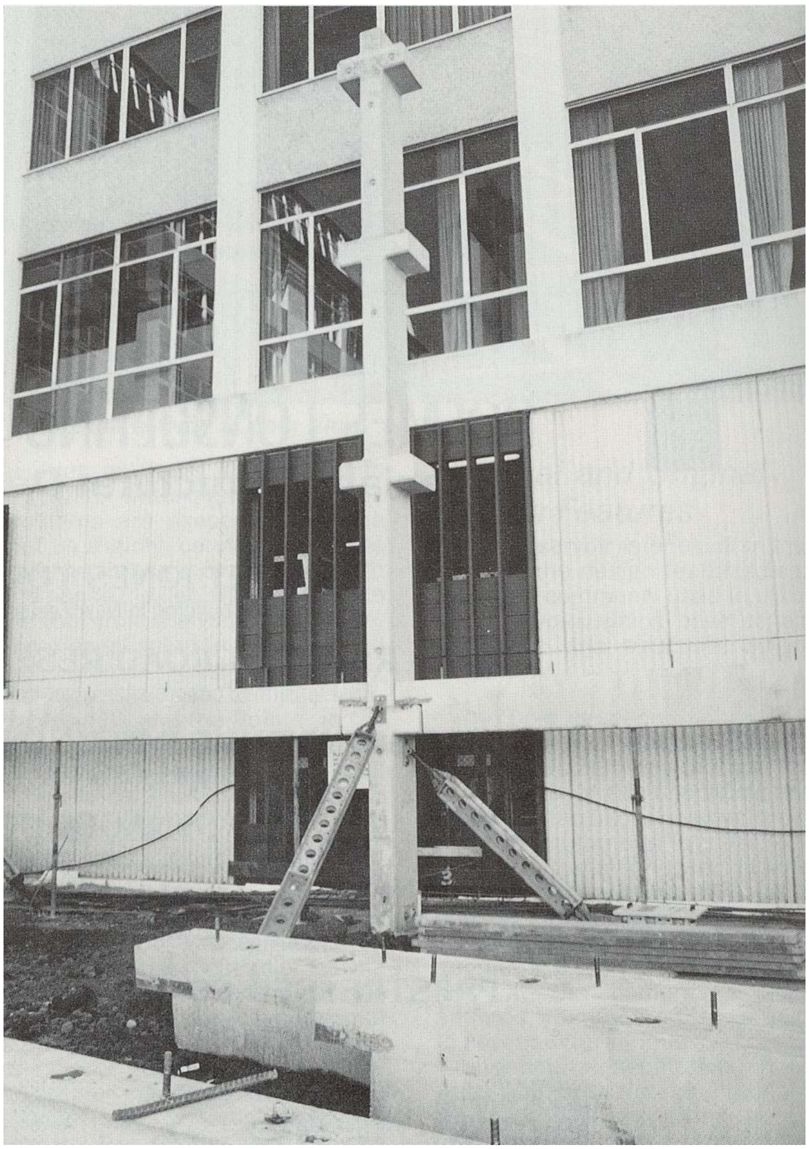


Figure 2: One of the 32 no. full height precast concrete columns with integral corbels to support precast concrete floor beams. Beams and columns only provide gravity support, with lateral support provided by concrete shear walls.

CONCLUSIONS

The Anzac Avenue Car Parking Building presents a successful New Zealand example of the design and construction of an inner city building for eventual deconstruction and reassembly on another site. It is significant that this has been achieved in a high earthquake zone. It is clear from this case study example that constructing in an area of high seismic activity need not be a barrier to the application of deconstruction strategies.

The structural strategies employed in this project could be appropriate for use on similar buildings in other countries prone to earthquakes. Further, the strategies could be applied to other building types designed for deconstruction with the appropriate consideration of the architectural elements.

The development cost premium to incorporate the deconstructability features into the project was very low. In a lifecycle cost analysis the owner will enjoy considerable savings over the cost of full demolition without recovery and the construction of an equivalent new building on another site.

Precast concrete is an appropriate material for use in deconstructable buildings, particularly those structures that have difficult environmental conditions to cope with. Concrete is inherently fire and corrosion resistant, not requiring the application of specialist finishes in most circumstances. The lack of applied finishes will reduce routine maintenance costs during the lifecycle of the structure and will facilitate the deconstruction and reassembly process. This case study suggests that reinforced concrete is markedly superior to steel in this situation.

The nature of the structural requirements for concrete structures is such that some portions of the building may need to be cast-in-situ. This will render those parts difficult to fully recover for reassembly in their original format. Designers should bear this in mind and rationalise such portions of a building so as to maximise the volume of building to be reassembled.

The use of simple and standardised detailing of all the building elements can help ensure that new configurations of the building are possible when relocating to a new site.

While the project demonstrates great potential for deconstruction and reuse of the building components on another site, several opportunities for improvement have been identified through this case study investigation. Reinforced concrete cross bracing or precast concrete shear walls could be incorporated in place of the cast-in-situ concrete shear walls, which will not be recoverable as building elements in the case study example. Although cast-in-situ concrete flooring has not been used throughout, it has been used over approximately 15 % of the total floor area. Development of the design and detailing to eliminate use of cast-in-situ concrete flooring is possible and will further improve the efficiency of recovery for reuse.

ACKNOWLEDGEMENTS

The staff and directors of Holmes Consulting Group Ltd. have been very generous with their time and knowledge in assisting with the research that was carried out for this project. In particular, the authors would like to thank Bruce Black and Sam Mulholland of the Auckland office.

REFERENCES

[1] Anon., Anzac Avenue Parking Building, New Zealand Concrete Construction, October 1990, pp 16 – 17.

[2] Black, Bruce (Director Holmes Consulting Group Ltd.), Oral Interview by Phone, 29 January 2003, and written interview 3 February 2003.

[3] Holmes Consulting Group Ltd., Anzac Avenue Carparking Building Structural Drawings, HCG Ltd., drawings S1 – S26

[4] Lee, Ross (Director, Stephenson & Turner Architects Ltd. – Retired), Oral Interview by Phone, 31 January 2003.

RE-USE POTENTIAL OF STEEL IN BUILDING CONSTRUCTION

Authors: E. Durmisevic (Delft University of Technology, Department of Building Technology, The Netherlands); Nico Noort (Corus Colors, The Netherlands)

ABSTRACT

This paper builds on the end-of-life results of the ECSC research project, entitled "LCA for steel construction" (see references), which was carried out by the steel industry in the Netherlands, the United Kingdom, and Sweden. This study confirmed the relatively minor environmental impact of downstream semi-manufactured products in phases of the building life cycle. It also shows that, at the end of life, 83% of steel construction products are recycled, 14% are re-used, and only 3% are landfilled. Therefore, steel can be recognized as material having almost a closed-loop material cycling. The re-use potential of steel products in buildings is clearly demonstrated through principles of modular construction, deconstruction, and reconstruction of steel frame buildings, as well as through widely applicable, moveable inner-wall systems in office buildings.

The Dutch Government is propagating re-use and deconstruction by sponsoring innovation in these areas through IFD projects (Industrial, Flexible & Demountable projects). Therefore, this paper builds upon the ECSC end-of-life results, and will present a few IFD innovations, illustrating the high re-use potential of steel structures achieved by optimisation of design parameters for disassembly.

KEY WORDS: Closed Loop; Life Cycle; Re-use Potential; Recycling Potential; Transformation

INTRODUCTION

Steel, as a construction material, provides many beneficial and essential services to society. To understand how, where, and why environmental impacts linked to steel in construction occur, and to quantify these impacts, the European Coal and Steel Commission (ECSC) funded a project, "LCA for Steel Construction," of which the final report was published in July 2002. Steel producers and steel construction institutes in the Netherlands, Sweden, and the United Kingdom carried out the project. The project builds upon a previous LCI study, undertaken by the International Iron and Steel Institute (IISI), addressing steel production processes of semi-finished products.

On the basis of the end-of-life results (recycling, re-use, and landfill) of the different steel products from the ECSC project, examples will be given to explore the re-use potential to increase the re-use percentage of products, thereby decreasing environmental impacts.

RESULTS OF THE END-OF-LIFE ANALYSES

ECSC examined the environmental burdens (pollutive emissions and use of resources) of all the processes associated with the life cycle of selected steel construction products in the Netherlands, Sweden, and the United Kingdom. These processes have been systematized into five phases.

- Phase 1 Production of "intermediate" (semi-finished) steel products, e.g., coil, plate, sections, etc.
- Phase 2 Production of finished steel construction products. Transport from the steel mill or stockholder to the manufacturing facility is included within this phase.
- Phase 3 Construction phase (to include on and off-site erection, fixing, and assembly of selected products for specific applications. Transport to the construction site is included in this phase).
- Phase 4 In-use phase (to include product life span, functional maintenance, repair and replacement of products within a structure or building under different environmental exposure and aesthetic conditions).
- Phase 5 End-of-life phase (to include demolition and deconstruction activities, reuse and recycling rates, scrap processing activities, and final disposal). Transport from the deconstruction site to the scrap handling and/or waste treatment site are included in this phase.

The environmental impact per life cycle phase has been presented through four categories: primary energy consumption, carbon dioxide emission, non-combustible waste generation, and VOC emissions. (Figure 1).

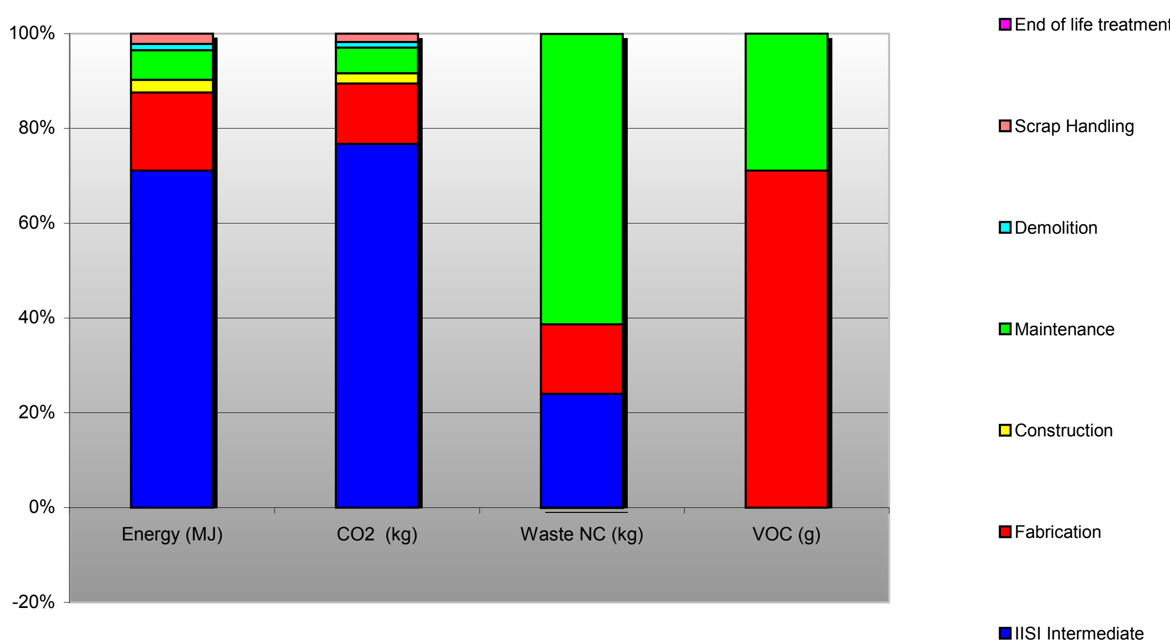


Figure 1: *Major contributions within the life cycle of Heavy structural steel, excluding allocation*

For all products studied, the environmental impact of the steel production phase is dominant. Considering energy consumption, steel production typically accounts for 75% of the whole life cycle impact (ranging from 55 to 89%). The major negative environmental impact of steel production is created by CO_2 emissions, and primarily reflects the means by which energy is generated in Western Europe (predominantly from fossil fuels).

The environmental impact is further summarized per the end-of-life scenario. From Table 1, on average, it can be stated that at the end of life, 83% of steel products are recycled, 14% of steel products are re-used, and 3% are landfilled. According to these figures, steell can already be recognized as material having almost a closed-loop material cycling. The closed loop of steel is explained by the fact that steel always has a positive value, and that the material properties of steel are preserved so that almost no down-cycling will take place. Increasing the percentage of re-use can decrease the environmental impact of steel. This saves production of semi-finished products, which typically accounts for 75% of the whole life impact of steel products [1].

Product	Recycling (%)	Re-use (%)	Landfill (%)
Girder	88	11	1
Lintel	88	10	2
Road barrier	65	34	1
Post coated inner wall components	59	7	34
Doorframes	90	9	1
Insulated inner wall box	87	11	2
Metalstud wall	92	7	1
Services	87	11	2
Light gauge steel (housing)	87	11	2
Purlins and rails	87	11	2
Composite floor decking	81	15	4
Composite sandwich cladding panels	53	37	10
Roof plate (coated)	81	15	4
Profiled cladding and roofing panels	81	15	4
Heavy structural sections	87	11	2

Table 1 *Average end-of-life scenario data*

In order to increase the reuse potential of steel products, the deconstruction potential of product and building structures should be increased.

DESIGN FOR DECONSTRUCTION

The term *deconstruction* has been used to describe the generic process of "breaking up" buildings and structures at the end of their useful life. Deconstruction is further sub-divided into the two processes of demolition and dismantling.

Demolition is defined as the process whereby a building is broken up with little or no attempt to recover any of its constituent parts for re-use (the products of demolition may, however, be recycled). Demolition represents one directional material flow, from extraction to demolition. Agenda 21 from the 1992 UNESCO conference in Rio stated that cyclic processes must replace linear ones to create sustainable development.

If we recognize the potential for a closed cycle of life, it is possible to divert the flow of materials from disposal and save the energy in them by introducing the disassembly phase (Figure 2).

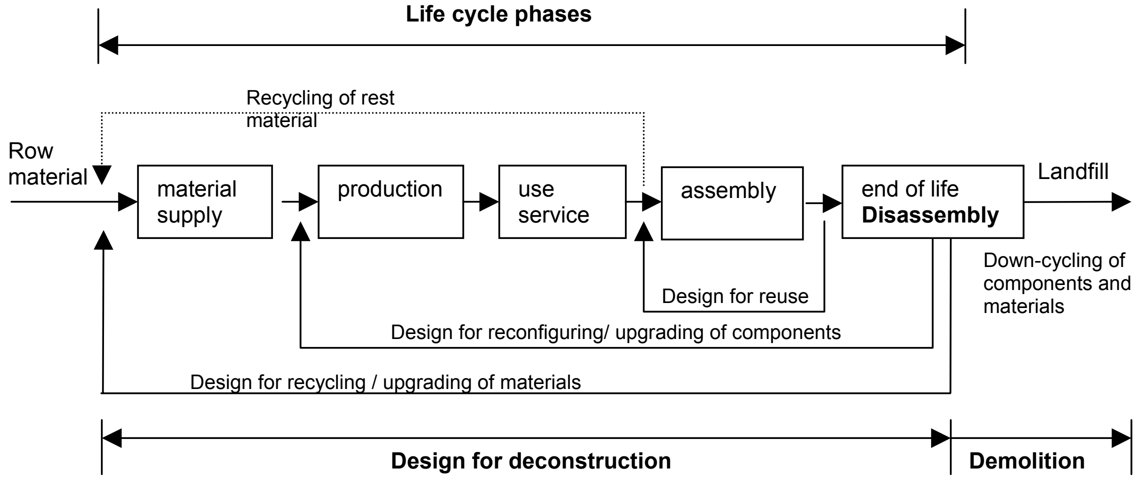


Figure 2: *Circular life cycle model of materials and products achieved by design for deconstruction*

Dismantling is defined as the process by which a building is selectively taken apart with the intention of reusing some (or all) of its constituent parts. *Recycling* is defined as the end-of-life recovery and reprocessing (by re-melting) of steel construction products to form new steel products. *Re-use* is defined as the end-of-life recovery and re-use of steel construction products (as a product filling the same function) with or without some reprocessing.

By designing product and building structures for disassembly, not only can environmental efficiency of steel products be improved, but steel can also contribute to reduce the total environmental impact of buildings. Besides re-use potential of steel products, re-use potential of other materials and systems can be improved by the use of steel. In that respect, steel can be seen as an important element of sustainable construction. Key aspects of design for deconstruction are independence and exchangeability of building parts within one building configuration. Independence of one component within a particular configuration can be provided by systematic clustering and ordering of building parts, so that one open hierarchical structure is created. Such open hierarchy can be defined by specification of an intermediary (frame) on different levels of a specific configuration (Figure 3).

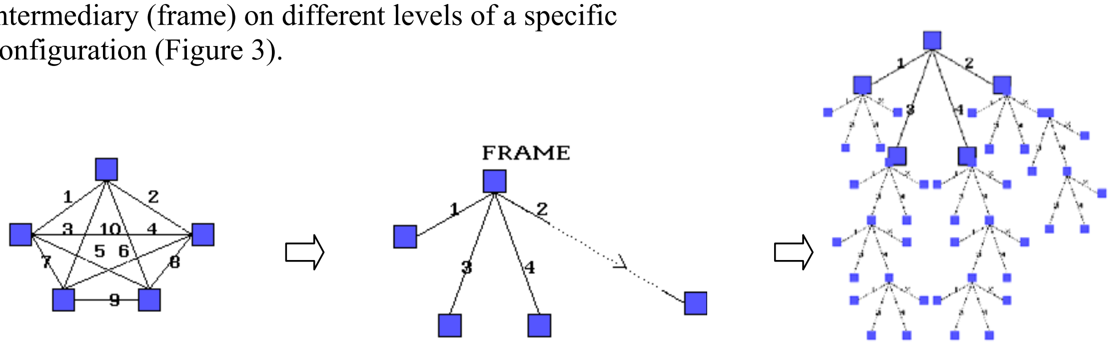


Figure 3: *From closed hierarchy, left, to open hierarchical structure, right [3]*

Elements that are ordered in the form of an open hierarchy are only connected to the frame (intermediary), and have no relationship with each other. In such a way, dependence of parts is minimized by a reduction of relationships between the parts.

Besides independence, exchangeability of building parts is another criteria of design for deconstruction.
Exchangeability of one component can be provided by design of an open product edge that will allow for parallel assembly sequences, as well as for the use of external accessory connections that provide independence between two connected elements.

Keeping in mind the level of independence and exchangeability of building parts, all building structures could be specified in a range from *fixed to deconstructable*. The main characteristic of *fixed* structures is maximum integration and dependence between building components caused by: (i) closed hierarchy of assembly which is not related to the component service life or expected time until obsolescence, (ii) application of sequential assembly sequences, (iii) design of integral joint types (components are shaped in such a way that bringing them together forms a joint), and (iv) use of chemical connections.
On the other hand, the main characteristics of *deconstructable* structures are: (i) use of accessory joint types (they require an additional third part to form the joint between two components), (ii) application of parallel instead of sequential assembly/disassembly, (iii) use of mechanical connections in place of chemical connections, and (iv) open hierarchy.

Thus, two factors will determine the reuse potential of steel products within building structures. First, the relational pattern between components that will result in certain type of hierarchy. Accordingly, hierarchy could be defined from stuck assembly, layered assembly, to star assembly. Second, the type of connections will result in different jointing methods. Accordingly, connections could be defined from chemical to click connections. (Figure 4)

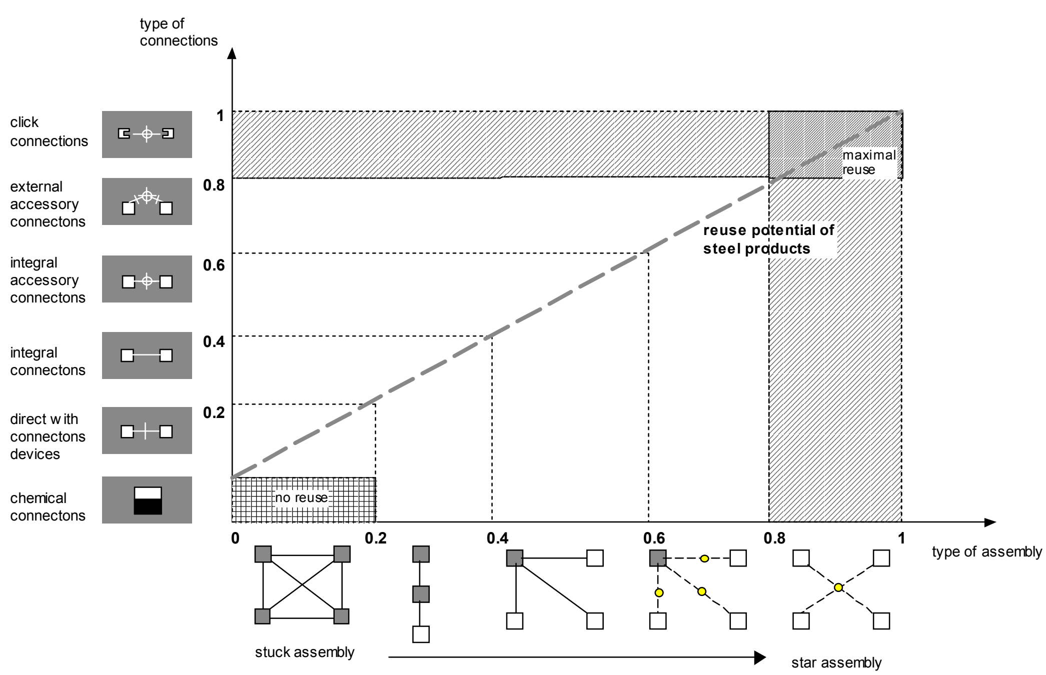


Figure 4: *Reuse potential as a function of type of assembly and type of connections.*

Increase of Re-use Potential of Steel by Design for Disassembly
Re-use of components is on the top of the environmentally-beneficial hierarchy of end-of-life scenarios. At the moment, 83% of steel products are recycled, 14% of steel products are re-used, and 3% of steel products are landfilled. One of the main reasons for the low re-use percentage is the design of structural configuration and its connections. Figure 5 shows reuse potential of a few products, determined by type of assembly and type of connections.

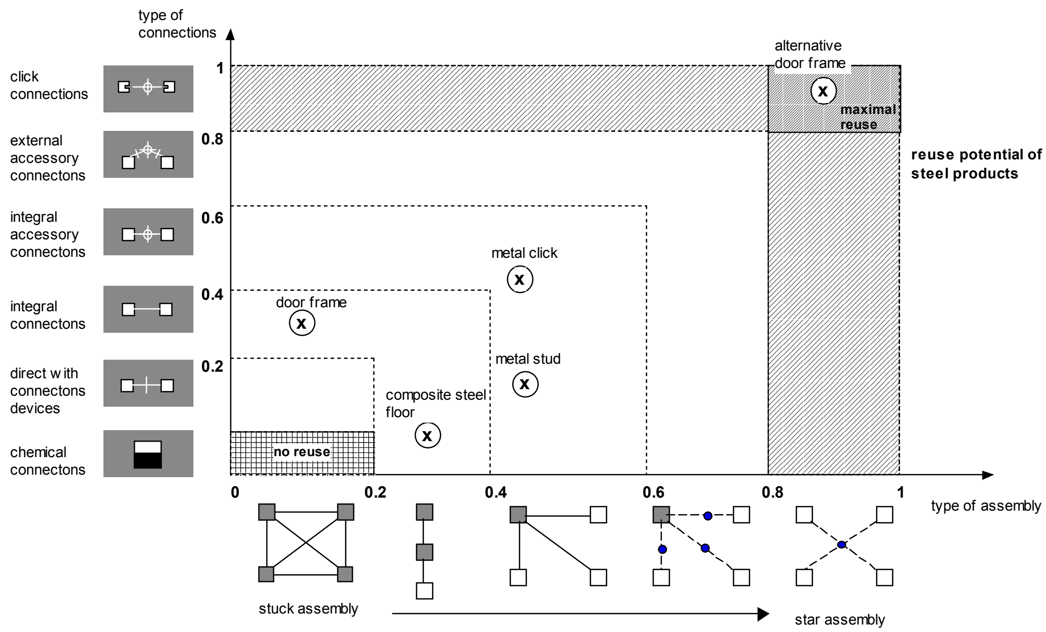


Figure 5: Re-use potential in relation to type of connections

Stuck assembly, for example, stands for not-accessible connections. In such a situation, one component can be replaced only by demolition or complex operation, which causes damage of the component.

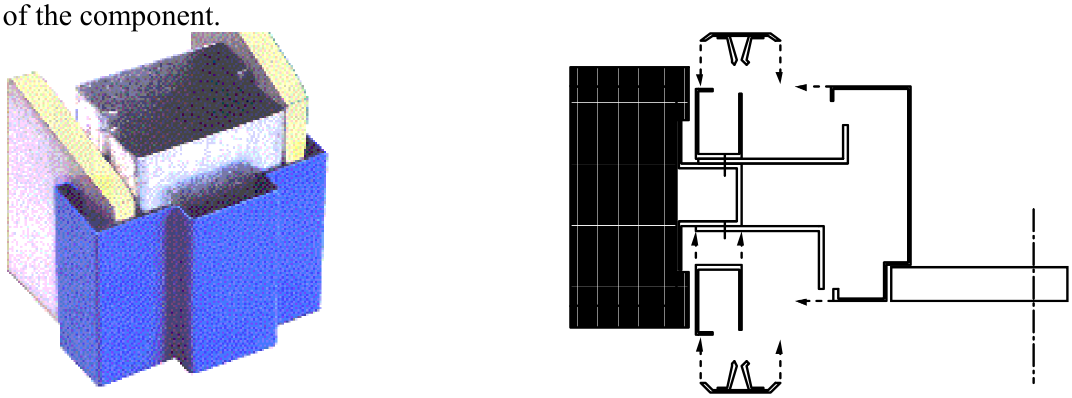


Figure 6 Left, conventional steel doorframe; Right, alternative for disassembly and re-use of steel frame

A standard steel doorframe in the Netherlands is one example where such a connection type is applied (Figure 6, left). An alternative to the conventional doorframe is presented in Figure

6, right, where assembly sequences and connections between the door-frame and the wall can be seen as a star assembly, since all components are connected via one intermediary. As such, components are independent from each other.

<u>Direct connections with additional devices</u> is another type of connection which causes low disassembly potential of steel products, since steel components are being damaged by nails or screws. As such, the quality of the steel element is weakened and, therefore, is not suitable for re-use. Such detailing is typical for metal stud walls and steel frames. This detailing can be improved by the design of special geometry of connection, which does not need additional connection devices (metal click wall), or by design of an intermediary between two products (Figure 7).

A metal stud wall has a re-use percentage of 7%. This percentage can be increased by the design of a connection that will provide a direct relationship between the stud and the wall panel, by the edge geometry or which will use an intermediary between the stud and the wall panel. This is the case with the metal click wall (Figure 7, below).

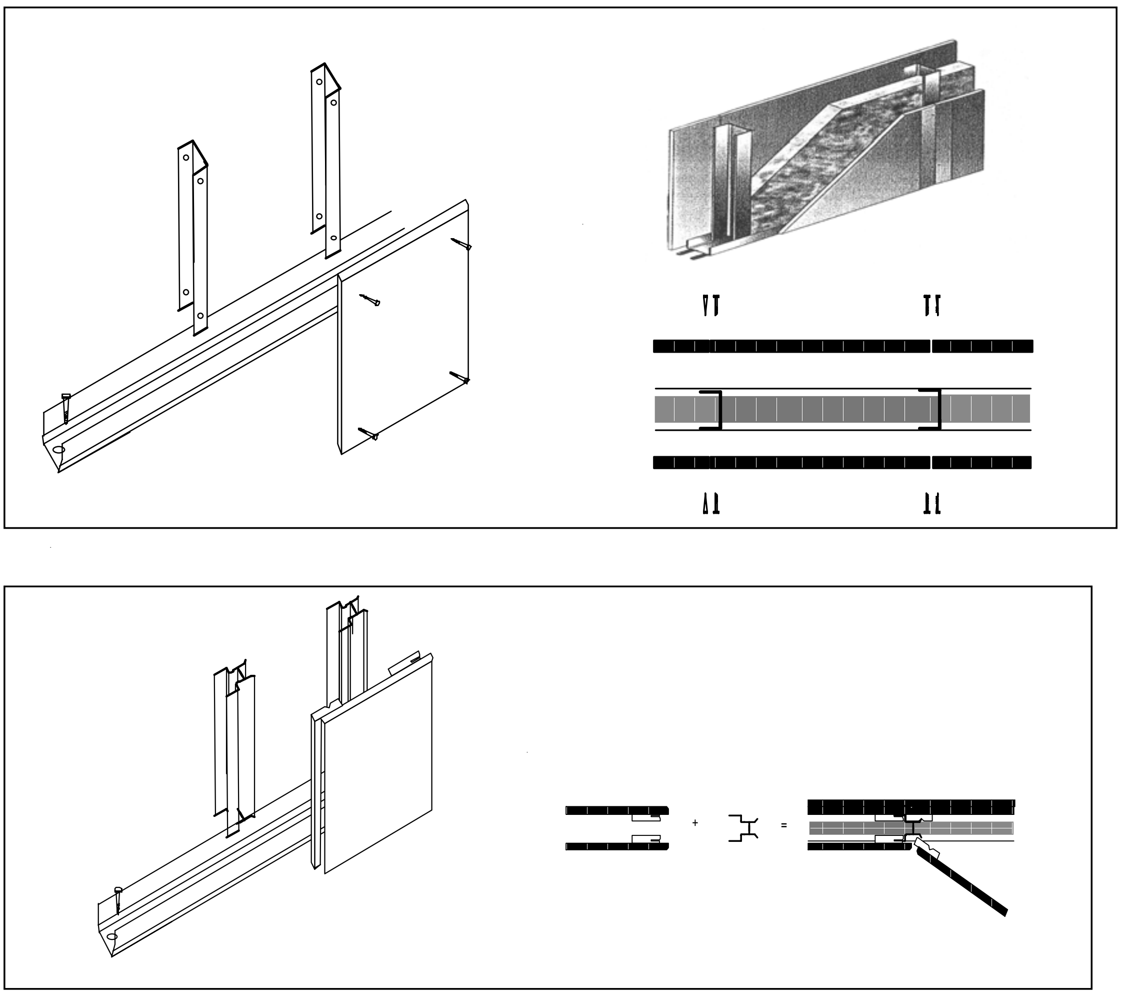


***Figure** 7 Above, metal stud wall; below, metal click*

These types of system walls are already widely used in office buildings, giving great adaptability to the floor plan in the changing requirements of the owner.

Increase of re-use potential of other materials by use of steel products

Besides improvement of re-use potential of steel products (through design for disassembly), steel can play an important role in improving re-use potential of other materials, such as concrete, brick, wood, etc. The ideal type of connection for deconstruction is an indirect connection, which has an intermediary between two components. Steel is a material that can be easily used as an intermediary between different materials (See Figure 8). Steel can improve the re-use potential of other materials as well.

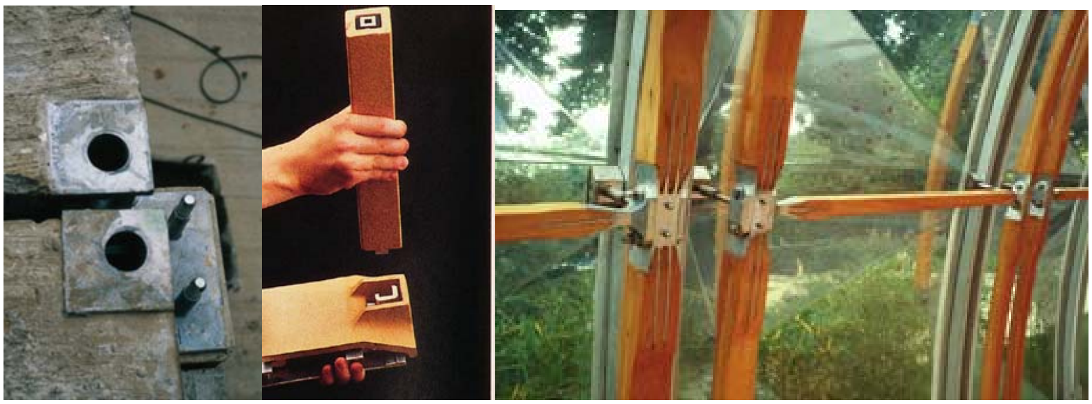


Figure 8: *Steel as an intermediary between concrete floor components, brick components, and wooden structural elements.*

The third role that steel can have in sustainable construction is in solving the problem of integration of different functions, such as installations, partitioning walls, and finishing. The current integration of these functions frequently causes demolition, especially in housing. Recently, a system has been developed in the Netherlands where the above-mentioned integration is solved by the introduction of the steel ducat, taking care of separation of different types of components (Figure 9).

Diagrams in Figure 9, left, represent the relationships between installation, wall, and finishing components in a traditional situation. Conventionally, electricity components are inserted into the wall service manually during the construction stage. After installing the components, wall service is flattened and plastered, making the network of cables invisible. The diagram in Figure 9, left, presents the relational dependence between components created by such an assembly strategy. Replacement of one component will influence all other components that are part of the partitioning wall. Figure 9, right, illustrates an alternative to the conventional approach. Independence between installation components and other parts of the partitioning wall structure is provided by element A, which stands for steel duct. This method provides a visible zone for installation components through the base of the wall and the doorframe, which is always accessible, and whose components are demountable (Figure 9, right).

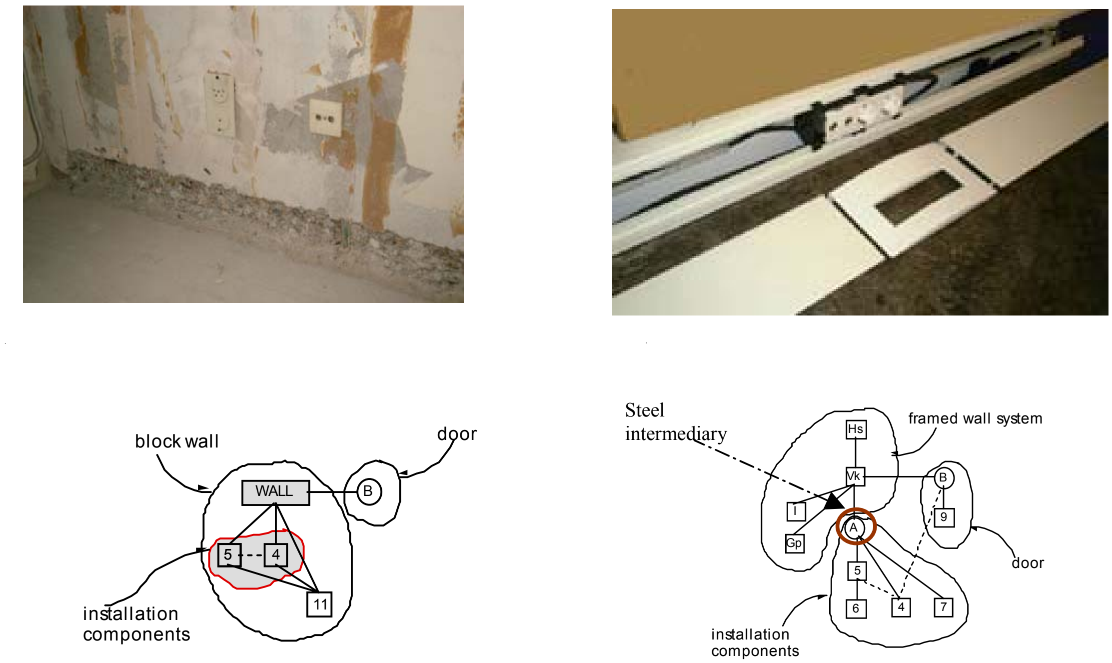


Figure 9: *Left, conventional integration of wall, installation, and finishing components; right, alternative to conventional approach by use of steel intermediary between different components [2]*

Finally, it can be stated that steel has great environmental potential and, therefore, can play an important role in sustainable construction. However, in order to use this potential, the way steel products are assembled and connected with other parts of a structure should be of major interest to the steel industry in the future.

CONCLUSIONS

The preliminary conclusions from an assessment of the relative impacts resulting from each life cycle phases include the following:

1. The ECSC study has confirmed the high recycling rates of steel construction products within Western Europe. On average, 83% of all steel construction products are recycled at the end of life, 14% are re-used, with only 3% landfilled. Although these results are encouraging, greater environmental benefits could be gained by increasing the proportion of products that are re-used.
2. Re-use percentage of steel products can be increased by a more conscious detailing process which will take into consideration assembly/disassembly planning, geometry of product edges, hierarchy of products according to life cycle coordination, and connection methods.

REFERENCES

[1] ECSC project: LCA for steel construction. Document RT913, Version 01, July 2002. Project management by Steel Construction Institute, Silwood Park, Ascot, Berks, SL5 7QN

[2] E.Durmisevic, B.J.H. te Dorsthorst; Building's transformation capacity as the indicator of Sustainability, A way to measure the environmental impact of flexible housing, Conference proceedings Open Building Mexico 2002

[3] J.Kapteijns, Ontwerpen van bouwknopen, OBOM TU Delft 1992

DECONSTRUCTION AND DESIGN FOR REUSE: CHOOSE TO REUSE

Authors: Timothy J. Williams, Research Coordinator; G. Bradley Guy, Associate Director
(Powell Center for Construction and Environment, University of Florida)

ABSTRACT

This paper/presentation will detail the theories and realities of a project to deconstruct a 1930's, 1,400 square feet wood-framed house for reuse into the construction of an approximately 3,600 square feet social services facility for at-risk young men. The paper/presentation describes how design for reuse can be applied to existing building materials in situ when the new building use is known prior to deconstruction. This presentation/paper will describe the reuse design, and processes, environmental issues, technical and regulatory issues involved in creating a model for other potential applications of deconstruction/reconstruction as a single continuous project.

KEYWORDS: Deconstruction; Building Materials Reuse; Design for Reuse

INTRODUCTION

Excerpt from Design Q&A by Charles and Ray Eames, 1967. The following questions were asked by Madame Amic and answered by Charles Eames.

> **Q:** What is your definition of "design?"
> **A:** A plan for arranging elements in such a way as to best accomplish a particular purpose.
>
> **Q:** Is it a method of general expression?
> **A:** No – it's a method of action.
>
> **Q:** Does the creation of design admit constraint?
> **A:** Design depends largely on constraints.
>
> **Q:** What constraints?
> **A:** The sum of all constraints. Here is one of the few effective keys to the design problem - the ability of the designer to recognize as many constraints as possible - his willingness and enthusiasm for working within these constraints - the constraints of price, of size, of strength, balance, of surface, of time, etc.; each problem has its own peculiar list.

Design Q&A was written at a time when most designers considered material constraints primarily in terms of costs, utility and aesthetics, and when resource scarcity and environmental impacts were not given their current emphasis. Regardless of a greater understanding of the environmental impacts of the built environment, the concept that the designer must solve human needs within a fully recognized set of constraints is timeless. Waste is not inevitable, but the result of design decisions – whether through intention or omission. Failing to consider the implications of building design on the use and waste of limited natural resources leads to significant problems.

US EPA has estimated that U.S. companies generate 136 million tons of building-related construction and demolition (C & D) waste per year, of which 92% is from renovation and demolition. With the US building stock rapidly aging and pressure rising to upgrade it, this waste stream can only increase. EPA has also estimated that only 20-30% of C&D waste is presently recycled.

The building industry has an enormous environmental impact. The U.S. Geological Survey has performed a "materials flow" analysis showing that, excluding materials used for food and fuel, construction activities consume 60% of the total materials used in the U.S. economy. The continued use of virgin materials for construction consumes enormous amounts of material and energy, while continued disposal of building waste fills up landfills and buries potential resources rather than extracting their maximum value for productive uses. Both upstream and downstream impacts of these practices increase emissions of greenhouse gases – from the loss of forests as carbon sinks, the burning of fossil fuels in virgin product extraction and manufacturing, and the release of methane (a greenhouse gas 21 times more powerful than carbon dioxide).

While recycling of C&D debris is an important part of the solution, efforts are growing within the solid waste community to find innovative reuse options that, in accordance with EPA's long-standing "solid waste hierarchy," preserve even more of the value incorporated in the original product while saving more energy and producing fewer greenhouse gas emissions than recycling could.

Deconstruction is defined as "the disassembly of buildings so as to safely and efficiently maximize the reuse and recycling of their materials." While limited salvage has long been a part of demolition practices, deconstruction aims to increase reuse options by pushing materials salvage beyond such items as windows, doors and light fixtures to include such elements as flooring, siding, roofing and framing where these materials have retained their value. In some cases, deconstruction can generate items that are no longer available anywhere – such as the old-growth Douglas fir and redwood lumber that has been removed from closing military bases.

Deconstruction has been growing, but it remains an immature industry that has not yet gained wide acceptance. In order to succeed, deconstruction needs to be developed to the point that industry and policy makers can understand it as a transparent, flexible, mainstream, and intelligent alternative to demolition.

Current roadblocks to the growth of deconstruction exist at the both the "supply-side" and the "demand-side" of building materials' life cycles. At the supply-side is the design of buildings and construction techniques and materials that hinder disassembly and reuse. At the demand-side is the failure of designers to specify used materials where appropriate; and the failure of building codes to address the reuse of building materials. Nascent research is beginning to address some of these problems, e.g., the University of Florida is studying the issue of "design for deconstruction" and the USDA Forest Products Laboratory is studying how to appropriately re-grade reused dimensional lumber. However, demonstration projects are needed to prove the validity and attractiveness of deconstruction and materials reuse options – particularly to the private sector.

Design for Reuse (DfR) seeks to demonstrate resource efficiency at both ends of the building lifecycle.

The Design for Reuse project used as a basis for this paper was begun with the understanding that waste and irresponsible use of our limited resources is the result of design, that DfR has the potential to mitigate the environmental impacts of building construction, and that in order for DfR to fully realize its potential benefits, it must be accepted from the beginning of the design process as a primary constraint around which the design problem must be solved. This has already been done in a number of industries such as manufacturing, software design, and content development.

The paper begins by examining some of the current DfR practices in other industries in light of what we can learn and apply to building design. From there, it follows the progress of a case study project with an emphasis on some of the ways in which a DfR project may differ from the traditional design process.

Ultimately, it hopes to demonstrate that efficient use of materials and waste minimization are integral constraints that need to be addressed in any building project. Through Design for Reuse, building designers can not only reduce waste, but also discover additional potential for creativity and excitement in design.

DESIGN FOR REUSE LESSONS FROM OTHER INDUSTRIES

Design for Reuse is a concept that is already widely recognized in a number of fields beyond building design and construction. From manufacturing to software design, the idea of getting additional use out of invested resources (material, energy, or human) is well established and supported. This paper will briefly explore what is being done in other industries in order to discuss what can be learned from these industries as well as what is different for DfR in the building industry.

In manufacturing, "design for reuse" has been used to refer to several different concepts. One use of the phrase involves the design of a manufactured product in such a way that it can be used multiple times. This could be repeated use for the same purpose, as in refillable containers, or a secondary use after the first is complete, as in the WOBO beer bottle which was designed to serve as a brick-like building block for use in housing (reference?). The other manufacturing concept is to reuse design or components within a product – e.g. using a shared car chassis throughout several years of a particular model of car or even across model lines.

Design to accommodate multiple, sequential uses of a product demonstrates that usefulness can have a longer timescale than first use – the product can outlast an initial use, for example packaging to be used as something else, or last through several uses, such as pallets that can be used multiple times. One factor that contributes to the probability that a product will last through several uses is durability, so that the first use does not wear it out. Extra investment in the original production can realize savings over the total life cycle. Another means of assuring that utility outlives several uses is to design for compatibility – more universal design of a component means more potential for reuse. Many building materials exhibit this quality. Standard dimensional lumber can be used in many different applications with ease. Standardized masonry units are also universally useful. Consistency of size across the US ensures that bricks from different origins or sources can be easily incorporated into a single project.

By planning to reuse individual components within models or across model lines, the automobile industry reduces design time and manufacturing set-up changes. Rather than beginning each model from scratch, refinements are made to an established and generic base design. The more flexible and universally useable the base design, the more likely and efficient reuse of that design will be (reference?).

In software design, design for reuse refers to program design that uses standardized packages of code that perform commonly needed roles. With some extra upfront investment to design reusable bits of programs, those bits can be utilized across many different software applications resulting in greater efficiency and reduced design time, making the companies which adopt this practice more competitive (reference?). When beginning to move towards incorporating design for reuse into their work, software companies are advised to keep some things in mind that are just as useful to building designers as software designers. The first step is to look at the current practices within the company to see if some informal reuse is already taking place and to evaluate existing work in light of reuse potential. This step involves working from what is available and is one of the main principles of reuse that will be explored later within this paper. After the initial assessment of the company's work is completed, subsequent work is evaluated in terms of how well new code facilitates eventual reuse by others. This is the key to achieving ever-greater design productivity. For buildings, designing for future reuse is the key to ever-greater material efficiency and waste minimization.

THE PROJECT

In most respects, the process of DfR will be the same as any other design project. Notable exceptions relate to specific communication with the client about goals and expectations for reuse, careful planning for and acquisition of salvaged materials, and in some cases, greater creativity and flexibility in the design itself to fully utilize the unique potential of reused materials.

Project Initiation and Client Communication

It is critical that the client is supportive and informed about the reuse of building materials in any project. That said, there is much that the architect or designer can do to explain the importance of reuse and allay client fears or concerns about the feasibility, quality, and appearance of reused materials.

The case study is this paper was somewhat unique in that the project began with an availability of materials rather than a programmatic need. Gainesville Regional Utilities (GRU), a municipally-owned utility possessed a vacant 1930's, 1,400 square feet wood-framed house, for which it had no functional use. Owned by successive generations of the Wesley family, the house was maintained and used as a residence for many years while land-use changes around the property resulted in the surrounding single-family residential neighborhood being replaced by the expansion of GRU facilities to meet the needs of Gainesville, Florida's growing population. With the passing of the last member of the Wesley family who wished to live in the house and the unsuitability of the structure for any of GRU's needs, the property was left vacant for several years. GRU investigated relocating the house in its entirety, but found this plan to be prohibitively expensive and could not find an interested and appropriate new user for the house "as-is".

After learning of the University of Florida's Powell Center for Construction and Environment's (PCCE) research and work in the growing field of deconstruction, GRU became interested in pursuing a partnership to find a new use for the Wesley House. Deconstruction of the house offers a method of removing the house with a minimum of waste while at the same time finding a new use for the materials available from the house in a manner that provides much more flexibility of reuse than simply moving the building.

After a search for potential recipients of the building materials, GRU found the Reichert House program for at-risk youth, which was preparing to begin design and construction of a new 3,600 square foot facility, and was greatly in need of support.

PCCE met with the director of the Reichert House Program and learned that some of the primary needs for the new facility were durability of the materials and affordability. Discussions about the reuse of the building materials revolved primarily around these issues with less attention devoted to questions about appearance, which is another concern that many clients will bring up in regard to reused materials. In terms of durability, while the finish materials from the Wesley House (primarily a large quantity of beadboard) were not suitable for some of the high-impact recreational spaces of the new facility, the Wesley materials could be used to advantage in a number of different areas of the building. Generally, PCCE and the Reichert House director felt that the beadboard could outperform the more standard drywall and plaster in terms of impact resistance and general wear. Another advantage of employing reused finish materials is that the pre-distressed condition of the beadboard could be used as a positive feature within the design. "New" is an inherently temporary condition. Polished surfaces, particularly in high-use areas, can quickly become marred or dented. Such inevitable imperfections will then standout noticeably from the rest of the finish surface giving an impression of wear and disrepair without active and costly maintenance. By using a material with an established history of use and a surface that is able to wear gracefully, the interior of the new Reichert House should be able to withstand years of hard use without requiring expensive maintenance to keep it looking the way that it was intended to be at the time of construction.

Acquisition of Materials

The acquisition of reused materials is distinctly different than acquiring new materials. New materials are typically available in any quantity desired and, with some planning, at any time they are needed. This has not always been the case. In many ways, designing for reuse is akin to historical building practices where local availability of materials, and conservation of materials was a primary design constraint. The “grave-to-cradle” approach directly ties the removal of one building (maximizing the efficiency of “mining” its resources) to the construction of another (minimizing the consumption of new resources).

Before beginning the design of the new facility or deconstructing the Wesley House, a careful inventory of the materials in the Wesley House was prepared. PCCE worked with the director of the Reichert House and the architect to review the inventory, set reuse goals for the new construction, and focus deconstruction efforts on materials that were the most suitable for reuse in this project. The material inventory was examined in light of a realistic salvage rate in order to calculate projected salvage yields. These projections established the potential area of the new facility that might reasonably be constructed from the salvage. After deconstruction, another inventory will be taken in order to verify that the required materials were salvaged.

Flexible Design

Throughout the design process, flexibility is invaluable. Initial reuse goals or material inventories may turn out to be unrealistic during deconstruction or material acquisition, or new material opportunities may present themselves and require a change of plans to fully take advantage of them. The principles of Design for Reuse were developed to help designers recognize and take advantage of the unique opportunities presented by reused materials and to approach the design with the necessary open-mindedness and flexibility.

Principles of Design for Reuse

These principles are not intended to be comprehensive, but to serve as a starting point and collection of stimulating ideas. The nature of the task of designing for reuse allows for a great deal of creativity on the part of the designer. The collective ingenuity of the design profession is bound to make any list of principles quickly obsolete as new strategies for dealing with the universal problems of resource inefficiency and waste are developed.

1. Work with what you have

The first principle is simple – a phrase that appears in almost all writings dealing with the reuse of salvaged materials. **Work with what you have** available (reference?). The fundamental difference between designing with reused as opposed to new materials is that the materials have already been fabricated or processed and dispersed into the built environment. If you examine the flow of new or recycled materials en-route from production to use in a building, the materials begin in large volumes and concentrations at production facilities and progressively smaller distribution warehouses until the final truckload delivers the precise quantity of materials needed at widely dispersed construction sites. The process is reversed when designing with reused materials. Salvage operations begin collecting dispersed and widely variable materials. The future certainly holds the promise that reuse networks and markets will duplicate the consistency and availability of first-run material production, but for the present working around what is available for reuse is more productive. It may also be best if reuse suppliers do not pattern themselves after first-run producers. One of the strongest arguments for reuse is the environmental benefit from conserving energy resources. The more energy invested in gathering materials, transporting them to regional distribution centers and then back out to individual job sites erodes the potential savings of reuse. It is part of embracing the design constraint of choosing reuse to adopt a different attitude towards resources. Instead of ignoring the hidden costs of material production and proceeding from the assumption that there is an infinite and cheap supply of whatever material is desired, reuse begins with the concept that supply is limited and valuable.

2. Kit-of-parts

One strategy for working with the materials that are available is to define a kit-of-parts from which to work. Like a child's stack of blocks or set of Lincoln Logs, the design problem becomes how to achieve the desired end with the pieces on hand. There are many models for how to define and use the kit. They range from the highly specific methods used in some historic preservation projects where building parts are literally numbered and reassembled, to a more modular approach with a certain number of construction elements that can be configured in nearly infinite relationships. The most useful way of working with a kit-of-parts will depend upon the project – the more limited the palette of materials, the more rigorous and careful the designer will have to be with the kit.

3. Opportunistic and systematic reuse

A refinement of the kit-of-parts strategy is to utilize a combination of "opportunistic" and "systematic" reuse (reference?). These terms have been adapted from the software design industry and define two levels of precision of reuse. Systematic reuse is a detailed and planned approach. Pieces to be reused are identified before construction and numbered or labeled. Each piece is specifically identified in the construction documents. Opportunistic reuse is less specific. A quantity of material is made available for the contractor or workers to use as needed in the project. An example would be a bundle of reused studs that can be pulled from as required throughout construction. Used in combination, opportunistic and systematic reuse provides a flexible system for dealing with fixed supplies of available reused materials. Depending upon the building design and structural or non-structural materials that are needed, systematic or opportunistic reuse will be more applicable. A post and beam structure will require a systematic approach as spans and strength of materials must be pre-determined. Non-structural surface materials may lend themselves more readily to opportunistic reuse whereby structural qualities are less important and finishes can change from surface to surface or even on one surface, as with a partial height wainscote. The availability and kinds of individual versus bulk materials will also affect systematic versus opportunistic reuse. A one-of-a-kind material is inherently a systematic reuse.

4. Soft-palette

The term soft-palette refers to a performance-based, flexible approach to specifying materials (reference?). When designing with a soft-palette the designer can give a description of the characteristics necessary for a particular part of the building, but leave the exact material to be used open until suitable materials are found. For instance, an exterior elevation can be drawn showing areas for "material one" and "material two", performance criteria for each material in terms of durability, weather protection, and quality of finish, but allow for a number of different materials to be used depending upon what is available at the time of construction. This may take away some of the control of the designer, but it would be understood that samples of prospective materials must be submitted for approval before use. This could also be seen as a return to the sort of architect/craftsman relationship prior to the 20th century, when the architect was responsible for the overall concept of the interior finishes, but the individual craftsman had a great deal of responsibility for the quality of the final product, selection of decorative elements, construction technique, etc.

5. Appearance of reuse

Working with what you have has meaning both in terms of availability and quantity, but also relative to the appearance and quality of the materials. Expectations that reused materials should be indistinguishable from new are not always realistic. It can be argued that almost immediately after occupation, all of the materials in a building become "used" whether they were originally new or not. "New" is an inherently brief characteristic, which is quickly and permanently replaced by "used". In many cases, with some work reused materials can be refinished or otherwise brought back to a like-new condition. Wood can be sanded down and oiled or polished. But it may not be necessary to do so. As long as the quality of the material is satisfactory, the appearance of it is more a question of aesthetics, which are infamously changeable. Many structural materials will spend their working lives hidden from sight behind layers of finish surfaces. Materials that will remain visible can be designed with rusticity or patina of use as an attractive part of the overall scheme. An important way of advancing the mainstreaming of reuse is to work to change perceptions of what materials are attractive, and what conditions are desirable. If newness is the only desirable appearance, then tearing out and replacing materials before the end of their useful lives will exacerbate waste problems.

Repeat, Rethink, Renew

The principle of **Repeat, Rethink, Renew** is both a hierarchy of the environmental benefits of reuse options and a set of reuse methods. Repeat refers to the direct reuse of a material in new construction exactly as it was used previously; a wall stud becomes a new wall stud, flooring becomes new flooring. Rethink involves the reuse of a material, with or without modification, in a manner that is different from its intended reuse, but in a way that is consistent with and appropriate for its inherent properties. Renew describes the combination of new materials with salvaged material in order to bring about successful reuse. The three R's of Reuse are comparable to the long-standing "solid waste hierarchy" of Reduce, Reuse, Recycle (reference?).

Repeat

Repeat involves the least expenditure of additional energy possible while giving a second life to the building material. When a framing member is directly reused as a framing member, no energy needs to be expended to ready the wood for reuse, no milling or addition of paint or other finishes. From a sustainability perspective, this is the most efficient of the reuse options.

Rethink

When employing the method of Rethink, an analysis of material properties or fitness for purpose takes precedence over the original function of the material. In fact, the more completely the original function can be forgotten or ignored, the easier it becomes to envision new possibilities. Rethink may require the modification of the material and may end up using more resources than Repeat. The house can be broken down into materials with specific qualities rather than specific functions or applications. Veneer plywood is used as a flat finish surface to cover the interior of a stud frame wall. It can be reused in exactly that way, but it need not be. Instead, the design can be based around a sheet of material with X dimensions, with X shear strength. If the veneer was cosmetically damaged in removal or was otherwise unsuitable for a finish surface, it does not necessarily follow that it can no longer fulfill a function. It could still be used as the skin of a structural panel, finish floor underlayment, or other substrate.

Renew

Renew is a reminder that reuse is not a way of designing that excludes or ignores the value of new materials in appropriate situations. Even badly worn flooring can be reused if sanded and treated with a fresh application of finish. Novelty siding from wood framed residential buildings is widely available for reuse in North Central Florida, but a batch of salvaged siding is usually a mixture of sound and water damaged boards. Combining new siding of similar profile with the salvaged siding allows reuse even when the available quantity of reused material is not sufficient to meet the total needs of a new construction project.

Design to Facilitate Future Reuse

One of the biggest obstacles to the reuse of building materials is that buildings up to the present have not been designed to facilitate the salvage of building materials. It is time and labor-intensive to disassemble existing building stock. In any reuse project, it is wise to incorporate some design for disassembly tactics to make future reuse or renovation easier.

Maintain or enhance value of material

In the optimal situation, reuse should maintain or enhance the value of the material. This is accomplished by appropriate use, fullest use, and careful consideration of applied finishes.

Appropriate use implies reusing materials in ways that are consistent with their performance characteristics. Wood siding removed from an older structure has already seen years of hard use. It is likely a rot and insect resistant species of wood. It is also likely to be somewhat worn and lacking in fine finish. An appropriate reuse of this material would be in an exterior application where its good performance can be continued and where its surface imperfections will not detract from its desirability. Interior flooring could not be reused in such an exterior application. While its hardness and durability may be appropriate, it may not be as weather resistant. Also, existing finishes that have been applied to the flooring are likely to be intended for indoor use only and could fail under the new conditions. Using interior materials on the exterior could be an example of inappropriate use, which would not maintain the integrity of the material.

Fullest use calls for the best and highest use of the material possible. It would be inappropriate to use old growth, high quality wood as a sub-floor that will never be seen once the new building is occupied. Better to use this material where it is visible and can be appreciated. Also, materials should be reused in as complete a state as possible. It is much easier to find a way to reuse a long board than a short one. Also, for later deconstruction, it takes just as much effort to salvage an 8-foot board as it does a 2-foot, but the 2-foot one is much less valuable. There is more value and flexibility in large pieces or quantities of uniform material.

A note on the **careful consideration of finishes** and adhesives; the use of lead-based paint, asbestos containing materials, and messy, difficult-to-remove adhesives has been a barrier to the successful deconstruction and reuse of materials. The required investment in time and money to remove and dispose of these contaminants has made many prospective deconstruction projects unfeasible. Learning from these past mistakes when designing for reuse will help preserve the materials on into the future.

CONCLUSIONS

Presently, the case study project involving the deconstruction of the Wesley House and the design and construction of the new Reichert House facility is in progress. The director of the Reichert House is supportive of the reuse of materials in a discreet section of the new Reichert House facility. PCCE is working with the architect-of-record for the Reichert House to refine a Contract for Design for Reuse, which sets reuse goals and calls for specific implementation of the DfR principles described in this paper. The fulfillment of the principles established in this paper will be "tested" through real-world application.

THE DIS-ASSEMBLY DEVELOPMENT OF SERVICE LIFE BASED CONSTRUCTED WORKS

Author: Wyatt DP (TR12 6SE. UK)

ABSTRACT

Constructed works and their facilities pose a significant challenge to 'closing the loop' between the incoming supply chain's service life and subsequent end-of-life deconstruction responses. But there is a case for end-of-life responses being addressed in design and service life planning, based upon the emergence of ISO 15686. Why? Simply because the ISO standard could bring those involved in waste stream management closer together to design and end-of-life recovery, and consider deconstruction and disassembly within a whole-life development. Doing so leads to the closing of the loop, based on the service life.

This paper suggests that designing and managing constructed works will require a grasp of the design's service life relationships, and an understanding of service life, detailing for dis-assembly, work sequencing practices, access needs, and deconstruction practices. Nevertheless, the building's design must be underpinned by the assurance of the manufacturer's life-test data, and be competently detailed for both assembly and disassembly. The design for disassembly must also be documented and communicated to those who are to build, maintain, and deconstruct that building configuration. At the same time, an appropriate service-life based philosophy must be developed, with definable key attributes based on performance. Then, the whole-life value of the supply chain and waste stream can be optimised within economic and environmental frameworks.

Because of the importance of the service life itself to deconstruction, it is also suggested that ISO Standard 15686 Service Life Planning be brought into the future development of TG39, especially for deconstruction of disassembly proposals in new work, and for application to existing buildings to be deconstructed. Concluding, consideration to both deconstruction and disassembly for reuse within a whole-life context would encourage end-of-life and whole-life supply chain management.

KEY WORDS: Dis-assembly; Service life planning; Whole Life Supply Chain Management, End of Life; Closing the loop

INTRODUCTION

The supply chain may be described as the foundation for the built environment, and as a contributor to the construction industry's ability to build, maintain, and upgrade its infrastructure, buildings, and facilities. The supply chain also lies at the heart of some of the problems relating to sustainability and securing sustainable development. The supply chain is responding positively to ISO 14000, while also responding to environmental accords and protocol agreements, and depressing ecological damage, CO_2 emissions, resource depletion, and waste. But, the ability to link up with recovery and to extend a return to the sender or some other outcome to secure a whole-life supply chain is largely underdeveloped in the constructed work's waste stream (Wyatt & Gilleard 1994).

We should look to a future within a whole-life supply chain management with a new paradigm shift. One that can secure an effective hook up between the outgoing supply chain and its end of life as a waste stream, and address the practicalities of such waste stream relationships. In doing so, we consider deconstruction in terms of recovery of the waste stream for new uses and, as more factory components and systems are used onsite, for their intact, and for reuse responses at the design stage. Perhaps through disassembly acts of docking, undocking, and re-docking, such responses may also be seen as sustainable actions, even if only to keep the embodied energy laid up in service.

END OF LIFE

Unlike most other processed products, a constructed work and its constituent parts remain in use significantly longer. Like death, end of life comes to all constructed works at some time that is often unknown at the time of the original design.

The end of life of the constructed work may relate to materials, components, and systems that are replaced and fit out during the constructed work's lifetime and its final clearance. But in many respects, attention is now needed at the end of life of such works. Here, the matters of obsolescence, abandonment, redundancy, and surplus to requirements pose problems, both in portfolio and asset-management terms, as well as to waste stream recovery.

And yet, the destructive act of demolition of a constructed work often takes place in a fiercely competitive environment. One which, in itself, is constrained by both the urban planning control response and often, low investment in recovery technology.

Equally, there are problems in securing practical pathways to closing the loop between the incoming supply chains and the constructed work in service embodied energy. In that sense, the CO_2 final account and adverse impact upon the landscape (i.e. in the supply chain sense), to some extent, has already occurred. Consequently, the deconstruction process optimises the equivalent CO_2 that would be expended from a new material or component supply chain through its material and component recovery.

Concluding, the deconstruction process, including disposal and dispersal, underscores the need for deconstruction to be related to both the design and composition of the constructed work, but within a whole-life management of the supply chains used.

WHOLELIFE SUPPLY CHAIN

Closing the loop between the incoming supply chain to build and a future waste stream implies the need for developing and adopting a whole-life supply chain management (WLSCM) practice within the constructed work life and its portfolio, as implied in Figure 1 below.

While separated by a constructed work's lifetime, both the project's incoming and outgoing material and component supply chains and their waste streams should be considered, in terms of their service life (i.e., the time that separates them from the construction and deconstruction).

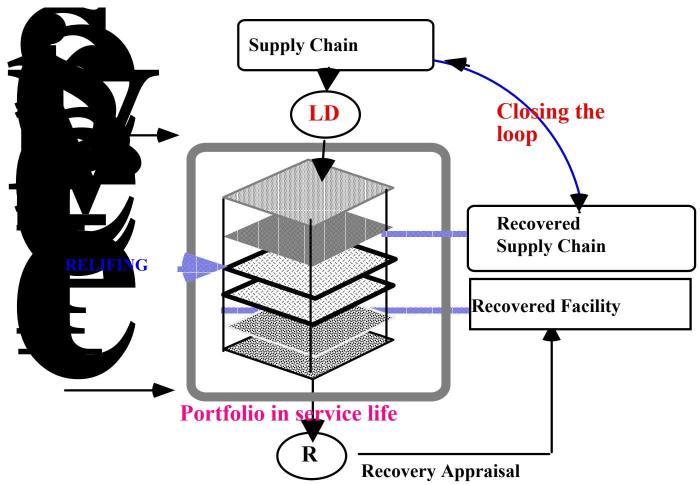


Figure 1 Wholelife Supply Chain Management Model

Footnotes to Figure 1,
(i) The Portfolio is represented by the embolden line surrounding the multi deck shown, with the supply chain shown as an input responding to the Life Design (LD). The multi-deck within the envelope represents the constructed work portfolio's own lifetimes and is discussed in an earlier paper (Wyatt 1983).
(ii) The constructed work may be relifed any number of times, or its facilities recovered. Likewise, the individual parts of a building may be maintained on station, in varying degrees of fitness, until R is reached
(iii) The WLSCM comes from the point of specification and the service life profile, shown to the left of the point of recovery and exit. Here, the trick is to optimise through relifing and recovery of the service life of the material component or constructed work.

The relifing responses can be seen as a positive response that may also lead to recovery of some part of the constructed work's original supply chain(s) used. But, there is also a conflict with the "nobler intent" of optimising the attributes of a service life of each component or material. Why? Simply, any life design is the sum of its systems with a range of performances. Even with a deconstruction and disassembly practice, possible recovery outcomes may be limited. Why? Because of the wide range of materials and components brought in from a large number of suppliers and, in one form or another, in varying quantities and from diverse locations.

Where the recovery of the supply chain takes place, one may discuss the start to closing the loop and, in a way, map out the canvas for the whole-life supply chain management, and its implications for disassembly by design and future deconstruction.

SERVICE LIFE AND ISO 15686

Because all materials and components have a *service life*, an embodied energy and a failure mode, we have now arrived at what may be seen as the start of major change in whole-life supply chain management and, by inference, deconstruction management.

Service life has been defined as: '*that period of time at which the building, parts or elements components and services of a building reach a state of performance which is unacceptable'* (BS ISO 15686 2000). The service life is, however, a measure, or resistance of time between the incoming supply chain that is configured to create space, or a facility and its outgoing waste stream. The service life stays with a material, component, system, and element. So, optimisation may come from designing for service life recovery with flexible designs, which permits picking up and casting off different supply and waste streams.

It is necessary to understand changing recovery technology, as well as the embodied energy assessment of the service lives of the constructed work, in an economic framework. Likewise, a need exists for a common language that facilitates whole-life communication and its recovery optimisation between Manufacturer and Recoverer, Client and End User, and the Design team and their Building. Meanwhile, the intent is to bring the areas shown in Figure 2 together and close the loop along the lines schematically shown.

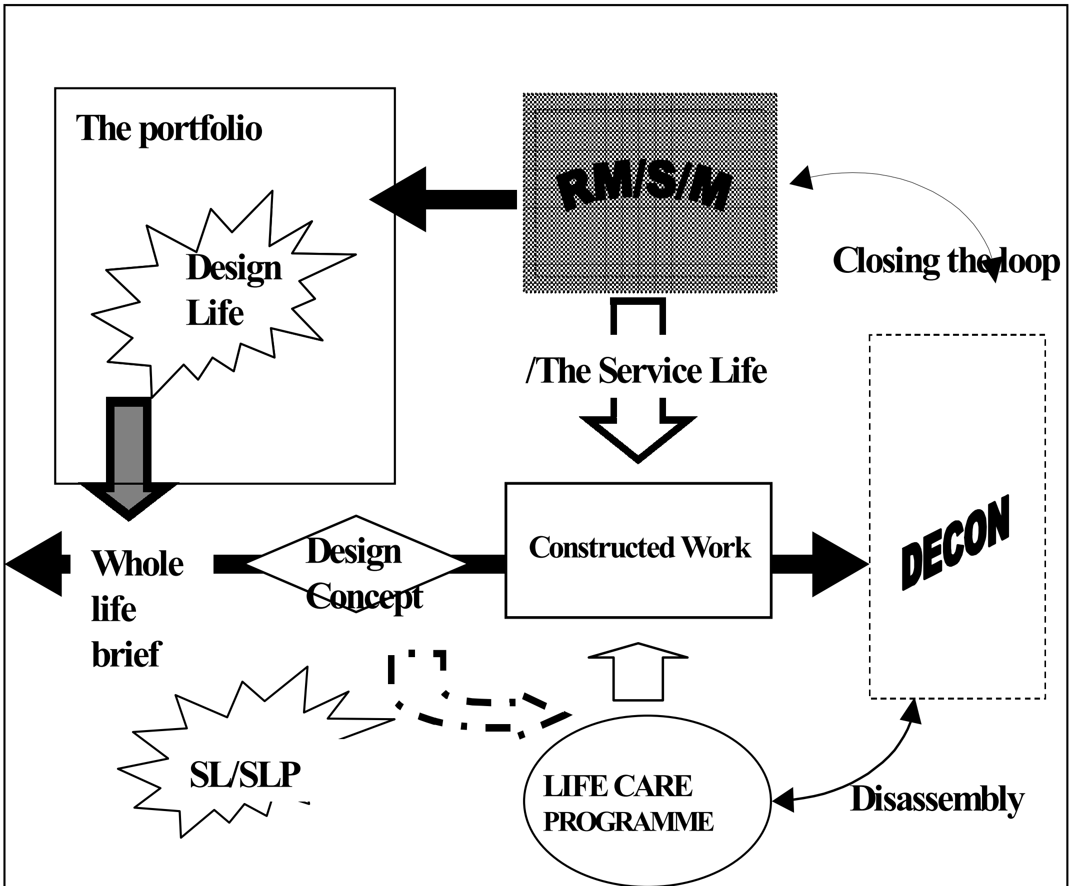


FIGURE 2 WHOLE-LIFE SUPPLY CHAIN MANAGEMENT

Footnotes to Figure 2
Relifing may also sustain and extend the "first life" of a constructed work. It may also form part of the "Decon" and End of Life responses, and form part of a recovery management. In both situations, durability will, however, be an important recovery for reuse consideration, where requirements for durability are expressed in terms of design service life.

(ii) Here (See also Table 1), the WLSCM response, in effect, would bring the many stakeholders, players, and actors together into some yet-to-be-defined relational architecture—perhaps through the focus of the constructed work, its supply chains, and the end of life waste stream deconstruction actions. Doing so secures both husbandry and stewardship in their respective environments.

In terms of recovery viability from deconstruction, there is an important constraint to be addressed in the area of durability requirements, especially in designing for deconstruction and, in particular, promoting disassembly and reuse in new works.

Note, too, that requirements for durability vary from building to building, and from one component or material to another. Such requirements relate to an intended fitness for use, and must include costs, frequency, and the extent of maintenance, replacement, and repair necessary or needed. Finally, the value of recovery may be degraded unless service life planning is robustly addressed. So, service life planning must be approached with care if the service life, durability, and recovered value are to contribute to disassembly and reduction of the waste streams of constructed works.

DIS-ASSEMBLY DEVELOPMENT THROUGH SERVICE LIFE PLANNING

The design life of the building provides a basis for the determination of the design's service life of the building specification, including materials and components. At the same time, service life planning presents a process that will help to ensure that a building or constructed asset's design meets, or exceeds, the regulatory and client performance requirements.

Such requirements may be expressed as different kinds of performances, with a range of service life durations, functional performance level(s), and economic and environmental performances.

This approach (illustrated in Figure 3) indicates the importance of disassembly in service life planning, and should be addressed in two broad areas. First, in the area of the constructed work's systems and components proposed, and second, in the area of the constructed work's kit or plant and equipment to be installed. It should be particularly clear in the second area that a high degree of return to sender could be promoted with given end of life considerations, and perhaps (unless disassembly is also possible) with component and element recovery.

Consequently, design and life-care management practices need to be brought closer together and need to contribute to developing the WLSCM response, so that economic service life may become recoverable.

In effect, the service and target service life, in their respective domains, play a significant part in designing for disassembly. While neither forms the focus of this paper, it is worth mentioning that in the field of service life planning, a considerable amount of common ground exists for a link with CIB W80, W60 and TG39.

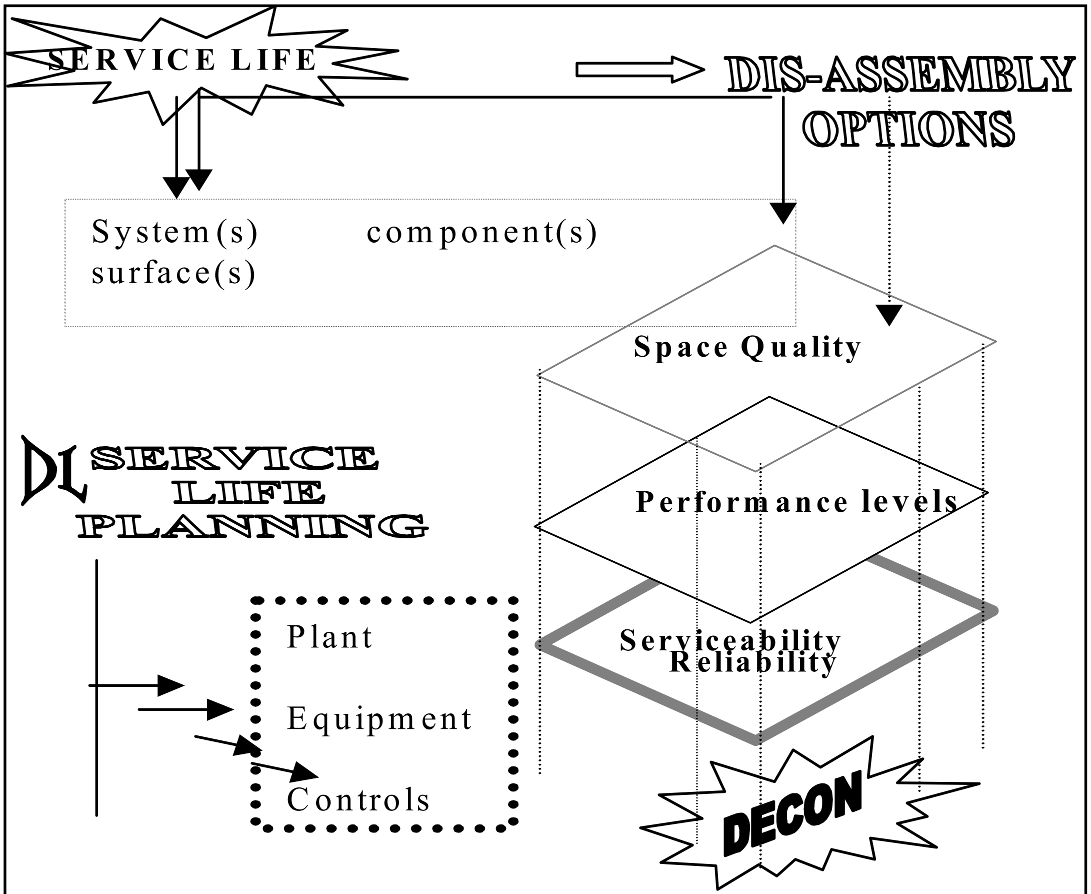


FIGURE 3 SERVICE LIFE DECONSTRUCTION

- Disassembly lifetime designs, through service life planning, should establish the overall breakdown of the constructed work into its elements, systems, and components. At the same time, some critical assessment of construction and dis-assembly would be expected in the following areas:

- First, there is a hierarchy, or common grouping of service life durations, often associated with the given design, including a number of service life designs and trade packages, as intimated in Figure 4.

- Second, in service-life design terms, there is usually a need to appreciate the disassembly issues of the individual designs of systems. Likewise, elements, materials, and components will have a range of service lives and durability quality. Here, the value of a diagnostic approach is likely to improve new proposals and existing "Decon-dis-assembly" appraisals, i.e., by adopting a fault tree analysis and failure mode effects analysis (MTTR/MTTF) approach.

- Third, the longer the life of a constructed work, the more problematic disassembly recovery options may become. The problem here is to predict a future that can handle recovery and reuse outside of the Portfolio or Project domains.

- Fourth, there may also be a threat arising from changing regulatory standards or from technology, business, or organisational requirements, that may invalidate the design or recovery intent at a near or distant future time.

Concluding, construction activities for disassembled sustainable buildings also require a life cycle analysis (LCA) response in their candidate product selection (Trinius W (2002)). At the same time, attention is directed to the fact LCA techniques (AFNOR 2000) have been adopted for other product areas where the service life of the products is often much shorter.

DIS-ASSEMBLY DESIGN

Decon needs to be included as an input into design and designing for recovery. So, in responding to service life planning, it is necessary to return to the relational nature of the players embraced in WLSCM, and their input or contribution to decon and service life planning.

Simply, the contributions of many players will be necessary for WLSCM to become a reality. Meanwhile, it is easier to focus upon designing for disassembly, recovery, and relifing, than to continue recycling from waste with the inputs needed. Disassembly practice through design is shown as follows:

TABLE 1 SERVICE LIFE PLANNING INPUTS FOR DISASSEMBLY DEVELOPMENT

PLAYERS	SUPPLY CHAIN PROVIDERS	STATUTORY INPUT	SERVICE LIFE PLANNING	END OF LIFE
Building Owner	Design Life	Fitness for purpose	Brief Scope	Carbon based optimisation
Funders	Market Requirements			
Portfolio Managers	Replacement Management	Performance audit and review for building brief	Schedule and Specification delimiters	Feedback and Recovery Optimisation
Asset Managers Facilities Managers	Life Care Implementation		**Performance Audit**	
Environmental Consultants	Life Cycle Assessments	ISO 14000+	Candidate product input	Environmental Suppression Damage
Project Managers	Whole life costed constructed work	Performance based CW	Delivery	Recovery and supply chain service life optimisation
Insurers		Insured Service Life	Insured Life Plan	Feedback
Design Teams	Whole Life Design	Fitness for purpose	Life care requirements	Waste stream suppression
Specialist Trades			MTTR MTTF	Relifing
Manufacturer/ Supplier	Performance based products	CPD compliance		RTS Option
Constructors	CMA DCMA	H&S	Reference Documents	Assembly
Deconstructor	DCMA			Disassembly

Footnotes
(i) Attention should be given to the design life methodologies and the service life data available, and its quality and reliability within the defined delimiters of that development's environmental costs, value, and end-users' space, culture, and the supply and waste stream CO_2 constraints.

(ii) The product brief (in effect) reflects the existing portfolio status needs, as well the immediate needs for new space, etc.

(iii) The design agenda should set the terms to optimise a portfolio-building space quality and serviceability, and present a strategy for securing sustainable outcomes with some notion of life and whole-life costing.

(iv) Component manufacturers need to be able to give guidance on disassembly, performance, and the reliability levels of their products. Indeed, they even need to be able to assist in giving comment on a design brief or design configurations planned.

(v) Each player has a part to play in, or contribute to, the decision making of service life planning deconstruction/disassembly. But to do so, it may be necessary to develop a common Decon-service life language that will link the Manufacturer to Decon-Recoverer, the Client to their End user, and the Design team to their Building and recovery optimisation.

The Design and disassembly life quality depends on getting the right brief for that client's standard, with a defined-life timeframe for that building that can also be validated, as hinted at later and in the Performance Audit in Table 1. Central to this comment is the need to focus upon evolving designs that are capable of being reconfigured, and where appropriate, capable of being reused elsewhere.

Establishing the right design life for a constructed facility remains difficult (Lucchini & Wyatt 2001). Often, the brief life given is one of general values, or couched in terms of performance, and to some extent, reliability requirements. But leaving the option of selecting the material and component supply chain to others who may not be designers may be unhelpful. So, Decon Practioners may need to develop an aide de memoir for disassembly to ensure that omissions and errors are minimised and input into service life planning.

DESIGN AND SERVICE LIVES

Designing and managing buildings on a service life time basis requires understanding of a design's service life relationships among its various materials, systems, and elements that will make up the building or constructed facility. Here, for example, consider performance, reliability, or the impact of durability on the service life and serviceability. All are critical for end-of-life development, recovery management, and future waste reduction.

The design team should know how flexible their design is. Likewise, ask the question of how might the service lives of the supply chain fail? Or, how might the most likely deconstruction methods or disassembly intentions impact space, jointing, and sequencing?

Where practical, one must establish the space, component, and system dependencies. Especially where a design configuration may result in future inflexibility or costly servicing, level requirements to sustain a disassembly outcome. Equally, there is an important domain that may require further work and has as much to do with design and construction methods as it does to deconstruction—the taxonomy of joints and jointing and breakdown analysis of the construction method of assembly. And, as always, consider the economic consequence of the financial measures.

SERVICE LIFE BREAKDOWN TREE

Disassembly requires an understanding of a wide range of jointing systems and assembly configuration, and their dependencies, as the service life in Figure 4 shows. In effect, each element or system and, in some instances, components have a service life profile made up of the different service lives of the supply chains they form.

In practice, this target life is likely to have different life durations for most of a constructed work's designed life. For example, building service systems may be assigned a number of target service lives that are different than, and may be shorter than, the building's proposed life that they make up.

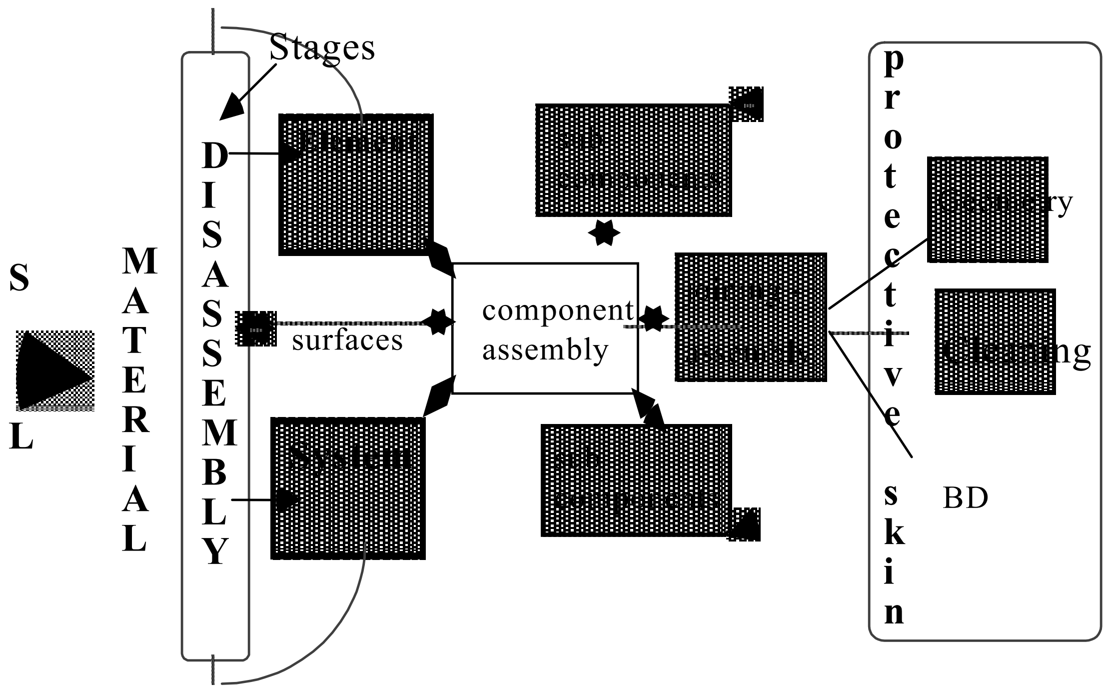


Figure 4 Disassembly Assembly Service Life Template

Footnotes

(I) The template layout is similar in outline for a system element or component and, in effect, develops as a systematic framework for service life planning and its many aspects, including D4D/A.

(II) The interfaces, joint systems, and responses shown in Table 2, and the attack regime are core issues in addressing disassembly.

In effect, one should seek to optimise service life strategies in such a way as to ensure that no shorter life part can threaten a system, element, component, or constructed work of a longer life or higher embodied energy value. Where there is a threat, then the case for ease of access and removal should be considered. (This will occur if the end of life planning links up with deconstruction in waste stream reduction).

Representing different service lives, as suggested earlier, occurs by way of a service life profile of the constituent part or life of the proposed building, and is mapped as a breakdown or decision tree. This breakdown tree may form the core of the design for disassembly. It is also relevant to all design trade packages, systems, and components made up of more than one sub-assembly.

It would therefore be sensible to think of the design life of a constructed work as a reference point, or benchmark, to which all the specified materials and components service lives may be related to, as suggested in Figure 5. Here, the systems and elements of the constructed work can be mapped in context. Then, where a high residual level of unused service life or embodied energy is anticipated or remaining at the end-of-life stage, an appropriate disassembly and life-care response can be proposed.

To facilitate this end, a disassembly construction method breakdown template should be considered, perhaps along the contextual arrangement shown in Figure 5, below, and Figure 4, above.

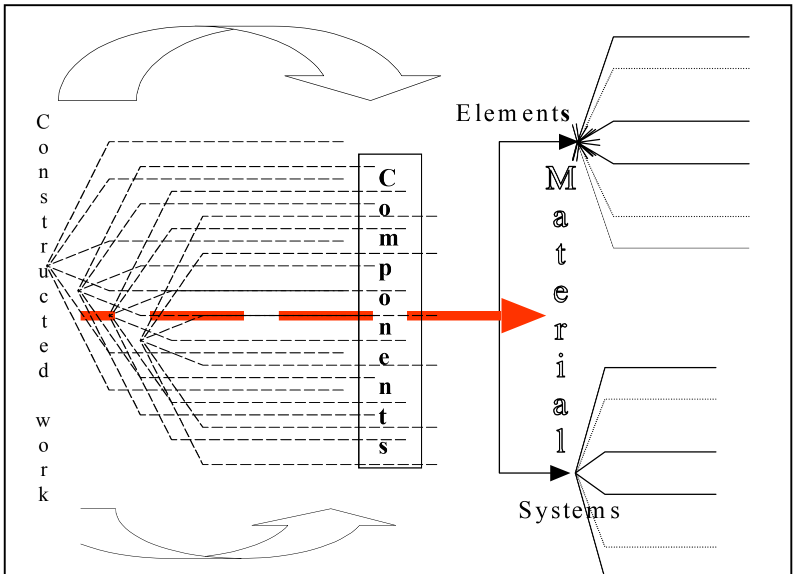


Figure 5 Design's Disassembly Break Down

Managing the disassembly configurations basis requires a grasp not only of the service life relationships, but also of detailing for both assembly and disassembly, work-sequencing practice, access needs, and the life care requirements. It also opens up the pathway and route for wholelife algorithms for given elements, like a concrete or steel frame, or any system or component family that will greatly aid end-of-life management.

Consideration must also be given to safety, access, assembly, cleaning, repair, replacement, and disassembly procedures. Such responses are seen as a matter of course and would, in any event, form part of a risk and method assessment for life-cycle assessment deconstruction options. Here, the focus may also include the candidate product and environmental assessments (Trinius W (2002): Chevalier 2001).

POST DESIGN CONSIDERATIONS

The validating of disassembly and deconstruction service life planning is also important. (ISO 15686-3 2002) (Wyatt & Lucchini 2001). The assumptions made in the disassembly response and service life designs should be clear. Likewise, whether the quality of the core or service life database at hand or in an archival form meets the constructed facilities own target life or service life profile requirements should be known. Such data or evidence must be capable of independent verification or validation, as the case may be. Where WLSCM becomes part of the life cycle assessment, then the practice-side of recovery will need to be robust to realize end-of-life responses.

Service-life planning should be seen as an integral part of both design and project management. Yet, disassembly does not end there. It is an area in need of development and feedback. Without condition-based assessment and service life feed-to-feed forward to help future disassembly or deconstruction practises, the design may be weakened. Such issues are also under consideration (ISO 15686-7).

To try to signal the disassembly in life, Table 2 is included to indicate that a disassembly proposal may need post-commissioning attention (sometimes at a defined interval, and other times, randomly).

Table 2 Service life Disassembly Responses

Location	Monitor	Inspect	Test	Clean	Service	Replace	End of Life Mode Notes	
D/A Status								
Space-								
Element								
System								
Component								
Material								
Surface								
Joint system								
Interfaces								

Finally, there is an economic consequence for the financial measures established in designing for end-of-life recovery. So, an effective life methodology should be able to demonstrate the consequence of, or decision on, the planned-options recovery and disassembly of a given or key area within a significant waste stream's content.

END-OF-LIFE RESPONSES

The need to optimise the service life of the resources used, and to manage their embodied energy laid down in all constructed work, makes practical sense. Nevertheless, in many respects, this is left until the end-of-life stages in the proposal for disassembly. Even with a design for disassembly, the service life is not without difficulty, especially anticipating the remaining life term of a building and its constituent parts.

Nevertheless, the following matters also need to be kept in mind in the design:

- Completeness and adequacy of service life assessment, durability conflicts, failure, and risk of the respective components, systems, fixings, and materials selected.
- The joint taxonomy
- Survey methods recommended, including service life testing for deconstruction and disassembly, and associated site procedures on yield, and service life or embodied energy retained. Also refer to Table 2.
- Disassembly recovery documentation
- Economic justification, especially where recovery does not involve a bespoken demand in closing the loop.
- Inventory recovery overheads with the problems of fluctuations in transportation costs and second-hand and supply chain markets.
- Disassembly, approvals, or acceptance occurring prior to executing work or tendering and liability.
- Out-of-service impact on occupied buildings, particularly for systems like building services, during the constructed work's life.
- Anticipated landfill and carbon tax threats in the future that may support disassembly and deconstruction, and encourage the supply-chain providers to move to recovery and WLSCM.

Concluding, the condition-based assessment area and the need for deconstruction surveys for end-of-life recovery may prove disappointing, but research is now needed to change this.

CONCLUSION

We should consider designing today for deconstruction and disassembly tomorrow, so that a high order of recovery is possible through WLSCM of the service life.

To contribute to this disassembly future, ISO 15686 will encourage the practice-of-life design and its life-care management. Doing so provides a basis for '"sustainable whole-life based practices" for the materials, components, and systems, brought together in a constructed work or facility. Nevertheless, the measurement base in whole-life assessment needs further development, including a systematic framework and scope for disassembly design.

Ultimately, all recycling ends up as a waste stream, so there may be a limited degree of freedom in the waste and recovery hierarchy. Nevertheless, optimisation may come from designing for recovery in a service life, or flexible design, which can pick up and cast off different supply and waste streams. Finally, to secure a practical recovery management approach, a philosophy centred upon the service life template embracing deconstruction and disassembly underscores the importance of: TG39, the need to integrate whole-life supply chain management into project design facilities, portfolio management, and the need to develop service-life based recovery and new works, where disassembly and closing the loop are part of the brief.

REFERENCES

AFNOR ISO TC /WG3 WD1 (2000) Environmental Management –Guidelines to integrating environmental aspects product development AFNOR France 23pp

BS ISO 15686 (2000) Building Facilities and Constructed Assets Part 1 Service Life Planning BSI UK 41pp

BS ISO 15686 (2002) Buildings and Constructed Assets Buildings Service life planning Part 3 Performance Audits and Reviews BSI UK 40pp

Chevalier JL et al (2001) Practioners tools for integrating products: Environmental aspects in Building design paper INF 80 CIB World Congress NZ 11pp

ISO/WD 15686-7 (2003) Buildings and Constructed Assets Performance evaluation and feedback of service life data. BSI London 23pp

Trinius W (2002) Paper 271 Environmental Impacts Service life planning: DISS. ISO 15686-6 Sustainable Building Conference 2002 5pp

Wyatt DP (1983) The Implications of Conceptual Modelling of GB Housing Stock for Resource and Housing Stock Management CIB Proceedings Stockholm 266-275

Wyatt DP and Gilleard JG (1994). Deconstruction: An Environmental response for Waste Management and Sustainability in the Construction Industry. CIB TG16. The First International Conference. Sustainable Construction. Florida. USA 113-124

Wyatt DP & Lucchini A (2001) Validating designs through performance reviews. CIB World Congress Wellington NZ 11pp

BIBLIOGRAPHY

Crowther P.1999 Designing For Disassembly To Extend Service Life And Increase Sustainability. Paper 190 Vol. 3. 8dbmc NRC.CRNC

Frohnsdorff G et al. 1999 International Standards For Service Life Planning Paper 144 Vancouver CRNC Vol. 2 8dbmc 1537-1542

Howard N, Edwards S Anderson J: BRE methodology for environmental profiles of construction materials, components and buildings. BRE 1999 p.65

Hovde, PJ 2000 "Factor methods for service life prediction - A state of the art report" Performance Based methods for service life prediction. NUST. Tronheim. Norway. 43pp

Kibert C 1994 Ed. Sustainable Construction Hansen et al Environmental Assessment of Building Projects Based upon a Life Cycle Approach CIB TG 16 203-212-

Siemes, T & Edvardson C. 1999 Duracrete. Service life design for concrete structures 8dbmc Proceedings NRC CRNC Vancouver Paper 125 Vol. 2 1343-1356

Wyatt DP & Lucchini A 1999 A Service Life Design For Life Care Management 8dbmc Proceedings NRC CRNC Vancouver Paper 159 Vol. 3 1687-1606.

WASTE MANAGEMENT PRACTICES IN UNITED STATES GREEN BUILDING PROGRAMS

Authors: Audrey K. Tinker and Dr. Richard A. Burt (Texas A&M University, College Station, Texas)

ABSTRACT

Construction projects produce enormous quantities of waste each year. In fact, wastes from new construction and renovation account for between 15-20% of landfill space. Created to stop construction's harmful affects on the environment, green building programs are springing up throughout the country. Currently there are over 10 major U.S. green programs that allow residences to be rated and receive a green designation for fulfilling minimum requirements. Each of the programs allots a percentage of the total points available to waste management issues.

Programs were analyzed to assess the importance each places on reducing landfill waste. Results indicate that the percentage of points dedicated to waste management ranges from 4-24%, with location as a major determinant. A master list was also developed for all of the waste reducing/recycling measures currently available. Major themes within the list were identified as were those items that were unique to individual programs.

KEYWORDS: Waste Management; Recycling; Green Programs

CONSTRUCTION WASTE MANAGEMENT

Construction waste management involves planning and implementing waste reducing strategies to minimize the amount of jobsite materials that end up in a landfill. Waste management includes reducing the amount of waste produced on a jobsite, reusing as many materials and fixtures as possible and recycling those items that can not be reused in their present form [1]. Estimates indicate that as much as 90% of construction waste is recyclable [2]. However, for the sake of financial feasibility estimates approximate that from 70%-%80% of new construction waste is recyclable and over 50% of all (new and demolition/renovation) construction waste can be diverted from the landfill [3]. Education, research, follow-up and the development of an effective waste management plan are required for all construction participants to ensure waste limitation goals are reached. Success requires effort on behalf of everyone, from the designers to the subcontractors [1].

The Effects of Construction on Waste Production

Construction in the United States is not only one of the largest industries, but also one of the largest waste producers. It is estimated that over 100 million tons of construction and demolition wastes are generated each year by the industry [3]. To put this in perspective, this amount comprises as much as 40% of total solid wastes produced in some areas [2]. As an average, 15%-20% of municipal solid waste comes from construction [3]. With many municipal landfills expected to reach capacity within the next ten years, there is a clear need to reduce these tremendous amounts for the sake of the environment and, as dumping fees escalate from reduced space, there is a financial need as well.

Construction Waste Management Methods

There are many ways the construction industry can help minimize its landfill waste. One of the areas that can produce the largest benefits is the demolition or deconstruction phase of a project. Here, building products and materials can be recycled for use in either the new/renovated structure that will be built or sent to resale stores for use on other projects. Examples include the over forty Habitat for Humanity "Re-Stores" functioning around the country as charitable tax-deductible outlets for previously used items with proceeds going to new home construction [4]. In the area of new construction, waste can be minimized through efficient building practices as well as through recycling waste material. Methods for each of these will be discussed below.

Renovation or demolition reuse/recycling begins prior to work on site with an assessment of the structure. Designers, owners and contractors work together to identify those materials and items that will be reused or recycled and determine how to most effectively manage those materials that cannot be reused in order to minimize waste [5]. The financial feasibility of managing this waste is often then analyzed to determine how much and what items should be included in the plan [3]. The resulting decisions should then be incorporated into the specifications to ensure compliance [5]. Next, sources of recycling and or disposal should be identified. Many large cities have created reference manuals to aid contractors in this area [3]. Additionally, in some areas construction waste firms have sprouted that act as intermediaries between the contractors and the waste handlers. They have developed networks of reuse, recycling and disposal and can offer 30%-60% reductions in waste management costs [2]. In other areas, however, few resources have been developed in this area and locating sources for reuse/recycling can be quite difficult.

Once deconstruction begins, contractors and subcontractors first separate reusable items such as doors, woodwork, hardware and metals. There are many profitable markets for these items or they can be donated to charities as mentioned above. Next, on-site separation of building materials should occur for such materials as brick, concrete, steel and other large wastes [5]. These are generally sorted into separate bins free from contaminants and other materials and then transported to a previously identified receiver. Finally, the contractor should monitor the process to determine the amount of waste reused or recycled and the amount of waste sent to the landfill [3]. This is important for many reasons that will be covered in the next section.

New construction offers additional opportunities for materials reuse and recycling with an emphasis on design and construction techniques that result in less waste. Some strategies include the use of modular design so that standard sized materials can be used with little or no cutting and/or the use of engineered materials. Many, such as structural insulated panels, are produced offsite and made-to-fit. If standard designs are used, waste can be minimized by designating centralized cutting areas, protecting materials from the elements and using quality control to reduce site waste [2]. Additionally, large shrubs and trees can be transplanted or protected for future landscaping [5]. As in renovation and demolition work, appropriate receivers must be identified to process the waste after jobsite separation.

Environmental Benefits of Waste Management
Waste management is one of the most effective ways the construction industry can aid in the creation of sustainable structures. Through these efforts, the needs of the present generation can be met without compromising the needs of future generations [6]. There are many environmental benefits from construction waste management. One of the greatest is the increased life of landfills that reduces the need to designate more land to this process. Additionally, materials decomposing in landfills produce greenhouse gas emissions. By reducing the amount of waste going to the landfill, the effects of global warming can be reduced as well. Energy is also saved because processing recycled materials typically takes much less energy than processing virgin materials. Finally, resources are conserved as previously used materials and products are reused instead of fabricating new products [7].

Financial Benefits of Waste Management
It would be idealistic to expect construction companies to buy into the idea of waste management for purely environmental reasons. The construction industry is based on the premise that the low bidder wins. Therefore, anything that would increase construction costs could reduce a company's competitive advantage. In order to gain support for waste management practices, it must be shown that cost savings or at least no additional cost will be incurred. Currently, in many cities throughout the nation, waste management has become a money generating strategy. However, in other locations, the costs are simply too high for waste management to be practical.

One of the greatest incentives for reducing landfill waste is the increase in tipping fees observed at many of the nation's landfills. For example, in Portland, Oregon during a six-year period, tipping fees rose from $17.50 per ton to $75.00 per ton. As a result, contractors found new outlets for their waste including recycling centers for drywall and wood that helped to decrease waste and thus cost [3]. The same can be seen in other areas of the country where landfill tipping fees can reach as high as almost $90 per ton. Studies have shown that when tipping fees reach approximately $50 per ton, the cost of reducing waste becomes competitive with disposal [8].

Resale of architectural items has also become a large market although no numbers exist as to profits realized from their sale. The range of benefits depends on the age and features of a structure, but in many markets, old doors, hardware, fixtures, piping and woodwork can command very high prices.

Finally, contractors can benefit indirectly from waste management by marketing themselves as "green builders" or by complying with the criteria of green building programs that provides a competitive edge over others in the industry. With the increase in green projects throughout the country, this can become a very lucrative designation as many owners and architectural firms now prefer to hire those contractors with proven experience in this area [9].

GREEN BUILDING PROGRAMS

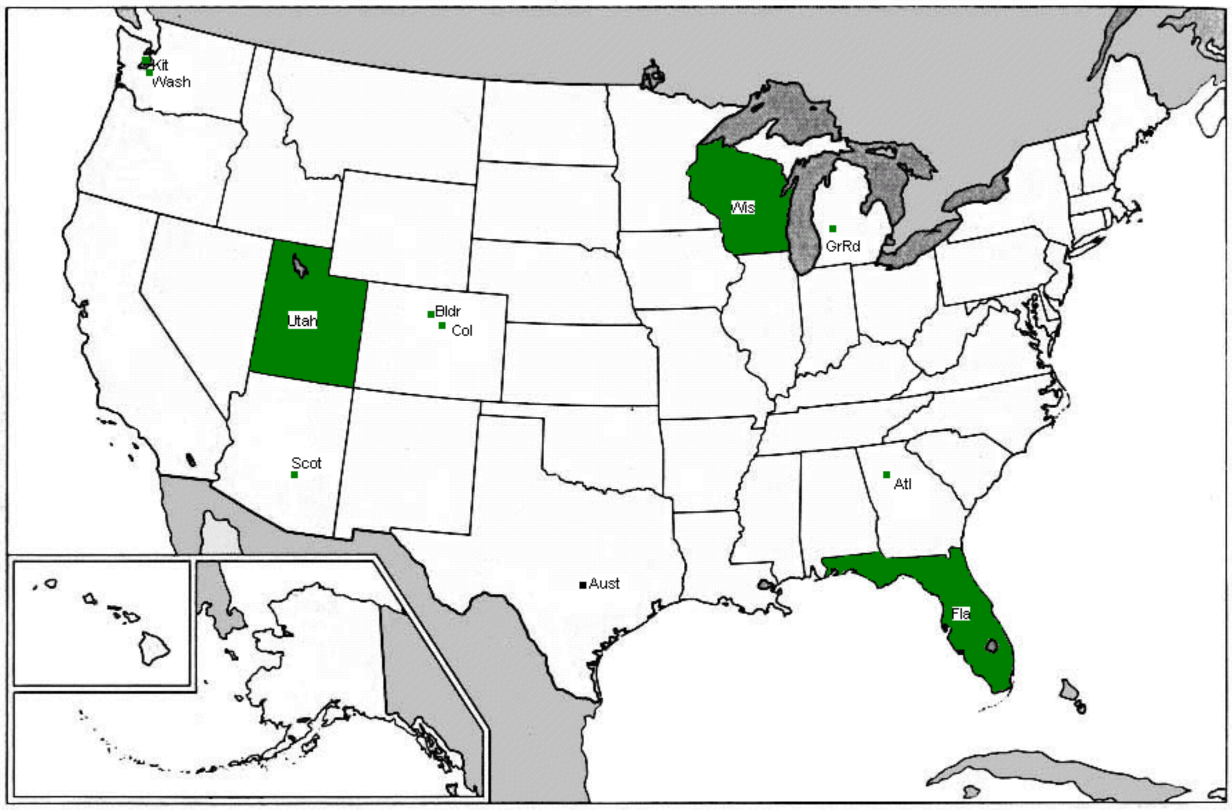
The first American green building program began in the early 1990's in response to an increasing awareness of the limits of the Earth's natural resources and the nation's dependence on oil [1]. The Austin Green Builder Program began as a residential program which today consists of five rating levels and 274 possible points based on the number of items incorporated into the design, construction and marketing of the home [10]. Today, there are at least twelve residential programs that offer home rating systems. Many other green residential programs exist as well, but instead of rating systems, they offer primarily educational and networking services for those interested in green building. Additionally, green building has spread to the commercial sector in a variety of programs, the most prominent being the Leadership in Energy and Environmental Design (LEED) Program. This is a national program developed by the United States Green Building Council that offers the opportunity of achieving four-level designations based on compliance with green designs, products and principles.

While only 4% of the total space built in the United States in 2001 could be considered green, this number is growing exponentially as many builders are realizing green building can not only help their corporate image, but their profits as well [11]. Additionally, owners are getting into the act as they are discovering that green structures not only reduce operating costs, but also attract young, highly intelligent workers that prefer companies that demonstrate a commitment to the environment [12]. Finally, state and local governments are increasingly establishing requirements for their own public-sector buildings as they realize the benefits of green building [13]. Therefore, it is likely that programs and participation will proliferate in the future.

Methods Used to Incorporate Waste Management Practices into the Programs

In this study, it was desired to determine the percentage of points in functioning green residential rating programs dedicated to reducing construction waste to landfills. Only eleven of the twelve programs that exist were included in the study because they make their point checklists available to the public. The programs included (the abbreviation is in parenthesis) were: the Scottsdale Green Building Program (Scot), Build a Better Kitsap (Kit), Built Green Colorado (Col), EarthCraft House of Atlanta (Atl), Green Built Program of Grand Rapids (GrRd), Green Built Home of Wisconsin (Wis), Austin Green Building Program (Aust), the Florida Green Building Coalition’s Home Program (Fla), Utah Green Built Homes (Utah), Built Green from Washington (Wash), and the Green Points Program in Boulder, Colorado (Bldr). These are indicated in Figure 1 below to give an idea of their locations around the country. Of the eleven programs, five include a waste management category and two include a recycling category. However, even though they may not have a separate category, all contain waste management issues; some have just assigned these to separate categories such as material efficiency.

Figure 1 Locations of U.S. Green Builder Programs.



Included in Table 1 below is a master list of those items that apply to waste management within all 11 residential programs and the LEED commercial program and a breakdown of how many programs include each item. Items are grouped by broad categories including: landscape, materials, management and owner. Items included in the "Landscape" category pertain to the recycling, protection and reuse of existing natural site features. The category of "Materials" includes methods to reduce the amount of new materials used, recycling of site materials and reducing material waste produced. "Management" includes jobsite and design practices used to minimize waste. Finally, the "Owner" category incorporates waste management methods into the home for continued waste reduction. Additionally, several of the programs include waste-related prerequisites that must be met but have no point value attached. These are listed at the top of the table, but are not included in the point tallies.

Table 1 Master list of waste management items.

Item	Kitsap	Earthcraft	Colorado	Scottsdale	Florida	Wisconsin	Utah	Boulder	Washington	Grand Rapids	Austin	LEED	Programs
Prerequisite				Build-in		Min. of 1			jobsite			store/collect	**w/ Item**
				recycling center		recycled mtl.			recycling plan			recyclables	
Landscape													
preserve existing vegetation and trees	3	5	6	1	2	1	1		6	1	4	1	11
save and reuse all topsoil	1	5	4		1	1	1		2	1			8
grind wood and stumps for reuse	2	5	1		2	1	2		5				7
replant or donate removed vegetation	2				2	2			5				4
recycle landclearing and yard wastes									5		2		2
Materials													
use efficient framing techniques	4	26	3			5	4				3		6
sell or donate reusable items from the job	1	1		1				5		2	2		6
recycle wood scrap	1	3				1			3		2		5
recycle cardboard and packaging	1	1				1			4		2		5
recycle metal scraps	1	1				1			2		2		5
provide weather protection for stored materials	1					1	1		1				4
reuse building materials	1							5	1			2	4
recycle drywall	2	3				1			3				4
recylcle asphalt roofing	3	1				1			4				4
recycle concrete/asphalt rubble	3		2			1			3				4
create detailed take-off and provide cut list to framer	2	10							2				3
use central cutting area or cut pakcs	2	3							2				3
reuse dimesional lumber	1							5	1				3
use reusable foundation forms						1	1		2				3
use reusable supplies for operations	1								1				2
sell or give away wood scraps	1								1				2
move leftover materials to next job or provide to owner	1								1				2
purchase used building materials for the job	2								2				2
recycle plastics		1				1							2
recycle paint									3				1
recycle carpet and padding									5				1
recycle flourescent lights and ballasts									5				1
specify salvaged or reclaimed material for 10% structural			5										1
specify salvaged or reclaimed material for 10% finishes			5										1
recycle a min. of 50% jobsite waste							1						1
Management													
prepare/post recycling/waste management or deconstruction plan	3	5	4	8	2	1	1	3				2	9
requires subcontractors to participate in waste reduction efforts	3				4	1	1		3				5
use suppliers w/ recycleable packaging or liberal return policies	2					1	1		1	1			5
dispose of non-recyclable hazardous waste legally	2					1	1		1				4
remodel an existing structure					10						3	3	3
plan and implement design related waste management plans					5	1							2
use standard building sizes in design	1								1				2
reduce hazardous waste through good housekeeping	1								2				2
reuse spent solvent for cleaning	2								1				2
recycle used antifreeze, oil, oil filters, and paint appropriately	2								1				2
local recycling contact		1											1
Owner													
build in recycling area and chutes	2	2	3	1		2	1		6	3			8
provide homeowner with compost bin	1			4	1	1	1		4		2		6
Maximum points available in waste management	55	73	33	15	29	27	17	18	89	8	22	8	
Maximum points available in Program	230	448	699	359	400	244	262	337	727	218	274	69	
% Devoted to Waste Management	**24%**	**16%**	**5%**	**4%**	**7%**	**11%**	**6%**	**5%**	**12%**	**4%**	**8%**	**12%**	

Percentage of Points Available For Waste Management Items

In order to assess the relative importance each program places on diverting construction waste from landfills, the number of points applicable to this area was determined for each program and then compared to the total points available. Maximum point values were used both for the total points available and the total possible points available by incorporating all waste management items. Only those items directly related to reducing landfill waste from the jobsite and in the future were included. However, items such as “Use recycled-content flooring” were not included as these are more design-oriented than jobsite-oriented and they do not contribute to reducing wastes created during construction or occupancy. Table 2 identifies the programs included and each one's respective percentage of items allotted to waste management.

Table 2 Percentage of Programs dedicated to waste management.

Program	Waste Pts. Available	Max. Pts. Available	Waste Percentage
Build a Better Kitsap	55	230	24%
Earth Craft House of Atlanta	73	448	16%
Built Green of Washington	89	727	12%
Green Built Home of Wisconsin	27	244	11%
Austin Green Building Program	22	274	8%
Florida Green Building Coalition	29	400	7%
Utah Green Built Homes	17	262	6%
Green Points Program of Boulder	18	337	5%
Built Green Colorado	33	699	5%
Green Built Program of Grand Rapids	8	218	4%
Scottsdale's Green Builder Program	15	359	4%

Landfill Costs in Green Program Areas

It has been shown that when landfill costs reach a certain level, it is more profitable for contractors to reduce waste production than pay landfill dumping fees [8]. To determine if green programs are designed to reflect conditions in their areas, such as a shortage of landfill space that would be reflected in high dumping fees, landfills for the areas included in the programs were contacted to determine their costs. Below in Table 3 are the approximate costs of dumping for each of the green program areas along with each program's percentage of points designated for waste from Table 2 to illustrate relationships between landfill costs and waste percentages.

Table 3 Landfill costs in each green building program area.

Program	Landfill Cost	Waste Percentage
Build a Better Kitsap	\$59.00/ton	24%
Earth Craft House of Atlanta	\$32.18-\$37.00/ton	16%
Built Green of Washington	\$88.17/ton	12%
Green Built Home of Wisconsin	\$20.75/ton (Green Bay)	11%
Austin Green Building Program	\$5.50-\$7.30/cy	8%
Florida Green Building Coalition	\$27.00-\$41.00/ton	7%
Utah Green Built Homes	\$22.00/ton	6%
Green Points Program of Boulder	\$22.50/ton	5%
Built Green Colorado	Not available	5%
Green Built Program of Grand Rapids	\$30.00/ton	4%
Scottsdale's Green Builder Program	\$24.25-\$26.25/ton	4%

Because the Florida program is a statewide program, three cities (Miami, Jacksonville, and Pensacola) were contacted and a range was provided for their costs. In the case of Utah and Wisconsin, landfill costs were used from Salt Lake City in Utah and Green Bay, Madison and

Milwaukee in Wisconsin. The main landfill for the city of Denver has private commercial contracts only and thus prices for commercial disposal could not be disclosed. Austin's landfills charge by the cubic yard in lieu of tons, therefore, a comparison is hard to make. It is evident however from the table that a huge disparity exists in landfill dumping fees.

Comparison of Green Programs' Waste Management

As can be seen from the above tables, much inconsistency exists between the percentages each program has allotted to waste management. Waste management percentages range from 4% to 24%. When landfill dumping fees are examined to determine if a correlation exists between them and the percentage of each program allocated to waste management it is evident some relationship exists, especially for the top three programs with high waste management item percentages correlating to high dumping fees. It is also interesting to note that the programs located in the southwest tend to have the smallest percentage of their programs dedicated to waste management and relatively low dumping fees.

CONCLUSIONS

It is well known that conditions vary from site to site across the country. In some areas water is plentiful, while in others droughts often occur. This is true for a range of items and the green residential rating systems reflect these differences. For instance, the Florida program includes a section for disaster mitigation because of the state's exposure to hurricanes, floods and termites, which would not be a concern in other areas. The results in Table 2 and Table 3 reinforce the fact that programs are site-specific in that in those areas where landfill space is plentiful and thus inexpensive there is less emphasis on reducing landfill waste. Instead point distributions in these areas are probably spread to more pressing local issues such as water or energy conservation. While few studies have been completed on the effectiveness of the green programs in each of the regions, it could be assumed that those items included in the varying programs checklists are designed to create more sustainable homes in their specific areas. This would explain why a nation-wide residential green building program might not be as effective as the area based programs, because the conditions vary so much throughout the United States. This also would indicate that waste management would not become a major issue in most areas until landfill space becomes limited and/or high costs of dumping create an environment where waste management is more financially appealing to builders.

REFERENCES

1 City of Austin's Green Builder Program. (n.d.). Construction waste management. *The Sustainable Building Sourcebook.*

2 **Zeigler, P. M., P.E.** (n.d.). *Construction waste management and recycling.* Retrieved October 29, 2002 from http://www.dep.state.pa.us/dep/deputate/pollprev/techservices/Paiof/best/build/constwastemang.pdf

3 **Mills, T., Showalter, E. & Jarman, D.** (n.d.). *The cost effective waste management plan.* Retrieved October 29, 2002 from www.arch.vt.edu/CAUS/BC/People/faculty/Thom/papers/waste.doc

4 Austin Habitat for Humanity. (2001). *Austin Habitat for Humanity Re-Store*. Available: www.re-store.com/

5 Santa Monica Green Building Program. (n.d.).*Construction management introduction* Retrieved October 29, 2002 from http://greenbuildings.santa-monica.org/construction/construction.html

6 World Commission on Environment and Development. (1987). *The Bruntland Report.* Available: www.srds.ndirect.co.uk/sustaina.htm

7 California Department of General Services. (2002). *Construction waste management.* Available: www.ciwmb.ca.gov/greenbuilding/training/statemanual/waste.doc

8 **Apotheker, S.** (1992). Managing construction and demolition materials. *Resource Recycling,* pp. 50-61.

9 King County Government. (2002). *Contractors guide.* Available: dnr.metrokc.gov/swd/bizprog/sus_build/ConGuide.pdf

10 National Association of Home Builders Research Center, Inc. (2002). *Summary of Existing Green Building Programs.* Available: http://www.nahbrc.org/Docs/MainNav/GreenBuilding/3643_Summarycomplete.pdf?TrackID=&CategoryID=1801&DocumentID=3643

11 **Freemantle, Tony** (2002, July 1). 'Green" approach ripening/ Houston is slowly joint the movement toward environmentally friendly building practices. *The Houston Chronicle*, pp. A1.

12 **Flanders, Jack** (2001, October). Sabre going green in grand style. *Texas Construction,* pp. 10-16.

13 State and local green building programs. (2002, May). *Environmental Building News,* 4-5.

"GREEN" DEMOLITION CERTIFICATION

Authors: G. Bradley Guy, Associate Director; Timothy J. Williams, Research Coordinator (Powell Center for Construction and Environment, University of Florida, Gainesville, FL 32611-5703)

ABSTRACT

This paper/presentation will describe a "green" demolition certification proposed as a means to validate environmentally and socially responsible building removals. Typical demolition practice includes varying levels of salvage and recycling. Deconstruction is a term that has emerged to describe a form of selective demolition. This certification is an attempt to overcome the semantics of the terms "demolition" versus "deconstruction" through a reasonable and practical method. The certification uses three categories: ***Building*** Credits, ***Planning*** Credits, and ***Environmental Health and Safety*** Credits. The certification has application for defining and documenting sound demolition waste management when a deconstruction plan or waste management plan is proposed as a means to approve demolition permits. The certification is also proposed to provide a basis for marketing and creating rewards for deconstruction and to act as an educational tool and guide for the implementation of specific organizational, municipal and Statewide building-related sustainable development goals. This paper will describe the certification method as proposed for further stakeholder development.

KEYWORDS: Deconstruction; Standards; Deconstruction Permitting; C&D Waste Management

INTRODUCTION

Demolition has the connotation of destruction. Webster's Dictionary defines demolish as "to tear down" "to break to pieces" and "smash." These terms clearly do not suggest a considered or selective approach including reuse and recycling. Greater levels of selective dismantling occur when there are economic benefits to any degree of source separation that will make the building debris more compatible for reuse or recycling, and to remove hazardous materials. For the purposes of this paper, "green" demolition is a form of building removal that maximizes environmental, social and economic benefits within the local municipality.

Goals of Green Demolition Certification

This Green Demolition Certification has been developed to provide guidance for a broad audience interested in environmentally and socially responsible management of demolition wastes. Its aim is to provide guidance, and a valid means to qualify a "green" building demolition, as compared to "standard" building demolition. Green Demolition exceeds the goal of removing a building from a site for disposal. It includes the diversion of the maximum amount of materials from the landfill and maximizing social and economic benefits to the community.

The Green Demolition Certification is intended to provide a means to support alternative building removal regulatory incentives, market deconstruction services, and validate environmentally and socially beneficial project outcomes. This certification is intended to help bridge the gap between large-scale mechanical-based demolition and predominantly hand demolition, so-called “deconstruction,” when the results can be equally beneficial to the community. It is also intended to help reward the best effort within the constraints of local reuse and recycling infrastructure and to normalize the achievement of a responsible building removal for different building types. Until such time as buildings are designed for deconstruction, and many of the inherent difficulties of source separation of the building materials from existing buildings are alleviated, a green demolition certification will require a certain amount of flexibility to reward both “best practice” and quantifiable waste diversion. The proposed certification can be used to develop environmentally responsible demolition practices, demonstrate commitment to such practices, and provide guidance to governmental entities seeking to enact policies for more environmentally sound C&D waste management. Lastly, the certification will act as a tool for raising public awareness and understanding of the societal impacts of building demolition, and the opportunities to alleviate those impacts.

The certification process uses a set of standards to compare different demolition processes and outcomes in order to rate them for environmental and social responsibility. It allows for differences in building types and the context of a particular project at the site and community levels. It uses three major categories of 1) ***The Building***, 2) ***Planning***, and 3) ***Environmental Health and Safety***, and specific criteria within each category. It gives policy-makers a means to validate a “green” demolition when developing demolition debris management regulations and incentives, and to communicate the outcomes of these regulations and incentives. The goals of a green demolition include:

Goals of Green Demolition

- Divert demolition debris from landfills
- Recover materials for reuse and recycling
- Contribute to the environmental and economic health of the community
- Provide a safe and healthful work environment
- Regard necessary building removals as a community development opportunity

Rationale for Certification

There is considerable confusion over what constitutes an environmentally and socially responsible building removal - other than relocating an entire structure intact. The highest and best reuse of an obsolete structure is through adaptive reuse in place or through relocation. The Green Demolition Certification is not intended to supersede these options. It is intended to address the process of building removal after these other options are deemed infeasible. Typical measurements of good environmental practice for building demolition include the amount of building materials that are recovered for reuse and recycling, either by weight or volume. These measurements may not provide an adequate reflection of an overall effort that will maximize all the possible mitigations of a building removal. Concrete and wood have very different densities and economic value, and therefore a measurement of tons of materials diverted may not reflect desired goals of preserving landfill space by volume, or maximizing economic development benefits. A valid effort to implement a responsible building removal may also be limited by factors beyond the demolition contractor’s control. This standard is an attempt to create a flexible means to guide, validate and reward those entities that seek to implement responsible building removals in a variety of building projects, and to allow local governments or building owners to gauge the performance of firms for the purposes of rewards, incentives, alternative regulatory approvals, and selection for future projects. Some of the audiences for a green demolition certification include:

Green Demolition Certification Audiences

- Building Owners
- Policymakers
- Contractors
- Architects
- Planners
- Researchers

BACKGROUND

There are many forms of building environmental or sustainable performance labels. The US Green Building Council Leadership in Energy and Environmental Design (LEED) Green Building Rating System is one well-known commercial green building certification in the US. It is a comprehensive system based upon five categories. These categories include: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Air Quality and Innovation and Design Process (www.usgbc.org). There are also many residential green building standards such as the Florida Green Building Coalition (FGBC) Green Home Standard (www.floridagreenbuilding.org). This standard uses the categories of Energy, Water, Site, Health, Materials, Disaster Mitigation, and a General category. The General category includes elements such as small house size, building on an urban parcel, and membership in the FGBC by the architect or builder.

Generally speaking, green building certifications require the building project to meet a minimum number of credits within an individual category, and then achieve a minimum number of total credits. Green building certifications often use either prescriptive or performance criteria to award credits. Prescriptive criteria detail exactly what must be built and how it is built, and performance criteria provide flexibility of means to achieve the ultimate goals of, for example, energy conservation performance over a "baseline" building configuration. In order to be as comprehensive as possible some criteria may be measurable outcomes, while others may depend upon processes. An example of a "process credit" is that one credit is awarded for using a LEED™ Champion, someone who has completed a training program for the LEED™ rating system. The LEED™ Green Building Rating System is also an example of the use of existing regulations and codes for sub-sets of the overall certification. As an example, the LEED™ Green Building Standard uses best-practice Federal and State-level building codes in the areas of energy-efficiency and indoor air quality.

One common approach for certification methods is the requirement for a certain number of prerequisites. A variation on this approach is adding a deficit of the minimum credits in one category to the total number of credits required for certification (FGBC). Even though a minimum of credits in one category is not achieved, the project must then add more elements or strategies overall to achieve the rating. Green building certifications are useful as a market differentiation tool for the user, and can conversely be used as guides to achieve a more environmentally responsible building project even if the formal certification is not obtained. In this case, self-certification is an important aspect of the green building certification.

Self-certification by the building designer, builders and other consultants themselves increases the learning experience for the building team. In this manner, they learn by doing, and will be able to inculcate the practice of green design and building into their firms. Self-certification also has the potential to reduce costs, with the same person that is responsible for implementing the green strategy is also documenting their own activities. Another approach to manage the process is a certifying agent, similar to a building commissioning agent, who functions as a manager of the certification process.

A final characteristic of green building certifications is levels of achievement for the certification. One option is a pass or fail certification, and the other is a series of levels, such as one star, two stars, three stars, etc. The one problem with a pass-fail is that it would be similar to many environmental laws whereby the goal is compliance, not necessarily increasing improvement in effectiveness or efficiency over time. In all cases, certification credits must be open to revision over time.

PROPOSED GREEN DEMOLITION CERTIFICATION

The Green Demolition Certification is earned through a credit system. Credits are awarded based upon compliance with a set of criteria. The initial proposal described here is based upon a pass-fail system in order. The criteria are categorized by 1) ***The Building***, 2) ***Planning***, and 3) ***Environmental Health and Safety***. There are also prerequisites within the Waste Reduction and Environmental Health and Safety categories for which no credits are awarded. Certification is awarded to any project meeting all prerequisites and earning twenty-five (25) or more credits from a total of fifty (50) maximum credits available. There are a variety of credit types, some are based on quantifiable measurements and others are based upon qualitative measurements, and may require further clarification as the process of developing the certification continues based upon stakeholder feedback.

Process

The Green Demolition credit system is designed to make certification possible for any building type. Older buildings with high salvage value materials in poor condition can compete with newer buildings of low salvage value but in better condition. Demolitions that focus primarily on total waste disposal reduction can qualify as well as demolitions that focus on removing selected materials. Overall, “green” projects salvage a high proportion of building materials and excel in other aspects of community-building, environmental education, job-training, and local economic development.

The certification uses a series of forms listing the criteria and the points available in each category. There are prerequisites in the Waste Reduction category and in the Environmental Health and Safety category. The user of the certification can look at the credits they will achieve with minimal effort and then at the credits that they will achieve with some effort. If the preliminary analysis of the project does not appear to qualify it for the Green Demolition Certification then the score sheets can be used to look for other areas to achieve the necessary credits. The final certification is based upon documentation of the actual fulfillment of the credits as proposed. A background document provides detail on the credit, why it is included in the certification, how it can be achieved, and the documentation required for receiving the credit. The procedure for using the certification is as follows:

1. Complete score sheets for preliminary analysis of "easy" credits.
2. Look for additional credits if needed.
3. Use checklist to count proposed credits.
4. Implement proposed strategies, insuring proper documentation.
5. Document achievement of credits using certification form and appropriate documentation.

Certification Categories

There are three main credit categories in the certification method. The ***Building*** category includes issues related to the physical removal of the building, the building site and surrounding context, and the amount of reuse and recycling that takes place from the building removal. This category contains 50% of the total number of credits available, i.e. twenty-five (25) of the total fifty (50) possible credits. The Waste Reduction and Materials Recovery portions of the certification contain a possible twenty (20) credits, representing 40% of total possible credits. The ***Planning*** category includes issues related to the broad context of the community, including enhancing the building materials recovery industry within the community, realizing the benefits of deconstruction for job-training opportunities, encouraging "smart" demolition that avoids the removal of historic building fabric, etc. The ***Environmental Health and Safety*** (EH&S) category addresses primary environmental and human health concerns related to hazardous materials and job-site safety. The EH&S category has the most number of prerequisites which also follow regulatory requirements. The intent of re-stating and making prerequisites for regulatory requirements is to facilitate best practices and continuing education for any entity undertaking selective demolition.

The categories of the certification are listed below with the accompanying credit amount or prerequisite.

Category 1: THE BUILDING

Site

- Minimize damage to surrounding vegetation or recover plants, and protect heritage trees (1)
- Grade and re-seed site after demolition (1)
- Erosion and sedimentation control plan (1)
- Minimize impacts on surrounding context (2)

Material Recovery - Use Building Worksheet (10)

Waste Reduction - Use Building Worksheet (10)

Total Possible Credits for ***The Building (25)***

Category 2: PLANNING
Land Use
Renovation / adaptation is not an option (1)
Contribute to urban infill or land restoration (1)

Industry Building
First time Green Demolition Certification (1)
Deconstruction with combined reuse store entity (1)
Makes use of local regulatory alternative waste management permit or incentive (1)

Community Building
Job-training program (1)
Donation of materials to Habitat for Humanity other community non-profit (1)
Not removal of National Register of Historic Places structure (1)

Materials Management Plan
Demolition is integral to renovation or construction project that will reuse salvaged materials (1)
Local redistribution of recovered materials (1)

Total Possible Credits for ***Planning (10)***

Category 3: ENVIRONMENTAL HEALTH AND SAFETY
Worker Health
Team led by green demolition trained contractor (3)
Workers have completed green demolition training (3)
Worker Safety and Performance incentive plan and implementation (3)

Hazardous Materials
Asbestos abatement by licensed contractor and as per OSHA and EPA (Prerequisite)
Lead worker plan and implementation as per OSHA (Prerequisite)
No reuse of lead-based painted materials over 0.06 % content (3)
Other hazardous materials management plan and implementation (3)

Job Safety
Engineering survey completed prior to start of work (Prerequisite)
Job Safety Plan prepared and communicated to all workers (Prerequisite)
Designated Safety Officer for project (Prerequisite)
All utilities disconnected from building prior to start of work (Prerequisite)

Total Possible Credits for ***Environmental Health & Safety Credits (15)***

Description of Credits

The Building – Site

Intent
Green Demolition is a holistic approach to the process of removing buildings. It is concerned with all of the impacts from the process, including impacts on the building site and surrounding properties, streets, and neighborhoods. Selective demolition has the capacity to inherently reduce these immediate environmental impacts through a reliance on hand labor and smaller equipment. An important goal of "green" demolition is the least possible disturbance or interruption of the non-building footprint site and surrounding areas.

Possible Credits	**SITE**
1	Building is removed without damage to vegetation beyond building footprint and minimum clearance for roll-offs and equipment required for work. This excludes ground cover, shrubs, and trees that are salvaged and transplanted before work commences. Heritage trees (as defined by local ordinance or cooperative extension service) must be maintained on site. Submit pre- and post demolition photographs and/or site plan with tree survey and protection plan. Tree protection measures include barricades and snow fence placed at a perimeter line of the drip line.
1	Building site is filled, graded, and seeded with ground cover after building removal to insure drainage and soil retention commensurate with pre-building conditions. Submit site plan for post-demolition and photographs for verification**.** This requirement excludes projects where the foundation or slab-on-grade will remain indefinitely.
1	An erosion and sedimentation control plan is developed and followed to minimize the loss of topsoil from the site during building removal. Submit erosion and sedimentation plan outlining measures taken.
2	The environmental impacts from the building removal such as noise, dust, and equipment/material placement and storage, upon surrounding properties and streets are minimized. Submit site plan of deconstruction or demolition project with adjacent buildings, sites and streets indicating immediate context. Site plan will indicate ingress/egress routes for vehicles, workers/visitors parking, placement of roll-offs, site trailer and equipment, materials storage, work areas, fencing, etc. to illustrate best attempts to minimize negative environmental impacts on surrounding areas.

Materials Recovery

Intent
The intent of this credit is to measure the value of resource conservation when considering the types of materials that are recovered. In general, this is measured by how well the green demolition succeeds at the "maintenance of embodied energy" (Primdahl, 2001). Materials that require a large amount of energy to produce, exact a larger toll on the environment. Therefore, reclaiming high-embodied energy materials increases environmental benefits of reuse and recycling.

Using the Materials Recovery Worksheet, the user will input the total weight of each building material in the building. A computer-based building deconstruction assessment tool is under development by the University of Florida that will allow the user to inventory an existing building and to produce a materials report that is compatible with the materials input for the Materials Recovery Worksheet. The inventory will produce a listing of all components of the building and the resulting constituent base materials. The total weight of each material is entered into the Materials Recovery worksheet in the Existing Inventory column. The recoverable quantity is estimated using the deconstruction assessment tool, as a percentage of recoverable materials when the initial building examination is conducted. This percentage is a factor that is then multiplied by the total existing inventory to determine the "recoverable" amount of materials. The possibility of an excessively low and conservative estimate of recoverable materials is offset by the fact that there is a prerequisite for a minimum mass of waste diversion in the Waste Reduction credit category. If the actual mount of materials that are recovered (achieving waste reduction credits) is more than estimate of recoverable materials, then recoverable materials would have to be revised. The difference between the existing inventory and the recoverable portion of materials is the estimated disposal amount. Upon completion of the project, the total amount that is actually recovered for reuse or recycling can be used to validate the recoverable percentage.

The total amount of materials by type that are actually recovered is multiplied by the respective embodied energy figure for that material to calculate a total embodied energy that is maintained, or in other words, is not disposed of in a landfill. The differentiation of maintenance of embodied energy between reuse and recycling is beyond the scope of the green demolition certification. This factor depends on the end use and percentage of recycled content in the new product as a substitute for virgin materials. No matter what percentage of materials are used as recycled content in a new product, the recovery of the materials at the job-site achieves the same demolition diversion goal whether the end use is reuse or recycling.

The Materials Recovery Worksheet calculations will produce several pieces of information that are used to determine the Materials Recovery credits that are awarded. In order to account for different building types and local reuse and recycling infrastructure, the Materials Recovery credits are based upon the percentage of recoverable materials rather than the total amount of materials, whether recoverable or not.

Materials Recovery Worksheet

Material	Existing Inventory (Tons)	Recoverable (Tons)	Recovered (Tons)	Embodied Energy (BTU/Ton)	Embodied Energy (BTU)	Disposal (Tons or C.Y.)
Acoustic ceiling tile				4.5		
Aluminum				44.7		
Asphalt shingle roofing				3.1		
Brick				1.3		
Carpet				30.0		
Ceramic tile				4.4		
Clay tile				1.3		
Concrete				0.4		
Concrete masonry unit				0.4		
Copper				10.4		
Drywall/plaster				0.8		
Engineered wood				0.8		
Fiberglass				5.3		
Glass				3.9		
Glu-lam				2.9		
Gypsum drywall				0.9		
Metals				8.0		
Particleboard				0.8		
Plastic laminate				21.8		
Plywood				1.8		
Polystyrene				21.0		
Terrazzo				0.5		
Vinyl/linoleum flooring				7.5		
Vinyl siding				2.6		
Wood				1.2		
Total						
Recovered / Recoverable (%)			X			
Embodied Energy Recovered /Recoverable (%)				X	X	
Diversion from Landfill (%)						X

There are three sub-sets of credits available in the Materials Recovery category. These are:

- The percentage of recovered to recoverable materials (3 credits)
  25-50% = 1 credit, 51-75% = 2 credits, 76-100% = 3 credits

- The percentage of recovered to recoverable embodied energy (3 credits)
  25-50% = 1 credit, 51-75% = 2 credits, 76-100% = 3 credits

- The percentage of total materials diverted from landfill (4 credits)
  25-50% = 1 credit, 51-75% = 2 credits, 76-100% = 4 credits

Each of these credits is based on quantifiable numbers that are dependent on local recovery infrastructure, the type of building and materials, and the building condition. Credits up to a total of 10 credits are possible in the Materials Recovery category

Waste Reduction

Intent
Green Demolition is foremost the diversion of debris from landfills in order to avoid the economic and environmental costs associated with disposal. These costs include tipping fees, the loss of habitat and biodiversity, groundwater or soil contamination from debris, and the ongoing costs to maintain, close, monitor and open landfills.

Waste Reduction Credits are determined by two main factors; the total volume of the building before demolition, and the percentage of diverted materials. Credits are given on a relative basis, combining the total volume and the percentage of diverted materials for a particular size of building. A minimum of 20% diversion from landfill by weight or volume of the mass of building materials is a prerequisite for any building of any size. As the size of the building increases, the percentage of diversion required to obtain the maximum of 10 credits is less. This acknowledges the benefits of diverting a larger total amount of materials due to the size of the building.

Method
1. Complete Materials Recovery Worksheet.
2. Calculate the total existing building volume and find the row in the Waste Reduction Worksheet that is associated with that total volume.
3. Find the column associated with the percentage of materials recovery to the total building materials mass (by weight or volume).
4. A minimum of 20% of total building materials mass by volume or weight must be recovered in order to receive the green demolition certification.

Waste Reduction Worksheet

Total Building Volume (length x width x height = C.Y.)	20	20-35	36-50	51-65	66-80	81-100
>15,000	P	6	8	10	10	10
<15,000	P	4	6	8	10	10
<9,000	P	2	4	6	8	10
<4,500	P	1	2	4	6	8
<1,500	P	0	1	2	4	6
<500	P	0	0	1	2	4

Recovery (%) to Total Mass
(weight or volume)

P = prerequisite

Land-Use

Intent
A green demolition is undertaken in the context of efficient land use. This can be either for urban infill to make use of existing urban infrastructure or where removal of the building allows for the creation of green space, or mitigates future disaster damage by removing buildings in areas that are prone to disaster. A serious negative consequence of "demolition by neglect" is the social and economic costs of blighted conditions and hindrance of urban revitalization. When a selective dismantling is undertaken to allow rebuilding in an urban setting, this more aggressive approach can prevent the long-term stagnation of leaving buildings in place that are no longer serving a healthy function for the community. Damaged buildings in rural areas will inevitably pose human and environmental hazards and prevent the reintroduction of native flora and fauna at the building footprint site. If hazardous materials are present, an aggressive approach to removing these materials for safe disposal is preferable to allowing them to leach into soils and groundwater over time from the decay of the building(s).

Possible Credits	**LAND USE**
1	If relocation or adaptive reuse of the structure is not an option based upon documentation provided by the Owner on company or personal letterhead then one credit is awarded for the "necessity" of the building removal over other options. Extending the life of buildings through rehabilitation or adaptive reuse is more sustainable in terms of the maintenance of embodied energy than a demolition in which even 100% of the materials are recovered. The Green Demolition Certification promotes this concept by rewarding projects in which selective dismantling is the "best" solution after rehabilitation and relocation options are deemed infeasible.
1	If the demolition contributes to sustainable urban planning by making room for in-fill or redevelopment of blighted areas, OR conversely the building removal is undertaken for the purposes of mitigation in natural areas or disaster debris removal where rebuilding will not take place and conservation lands are created. This is documented by a letter and or map indicating the site and future plans for construction at an urban site, or preservation at a rural site.

Industry Building

Intent
The Industry Building credits of the Green Demolition Certification are intended to validate the infrastructure that will make materials salvage economically viable. This is because the success of deconstruction and materials recovery is highly dependent upon revenues from the recovered materials. This infrastructure includes the reuse and recycling business development that provides the market for recovered materials, and regulatory incentives for demolition debris management.

Possible Credits	**INDUSTRY BUILDING**
1	A first time application for a Green Demolition Certification is rewarded by one credit as an encouragement to contractors who are willing to explore Green Demolition as an alternative to standard practice.
1	If the building removal project is undertaken by a combined deconstruction and used building materials resale business or recycling one credit is awarded. Documentation is achieved by providing proof of the reuse or recycling business as a component of the demolition contractor business.
1	If the Green Demolition Certification is used to validate a construction and demolition (C&D) waste management permitting process then one credit is awarded. This provides an internal incentive for making the certification an integral part of the C&D permitting process. Documentation is provided by a copy of local ordinance or regulation that requires C&D recycling or management as part of permitting process.

Community Building

Intent
Green Demolition can support the economic development of communities by providing jobs and job-skills training, and affordable building materials. At the same time, not removing a community's irreplaceable historic fabric should be rewarded. The certification provides a credit for removal of buildings that are not on the National Register of Historic Places, as an important component of a community's architectural and building fabric.

Possible Credits	**COMMUNITY BUILDING**
1	If the project makes use of a job-training program and/or apprenticeships one credit is awarded.
1	If a portion of the recovered materials is donated to a non-profit providing or using affordable reused building materials such as Habitat for Humanity, one credit is awarded. This credit also supports the benefits of non-profit tax deductions for the donation of materials by the building Owner or Contractor to a non-profit organization.
1	If demolition does not remove a building that is listed on the National Register of Historic Places one credit is awarded. As demolition should be considered a necessity over rehabilitation and historic urban character is a community value to be preserved, this credit is intended to balance the interests of preservation and building removal through an established third-party standard.

Materials Management Plan

Intent
Careful planning is essential to the success of a Green Demolition. Ensuring that the demolition contractor and all workers are aware of the techniques and goals for material recovery will improve recovery rates. Material flow away from the building is as complicated and needs to be as carefully coordinated as material flow onto the site during a construction project. The most fundamental green demolition planning strategy is having a use or market for the recovered materials before work begins. The development of sales strategies for the recovered materials such as on-site sales, bulk sales, use of media, design for reuse of materials into new projects all provide the foundation for a high recovery rate for the proposed project.

Possible Credits	**DEMOLITION PLAN**
1	If the green demolition is directly associated with a renovation or construction project that utilizes the recovered building materials one credit is awarded. Green Demolition is a method for mining existing building stock for raw materials for new building projects. Materials reuse on-site is the most efficient form of reuse and the additional effort required to incorporate recovered materials into new building design is rewarded by this credit. This is documented by a listing of materials that are recovered and that are reused within a one-year time frame at the same site or other projects
1	One credit is awarded if fifty (50) percent of all recovered materials are redistributed within a 50-mile radius of the project site. The recovered materials distribution radius will be dictated by the market for, and the value of, the recovered materials. The reuse of materials within the community is preferred over the export of materials to other communities for both social and environmental benefits. This may be difficult to document. One method is the use of on-site sales and the use of a local reuse retail store.

Worker Health

Intent

Supervision and training are prerequisites for a safe and efficient project and work place. Treating accident prevention as both a top down and bottom up activity will insure full communication and shared responsibility amongst all members of the entity undertaking the green demolition. Although safety has its own reward of no injuries, an incentive program for workers to exceed minimums and receive rewards for best practice is common in the construction industry. Some incentive programs are based upon company spirit and others are more pragmatic using salary bonuses or other kinds of in-kind benefits such as meals, goods, T-shirts, preferred parking spaces, and awards, as examples. Worker health and productivity are the basis of any successful enterprise and since Green Demolition Certification is based upon exceeding the minimums, credits for training and safety rewards are important components of the certification.

Possible Credits	**WORKER HEALTH**
3	If the contractor or job supervisor has been trained in Green Demolition Certification three credits are awarded. A well-managed project with consideration for the elements that make-up a green demolition will insure a successful overall effort and the completion of the other elements of the certification. Certification that the job supervisor or contractor has received green demolition training as per The Deconstruction Institute guidelines is required for the credits.
3	If workers have completed Green Demolition Certification training or training approved by the National Association of Demolition Contractors and/or OSHA, for demolition safety, three credits are awarded. Safety and industry training are critical to a safe and healthy project, and worker training is rewarded with multiple credits. Training plan for green demolition and training log for workers as prepared by the contractor is required for submittal.
3	Three credits are awarded if a worker safety and performance incentive plan that exceeds minimum safety and contract requirements is created and implemented on the green demolition site. Record of safety incentive plan or record of accident free days by company to indicate no serious accidents reportable under OSHA Form 200 requirements within the last 6 months can both be used to qualify for this credit.

Hazardous Materials

Intent

Green Demolition Certification requires the correct and safe handling and disposal of all hazardous materials. Since Green Demolition can involve more hand labor than traditional mechanical demolition, workers may be subjected to a greater exposure to hazards. For the health of workers and the environment, the most prudent standard of care should be followed, including all Federal and State regulations.

Possible Credits	**HAZARDOUS MATERIALS**
P	Asbestos survey and abatement as per OSHA and NESHAPS regulations using certified and licensed asbestos survey and abatement contractor(s). A copy of survey and clearance are required for this credit.
P	Lead work plan is developed and implemented as per OSHA CFR 29 1926. If the building is surveyed and does not contain any lead-based paint (LBP) then the lead work plan is fulfilled by the LBP survey. If the building contains LBP, then the plan must include all OSHA requirements for worker protection in a lead environment as required.
3	Any lead-based painted materials exceeding 0.06 % lead content are either disposed of, or abated prior to redistribution to the general public. As some materials are redistributed with lead content inadvertently, it is important to raise awareness of the issues of LBP materials reuse. Acknowledgement by the green demolition entity that it understands and addresses LBP issues is rewarded with three credits.
3	The hazardous materials management plan includes proper recycling and disposal of all other hazardous materials besides asbestos and lead-based paint, including refrigerants, chemicals and paints, mercury, PCBs, etc. and is rewarded with three credits. This credit is intended to reward the site separation of all hazardous materials including those that may be left where only a partial removal of salvageable materials takes place. This is documented by descriptions of hazardous materials and/or invoices and receipts from hazardous materials disposal facilities.

Job Safety

Intent
Providing a safe environment for all workers involved with Green Demolition is essential. Therefore the Job Safety elements of the Green Demolition Certification are all prerequisites.

Possible Credits	**JOB SAFETY**
P	A pre-demolition engineering survey is required before the start of work and to be used in the preparation of the project work plan.
P	A Job Safety Plan is a requirement and to be prepared and communicated to all workers and supervisory personnel before commencement of project.
P	A designated safety officer to monitor all job-site safety concerns and enforce the job safety plan is a requirement.
P	Although deconstruction may be accomplished with a partial utilities cut-off, insuring the highest standard of care outside the building prior to the start of work.

CONCLUSIONS

This paper is the description of a proposed Green Demolition Certification similar to many green building standards. The Green Demolition Certification can be used alone or as a component of an overall green building rating system where a project involves the removal of an existing building. As trends towards inner city revitalization increase and the reuse of urban lands, including Brownfields, continues, it will be important to carry out these revitalization efforts in ways that minimize building materials waste and support community economic and social revitalization. The goal of the certification is an educational document, a guide to the many elements of a green demolition, and a means to validate regulatory and market-based differentiation of higher standards of materials recovery, community benefit, and environmental health and safety for a building removal project. The certification as it is proposed makes use of common practices found in many green building certification methods and is based upon a pass-fail certification as a means to encourage use of the certification. As the certification method is tested for effectiveness and ease of use, it can be modified to use a series of levels of achievement.

REFERENCES

Florida Green Building Coalition, Inc. Green Home Standard - www.floridagreenbuilding.org

Guy, B and Gibeau, E., "A Guide to Deconstruction," self-published, 2002.

National Association of Demolition Contractors, "Demolition Safety Manual."

OSHA Code of Federal Regulation 29 1926 - www.osha.gov

Primdahl, Jim, personal conversations with author, September, 2002.

US Green Building Council Leadership in Energy and Environmental Design (LEED™) Green Building Rating System - www.usgbc.org

ENVISIONING THE IDEAL BUILDING REMOVAL PROGRAM (FOR CLOSED AND ACTIVE MILITARY BASES)

Authors: Mr. Michael Houlemard; Mr. Stan Cook (Fort Ord Reuse Authority, 100 12th Street, Building 2880, Marina, CA 93933)

INTRODUCTION AND FINDINGS

The reuse of the former Fort Ord will require the removal of 1,200+ World War II (WWII) era wooden buildings laden with Lead Based Paint (LBP) and Asbestos. Further, 1,100+ housing units of varying ages may need to be removed due to deterioration and vandalism. Add to these approximately 1,600 units of housing to be replaced by the US Army and the total is approximately 4,000 buildings to be removed form the former Fort Ord. To address these needs the Fort Ord Reuse Authority (FORA) instituted the Pilot Deconstruction Project in 1996 which has been funded by the David and Lucile Packard Foundation.

As a direct outcome of its years of work in addressing the complex issues associated with the removal of World War II vintage wood structures from the former Fort Ord, FORA has developed the concept of the "Ideal Building Removal Program." The Ideal Building Removal Program is intended to be comprehensive by combining: deconstruction techniques assisted by the speed and efficiency of heavy equipment, optimal reuse and recycling, training opportunities, livable wages to removal workers, local contracting and labor, abatement and conversion (where possible) of hazards to safe usable products, and production of usable energy.

The Ideal Building Removal Program would:

1. Have the following support from the State and Federal Governments:
   - Formally acknowledge the scale/volume of the building removal issue on closed and active military bases and address resolution as a statewide and national problem.
   - Build State/Federal partnerships to fund and regulate the removal of military buildings. (Partnerships to focus on both closed & active bases.)
   - Work to harmonize regulations and financial assistance. Focusing on unlocking the State's long term savings and economic development opportunities after building removal and to mitigate the "up front" fees that are typically charged by regulatory agencies during a building removal process.
   - Foster efforts that sustain local or regional control of building removal efforts.
   - Provide sufficient upfront funding to develop/refine comprehensive building removal programs: Grant approximately 1% of the estimated basewide building removal costs as a planning/engineering advance to develop base specific comprehensive building removal plans.
   - Provide "seed funding" to begin building removal and unlock land value – For example: upfront no/low interest 5-7 year loans to finance approximately 25% of the basewide building removal cost. Seed funding specifically earmarked and limited to covering actual building removal costs.
   - Fund provisions to provide ongoing technical assistance and sharing of lessons learned.

2. Be economically viable.

3. Be environmentally sound.

THE PROBLEM

The closure of the Fort Ord US Army Military Reservation (Fort Ord) in 1994 left over 7,000 buildings to be programmed for civilian reuse of these. Local jurisdictions must remove 1,200+ WWII Era structures and 1,100+ housing units, while the US Army will be removing 1,600 units of housing. The total number of buildings to be removed is approximately 4,000.

Several reasons dictate that these buildings be removed. None of these buildings meet civilian building code requirements and contain remnant hazardous materials that require abatement. These substandard facilities must be removed to economically replace the antiquated and failing infrastructure. The material from the buildings is not immediately safe for reuse or land filling. The cost to remove these buildings is prohibitive. The Fort Ord Reuse Authority (FORA), using baseline data from the US Army, originally estimated the cost of demolition and removal of just the WWII Buildings to exceed $100 million. Since 1997 this number has increased to $120 million, and then decreased to $55 million before settling around the current $75 million figure.

ALTERNATIVES EVALUATED

Working collaboratively with the University of California Santa Cruz (UCSC) Extension and the Presidio of Monterey Base Realignment and Closure (BRAC) Office, FORA established the Pilot Deconstruction Project a specialized program to test the feasibility of a more environmentally effective approach to remove Fort Ord's substandard facilities and abate the remnant hazards. Concepts that were tested include:

1. deconstruction,
2. aggressive recycling,
3. relocation for reuse, and
4. remodeling to make the structures usable.

Assumptions that were made up front are:

1. Lead Based Paint (LBP) is a hazard and that all removal processes must address LBP and work within applicable laws and regulations concerning LBP.
2. The task of building removal will be turned over to private enterprise by FORA.
3. All hazards must be abated before materials/buildings can leave the base for reuse.

The project deconstructed 5 distinct building types, relocated 3 buildings, remodeled 3 buildings and monitored the cost, timing, and job creation results of these efforts. Use of the multiple techniques for dealing with the buildings on the base was central to testing the potential to reuse materials within the structures and to examining alternatives to landfilling.

DISCOVERIES BASED ON ALTERNATIVES EXPLORED

There were significant and basic discoveries from the Pilot Deconstruction Project concerning the regulatory agencies, worker training, the building materials and building reuse.

1. The regulatory agencies were very happy to cooperate with politicians, contractors and citizens to provide guidance throughout the Pilot Deconstruction Project. This support was formalized through the Technical Support group that meet regularly to assess the progress of the project and to provide needed guidance concerning the applicability of regulations ranging from worker safety, hazard abatement techniques, and acceptable reuse and disposal scenarios.

2. The applicability of lead and asbestos regulations are dependent on the following:
    - Type of structure,
    - Size of the structure,
    - Previous use of the structure,
    - End-use of a structure or its component materials,
    - Owner of the structure,
    - Location/ relocation of the structure.

3. The following are needed for anyone who would work on the removal of the former Fort Ord buildings:
    - Lead Training (Minimum 8 hour Lead Awareness training for de-nailing positions, 40 hour Lead Worker training for deconstruction positions, Additional 40 hour Lead Supervisor training for supervisory positions)
    - Blood Lead level monitoring.
    - Training for deconstruction crews on deconstruction techniques and the value of the materials they are handling

4. It was discovered that complexity creates confusion and in combination with hazardous material regulations these typically result in buildings being demolished and landfilled.

5. The following were found to impact the reuse of buildings, the recovery of salvageable materials and the reuse and relocation of buildings:
    - The building stock on Fort Ord consists of a small number of distinct building types, which aides in salvage and building removal projections.
    - Deconstruction is more effective when materials are segregated as soon as possible and processed to meet specific market needs.
    - The existing buildings contain high quality, low value materials whose reuse is complicated by LBP. To make matters worse, lead based paint was originally thinned with leaded gasoline resulting in the lead contamination substantially penetrating the substrate material.

- The buildings each have unique histories of maintenance and repairs which complicates hazardous material abatement projections.
- Additional field surveys were required to augment the existing US Army environmental information. Approximately 30% more asbestos containing materials were found than were previously identified.
- The presence of LBP restricts the potential for reuse or relocation of buildings where there is a potential for contact with children.
- Up to 50% of building removal cost is attributable to hazardous material abatement.
- An upfront program for systematically evaluating the unknown hazardous materials is required.
- Post-deconstruction soil sampling showed that the activities of deconstruction did not create any LBP soil contamination

These points were identified by a material inventory and market value study and other research looking at the sale of clean salvaged materials.

SELECTED APPROACH

Based on the discoveries of the Pilot Deconstruction Project, FORA has made some decisions and selected an approach to building removal that is being implemented on a small-scale basis. The approach begins with a commitment to flexibility so that new ideas and technologies can be evaluated and incorporated as needed. And the approach seeks upfront pre-approval of building removal techniques by all regulatory agencies –establishing the Fort Ord Inter-Agency LBP Working Group with the aim of developing and sharing a standard process for seeking the agencies' approvals for new technologies and techniques as they are found. This Working Group is composed of representatives from construction, regulatory agencies, and salvage industries.

The research from the Pilot Deconstruction Project shows that LBP impacts all aspects of building removal including: project planning, worker safety, material reuse, material disposal, and site clean up. FORA, through the Fort Ord Inter-Agency LBP Working Group, has made a commitment to work upfront with project planners to provide advice and guidance on all LBP related issues. FORA has made a commitment to involve private sector enterprises in the research done to support building removal efforts – with the understanding that the private sector will be removing the majority of buildings on the former Fort Ord.

FORA has developed a simple "Hierarchy of Building Reuse" to guide all of its building removal activities. This model hierarchy simply ranks the preferred options for building removal at Fort Ord. The Hierarchy of Building Reuse is:

1. Remodel and Reuse. (Does leaving this building in place meet project needs?)
2. Relocate and Remodel. (Can this building serve a function somewhere else?)
3. Deconstruction. (Can the materials be safely and economically reused?)
4. Demolition with Aggressive Recycling. (What can be kept out of the landfill?)

The first thing that FORA has done to support the Hierarchy of Building Reuse model is to allow in contracts additional time for building removal if the contractor can demonstrate that they will be diverting a set amount of materials from the landfill where salvage for reuse is preferred - where recycling is acceptable and relocation of buildings for reuse is encouraged.

FORA has tested the spectrum of building components and materials identified by the Pilot Deconstruction Project in each type of WWII wood building to identify LBP contamination patterns and has shared this information with the regulatory agencies and contractors to help guide their specific building removal plans.

FORA is encouraging reuse and relocation by offering buildings to organizations and the general public for relocation and reuse providing they remediate any hazardous materials before moving them from the site. FORA is also planning to use a combination of relocated and new buildings as its new offices that will showcase the possibilities available by relocating and reusing buildings.

FORA is both sharing its findings concerning building removal with the other organizations that will be receiving land and buildings on the former Fort Ord and collecting and archiving the lessons learned by other organizations. FORA has been proactive in finding, field testing, and building acceptance for new technologies that will benefit building removal projects basewide.

FORA recognizes that even the preferred options of Remodeling, Relocation and Deconstruction in the Hierarchy of Building Reuse still result in some waste that needs to be landfilled. Therefore, FORA is supporting a request to the state, by the local landfill, for a disposal variance that would allow the acceptance and disposal of lower-level lead-contaminated building materials locally. Items with higher levels of lead contamination such as paint chips and other contaminants such as asbestos, PCB and mercury will go to Class I disposal facilities until economically feasible approved methods of recycling are found for these materials.

IMPACT OF THE APPROACH SELECTED

The effects of FORA's approach to building removal are starting to show. The Fort Ord Inter-Agency LBP Working Group is gaining expertise and comfort with processing approval for building removal techniques. FORA's building removal contractors are showing evidence of diverting approximately 70% of the WWII era structures from landfills. Developers, planners and contractors are coming to FORA to gather and share information on removing buildings rather than demolition and landfill. FORA has been asked by the new campus of Californian State University Monterey Bay to provide guidance in a current US Army funded deconstruction program that incorporates a materials recovery center in an effort to "close the loop" with the building materials on the former Fort Ord. Local contractors are making investments in special equipment with an eye on recovering more high-end building materials for reuse rather than recycling.

Now local and statewide regulatory agencies can identify each other and have developed relationships that allow them to feel comfortable sharing information and lessons learned as they actively work together to find solutions to building removal problems –resulting in time savings for everyone. The exchange of information and ideas coupled with the trust that is developing has also resulted in awareness by all that there are more questions that need to be answered before an efficient and environmentally sound building removal program can mature and be accepted. Some of the ongoing concerns (and opportunities) include:

1. Conflicts among regulations preventing safe reuse and recycling efforts,
2. The fragmenting effects created by multiple ownership of the former Fort Ord,
3. The most effective ways to collect and share the information needed by all,
4. Creating and maintain a tracking system that will last throughout the building removal process,
5. Matching building removal needs with the funds available,
6. Equitably prioritizing and coordinating building removal needs,
7. Creating a market for reusable and recyclable materials in the $5 -6 Billion of new construction that will be occurring on the former Fort Ord,
8. Finding upfront seed funding to jump start any building removal program.

LESSONS LEARNED

FORA has learned that there are currently no federal or state funds earmarked to jumpstart building removal efforts, just as there have not been any funds available to plan such a massive building removal project as is required at the former Fort Ord.

The communities, regulators and the federal government are learning that regulations developed to protect the environment and public health ironically hamper the use of new technologies that are emerging to assist in more environmentally sound building removal practices. Creating an environment that changes these conflicts into compatibilities for the good of the environment and the public takes work, openness and long-term commitment.

It appears that all parties will benefit if they are proactive in incorporating the following concepts into building removal:

1. Developing a one-stop permit process for deconstruction/demolition that distributes information to all of the applicable regulatory agencies.
2. Creating a local market for salvaged materials by stipulating reuse in new construction, thereby stimulating higher salvage values and deconstruction wages.
3. Developing a range for deconstruction worker wage rates that will allow training and increase through a level that will retain trained, qualified workers.
4. Ensuring that demolition and deconstruction permits allow time for salvage
5. Ensuring that demolition remain an option for structure removal if it is not economical to reuse, relocate or deconstruct. The most economical form of building removal will probably be a hybrid of deconstruction and demolition techniques.

6. Utilizing existing distribution channels for the materials salvaged from the buildings for reuse to gain general acceptance for this approach, resulting in increased demand and value for the salvaged materials.
7. Examining new uses for the salvaged materials that will add value to them by processing, or marketing.
8. Maintaining an inventory of salvaged materials available for reuse.

WHAT'S NEXT

The largest hurdle to overcome is finding money for a building removal effort of this size. In the case of Fort Ord the US Army has given the local communities the land but they must reuse or remove the buildings. The Communities are to receive the buildings "as is, where is". This means that the communities will receive substandard buildings covered with LBP and filled with asbestos that need to be removed. The US Army has discounted the price of the land to compensate for the cost of building removal.

Unfortunately, there are no seed funds available to remove at least a first round of buildings so that the land can be sold to pay for an umbrella building removal program. This leaves the communities to pass the cost of building removal on to development firms by discounting the land value – resulting in a scenario where multiple ownership interests must be informed and coordinated.

FORA is spearheading a basewide collective "building removal tracking system" that will track individual projects and their materials throughout the removal process to their final destination. (Ideally this tracking process will incorporate a web-based library where survey, notices and permits for each building can be archived and viewed on line.)

"Mining" any reusable and recyclable materials will require first removing the "overburden" of hazardous materials. The effects of changing LBP regulations on labor, materials sales, site clean-up and removal techniques continue to be unsettling. The Fort Ord Inter-Agency LBP Working Group is needed for some time to coordinate the efforts of all regulatory agencies developers and contractors concerned with the building removal and disposal of building materials. The Working Group will be instrumental if the local landfill's Disposal Variance Request is to be processed in a manor that will be effective and not conflict with each agencies efforts to protect public health, the environment and still support recycling and reuse of building materials.

Finally, the most important next step is to turn the task of building removal over to private enterprise and provide them with support until relatively standard, safe, environmentally sound, economically viable building removal processes are in place and accepted by all.

ELEMENTS NEEDED TO CREATE THE IDEAL BUILDING REMOVAL PROGRAM

1. State and federal governments to formally acknowledge the scale/volume of building removal on closed and active military bases and address resolution as a statewide and national problem.
2. Build state/federal partnerships to fund and regulate the removal of military buildings. (Partnership to focus on both closed & active bases.)
3. State and federal governments to harmonize regulations and financial assistance. Focus on unlocking the State's long term savings and economic development opportunities after building removal and to mitigate the "up front" fees that are typically charged by regulatory agencies during a building removal process.
4. Foster efforts that sustain local or regional control of building removal efforts.
5. Provide sufficient upfront funding to develop/refine comprehensive building removal programs. Grant approximately 1% of basewide building removal estimated costs as a planning/engineering advance to develop base specific comprehensive building removal plans.
6. Provide Seed Funding to begin building removal and unlock land value. This would be in the form of upfront no/low interest 5-7 year loans to finance approximately 25% of the basewide building removal cost. Seed funding specifically earmarked and limited specifically to covering actual building removal costs.
7. Fund provisions to provide ongoing technical assistance and sharing of lessons learned.