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Design out Waste

A design team guide to waste reduction in construction and demolition projects

The following set of factsheets have been prepared to inform design teams of the waste reduction opportunities that exist during the design phases:

FS2	Principles for Desiging out Waste
FS3	Procurement and Tendering for Waste Reduction
FS4	Reuse and Recycling Opportunities
FS5	Materials Optimisation and Standardisation
FS6	Off-site and Modern Methods of Construction
FS7	Deconstruction and Flexibility
FS8	Resources and References

The factsheets are informed by a review of waste management practices during the design and construction-phases on two Irish case studies, the Human Biology Building (HBB) and the Mater Adult Hospital (MAH) and relevant UK case studies and cost analysis[1]. A list of resources and references are also provided on a separate factsheet. The factsheets are colour coded to highlight the following elements:

- MAH and HBB Case Studies
- UK WRAP Case Studies
- Cost Analysis
- Legislation and Policy
- Resources and References

The factsheets were prepared as an output from an EPA-funded project under the STRIVE Programme carried out by the Department of Building and Civil Engineering in GMIT[2] in collaboration with Scott Tallon Walker Architects and John Sisk and Son Building Contractors.

[1] The considerable and excellent resources produced by WRAP will be used throughout the factsheets as there is a lack of C&DW data on Irish projects.

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Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

GMIT

The research programme is administered on behalf of the Department of the Environment, Community and Local Government by the EPA which has the statutory function of co-ordinating and promoting Irish environmental research.

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Background

Construction and demolition waste (C&DW) production has undergone a dramatic rise and fall over the past decade, reflecting the unprecedented economic growth and subsequent sharp decline in Ireland.

The Environmental Protection Agency (EPA) has estimated that C&DW production rose from 3.7 million tonnes (Mt) in 2001 (EPA, 2003) to a peak of 17.8 Mt in 2007, (EPA, 2009a) with a subsequent decline to just over 3 Mt in 2011 (EPA, 2013).

Irrespective of these dramatic fluctuations in generation rates, C&DW has continuously been one of the largest contributing waste sources in Ireland.

Opportunities in Design

The initial design and planning phases offer the best opportunities to prevent and minimise C&DW production (BSI, 2013). Previous research[1] has found that poor design contributes significantly to C&DW generation, with Innes (2004) suggesting that **33% of all on-site waste is due to a failure to implement waste reduction measures during the design stages.**

Definition

Waste is a human concept defining a material with no intrinsic worth or value, or a material discarded despite its inherent worth or value. The EPA definition of C&DW

as outlined in their annual National Waste Reports is:

"...all waste that arises from construction and demolition activities including excavated soil from contaminated sites. Those wastes are listed in Chapter 17 of the European Waste Catalogue (EWC)."

EPA (2012)[2]

Legislation and Policy

The modernisation of waste management practices in Ireland has been directly influenced by EU legislation, policies and strategies, especially through the implementation of the Waste Management Act, 1996 (DoEHLG, 1996). Subsequent legislation, policy actions[3] and guidance documents[4] have set targets, improved regulation and infrastructure, promoted a preventative approach and outlined waste management best practice. This evolution towards a more resource efficient and sustainable materials management approach has been endorsed with the transposition of the revised 2011 EU Waste Framework Directive (S.I. 126 of 2011) (EC, 2008) into Irish law. **This means that for the first time, the waste hierarchy (Figure 1) is legally established in a national statute and should therefore apply as a priority.**

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[1] Bossink and Bouwers, 1996; Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Chandrakanthi et al., 2002, Osmani et al., 2008

[2] While this definition provides a simple template to work from, it is worth noting that the C&DW stream can overlap into other sections. Chapter 8 lists waste from the supply and use of coatings (paints and varnishes), adhesives and sealants, Chapter 15 lists packaging waste and Chapter 20 deals with municipal waste (Llatas, 2011).

[3] Waste Management: Changing Our Ways (DoEHLG, 1998); Preventing and Recycling Waste: Delivering Change (DoEHLG, 2002); Waste Management: Taking Stock and Moving Forward (DoEHLG, 2004).

[4] Construction and Demolition Waste Management: A Handbook for Contractors and Site Managers (CIF)/FAS (2002); MCOS/ NCDWC/ (CIF) (2004) A Guide to Construction and Demolition Waste Legislation; Best Practice Guidelines on the Preparation of Waste Management Plans for Construction and Demolition Projects (DoEHLG, 2006).

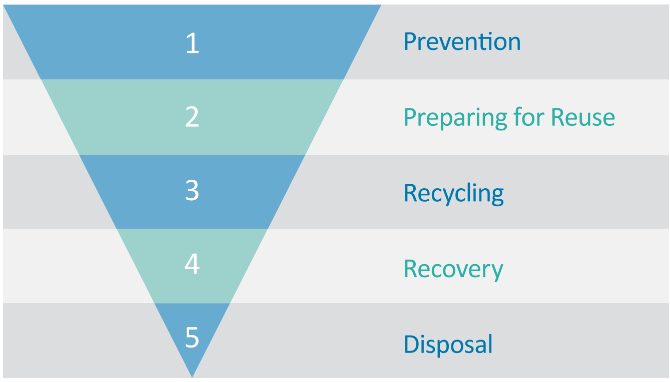

Figure 1 Waste Management Hierarchy as outlined in the Directive 2008/98/EC on Waste (EC, 2008)

This places a duty on the construction sector to review their waste management practices in order to move further up the waste hierarchy towards minimisation and ultimately, prevention. The recent publication of A Resource Opportunity: Waste Management Policy in Ireland (DoECLG, 2012) supported this approach and proposed specific producer responsibility requirements for C&DW projects over certain thresholds.

Designing out Waste

The UK Waste and Resources Action Programme (WRAP) has identified five key principles that design teams[5] can use during the design process to reduce waste:

- Design for Waste Efficient Procurement
- Design for Materials Optimisation
- Design for Off-Site Construction
- Design for Reuse and Recycling
- Design for Deconstruction

These principles can be integrated into a design review process using an opportunity matrix (Figure 2) to identify and evaluate waste reduction measures and their effect on cost, time, quality and buildability.

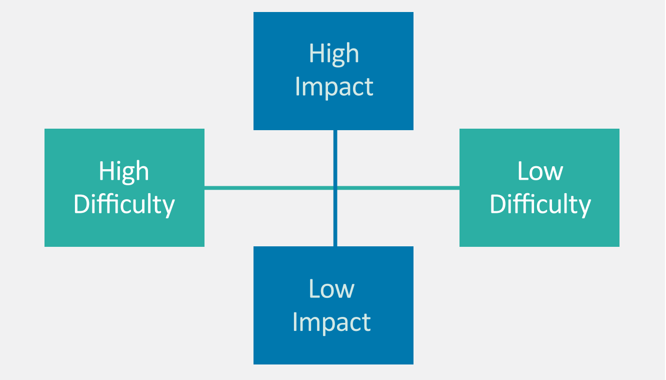

Figure 2 WRAP's opportunity matrix to evaluate waste reduction ideas

[5] Design teams include architects, civil and structural engineers, building surveyors, landscape architects, consultants and manufacturers, who contribute to, or have overall responsibility for, any part of the design, or who specify or alter a design, or who specify the use of a particular method of work or material, such as design manager, quantity surveyor who insists on specific material or a client who stipulates a particular for a particular project (BSI, 2013).

WRAP

WRAP carried out a series of detailed design reviews of selected 'live' case studies[6] to identify cost-effective and feasible waste reduction opportunities. The proposals were assessed by impact and difficulty[7] with the following 'high impact-low difficulty' proposals:

Design for Waste Efficient Procurement

- Use contractual documents to set waste performance requirements.
- Specify responsibly sourced materials and recycled content.
- Preparation of a Site Waste Management Plan (SWMP) and sub-contractor waste minimisation plans.
- Consider materials logistics e.g. Just-in-time deliveries, consolidation centres.
- Reduce packaging requirements in materials procurement.
- Collaborate with the supply chain.

Design for Materials Optimisation

- Simplify the building form, layout and elements.
- Standardise design, e.g. room sizes, floor to ceiling heights and material sizes.
- Use local materials and reduce the number of materials used.
- Specify recycled content.
- Consider maintenance, service and replacement requirements of each component.

Design for Off-Site Construction

- Use volumetric and modular construction.
- Use off-site prefabrication of structural elements.
- Use off-site prefabricated pods, i.e. bathrooms.
- Use off-site prefabricated and pre-cut building elements.

Design for Reuse and Recycling

- Reuse existing sites and buildings.
- Reuse building components and demolition materials.
- Use recycled building components and demolition materials.

Design for Deconstruction

- Use precast and steel frames.
- Use lime mortar to facilitate the future reuse of bricks.
- Use flexible construction methods to enable change of use.
- Consider reuse potential once design life is complete.

€ The proposals from the detailed design reviews of WRAP 'live' case studies were brought forward for quantitiative analysis to assess potential cost savings and reductions in waste production.

It was estimated that over £1.3 million could potentially have been saved in total project costs over the 10 case studies. This included a reduction in waste disposal costs of over £650,000 and a reduction in value of materials wasted of over £280,000. The reduction in waste production was also significant, with an estimated figure of 37,362 tonnes, which also reduced the transportation requirements.[8]

WRAP

WRAP have developed the following tools to help design teams evaluate waste prevention and minimisation design proposals: Designing out Waste tools for Buildings, Civil Engineering and the Net Waste tool. All of these tools have supporting guidance documents and video tutorials.

Site Waste Management Plans (SWMPs)

In Ireland, planning authorities are empowered under section 34(4)(1) of the Planning and Development Act 2000 (DoEHLG, 2000), to attach conditions relating to C&DW management including the preparation of SWMPs for projects over certain thresholds (Box 1).

Box 1. Construction and Demolition Waste Management Plan Thresholds in Ireland

- New residential developments of 10 houses or more.
- New developments other than above, including institutional, health and other public facilities with an aggregate floor area in excess of 1250m^2.
- Demolition/renovation/refurbishment projects generating in excess of 100m^3 in volume of C&DW.
- Civil engineering projects producing in excess of 500m^3 of waste, excluding waste materials used for development works on the site.

Anecdotal evidence suggests a lack of consistency across the local authorities in requesting the preparation and implementation of SWMPs, even if projects exceed the stated thresholds. **The Best Practice Guidelines on the Preparation of Waste Management Plans for Construction and Demolition Projects (DoEHLG, 2006), recommends that plans should be prepared in the early stages of project development.** The recommended contents of a SWMP are: project description; waste forecasts; project targets; proposed strategies and associated costs; materials logistics; responsibilities; auditing and record keeping procedures; education and communication requirements; pre-demolition and pre-refurbishment audits (if applicable); and evidence of supply chain coordination.

[6] Southwark Primary School in Nottingham; Tate Modern 2 in London; Southgate College redevelopment in Enfield; Elizabeth Garrett Anderson Language College in Islington; Brighouse and Sowerby Bridge Leisure Centres in Yorkshire; Defence Medical Rehabilitation Centre in Surrey; Plymouth Hospital; Queenshill Court Sheltered Housing in Leeds; Colchester and Chelmsford Magistrates' Courts; and the relocation of Holte, Mayfield and Lozells Schools in Birmingham.

[7] The four categories were: A - high-impact with low difficulty; B – high impact with high difficulty; C – low impact with low difficulty; D – low impact with high difficulty.

[8] Five of the case studies also gave estimates of embodied carbon reductions based on the embodied carbon in materials and waste giving a total reduction in embodied carbon of 1,878 tonnes.

The preparation of a SWMP in the early design and feasibility phases will communicate the waste reduction commitment to all parties and will provide a framework to carry out a design review workshop as part of the process.

WRAP

WRAP have developed the following tools to help design and construction teams prepare effective SWMPs : SWMP Template; SWMP 'Lite'; SWMP Tracker, which are supported by a series of video tutorials and guidance documents.

The True Cost of Waste[9]

The true cost of waste is not just the waste collection/disposal cost, but the value of the materials in the skip; plus the cost of site storage, handling and management and the loss of revenue from not selling, recycling or reusing 'waste'. Design teams should aim to spend less on the purchase of materials through waste efficient procurement (reuse of materials and specifying recycled content where appropriate) and less on waste disposal through designing out waste strategies, materials logistics planning, source segregation and supply chain collaboration.

€ WRAP have calculated from a series of case studies[10] that projects can save from 0.2% to 2% of construction value by reducing waste and the cost of disposal.

An EnviroWise case study in the UK found that the true cost of a mixed construction waste skip was over 15 times (£1,343) the cost of the skip hire (£85). This included the labour cost to fill it (£163) and the value of the skip materials (£1,095). This did not include costs for site sorting, handling and management on site.

[9] 'Waste' in this instance is defined as materials found in a site skip and does not include substitution, production or negligence waste (indirect waste) as defined by Skoyles and Skoyles (1987).

[10] Housing, commercial, public and refurbishment projects.

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The construction industry is characterised by a high fragmentation of responsibilities, processes and resources usually consisting of cross-functional, temporary teams that must work together to provide complex and customised solutions within a specified time period (Pesämaa et al., 2009).

The selection of a procurement system is traditionally framed within the 'iron triangle' of cost, time and quality (Eriksson and Westerberg, 2011); but is also influenced by flexibility, complexity, responsibility, risk allocation and avoidance, innovation, disputes and arbitration. This, in turn, is influenced by client (public, private, experienced, inexperienced) and project characteristics (size, type, construction type, site location, site risk factors, use of innovative technology, payment method, degree of project complexity and flexibility) (Gamage, 2011). WRAP recommends the integration of procurement clauses at project stages[1], to account for the different procurement routes[2] available. The design team has a key role to play in developing policy, setting targets and establishing tendering requirements.

Policy Development, Setting Targets and Contract Clauses

The preparation of organisational and/or project-specific environmental or waste management policies will establish the overarching waste management objectives and will inform the setting of project benchmarks/targets. Typical Key Performance Indicators (KPI) include:

- Percentage of waste diverted from landfill.
- Weight (tonnes) or Volume (m^3) of waste generated per construction value.
- Weight (tonnes) or Volume (m^3) of waste generated per construction floor area (m^2).

BREEAM[3] sets the following New Construction KPIs based on the amount of waste generated per $100m^2$ (gross internal floor area)[4]:

- ≤ $13.3m^3$ or ≤ 11.1 tonnes
- ≤ $7.5\ m^3$ or ≤ 6.5 tonnes
- ≤ $3.4\ m^3$ or ≤ 3.2 tonnes
- ≤ $1.6\ m^3$ or ≤ 1.9 tonnes

The Mater Adult Hospital (MAH) project set a waste generation target of < $9.2m^3/100m^2$ or < 4.7 tonnes/$100m^2$, based on the 3 credits available in the BREEAM Healthcare 2008 guidelines. $13,087m^3$ of construction waste was generated over 36 months, to Phase 1A completion. This equated to $11.9m^3/100m^2$, which achieved 2 credits.

The SWMP prepared for the Human Biology Building (HBB) set the following KPIs:

- A minimum of 90% by weight or 80% by volume of the material in the existing buildings to be reused and/or recycled.
- A minimum of 75% by weight or 65% by volume of non-hazardous construction waste generated by the construction works to be diverted from landfill.
- A non-hazardous construction waste benchmark to <$15m^3$ or 7.7 tonnes/$100m^2$ (internal floor area)[5].

The waste management objectives and targets set out in the project brief should be detailed in the contract documentation through the preparation of contract clauses covering compliance, collaboration and project-specific elements, i.e. reduced materials consumption and wastage, increased reuse and recycled content, etc.

[1] The project stages include: policy; preparation and design; pre-construction and construction; handover, post-completion and use.

[2] Reseach has found that the more cooperative models of procurement i.e. Design and Build do provide a more coordinated and collaborative environment in which the project objectives of cost, time, quality, function and safety can be met (Chan, 2000; Gamage, 2011).

[3] Taken from the BREEAM UK 2014 Non-Domestic New Construction Technical Manual.

[4] Alternatively, 1 credit can be awarded through achieving the following diversion from landfill targets: non-demolition (70% vol. or 80% t); demolition (80% vol. or 90% t).

[5] These benchmarks were within the BREEAM Healthcare 1-credit range of 13.3 to $16.6m^3/100m^2$ or 6.6 to 8.5 tonnes/$100m^2$.

Establish Waste Efficient Procurement Practices

The Pre-Qualification Questionnaire (PQQ) and Invitation to Tender (ITT) stages will provide an opportunity to identify waste reduction as a pre-requisite project objective to achieve the targets set out in the policy phase. The PQQ will assess the capacity and competence of all parties who will be involved in the delivery of the project. The PQQ response should demonstrate experience and provide evidence of implementing waste prevention, reuse and recycling strategies including supply chain collaboration.

The ITT phase will require a more detailed outline of these strategies including: design out waste principles; target setting; maximising reuse and recycled content; preparation of a waste management plan (WMP) and cost analysis. The ITT response should detail specific project objectives in regard to: the implementation of a SWMP; waste forecasts and setting of KPIs; the use of benchmarking and reporting tools; and cost analysis of proposed strategies. The waste reduction strategies outlined and evaluated during the PQQ and ITT stages will inform the preparation of the appointment contracts for the design team, main contractor, sub-contractors, suppliers and waste management contractors.

Pre-start meetings should agree on specific waste targets and waste reduction strategies. Peformance should be monitored throughout the construction process to evaluate the effectiveness of the waste reduction strategies outlined in the PQQ and ITT documentation and to identify any further opportunities for waste reduction.

The action plan of Green Public Procurement (GPP) Green Tenders, published by the DoECLG in 2012, recommended that the procurement procedures for design teams should include both a qualitative and quantitative assessment, including a demonstration of environmental design experience and/or qualifications. In addition, all construction materials should be assessed for environmental impact, including embodied energy and CO_2, resource use, responsible sourcing, construction waste, durability, recyclability and method of disposal. The subsequent publication of Green Procurement: Guidance for the Public Sector (EPA, 2014), set out the following core GPP criteria:

- The project team must provide evidence of technical and professional capability in regard to environmental aspects of a contract through an environmental management system (EMS) or an environmental policy, supported with appropriate training and evidence of previous environmental management experience.
- The contractor should prepare an outline construction environmental plan, which will include a C&DW management plan.
- An environmental management training plan must be developed to cover waste minimisation, management and selective waste collection strategies.
- Secondary aggregate and recycled materials should be specified in place of virgin materials.
- A site water and surface water management plan should be prepared by the contractor.
- The management of fuel and any other hazardous materials should be outlined.
- The contractor should prepare noise and dust management plans.

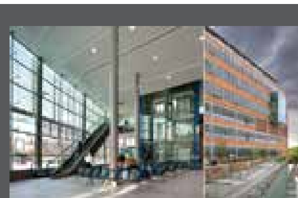
The tendering strategy for the HBB project used a Most Economically Advantageous Tender (MEAT) scoring strategy, where the preparation of a waste minimisation and management plan was to account for 2.5% (over €350,000) of the available marks.

The early involvement of project stakeholders on the MAH project facilitated the use of design ‘freezes’, e.g. for the lift shafts, to ‘lock-in’ the specification of the slipform system.

Preparation of the WMP

The WMP should be prepared during the design phases to: set out the project waste management targets and list associated responsibilities; forecast potential waste generation; recommend reduction and recovery strategies; and detail the benchmarking methodology to be used. Subsequently, the WMP should be used as an implementation, benchmarking, monitoring and reporting tool throughout the construction process.

The procurement of project work packages should be directly linked to the WMP, to ensure that specialist input is obtained on waste reduction targets and strategies throughout the design and construction process.



The six main sub-contractors on the MAH project, each prepared a waste minimisation plan before commencing work on site, which detailed: waste targets, skip management and segregation policies, material optimisation strategies, and supplier take-back arrangements.

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The fundamental design decision to reuse an existing building or demolish it for a new building will determine, to a large extent, the level of waste prevention in a project. In accordance with the waste hierarchy, the design team should explore reuse, recovery and recycling opportunities, in that order.

Reuse existing buildings and site elements

The design team should explore the option of reusing existing buildings and site elements at the earliest opportunity in the design process. This will require a detailed analysis of the existing building's structural integrity, services, expected lifespan, performance, quality, fixtures and fittings, regulatory compliance and ground conditions to determine the feasibility of reuse.

This will include detailed ground investigations to determine any contamination and an evaluation of the potential use of remediation and ground improvement techniques, if required[1]. The existing topography should be used to minimise excavation works, where possible. In some cases, existing buildings could be used as site offices/ facilities for the duration of the project.

Carry out a pre-refurbishment survey to identify reuse, recovery and recycling opportunities

If the design team decide to reuse and upgrade existing buildings or parts of these buildings, a pre-refurbishment survey should be carried out to determine the extent of the works (including demolition) and identify any specific constraints, i.e. removal of hazardous materials, continued occupation during refurbishment works, restricted work space, health and safety issues. The survey should also identify what materials can be retained and what should be replaced (by reclaimed or recycled content materials, if possible).

1 'WRAP proposes that 'beneficial reuse' should include treatment such as geosystems or cementitious agents, to enable materials to be

WRAP

A review of 29 WRAP Refurbishment Resource Efficiency case studies highlighted the waste reduction benefits of reusing existing buildings, elements and materials. Key reuse strategies included the retention and upgrade of existing buildings, facades, roofs, windows, doors, fireplaces, ceilings, WCs, sinks, ceiling and floor tiles, roof tiles, bricks, stonework, flooring, furniture and fixtures and fittings. Key upgrade strategies included; the use of new prefabricated elements; specification of materials with recycled content and locally sourced materials; environmental profiling of new materials using the BRE Green Guide; use of reclaimed materials; and the use of Building Information Modelling (BIM) to identify clash detection and materials optimisation opportunities.

Resource efficient products should be specified for refurbishment works with WRAP providing examples for lighting, ceilings, air conditioning and space heating, insulation, sanitary ware, ductwork, joinery/timber, pipes and fittings, ready-mixed concrete, flooring, plasterboard and windows.

There is a lack of waste data internationally for refurbishment projects but the UK CRW did produce the following preliminary waste generation benchmarks, which are useful to set design phase targets:

- 13.5m3/100m2 or 10.3 t/100m² for Commercial Retail.
- 14.1m3/100m2 or 6.4 t/100m² for Commercial Offices.
- 17.8m3/100m2 or 10.9 t/100m² for Residential.

€ The WRAP Refurbishment Resource Efficiency case studies also identified signficant cost savings ranging from:

- **£14,000** through the reuse of the facade in the restoration of a listed office building in Scotland to **£26,000** through the reuse of furniture and fittings in an £500,000 office fit out in London.
- **£200,000** through the return of unused materials to suppliers to **£300,000** by reusing furniture in the refurbishment of an office space in London.
- Approximately **£1 million** in the fit out of a mixed use development in London through the reuse of ceiling tiles and the existing raised floor and in an £16.5 millon office accommodation refurbishment in Blenheim through the reuse of flooring.
- **£40 million** by choosing refurbishment over demolition and new build in a 1960s council office building in Winchester (costing £40 million).

If non-hazardous materials recovered from the refurbishment works cannot be reused on site, the design team should explore alternative reuse options such as material exchange forums[2], architectural salvage, charity donations, take-home schemes, etc. Following this analysis, appropriate off site options should be considered including: reuse/recycling at permitted sites and/or recycling at licensed waste management faciities[3].

Carry out a pre-demolition audit to identify on site and off site reuse, recovery and recycling opportunities

If the reuse and/or refurbishment of existing buildings or part of the buildings is not feasible and/or does not meet the project/client requirements, then a new development will be required, which may require extensive demolition and site clearance works. If this is the case, the design team should develop a resource recovery plan in accordance with the ICE Demolition Protocol and AggRegain/WRAP guidance documents.

A key element of this approach is the preparation of a pre-demolition plan, which should inform the design assessment and identify opportunities to incorporate recovered and recycled demolition materials in the new build. This assessment of demolition material potential for recovery is informed by a desk study, site visit(s), quality assessment of materials and the preparation of the Demolition and New Build Bills of Quantities and the production of indices. Where on-site opportunities are limited, the plan should identify appropriate off-site options including reuse on other sites, in other applications[4] or transportation to a local recycling facility for processing.

Key targets for demolition work include the **Demolition Recovered Material Potential** (DRMP), which represents the tonnage of material that could be recovered; **Demolition Recovery Index** (DRI), which compares the percentage of recovered material to the total quantity of materials arising. Where possible, the recovered components and materials should be used at their highest functional value, once they fulfill the design requirements of the new build.

Issues such as client requirements, health and safety implications, programme requirements, hazardous or contaminated materials, presence of existing markets, site location and space (for source segregation), weather conditions and associated costs should be carefully examined to determine the most appropriate materials recovery plan, specific to the proposed works.

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[2] Examples include the: the SMILE Exchange in Ireland and the SEESA Site Swap Shop; RECRIPO; Construction Material Exchange Scotland; SalvoMIE; Surplus Match in the UK.

[3] The EPA maintains a database of licensed facilities and permitted sites.

[4] The National Federation of Demolition Contractors in the UK have produced a series of Demolition and Refurbishment Information Data Sheets (DRIDS).

Reuse and Recycling Opportunities

A preliminary pre-demolition audit of the existing National Diagnostic Centre building and the Marine Science outbuilding on the HBB project identified opportunities for the recovery of external windows, doors, lighting and signage, ventilation and storage units, internal furniture and fittings, structural elements (steel trusses and external stonework) and the requirement for hazardous material (asbestos) removal. It was recommended that the external stonework be reused as a low landscaping wall around the southern elevation, with resulting masonry and reinforced concrete materials, arising from the demolition works of the building shell, to be sent off-site for recycling.

It is estimated that 7,500m^3 of excavated material and 3,500m^3 of solid rock was to be removed from site during the enabling and excavation works. It was recommendend that on-campus reuse opportunities should be examined in parallel with appropriate local off-site recovery and recycling.

The extent of material segregation during demolition works can depend on the demoliton technique (soft strip by hand and mechanical) and attachments used on site (hydraulic/mechanical grab, steel and concrete shear, scraper bucket, mobile elevating work platforms). Where possible, a selective demolition method should be employed, which will include an initial soft strip by hand; removing furniture and fittings, permanent fixtures (windows, doors etc.) and reusable or recyclable elements. This will be followed by the removal of hazardous materials if required, the dismantling of the structure and the segregation of materials on or off site. Uncontaminated excavation materials may have a high reuse on-site potential depending on the project type and site conditions. If reuse on site is not an option, reuse off-site and recycling opportunities should be examined.

WRAP

Five WRAP Demolition Exemplar case studies demonstrated exceptionally high **recycling rates ranging from 93% to 98%**, despite employing different demolition methods. Key findings included the importance of: good communication between project stakeholders and the early involvement of demolition contractors; good local knowledge of markets and recycling facilities; immediate source segregation on site and off site recycling to facilitate high recycling rates; the programme and site space limitations; and the need for material quality protocols to facilitate reuse.

In addition, a review of seven ICE/WRAP Demolition Protocol case studies identified potentially high recovery rates (**>90%**) from demolition works, including significant opportunities for the reclamation of building elements, i.e. mechanical plant, fixtures, fitting and finishes, carpet tiles and traditional bricks and the recycling of demolition materials (recycled aggregate or recycled concrete aggregate on site) for use as recycled content in the new build. Further environmental benefits included a reduction in vehicle movements and primary material requirements and the associated prevention of CO_2 emissions.

The London Olympic Park Learning Legacy case study demonstrated an exceptional high recycling rate with **98.5 per cent** (by weight) of demolition material reused or recycled, **diverting 425,000 tonnes from landfill**. Reclamation efforts included nine steel portal frame buildings and materials such as bricks, paving and kerbs.

The ICE/WRAP Demolition Protocol case studies also demonstrated signficant cost savings arising from:

- The substitution of reprocessed demolition materials for primary aggregates on a regeneration project of five schools in Glasgow, resulting in a **£150,000** saving; in a demolition project of four 9-storey tower blocks in Barking, resulting in a **£40,600** saving; in the Wembley Stadium Access Corridor project, resulting in a **£23,910** saving and in the Maze/Long Kesh Prison regeneration project, resulting in a saving of **£640,000** to **£730,000**.
- The planning and conceptualisation of the Wylfa Power Station decommissioning project identified potential cost savings of: **£234,000** from the recycling of demolition materials, if used as recycled aggregates on site and **£748,632** from an adaptive site and building reuse approach. In addition, materials recovered from the demolition works were estimated to have a market value of over **£400,000** (£300,000 value for 3,000 tonnes of steel and £132,000 value for non-ferrous material).

Specify the use of Recycled Content Materials in any New Build

If demolition works are to take place, a detailed and thorough pre-demolition plan should identify reuse and recycling opportunities for demolition materials that can be used in the new build. This may require either on-site or off-site processing to produce both high value and low value recycled materials.

If the demolition works do not allow for recovery/recycling or no demolition takes place, the design team can procure products with recycled content[5] for use in the new build. Both approaches will contribute to the recycled/reclaimed content (RC) KPI of the new build, which represents the value of the recycled/reclaimed materials used in the new build divided by the total value of the materials used.

A review of 48 WRAP *Recycled Content in Construction* residential, education, retail, healthcare, office, mixed use, infrastructure (prison, wastewater treatment works, waste recycling facilities, car parks, bridges), sports facilities, business park and town centre redevelopment case studies identified Quick Wins in: concrete elements, steel elements, roof and wall insulation, roof coverings, facing brickwork and blockwork, general fill and bedding, flooring and floor finishes, ceiling tiles, asphalt road materials, service pipes, site fencing, plasterboard wall finishes, timber board products, furniture and fittings, site-won recycled aggregates and wall finishes.

WRAP recommends a minimum baseline recycled content requirement of 10%, moving towards 'good practice' by employing some or all of the recycling content Quick Wins. The 48 WRAP Recycled Content in Construction case studies illustrated signficant potential for readily achieving >10% at no extra cost. To support the use of recycled aggregates, WRAP have also developed the Quality Protocol for the production of aggregates from inert waste.

WRAP

WRAP have developed the **Recycled Content in Construction database** and the **Net Waste Tool** to enable the design team to estimate the likely recycled content by value in a new build and select appropriate materials.

Irish policy on Green Procurement is outlined in Green Tenders: An Action Plan on Green Public Procurement (DoECLG, 2012) and Green Procurement: Guidance for the Public Sector (EPA, 2014), which both provide recommendations for the construction sector.

[5] The recycled content of a product is defined in ISO 14021 as '...the proportion, by mass of recycled material in a product or packaging...'

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Design out Waste

A design team guide to waste reduction in construction and demolition projects

Materials optimisation focuses on using less materials in the design and producing less waste during the construction process.

The Designing out Waste guidelines developed by WRAP recommend the **minimisation of excavations, the simplification and standardisation of the design and materials choices and dimensional coordination** as effective strategies to reduce the amount of materials used in the design, leading to less waste being produced during the construction process.

Examples of how to reduce excavation work include investigating the appropriate use of ground improvement techniques, such as: geosystems to reinforce weak foundation soils; foundation drains to accelerate settlement; vibro-columns and dynamic consolidation to strengthen the foundation soils; lightweight fill to reduce loading; and staged construction to allow consolidation of the foundation before construction (WRAP).

A series of 8 WRAP case studies demonstrating the use of sustainable geosystems in civil engineering applications[1] reported the substantial reuse of site-won materials, which reduced the need for imported materials. This resulted in significant reductions in embodied CO_2 and cost savings.

Consideration of design solutions such as simple building forms with reduced complexity will reduce offcuts and enable a standardisation of the construction process, thereby reducing the amount of materials used. This repetition of design, within a building or across a range of buildings, will facilitate designing to material dimensions based around standard manufactured materials sizes[2] or to pre-ordered materials dimension sizes. This will lead to a reduction in waste from offcuts and time spent on site cutting.

On the MAH project, the internal plasterboard ceiling finish specification was changed to a 'grid-and-tile' system to accommodate the required services openings. The services design required hundreds of access panels, to facilitate maintenance of fire dampers, stop valves, ducting, etc. The 'grid-and-tile' system negated the need for access panels, thereby preventing considerable plasterboard offcuts, estimated at 6,200m^2 of plasterboard waste[3].

Plasterboard, reinforcement and metal stud partition waste were also reduced through the preparation of sub-contractor waste minimisation plans, which specified that these elements were ordered to size and pre-cut off site.

[1] Steep slopes and retaining walls; ground stability applications; road and pavement applications; working platforms; erosion control and protection; landfill applications.

[2] It is recognised that designing to standard material dimensions is difficult in practice as one material dimension will impact on several others.

[3] This estimate was based on a 14% wastage rate, which represented the waste generation rate of the partitions contractors on site.

The construction methods[4] used on site can also contribute to material optimisation, e.g. the use of precast and prefabricated elements and the reuse of formwork.

The eleven-storey lift shafts[5] and the four main stair cores on the MAH Project were built using a reusable independent formwork system called Slipform, which is a method of vertically extruding a reinforced concrete section (core walls) in high-rise structures, i.e. lift shafts, stair shafts, towers, etc. The use of the slipform system had a number of benefits including:

- Minimal use of the crane, scaffolding and temporary works.
- As the formwork system moved upwards, the exposed concrete was finished and integrated into the construction process;
- Once the shafts were completed, the system was disassembled, cleaned and made ready for use on a different project with little or no formwork waste created.

Where possible, the repetition of design and the construction process should be encouraged, without compromising the design concept and client requirements. This will allow for greater efficiences throughout the supply chain, particularly during the manufacturing and site installation phases.

The Department of Education and Skills Planning and Building Unit have developed a design template for low-energy educational buildings using a generic repeat design (GRD) approach, focusing on compactness, passive solar design, daylighting, ventilation, acoustics, thermal performance and energy usage. This design approach does offer considerable opportunities for waste reduction through standardisation, dimensional coordination and material selection.

Using less materials in design detailing is another optimisation strategy to be considered by the design team, e.g. the use of voided biaxial slabs instead of standard reinforced concrete slabs.

WRAP

WRAP have produced a series of Designing out Waste Design Detail Sheets for exposed ceilings, rotary displacement piles, castellated and cellular beams, post-tensioned floor slabs, voided biaxial slabs, flexible plumbing systems, aerated concrete blocks with thin joint mortar, polished concrete floors, door jambs and tiling. Each detail was assessed for: it's reduced material use and waste creation potential; cost and time implications; carbon reduction and recycling potential; and constructability and replicability, impact on structure, procurement issues, off-site construction, salvaged components, longevity, packaging, standardisation, dimensional coordination, repairability and deconstructability.

[4] Sometimes referred under the broad definition of 'low waste technologies'.

[5] This consisted of 14,000m2 of core walls up to a height of 54m.

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Off-Site and Modern Methods of Construction (MMC) offer significant potential for minimising construction waste.

WRAP (2007) investigated the current practices and future potential in MMC and estimated the following waste reduction percentages for each of the methods listed[1].

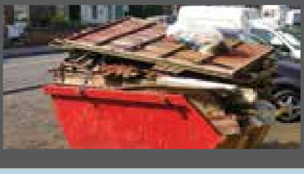
MMC	% Reduction
Volumetric building syst.	70-90
Timber frame system	20-40
Concrete panel system	20-30
Steel frame housing system	40-50
OSB SIPS	50-60
Composite panels	20-30
Precast cladding	40-50
Light Steel Frame systems	40-70
Bathroom/ kitchen pods	40-50
Precast flooring	30-40
Thin joint masonry	30-40
ICF	40-50
Tunnel form construction	50-60

A number of options are available to the design team, including:

- Volumetric Modular, which are fully assembled 3-dimensional units or modules used either as 'standalone' units or combined to form a complex unit or modular building.


The new NATO headquarters accommodation block WRAP case study reported a **48% reduction** in waste using a modular approach. This was benchmarked at having generated **5.2m^2 less waste per 100m^2 of construction**. Other benefits included: less deliveries to site; less workers on site; improved health and safety; and fewer waste collections. A review of the Yorkon manufacturing process found that **only 1.8%** waste was generated from the overall quantity of the material used, of which 85% is recycled[2]. As of January 2012, the company has achieved a **zero waste to landfill** target.

- Panellised Modular Building Systems, which are delivered in flat-pack format and assembled on site. The main types include: timber frame; steel frame; wood-based structural insulated panel systems (SIPS[3]) and structural insulated roofing panels (SIRPs); and concrete and cement structural panel systems, i.e. cross-wall.




WRAP has suggested that the use of timber frame methods could potentially reduce site waste by **20 to 40%**. Two WRAP Waste Minimisation through Off-Site Construction case studies found that very low levels of waste **(2-3%)** were generated during the timber frame manufacturing process. Similarly, the use of light steel frame construction was reported to have the potential to reduce site waste by **40 to 70%** with waste levels of **1%** reported for the manufacturing process.

[1] Each estimate was based on different levels of confidence ranging from 'broad' to 'reasonable'.

[2] The WRAP report states 65% but the most up-to-date figure from the Yorkon website states 85%.

[3] Interestingly, the BRE Trust have identified SIPS as a 'difficult' demolition waste due to their composite nature, which has implications for future reuse and recycling.

A comparative analysis carried out by WRAP of an advanced timber frame panel system, versus a traditional brick and block system, in a UK residential development, found no difference in cost, but did find a **27% reduction** in site waste labour requirements.

- Pre-maufactured pods, which are discrete volumetric units that are factory fitted with building services, but do not form part of the building envelope.

WRAP has suggested that the use of prefabricated pods has the potential to reduce on site waste by **50%**. A WRAP Waste Minimisation through Off-Site Construction case study reported that the manufacturing process produces less than **1%** waste, most of which is recycled.

- Building envelope components including composite panels, precast concrete cladding and light steel framing systems.

The main off-site construction design decisions for the MAH project focused on the building envelope components, resulting in the specification of the insulated concrete cladding panels from Techrete and bespoke[4] terracotta and glazing modular facade panels from Architectural Aluminium.

- Structural precast concrete building components not used in the building envelope, including hollowcore and solid flooring, basement systems, columns, staircases, balconies, wall panels, insulated concrete formwork, tunnel form construction, thin joint masonry, etc.

WRAP has suggested that the use of precast concrete components has the potential to reduce on site waste by **50%**. A WRAP Waste Minimisation through Off-Site Construction case study reported that the manufacturing process produces less than **1%** waste, most of which is recycled. Further research by Jallion et al. (2009) found that the use of precasting methods in private sector projects resulted in an **52% average reduction in waste production increasing to an average of 57% average reduction in public sector projects[5].**

The Stairmaster formwork system was used for the construction of the internal staircases on the MAH project. The system had the structural steel built-in, providing a solid section for the concrete pour which reduced the need for temporary formwork on site.

Of course, waste reduction is only one aspect of the design development. The evaluation of functional and structural requirements, procurement routes, buildability, programming, site conditions (access, height restrictions, confined sites, etc.), health and safety, cost, etc. will also determine the potential applicability of off-site construction and MMC.

[4] Each unit was produced individually depending on the internal and external requirements of where that unit was to be placed.

[5] These estimates were based on a detailed case study analysis of 14 private and public sector building projects in Hong Kong that were completed between 2002 and 2004.

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Deconstruction can be defined as a process similar to disassembly[1] but with the intention of reusing the components. Flexibility or adaptability refers to a multi-use building, which allows for an easy change in its purpose (BRE, 2001).

Design for deconstruction facilitates a move away from linear thinking towards **circular thinking** and encourages a **whole lifecycle approach**. This 'upstream' strategy aims to design out waste by identifying opportunities to extend the lifespan of buildings through flexible use, reduced maintenance and refurbishment requirements and the utilisation of buildings at their end-of-life, through the reuse of building elements and components and the recycling of materials.

Some key issues to consider when developing a deconstruction strategy include: **the whole lifecycle of a product or material; the potential for component reuse/recycling; and the processes of deconstruction when designing components and buildings** (CIRIA, 2004). Some possible end-of-life scenarios for buildings are illustrated in Figure 1 (Crowther, 2001).

The Scottish Ecological Design Association (SEDA) (2005) have produced a useful deconstruction guidance document[2], recommending the visualisation of a building as consisting of different **layers with anticipated lifespans** (Figure 2) (Brand, 2004).

This provides an opportunity to reduce waste from incremental processes i.e. refurbishment, retrofit, fit-out changes and wear and tear of components at the end of their service life, as each layer is defined by function and expected lifespan. So, those components with shorter lifespans should be easily accessible, close to the surface and should not disrupt the more durable components when replaced.

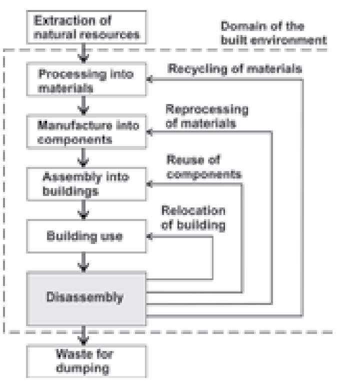

Figure 1 Possible End-of-life Scenarios for the Built Environment (Crowther, 2001)

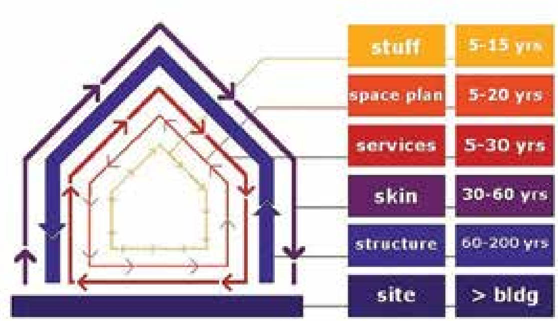

Figure 2 Building layers according to anticipated lifespan (Brand, 2004)

In addition to this 'layering' approach, the following deconstruction detailing principles are recommended (Crowther, 2001; SEDA, 2005):

- Design buildings to be adaptable and flexible in plan, detail and structural terms.
- Use assembly technologies compatible with standard building practice.
- Minimise the number and type of different materials used on a project.
- Avoid the use of potentially toxic or hazardous materials.
- Minimise the number and types of connections required, using simple mechanical connections where possible.
- Adopt a fixing regime, which allows all components to be easily and safely removed facilitating replacement with simple fixings .

[1] Disassembly can be defined as a process of taking apart components without damaging them, but not necessarily to reuse them.

[2] The guidance document also contains a series of details providing alternative deconstruction specficiations for: steel frame with concrete block cavity wall; timber frame with concrete outer block leaf; steel frame with glazed facade; concrete frame and panel; and refurbishment of masonry construction.

[3] Connectors should be designed to enable components to be both independent and interchangeable.

- Durable materials should be used to facilitate maximum reuse opportunities.
- Avoid composite materials and make inseparable products from the same material.
- Avoid the use of resins, adhesives and coatings in building elements and components as they will compromise the potential for reuse and recycling.
- Ensure components are readily accessible and removable.
- Provide adequate tolerance to allow for (repeated) assembly and disassembly.
- Provide for handling components during assembly and disassembly.
- Carefully plan services and service routes for easy maintenance and replacement.
- Provide a full inventory for each component and material used and retain information on the building and its assembly process in the Deconstruction Plan.

The Engineering Environmental Buildings Research Group at the University of Sheffield have developed a useful lifecycle assessment methodology, Sakura to determine the environmental benefits of designing for deconstruction (Tingley and Davison, 2012).

In the MAH Project, internal partitions were designed to be removed and altered to facilitate the reconfiguration of the internal layout. The steel frames and screwed-on metal facades used for roof-top plant area (above) can be easily deconstructed at the end of their life.

WRAP

WRAP have produced a series of case studies demonstrating design for deconstruction (DfD) and flexibility strategies including the use of:

- Prefabricated elements that can be easily disassembled and reused e.g. steel frame, metal roofing systems and timber facades;
- Non-composite materials;
- Modular finishes e.g. carpet tiles, and unpainted softwood internal cladding panels;
- Infill floors and internal staircases that allow for easy dismantling, to allow for adaptation of the building over time; easily deconstructable bolt connections on columns and beams; and
- Specification of materials that are fully recyclable, e.g. plasterboard used in temporary partitions and the crushing of concrete frame after demolition.

These strategies were embedded into an overall good practice approach, incorporating: a reduction in materials quantity used; the specification of recycled content; the measurement and reduction of embodied carbon; a reduction in water use; an increase in lifespan of the building elements and components; and a zero waste to landfill target.

Learning Legacy - London 2012

The 2012 London Olympics Basketball Arena was designed as a temporary venue, incorporating deconstruction and reuse principles from the start. The 35m high x 115m long structure was wrapped in 20,000m² of recyclable white PVC membrane, stretched over three different arched panel variations. Installation adjustments such as the zipping together of fabric weather flaps between adjacent panels (to avoid having to slice panels out) were made to facilitate deconstruction.

A flexible internal layout was designed for International Broadcast Centre (IBC) to accommodate a range of post-Olympics' uses. Bolted steelwork connections were used and mechanical/electrical services were positioned on the external gantry to allow for easy removal after the Games.

The 2004 CIRIA guidance document, **Principles of Design for Deconstruction to Facilitate Reuse and Recycling** sets out a series of general DfD principles by building element, which is supported by a number of case studies.

The 2008 SEDA Guidelines on Design and Detailing for Toxic Chemical Reduction in Buildings highlighted toxicity as a building lifecycle issue that embraces manufacture to final end-use or disposal. Alternative details are provided for steel frame and concrete block cavity wall, timber kit construction, steel frame construction, rehabilitation and precast concrete to demonstrate benign design and specification approaches.

Resources

- AggRegain/WRAP Demolition Waste Guidance **www.aggregain.wrap.org.uk/demolition/the_ice_demolition_protocol/**
- BRE (2001) Deconstruction and Reuse of Construction Materials.
- BRE Green Guide **www.bre.co.uk/greenguide/podpage.jsp?id=2126**
- British Standards Institution (2013) BS 8895-1:2013, Designing for Material Efficiency in Building Projects – Part 1: Code of Practice for Strategic Definition and Preparation and Brief.
- CIRIA (1998) Waste Minimisation and Recycling in Construction: Design Manual.
- CIRIA (1999) Waste Minimisation and Recycling in Construction: Boardroom Handbook.
- CIRIA (2001) Demonstrating Waste Minimisation Benefits in Construction.
- CIRIA (2004) Principles of Design for Deconstruction to Facilitate Reuse and Recycling.
- Department of Education and Skills Planning and Building Unit, Design Guidance on Generic Repeat Design.
- EcoRecycle Victoria (1998) Designing In Waste Minimisation.
- ICE Demolition Protocol and Guidance **www.aggregain.wrap.org.uk/demolition/the_ice_demolition_protocol/**
- NCDWC, Guidelines for the Prevention, Minimisation, Reuse and Recycling of Construction and Demolition Waste in Ireland, unpublished.
- Poon, C.S. and Jaillon, L. (2002) A Guide for Minimising Construction and Demolition Waste at the Design Stage, Hong Kong Polytechnic University.
- Sakura Deconstruction Tool **www.dfd.group.shef.ac.uk/**
- SEDA (2005) Design and Detailing for Deconstruction **www.seda.uk.net/index.php?id=127**
- SEDA (2008) Design and Detailing for Toxic Chemical Reduction in Buildings **www.seda.uk.net/index.php?id=127**
- UK CRW Refurbishment Waste Benchmarking Report
- UK National Federation of Demolition Contractors, Demolition and Refurbishment Information Data Sheets (DRIDS) **www.nfdc-drids.com/**
- US EPA Design for Deconstruction guidelines and other publications relevant to the Lifecycle Building Challenge **www.lifecyclebuilding.org/resources.php**
- WRAP (Waste and Resources Action Programme), 2007. Current Practices and Future Potential in Modern Methods of Construction **www.modular.org/marketing/documents/WRAP_ModernMethodsConstruction_Report.pdf**
- WRAP (Waste and Resources Action Programme), 2009. Design Detailing for Materials Resource Efficiency. Project code: WAS400-040, 26 November 2009 **www.wrap.org.uk/sites/files/wrap/Design%20detailing%20-%20evidence%20base%20report%20-%20v2.pdf**
- WRAP (Waste and Resources Action Programme), (undated) Designing out Waste: A Design Team Guide for Buildings **www.wrap.org.uk/content/designing-out-waste-design-team-guide-buildings-0**
- WRAP (Waste and Resources Action Programme), (undated) Designing out Waste: A Design Team Guide for Civil Engineering **www2.wrap.org.uk/downloads/Designing_out_Waste_-_a_design_team_guide_for_civil_engineering_-_Part_1_interactive_1.3f1366e0.9111.pdf**
- WRAP (Waste and Resources Action Programme), (undated) Designing out Waste: Landscape Opportunities **www.wrap.org.uk/sites/files/wrap/Designing_out_Waste_landscape_opportunities.pdf**

References

- Bossink, B.A.G. and Brouwers, H.J.H. (1996) Construction waste: quantification and source evaluation, ***Journal of Construction Engineering and Management***, V122(1), 55-60.
- Brand, S. (2004) ***How Buildings Learn: What happens after they are built?*** Viking Penguin, New York.
- BRE (2001) ***Deconstruction and reuse of construction materials***, BRE418, CRC Ltd., London.
- BREEAM UK (2008) Healthcare New Construction Technical Manual.
- BREEAM UK (2014) Non-Domestic New Construction Technical Manual.
- British Standards Institution (BSI) 8895-1:2013 Designing for material efficiency in building projects – Part 1: Code of Practice for Strategic Definition and Preparation and Brief.
- Chan, A.P.C. (2000) Evaluation of enhanced design and build system-a case study of a hospital project, ***Construction Management and Economics***, V18, 863-871.
- Chandrakanthi, M.; Hettiaratchi, P.; Prado, B.; and Ruwanpura, J. (2002) Optimisation of the waste management for construction projects using simulation, in: ***Proceedings of the 2002 Winter Simulation Conference***, December 8-11, San Diego, California, 1771-1777.
- CIRIA (2004) ***Design for deconstruction: principles of design to facilitate reuse and recycling***, London: CIRIA.
- Construction Industry Federation (CIF)/FAS (2002) ***Construction and Demolition Waste Management – A Handbook for Contractors and Site Managers.***
- Crowther, P. (2001) Developing an inclusive model for design for deconstruction, ***Deconstruction and material reuse: technology, economics and policy, Proceedings of the CIB Task Group 39***, Deconstruction meeting, Wellington, New Zealand, 6 April 2001 (pp. 1-26), CIB publication 266, paper 1.
- Department of the Environment and Local Government (DoELG) (1998a) ***Waste Management: Changing our Ways***, a policy statement published by the DoELG.
- Department of the Environment, Community and Local Government (DoHCLG) (2012) ***A Resource Opportunity – Waste Management Policy in Ireland.***
- Department of the Environment, Heritage and Local Government (DoEHLG) (1996) ***Waste Management Act 1996.***
- Department of the Environment, Heritage and Local Government (DoEHLG) (2000b) ***Planning and Development Act, 2000.***
- Department of the Environment, Heritage and Local Government (DoEHLG) (2002) ***Preventing and Recycling Waste: Delivering Change,*** a policy statement prepared by DoEHLG.
- Department of the Environment, Heritage and Local Government (DoEHLG) (2004a) ***Waste Management: Taking Stock and Moving Forward***, a policy document prepared by DoEHLG.
- Department of the Environment, Heritage and Local Government (DoEHLG) (2006) ***Best Practice Guidelines on the Preparation of Waste Management Plans for Construction and Demolition Projects.***
- Department of the Environment, Heritage and Local Government (DoEHLG) (2012) ***Green Tenders: An Action Plan on Green Public Procurement***
- Ekanayake, L.L. and Ofori, G. (2000) Construction material waste source evaluation, ***Proceedings from Strategies for a Sustainable Built Environment Conference***, Pretoria, August 23-25, 1-6.
- Environmental Protection Agency (EPA) (2003) ***National Waste Database Report 2001***, Johnstown Castle, Co. Wexford, Ireland.
- Environmental Protection Agency (EPA) (2009) ***National Waste Report 2007,*** Johnstown Castle, Co. Wexford, Ireland.
- Environmental Protection Agency (EPA) (2012) ***National Waste Report 2010,*** Johnstown Castle, Co. Wexford, Ireland.
- Environmental Protection Agency (EPA) (2013) ***National Waste Report 2011,*** Johnstown Castle, Co. Wexford, Ireland.
- EPA (2014) ***Green Procurement: Guidance for the Public Sector***
- Eriksson, P.E. and Westerberg, M. (2011) Effects of cooperative procurement procedures on construction project performance: A conceptual framework, ***International Journal of Project Management***, V29(2), 197-208.
- European Commission (EC) (2008) Directive 2008/98/EC (Waste Framework Directive) of the European Parliament and of the Council of the 19 November 2008 on waste and repealing certain Directives.
- Faniran, O.O. and Caban, G. (1998) Minimising waste on construction project sites, ***Engineering, Construction and Architectural Management***, V5(2), 182-188.
- Gamage, I.S.W. (2011) ***A waste minimisation framework for the procurement of design and build construction projects***, a doctoral thesis submitted in partial fulfillment of the requirements for the award of Doctor of Philosophy of Loughborough University, July 2011.
- Innes, S. (2004) Developing tools for designing out waste pre-site and on-site, ***Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction.***
- Jallion, L.; Poon, C.S.; Chiang, Y.H. (2009) Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong, ***Waste Management***, V29(1), 309-320.
- MCOS/National Construction and Demolition Waste Council (NCDWC)/Construction Industry Federation (CIF) (2004) ***A Guide to Construction and Demolition Waste Legislation.***
- Osmani, M.; Glass, J.; Price, A.D.F. (2008) Architects' perspectives on construction waste reduction by design, ***Waste Management***, V28(7), 1147-1158.
- Pesämaa, O.; Eriksson, P. and Hair, J. (2009) Validating a model of cooperative procurement in the construction industry, ***International Journal of Project Management***, V27(6), 552-559.
- Scottish Ecological Design Association (SEDA) (2005) Design for Deconstruction, SEDA Guidelines for Scotland: No. 1
- Scottish Ecological Design Association (SEDA) (2008) Design and Detailing for Toxic Chemical Reduction in Buildings, SEDA Guidelines for Scotland: No. 3.
- Skoyles, E.R. and Skoyles, J.R. (1987) ***Waste Prevention on Site***. Mitchell, London.
- Tingley, D.D. and Davison, B. (2012) Developing an LCA methodology to account for the environmental benefits of design for deconstruction, ***Building and Environment***, V57, 387-395
- WRAP (2007) ***Current practices and future potential in modern methods of construction.***

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