Material change for a better environment

Case study: Designing out Waste

Plymouth Hospital

A design review of the project to build a new hospital in Plymouth identified easy to implement ideas to reduce construction waste with the potential to reduce total project costs by at least £123,076, reduce the amount of waste produced on site by 2045 tonnes and avoid 340 lorry movements from the site.

Project code: WAS400-002
Research date: July 2008 – March 2009 **Date:** March 2010

WRAP's vision is a world without waste, where resources are used sustainably.

We work with businesses and individuals to help them reap the benefits of reducing waste, develop sustainable products and use resources in an efficient way.

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Front cover photography: Artists impression [Fosters+Partners]

Executive summary

Designing out Waste during the design stage of a construction project presents a significant opportunity to reduce waste from occurring on site, reducing the construction industry's waste burdens and improving the efficiency of material usage. These can provide clear cost savings and reductions in embodied carbon.

Through working with design teams on live projects, WRAP (Waste & Resources Action Programme) has created a series of exemplar case studies which demonstrate the benefits of taking action at the design stage to reduce waste and embodied carbon by making changes that either saved money or were cost neutral based on the five key principles of Designing out Waste:

- Design for Reuse and Recovery;
- Design for Off Site Construction;
- Design for Material Optimisation;
- Design for Waste Efficient Procurement; and
- Design for Deconstruction and Flexibility.

This report describes the work conducted by WRAP with the architects Foster+Partners, Circle Health and their framework contractors to demonstrate these principles in practice by identifying cost-effective and feasible waste reducing opportunities in the design of the new Plymouth Hospital.

The Designing out Waste process comprises three stages:

- **Identify** – engagement with the design team in a design review workshop to identify and prioritise opportunities to reduce waste based on the five key principles of Designing out Waste;
- **Investigate** – qualitative and quantitative analysis of prioritised alternative designs compared with the base design, including calculation of cost, waste and carbon savings; and
- **Implement** – selection of solutions to implement into the design and build based on the outcome of this analysis.

The ideas generated at the workshop were evaluated by the design team in terms of their waste reduction potential and their feasibility for implementation on the project. Two of these ideas were selected as being the most appropriate for quantitative analysis:

- reuse of excavated topsoil for soft landscaping instead of disposing of it and importing new topsoil; and
- use of prefabricated doorsets delivered just in time instead of traditional construction (i.e. hanging doors on site).

A comparative assessment of these two opportunities to reduce waste (i.e. base design versus alternative design) was undertaken to determine the difference in the overall construction cost, quantity of waste, number of lorry movements avoided, cost of waste disposal and the value of material wasted. The table below summarises the results of this assessment for the two design solutions.

Implementing the two alternative designs would:

- reduce total project costs by £123,076 (assuming none of the unwanted topsoil is sold);
- reduce waste arisings on site by 2045 tonnes;
- avoid 340 lorry movements;
- reduce waste disposal costs by £51,127; and
- reduce the value of materials wasted by £7244.

The effect of fewer lorry movements from the site would not only reduce the overall energy consumption of the construction process and hence direct emissions of carbon dioxide, but also local nuisance impacts such as noise and dust, and wear and tear to the local infrastructure. Another significant benefit from the use of the prefabricated doorsets would be the simplification of on-site operations.

Results of quantitative analysis of design solutions for the Plymouth Hospital project

Design solution	Total project cost [A] saving	Waste reduction (tonnes)	Number of lorry movements avoided	Reduction in cost of waste disposal	Reduction in value of wasted materials
Reuse of excavated soil (none of rest sold)	£107,310	2044	340 [B]	£51,100	N/A
Prefabricated doorsets	£15,766	1.05	0	£27	£7244
Total	**£123,076**	**2045**	**340**	**£51,127**	**£7244**

A: Cost of construction + waste disposal cost

B: Based on 15 m^3 lorries.

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1.0 Introduction

The construction industry is the biggest user of materials in the UK economy, consuming more than 400 million tonnes of materials each year. It also generates over 120 million tonnes of construction, demolition and excavation waste each year – over a third of all waste – only half of which is currently recycled or reclaimed back into construction.

The WRAP Construction Programme is helping the construction industry cut costs and increase efficiency through the better use of materials and reduction in waste. It aims to set new standards for good and best practice in resource and waste management in the construction industry, and provides free access to tools and knowledge to allow clients, designers and contractors to increase the materials resource efficiency of their projects and to increase industry awareness of the commercial benefits of doing so.

The best opportunities to reduce materials use and waste in construction occur by working at the earliest stages possible in the construction process. Empowering design teams to identify and act upon these opportunities to design out waste is therefore key to achieving the Government's and industry's commitment to Halving Waste to Landfill by 2012.

Decisions made throughout the evolution of a design can have a major impact on the levels of materials used during a project and waste that arises during the physical construction and future demolition. Often these decisions are made based on considerations such as site constraints, client requirements for improved performance or finish, or compliance with Building Regulations but, currently, these considerations rarely include improving materials resource efficiency or reducing waste.

'Designing out Waste' during the design stage presents a major opportunity to prevent the creation of waste on site thus improving resource efficiency, reducing waste to landfill and saving carbon – and reducing project costs. The five key principles of Designing out Waste are:

- Design for Reuse and Recovery;
- Design for Off Site Construction;
- Design for Material Optimisation;
- Design for Waste Efficient Procurement; and
- Design for Deconstruction and Flexibility.

WRAP has worked closely with the construction industry to develop a simple three-step structured process for 'Designing out Waste' to help design teams apply these principles to reduce the amount of construction waste produced through early changes to design, specification and procurement. A guide, *Designing out Waste: A design team guide for buildings*,[1] presenting this Designing out Waste process was published by WRAP in June 2009 and is recognised by RIBA within its CPD Core Curriculum.

This report describes work conducted as part of a WRAP project to work with the design teams of major live construction projects. The WRAP project had four main objectives:

- to identify opportunities to reduce the amount of construction, demolition and excavation waste produced at the outline design stage;
- to positively influence projects by gaining client, contractor and design team buy in to identify and adopt appropriate waste reduction design solutions;
- to gather evidence of the waste, cost and embodied carbon savings as a result of the adopted solutions; and
- to follow and test WRAP's design guidance and Designing out Waste process.

A number of construction projects were selected to be involved in this WRAP project and to produce exemplar case studies. This report summarises the findings of work by Davis Langdon (on behalf of WRAP) conducted with Foster+Partners to identify and investigate opportunities for Designing out Waste on the Plymouth Hospital project for Circle Health.

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[1] *Available from the WRAP website (www.wrap.org.uk/designingoutwaste)*

1.1 The construction scheme

Circle Consortium is a private healthcare consortium currently developing a series of private hospital projects in Plymouth, Bath and other locations throughout the UK. Each hospital shares a unified design concept being developed by Foster+Partners, a leading global architectural practice.

The Plymouth project is at RIBA Stage C and was used as the core project in this study as there is sufficient flexibility at this stage of the design to allow alternative solutions to be considered and implemented on the project. The Bath project is currently on site and is being used by the design team as the 'model' for other hospital developments to be developed against; information and data from Bath were used to supplement the analysis for Plymouth.

There is a unified design concept for both the Plymouth and Bath projects which involves a hospital building designed around three distinct functional tiers:

- lower level tier – ancillary and clinical section;
- middle level tier – office accommodation and main pedestrian entrance; and
- upper tier – 'hotel' accommodation consisting of en-suite patient rooms.

The lower level tier (ancillary/clinical) is considered to be the variable section of the building, changing in response to site conditions and specific project functional requirements. A central atrium links all three levels vertically. There is car parking adjacent to the building which can be either open air or covered depending on the site levels and specific circumstances of each project.

The frame, floor slabs and retaining structures are all of in situ reinforced concrete due the requirement for extensive servicing. The main grid is 7.8m × 7.8m with sub-grids of 6.5m × 7.8m in the 'office' and 'hotel' tiers. The floor-to-floor height of the ancillary/clinical tier is 4.5m while the office and hotel tiers are 3.6m.

The envelope to the middle level tier has a full-height, high specification glazing system, while the upper tier has a brass, rain-screen cladding system similar to overlapping vertical tiling or shingles. The upper tier is to be constructed using a prefabricated system.

1.2 The project team

Davis Langdon was contracted by WRAP to:

- facilitate the design review workshop (see section 2);
- carry out the subsequent cost, waste and environmental assessments; and
- develop the exemplar case study.

The project team is made up of:

- Circle Health (client);
- Foster+Partners (architects);
- Taylor Woodrow (main contractor for Bath, framework contractor for Plymouth);
- ISG Pearce (framework contractor for Plymouth);
- Morgan Ashurst (framework contractor for Plymouth); and
- Plincke (landscape architects).

2.0 Designing out Waste process

The Designing out Waste process devised by WRAP involves three stages:

1. **Identify** alternative design solutions which reduce materials use and/or creation of waste, and **prioritise** those that will have the biggest impact and be easiest to implement. This stage requires some form of design review, and WRAP's Designing out Waste guide presents the format for a facilitated design review workshop which ensures a robust approach involving all the design team.
2. **Investigate** the prioritised solutions further and **quantify** the benefits in terms of reductions in waste, cost and carbon. This enables evidence-based decision-making on which design solutions to implement.
3. **Implement** the agreed solutions in the project through the plans, specifications and contracts. **Record** the solutions in the Site Waste Management Plan to ensure they are fully communicated to the contractor and the quantified benefits are communicated to the client.

Designing out Waste: a design team guide for buildings recommends undertaking the design review workshop during RIBA Stage C.

2.1 Design review workshop

The design review workshop was held on 18 September and 16 October 2008 at Davis Langdon's offices in London. It was attended by:

- Mark Cammies, Health Circle Projects;
- Richard Saunders, Head of Construction, Health Circle Projects;
- Rory O'Connor, Health Circle Projects;
- Cos Evangelou, Health Circle Projects;
- Jerry Williams, Production Director, Taylor Woodrow;
- Mike Laide, Senior Design Manager, Taylor Woodrow;
- Colin Best, Projects Director, Morgan Ashurst;
- Ian Campbell, Morgan Ashurst;
- Ian Farrell, Operations Manager, ISG Pearce;
- Richard Price, ISG Pearce;
- Geoff Thomas, ISG Pearce;
- Darron Haylock, Partner, Foster+Partners;
- Thouria Istephan, Partner, Foster+Partners;
- Philippe Brysse, Associate, Foster+Partners;
- Alex Amato, Associate, Davis Langdon; and
- Nicolette Fenech, Consultant, Davis Langdon.

The workshop had three separate but consecutive sessions:

- Awareness session – review of Designing out Waste principles, and a summary of the construction project;
- Creativity session – ideas generation; and
- Reasoning session – ideas classification and prioritisation.

2.1.1 Awareness session

The first session included a brief overview of WRAP's construction programme, materials resource efficiency and the aims of the design review workshop. The design team then gave a short presentation on the Queenshill Court scheme, highlighting some of the specifications from the design brief and project restrictions.

2.1.2 Creativity session

A brainstorming session was then undertaken where all members of the team were encouraged to suggest ideas of how waste could be prevented or reduced. The aim was to create an atmosphere where ideas were stimulated through people thinking 'outside of the box'. Attendees were encouraged to 'brainstorm' a series of design opportunities that would effectively reduce construction waste in the project. The role of the facilitator was to encourage the design team to have a free flow of ideas, and to identify as many opportunities as possible. All ideas, regardless of feasibility, were recorded.

2.1.3 Reasoning session

Following the brainstorming session, the ideas were then evaluated by the group for their waste reduction potential and their feasibility for implementation on the project in terms of cost, programme and quality. Although a rough initial assessment, this helped to quickly identify the top opportunities with the greatest impact on waste and the most likely to be pursued on the project. All ideas were prioritised by the team by classifying as either A, B, C or D as per the simple 'opportunity' matrix shown in Figure 1:

- Section A – High impact on waste reduction, easy to implement.
- Section B **–** High impact on waste reduction, difficult to implement.
- Section C – Low impact on waste reduction, easy to implement.
- Section D **–** Low impact on waste reduction, difficult to implement.

Once ideas were allocated to A, B, C or D, discussions focused on the top areas of opportunity to take forward. These were marked by a star on the note card.

Table 1 lists all the ideas generated and their associated classification and categorisation in terms of impact on waste reduction/feasibility.

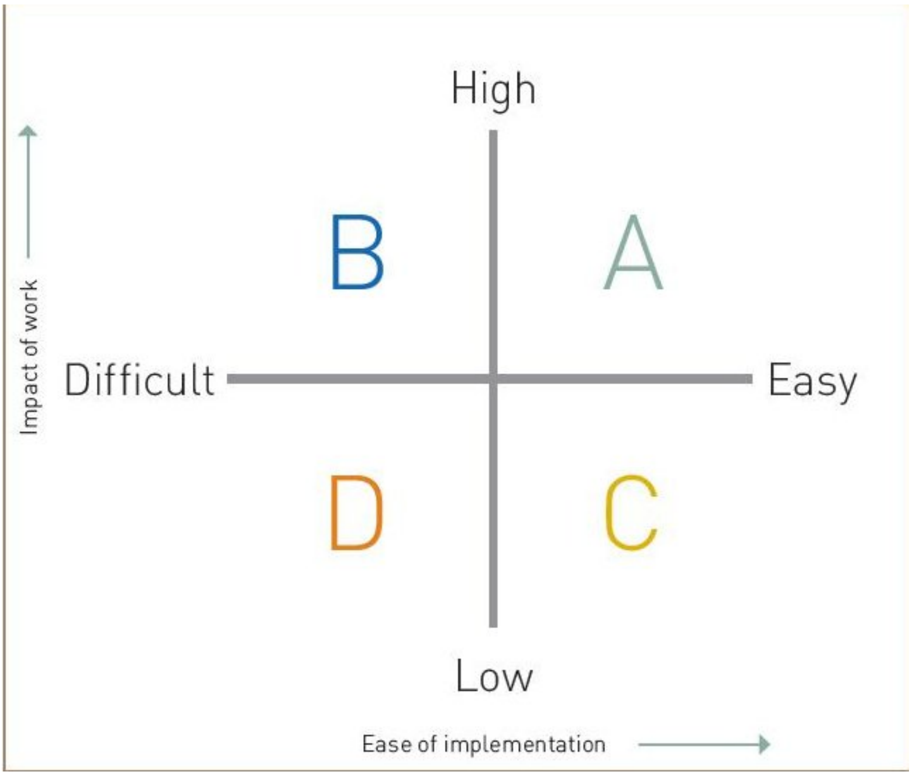

Figure 1 Opportunity matrix used to evaluate waste reduction ideas

Table 1 Ideas to reduce waste in design

A – High impact on waste reduction, easy to implement	
Design for Materials Optimisation	Specification review, e.g. double or single board.
	Specifying recycled content in materials.
	Co-ordination of planning grids with materials throughout the building.
	Full door height or doors with fanlights versus overboard.
	Rationalisation of partition layouts with suspended ceiling.
'B' – High impact on waste reduction, difficult to implement	
Design for Reuse and Recovery	Software modelling noted above but with the input and co-ordination of the subcontractor.
	Reusable packaging for standard elements to optimise the process.
	Establish project wastage key performance indicators (KPIs).
	End-of-life considerations taken into account during design requiring input from manufacturers and subcontractors.
	Eliminate basement and associated excavation.*
	Net amount of material required measured accurately by quantity surveyor.
Design for Off Site Construction	Off site construction, form finding software approach to vinyl flooring.
	Precast/minimise variants of stairs.
	Pod/off site construction of operating theatres.
Design for Materials Optimisation	Find an alternative to black tarmac (slate with resin?).
	Recycled content – recycled slate/demolition in concrete or screed (need for on site mixing plant).
'C' – Low impact on waste reduction, easy to implement	
Design for Off site Construction	Floor build ups – void formers to reduce in situ concrete requirement.
Design for Materials Optimisation	Smaller plasterboards as easier to handle – need for discussion with specialist subcontractors.

The group then identified the most viable alternative design opportunities to take forward for the quantitative analysis according to the following criteria:

- The selected alternative design would reduce the extent of construction site waste by either reducing the quantity of waste during construction and/or in future repair;
- The alternative designs would not increase the project cost, not have a significant negative effect on the design or construction programme, nor compromise the original design intent; and
- The alternative designs selected had the collective buy-in of the design team and were applicable at this stage of the design process.

After discussions by Davis Langdon and the design team, two ideas were selected for quantitative analysis (Table 2). The design team also agreed to take forward the idea of using prefabricated operating theatres instead of their traditional construction on site, but there were insufficient data available to allow detailed analysis of the potential cost and environmental benefits.

Table 2 Ideas selected for quantitative analysis

Base design	Alternative design
Transport all excavated topsoil off site, then import new topsoil and compost for landscaping.	Reuse of excavated soil on site after treatment for soft landscaping.
Doors fitted on site	Use of prefabricated doorsets (door leaf including all ironmongery components and architraves).

2.2 Quantitative analysis

The impact of the changes was quantified by comparing the original design (base design) with the alternative design. A quantitative analysis was undertaken of the potential cost, waste and embodied carbon savings by making this change.

The design team and/or specialist subcontractors provided drawings and specifications for each alternative design. The Davis Langdon quantity surveyor was then able to provide the material take off, bill of quantities and unit rates necessary to analyse the potential cost, waste and environmental impact of each design solution.

2.2.1 Calculate

The first step in the assessment was to calculate the following factors to inform the analysis:

- **Total construction cost of design** – based on the material composition of the design and unit rates (including labour, plant and material costs) provided by the quantity surveyor;
- **Quantity of waste** – application of industry material wastage rates (%) to material quantities (m^3) summed to give the volume of waste (m^3) arising from the base design and alternative design. Standard conversion factors applied to convert to mass (tonnes);
- **Cost of waste disposal** – volume of waste (m^3) calculated above multiplied by the unit cost of waste disposal; and
- **Value of materials wasted** – material unit rates (£) multiplied by the volume of waste (m^3) to determine the cost.[2] This cost was multiplied by the materials percentage to exclude plant and labour and determine the value of materials wasted (£); and
- **Number of lorry movements to remove waste from site** – based on volume of waste (m^3) to be transported, being collected from site in 8yd^3 (6.1m^3) skips or 15m^3 lorries;

[2] The value of materials wasted provides a measure of a component of the total construction cost which is spent but does not form a useful function in the finished building. It also represents a measure of unnecessary depletion of finite natural resources which could be avoided by reducing waste through the alternative design change.

WRAP's *Net Waste Tool, Guide to Reference Data, Version 1.0* (May 2008)[3] was used to source Good Practice wastage rates, rates of disposal and uncompacted bulking factors.

The detailed calculations are presented in Appendix A.

To estimate the quantity of waste diverted from landfill due to the changes in design, recycling/recovery rates would need to be applied to the quantity of waste arising on site. These rates depend on the site waste management strategy chosen for the site, which is usually not fixed at the design stage of the project. WRAP provides guidance on planning and implementing Good Practice site waste minimisation and management construction projects.[4]

2.2.2 Compare

The second step was to compare for the base design and alternative design of the different ideas on the shortlist:

- total construction cost;
- quantity of waste created on site;
- cost of waste disposal;
- total project cost (total construction cost + cost of waste disposal);
- number of lorry movements needed to remove waste from site; and
- value of materials wasted.

The results of the quantitative analysis of the three waste reducing opportunities are summarised in section 3.

Following the quantitative analysis, the results were presented to the design team, client and contractor. The team were asked to take on board ideas that could reduce on site waste and be a cost benefit or cost neutral to the project.

3.0 Cost, waste and carbon savings from selected solutions

3.1 Reuse of excavated topsoil on site for landscaping

The design incorporates extensive soft landscaping features adjoining the building, providing an opportunity to reuse a proportion of the existing topsoil. This will reduce the amount of topsoil to be transported off site (for sale and/or disposal to landfill) and eliminate the need to import fresh topsoil later in the construction sequence for the proposed landscaping features.

The quantification analysis compared the following options for the Plymouth site:

- **Base design:** transporting all excavated topsoil off site (A none sold, B half sold), then importing new topsoil and compost for landscaping; and
- **Alternative design:** retain some of the excavated topsoil on site for reuse and treat it to meet the specification of the soft landscaping (mixing with compost and application of weedkiller), transporting remaining material off site (A none sold, B half sold).

The base design assumes that all the excavated topsoil is transported off site with fresh topsoil and compost being brought on site when required for landscaping in the appropriate amounts.

The existing topsoil on the Plymouth hospital site is to be excavated to a depth of approximately 500mm. The total area of the Plymouth site is 20,062m^2, giving a total excavated volume of topsoil of 10,031m^3. The amount of topsoil required for landscaping is 2555m^3 at a depth of 500mm and the amount of compost is 1022m^3 at a depth of 200mm.

From the Stage C landscape drawings, it was estimated that approximately one third of the existing topsoil could be reused for soft landscaping. There is adequate space on site to retain and treat this quantity of topsoil until it

[3] *Available from www.wrap.org.uk/nwtool*

[4] *www.wrap.org.uk/construction/tools_and_guidance/waste_minimisation_and_management/waste_man_guidance.html*

can be placed. The treatment required to meet the soft landscaping specification was assumed to be mixing in compost (approximately a third by volume) and spraying with weedkiller.

It was difficult to put a credible resale value to the existing topsoil as this will depend on local demand at the time the topsoil is available. It was therefore assumed that:

- just 50% of the topsoil could be resold;
- the sale value was £15/m^3 with transport costs of £12.50/m^3, giving an income of £2.50/m^3.

Figure 2 shows the volumes of the different material streams in the base and alternative designs.

Figure 2 Design options considered

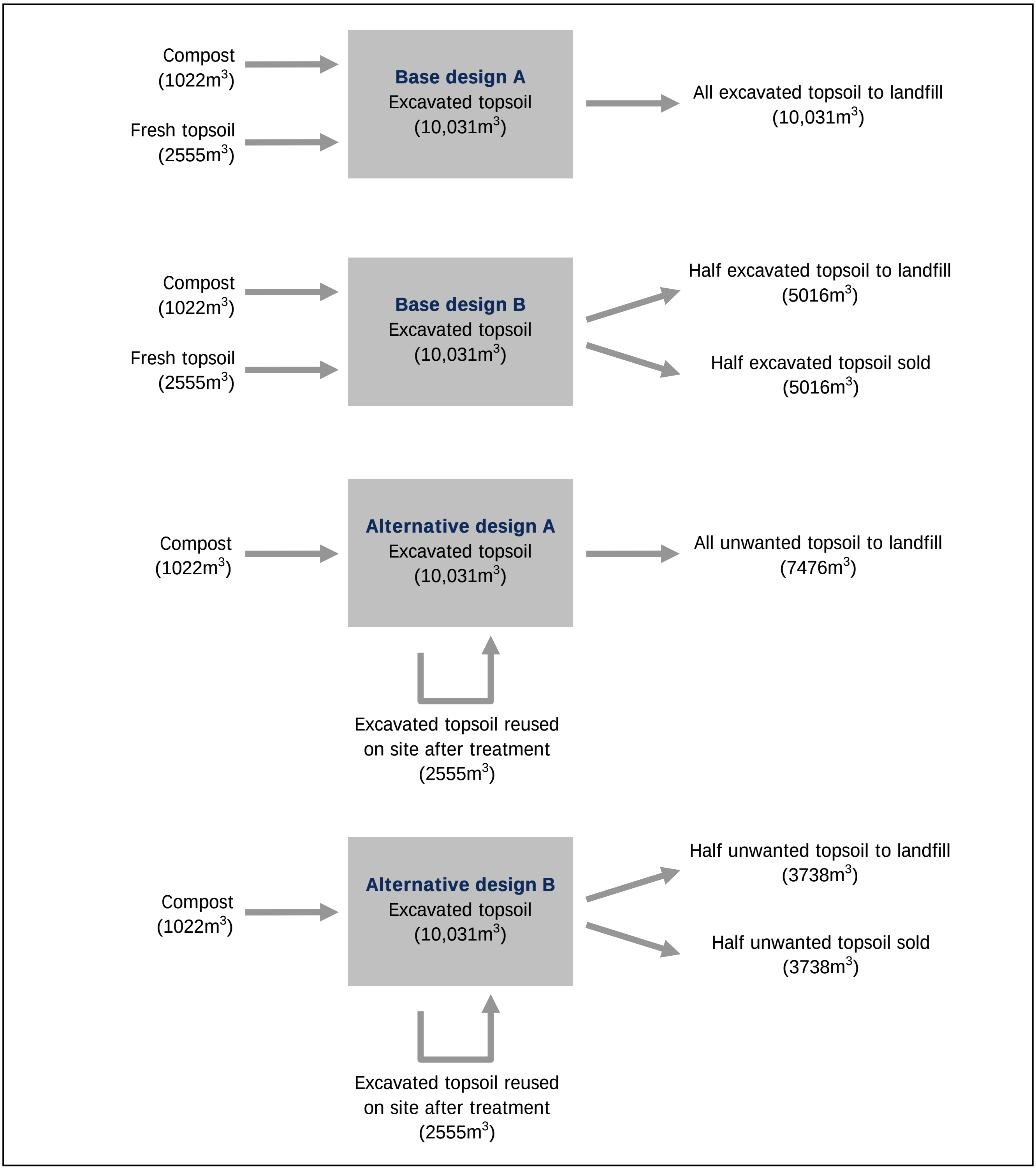

Table 3 summarises the costs and amounts of waste sent to landfill for the base design and alternative design with and without sale of (unwanted) excavated topsoil. Table 4 highlights the potential cost and environmental benefits of the alternative design compared with the base design (all excavated topsoil to landfill). Appendix A gives a full breakdown of the cost and waste savings.

Selling the excavated topsoil has a significant impact on waste disposal costs and the amount of waste sent to landfill – even for the base design of not reusing any of the excavated topsoil on site (Table 3). The savings made from selling excavated topsoil will increase exponentially as the amount of excavated material sold increases.

Table 3 Summary of quantification analysis

	Base design A	Base design B	Alternative design A	Alternative design B
Cost of excavation	£30,093	£30,093	£30,093	£30,093
Cost of imported compost	£30,660	£30,660	£30,660	£30,660
Cost of imported topsoil	£76,650	£76,650	–	–
Cost of movement and treatment of excavated topsoil on site	–	–	£20,440	£20,440
Cost of waste disposal	£200,620	£100,310	£149,520	£74,760
Income from sale of excavated topsoil	£0	£12,539	£0	£9345
Total net cost	**£338,023**	**£225,174**	**£230,713**	**£146,608**
Number of lorry movements	907	907	567	567
Total waste to landfill (tonnes)	8025	4013	5981	2990

A = all (unwanted) excavated topsoil sent to landfill
B = half (unwanted) excavated topsoil sent to landfill

The greatest cost and environmental benefits would be obtained by reusing as much excavated topsoil as is required for landscaping and selling as much as possible of the unwanted material (Table 4). Even with the additional costs of moving and treating the excavated topsoil, reusing it on site will save £107,610 and divert 2044 tonnes of waste from landfill if none of the unwanted topsoil is sold. Selling half the unwanted topsoil for a net income of £2.50/m^3 will increase the cost savings substantially to £191,415 and the amount of waste diverted to 5035 tonnes.

The amounts of material transported off site and brought on site would require 907 lorry movements under the base design and 567 for the alternative design, a reduction of 340 (material taken off site to be sold would still require transportation).

Table 4 Cost and environmental benefits compared with base design (100% excavated topsoil to landfill)

	Base design B: sale of half excavated topsoil	Alternative design A Reuse some excavated topsoil with none of the rest sold	Alternative design B Reuse some excavated topsoil with half rest sold
Total net cost saving compared to base design A with no sale of excavated topsoil	£112,849	£107,310	£191,415
Reduction in number of lorry movements	0	340	340
Reduction in waste to landfill (tonnes)	4012	2044	5035

The project team also suggested other opportunities for the reuse of the topsoil.

- The topsoil could be transformed into a permanent local public amenity/artwork (e.g. the mounds recently created adjacent to the A40) or used to create local green leisure areas for the local community.
- The local council could play an important role in the resale of suitably treated topsoil acting as a broker, finding potential customers on local sites from its knowledge of development in the area.

3.2 On-site door construction versus prefabricated doorsets

The following options were considered:

- **Base design:** doors fitted on site.
- **Alternative design:** prefabricated doorsets.

There are 318 doors in the design of the Plymouth hospital, of which 148 are type 1 and 170 are type 2:

- **Door type 1:** single leaf door 1000mm wide, single glazed panel, leaf to have hardwood veneer lipped on all edges; rebated frame, loose architrave all in hardwood, complete with ironmongery.
- **Door type 2:** double leaf door 2000mm wide, upper and lower glazed panels. Door leaf to have hardwood veneer lipped on all edges; double swing doors, frame to suit with loose architraves all in hardwood, complete with ironmongery.

The alternative design proposed manufacture of the doorsets off site for delivery just-in-time (JIT) as a completed packaged unit. This would reduce:

- amount of labour required;
- waste generated from hanging the doors, doorframes, architraves and fitting the ironmongery; and
- amount of damage generated.

Table 5 summarises the results of the quantification analysis. Appendix A gives a full breakdown of the cost and waste savings.

Using prefabricated doorsets instead of traditional door construction on site would:

- save £15,856 in total project costs (including a saving of £9576 in the cost of replacing and disposing of damaged doors);
- reduce the amount of waste by 2 tonnes (weight equivalent to nine damaged doors); and
- reduce the value of materials wasted by £7244.

Table 5 Summary of quantitative analysis

Element	Base design	Alternative design	Difference
Total cost of construction	£362,680	£356,400	£6280
Number of damaged doors	12	3	9
Total cost of replacing damaged doors	£12,784	£3325	£9549
Total cost of disposing of damaged doors	£40	£13	£27
Total project costs	£375,504	£359,738	£15,856
Total value of materials wasted	£9584	£2340	£7244

4.0 Discussion

4.1 Potential savings

The design team assessed two ideas in detail:

- reuse of excavated soil for landscaping; and
- use of prefabricated doorsets;

Table 6 shows the significant benefits to the project of implementing the two alternative designs. Without any sale of unused excavated topsoil, the total project cost saving is £123,076 of which £51,127 is due to savings in waste disposal costs. In addition there is a saving in the total value of materials wasted of £7244. Implementing the two design solutions would reduce waste arisings on site by 2045 tonnes. This would avoid the need for approximately 340 movements of a typical eight-wheeled lorry with an average capacity of 15m^3.

The effect of reduced transport movements from the site was considered an important benefit by the design team as this would reduce both direct carbon dioxide emissions and local nuisance impacts such as noise and dust.

If say half the rest of the excavated topsoil was sold, the total project cost saving would be £258,999 of which £51,127 is due to savings in waste disposal costs. The reduction in waste arisings on site would be 5035 tonnes. The number of avoided lorry movements remains at 340. The saving in the value of materials wasted would also not be affected by the sale of the topsoil and this relates purely to the use of prefabricated doorsets.

Table 6 Benefits of the two design solutions

Design solution	Total project cost [A] saving	Waste reduction (tonnes)	Number of lorry movements avoided	Reduction in cost of waste disposal	Reduction in value of wasted materials
Reuse of excavated soil (none of rest sold)	£107,310	2044	340 [B]	£51,100	N/A
Prefabricated doorsets	£15,766	1.05	0	£27	£7244
Total	**£123,076**	**2045**	**340**	**£51,127**	**£7244**

A: Cost of construction + waste disposal cost

B: Based on 15m^3 lorries.

4.2 Comments on the design solutions

4.2.1 Use of prefabricated doorsets

The design team subsequently decided to adopt the use of prefabricated doorsets. In the contractor's experience from using both systems, prefabricated doorsets always provided cost and environmental benefits. The design team also highlighted two other benefits from using the prefabricated doorsets:

- **Quality**. Higher quality was achieved with the doorsets compared with doors hung on site, the benefits of factory production being reflected in accuracy and workmanship; and
- **Programme efficiency**. There was a reduction both in the trades required on site and in labour for operations such as handling, door hanging and fitting ironmongery.

Appendix A Quantitative analysis results

Reuse of excavation soil on site for landscaping

The quantification analysis compared the following options for the Plymouth site:

- **Base design:** transporting all excavated topsoil off site (A none sold, B half sold), then importing new topsoil and compost for landscaping; and
- **Alternative design:** retain some of the excavated topsoil on site for reuse and treat it to meet the specification of the soft landscaping (mixing with compost and application of weedkiller), transporting remaining material off site (A none sold, B half sold).

The unit costs specified for each different component are taken from *Net Waste Tool, Guide to Reference Data, Version 1.0* (May 2008).

Base design A: disposing of all excavated topsoil to landfill, importing new topsoil and compost for landscaping

This option assumes:

- all the excavated material (10,031m^3) is removed from the site and sent to landfill (i.e. none is sold); and
- fresh topsoil and compost are imported to equate to the amount of topsoil required on site for landscaping.

The total cost of base design A is £338,023 (Table A1).

The total amount of material being transported is 13,608m^3 (10,031m^3 of excavated topsoil off site, and 2555m^3 of fresh topsoil and 1022m^3 of compost brought to site). An 'eight-wheeled tipper' lorry has an average capacity of 15m^3 (equivalent to 20 tonnes), resulting in 907 lorry movements to remove and import material from/to site.

Table A1 Breakdown of quantities and costs for base design A for Plymouth site

Total area of the Plymouth site	20,062m^2
Cost of excavation	
Landscaping material	Topsoil (assumed 500mm depth)
Volume of excavated material	10,031m^3
Unit cost of excavation [A]	£3/m^3
Total cost of excavation	£30,093
Cost of waste disposal	
Landscaping material	Excavated topsoil
Volume of waste	10,031m^3
Total waste [B]	8025 tonnes
Unit cost of waste disposal [A]	£20/m^3
Total cost of waste disposal	£200,620
Cost of imported topsoil for landscaping	
Landscaping material	Imported fresh topsoil (assumed 500mm depth)
Volume of imported topsoil	2555m^3
Unit cost of imported topsoil [A]	£30/m^3
Total cost of imported topsoil	£76,650
Cost of imported compost for landscaping	
Landscaping material	Compost (assumed 200mm depth)
Volume of imported compost	1022m^3
Unit cost of imported compost [A]	£30/m^3
Total cost of imported compost	£30,660
Transport	
Total volume of material transported	13,608m^3
Number of lorry movements	907
Total cost of base design	**£338,023**

A: *Net Waste Tool, Guide to Reference Data, Version 1.0*, May 2008

B: Conversion of m^3 to tonnes = volume (m^3) × density of topsoil (0.8 tonnes/m^3)

Base design B: selling half excavated topsoil and disposing of half to landfill, importing new topsoil and compost for landscaping

In this option:

- half the excavated topsoil is transported off site and sold;
- half the excavated topsoil is sent off site for disposal to landfill; and
- fresh topsoil and compost are imported to equate to the amount of topsoil required on site for landscaping.

The total cost of base design B is £225,174 (Table A2).

The total amount of material being transported is 13,608m^3 (10,031m^3 of excavated topsoil sent off site – half for sale – and 2555m^3 of fresh topsoil and 1022m^3 of compost brought to site). An 'eight-wheeled tipper' lorry has an average capacity of 15m^3, resulting in 907 lorry movements to remove and import material from/to site.

Table A2 Breakdown of quantities and costs for base design B for Plymouth site

Total area of the Plymouth site	20,062m^2
Cost of excavation	
Landscaping material	Excavated topsoil (assumed 500mm depth)
Volume of excavated material	10,031m^3
Unit cost of excavation [A]	£3/m^3
Total cost of excavation	£30,093
Cost of waste disposal	
Landscaping material	Excavated topsoil sent off site for disposal
Volume of excavated material	5015.5m^3
Total waste [B]	4013 tonnes
Unit cost of waste disposal [A]	£20/m^3
Total cost of waste disposal	£100,310
Revenue from sale of excavated topsoil	
Landscaping material	Excavated topsoil sent off site to be sold
Volume of topsoil sold	5015.5m^3
Unit net income [C]	£2.50/m^3
Total revenue	(£12,539)
Cost of imported topsoil for landscaping	
Landscaping material	Imported fresh topsoil (assumed 500mm depth)
Volume of imported topsoil	2555m^3
Unit cost of imported topsoil [A]	£30/m^3
Total cost of imported topsoil	£76,650
Cost of imported compost for landscaping	
Landscaping material	Compost (assumed 200mm depth)
Volume of imported compost	1022m^3
Unit cost of imported compost [A]	£30/m^3
Total cost of imported compost	£30,660
Transport	
Total volume of material transported	13,068m^3
Number of lorry movements	907
Total costs of base design	**£225,174**

A: *Net Waste Tool, Guide to Reference Data, Version 1.0*, May 2008

B: Conversion of m^3 to tonnes = volume (m^3) × density of topsoil (0.8 tonnes/m^3)

C: Sale value assumed to £15/m^3 and transport costs £12.50/m^3, giving net income of £2.50/m^3.

Alternative design A: reuse some excavated topsoil on site, disposing of the rest to landfill

In this option:

- 2555m^3 of the excavated topsoil is retained on site and reused;
- this excavated topsoil is treated by incorporating compost and weedkiller; and
- the rest of the excavated topsoil is transported off site for disposal to landfill.

The total cost of alternative design A is £230,713 (Table A3).

The total amount of material being transported is 8498m^3 (7476m^3 of excavated topsoil off site to landfill and 1022m^3 of compost brought to site). An 'eight-wheeled tipper' lorry has an average capacity of 15m^3 (equivalent to 20 tonnes), resulting in 567 lorry movements to remove and import material from/to site.

Table A3 Breakdown of quantities and costs of alternative design 2 for Plymouth site: no excavated material sold

Total area of the Plymouth site	20,062m^2
Cost of excavation	
Landscaping material	Topsoil (assumed 500mm depth)
Volume of excavated material	10,031m^3
Unit cost of excavation [A]	£3/m^3
Total cost of excavation	£30,093
Cost of moving material on site	
Landscaping material	Excavated topsoil for reuse (assumed 500mm depth)
Volume of topsoil required	2555m^3
Unit cost of moving topsoil [A]	£3/m^3
Total cost of moving topsoil	£7665
Cost of treatment and weedkiller for reuse	
Landscaping material	Excavated topsoil for reuse (assumed 500mm depth)
Volume of topsoil treated	2555m^3
Unit cost of treatment [A]	£5/m^3
Total cost of treating excavated soil	£12,775
Cost of waste disposal	
Landscaping material	Excavated topsoil sent off site
Volume of excavated material	7476m^3
Total waste [B]	5981 tonnes
Unit cost of waste disposal [A]	£20/m^3
Total cost of waste disposal	£149,520
Cost of imported compost for landscaping	
Landscaping material	Compost (assumed 200mm depth)
Volume of imported compost	1022m^3
Unit cost of imported compost [A]	£30/m^3
Total cost of imported compost	£30,660
Transport	
Total volume of material transported	8498m^3
Number of lorry movements	567
Total costs of alternative design	**£230,713**

A: *Net Waste Tool, Guide to Reference Data, Version 1.0*, May 2008

B: Conversion of m^3 to tonnes = volume (m^3) × density of topsoil (0.8 tonnes/m^3)

Alternative design B: reuse some excavated topsoil on site, selling half the remainder and disposing of the rest to landfill

In this option:

- 2555m^3 of the excavated topsoil is retained on site and reused;
- this excavated topsoil is treated by incorporating compost and weedkiller; and
- the rest of the excavated topsoil is transported off site, half is sold and half is sent to landfill.

The total net cost of alternative design B is £146,608 (Table A4). The potential income would be £9345. Waste disposal costs would also fall by £74,760 (i.e. 3738m^3 × £20/m^3).

The total amount of material being transported is 8498m^3 (7476m^3 of excavated topsoil off site and 1022m^3 of compost brought to site). An 'eight-wheeled tipper' lorry has an average capacity of 15m^3 (equivalent to 20 tonnes), resulting in 567 lorry movements to remove and import material from/to site.

Table A4 Breakdown of quantities and costs of alternative design 2B for Plymouth site: half excavated material sold

Total area of the Plymouth site	20,062m^2
Cost of excavation	
Landscaping material	Topsoil (assumed 500mm depth)
Volume of excavated material	10,031m^3
Unit cost of excavation [A]	£3/m^3
Total cost of excavation	£30,093
Cost of moving material on site	
Landscaping material	Excavated topsoil for reuse (assumed 500mm depth)
Volume of topsoil required	2555m^3
Unit cost of moving topsoil [A]	£3/m^3
Total cost of moving topsoil	£7665
Cost of treatment and weedkiller for reuse	
Landscaping material	Excavated topsoil for reuse (assumed 500mm depth)
Volume of topsoil treated	2555m^3
Unit cost of treatment [A]	£5/m^3
Total cost of treating excavated soil	£12,775
Cost of waste disposal	
Landscaping material	Excavated topsoil sent off site for disposal
Volume of excavated material	3738m^3
Total waste [B]	2990 tonnes
Unit cost of waste disposal [A]	£20/m^3
Total cost of waste disposal	£74,760
Revenue from sale of excavated topsoil	
Landscaping material	Excavated topsoil sent off site to be sold
Volume of topsoil sold	3738m^3
Unit net income [C]	£2.50/m^3
Total revenue	(£9345)
Cost of imported compost for landscaping	
Landscaping material	Compost (assumed 200mm depth)
Volume of imported compost	1022m^3
Unit cost of imported compost [A]	£30/m^3
Total cost of imported compost	£30,660
Transport	
Total volume of material transported	8498m^3
Number of lorry movements	567
Total costs of alternative design	**£146,608**

A: *Net Waste Tool, Guide to Reference Data, Version 1.0*, May 2008

B: Conversion of m^3 to tonnes = volume (m^3) × density of topsoil (0.8 tonnes/m^3)

C: Sale value assumed to £15/m^3 and transport costs £12.50/m^3, giving net income of £2.50/m^3.

Table A5 Summary of quantification analysis

	Base design A	Base design B	Alternative design A	Alternative design B
Cost of excavation	£30,093	£30,093	£30,093	£30,093
Cost of imported compost	£30,660	£30,660	£30,660	£30,660
Cost of imported topsoil	£76,650	£76,650	–	–
Cost of movement and treatment of excavated topsoil on site	–	–	£20,440	£20,440
Cost of waste disposal	£200,620	£100,310	£149,520	£74,760
Income from sale of excavated topsoil	£0	£12,539	£0	£9345
Total net cost	**£338,023**	**£225,174**	**£230,713**	**£146,608**
Number of lorry movements	907	907	567	567
Total waste to landfill (tonnes)	8025	4013	5981	2990

Traditional door construction versus prefabricated doorsets

The quantification analysis compared:

- **Base design:** doors fitted on site.
- **Alternative design:** prefabricated doorsets.

The two types of doors considered in both systems are as follows:

- **Door type 1:** single leaf door 1000mm wide, single glazed panel, leaf to have hardwood veneer lipped on all edges. Rebated frame, loose architrave all in hardwood; and
- **Door type 2:** Double leaf door 2000mm wide, upper and lower glazed panels. Door leaf to have hardwood veneer lipped on all edges. Double swing doors, frame to suit with loose architraves and all in hardwood.

There are 318 doors in the design of the Plymouth hospital, of which 148 are type 1 and 170 are type 2.

Traditional door construction

Table A6 gives a breakdown of unit rates of the materials required for the traditional door construction.

Table A6 Base design – unit costs for traditional door construction [A,B]

	Cost
Single leaf door	£785 (LP&M)
Double leaf door	£1450 (LP&M)
Replacing a damaged single door leaf	£710/door
Replacing a damaged double door leaf	£1243/door
Value of materials wasted (single door leaf)	£510 (65% of new cost)
Value of materials wasted (double door leaf)	£943 (65% of new cost)
Cost of waste disposal (assumed)	£108 for an 8yd^3 skip (6.1m^3)

A: *SPON'S Architects' and Builders' Price Book*, 134th edition, 2009

B: LP&M = sum of labour, plant and material

After discussions with the project team, it was agreed that currently when using a traditional method of construction, on average the number of doors damaged due to ongoing trade work is between 10 and 15. For the purpose of this exercise, it was assumed that 12 doors would be damaged, i.e. 4% of the total number purchased.

Total cost of construction is £362,680 (Table A7).

Total cost to replace 12 damaged doors is £12,784 (Table A8).

Total cost to dispose of 12 damaged doors is £40 (Table A9).

Total value of wasted materials is £9584 (Table A10).

Table A7 Base design – cost of construction

Element	Total number of doors	LP&M unit rate	Total LP&M cost
Door type 1	148	£785	£116,180
Door type 2	170	£1450	£246,500
Total	**318**		**£362,680**

Table A8 Base design – cost of replacing damaged doors

Element	Number of doors damaged	Unit rate for replacement (LP&M)	Cost of replacement
Door type 1	4	£710	£2840
Door type 2	8	£1243	£9944
Total	**12**		**£12,784**

Table A9 Base design – cost of disposing of damaged doors

Element	Number of doors damaged	Tonnes of waste	Volume of waste (m^3)	Cost of disposal
Door type 1	4	0.32	0.44	£7.79
Door type 2	8	1.26	1.80	£31.87
Total	**12**	**1.58**		**£39.66**

Table A10 Base design – value of materials wasted

Element	Number of doors damaged	Unit rate for replacement	Cost of replacement
Door type 1	4	£510	£2040
Door type 2	8	£943	£7544
Total	**12**		**£9584**

Prefabricated doorsets

This option involves the doorset being constructed and assembled off site and delivered on site at a later stage in the construction programme.

Table A11 gives a breakdown of unit rates of the materials required for the prefabricated doorsets.

Table A11 Alternative design – unit costs for prefabricated doorsets [A,B]

	Cost
Single leaf door	£800 (LP&M)
Double leaf door	£1400 (LP&M)
Replacing a damaged single door leaf	£765/door
Replacing a damaged double door leaf	£1280/door
Value of materials wasted (single door leaf)	£520 (65% of new cost)
Value of materials wasted (double door leaf)	£910 (65% of new cost)
Cost of waste disposal (assumed)	£108 for an 8yd^3 skip (6.1m^3)

A: *SPON'S Architects' and Builders' Price Book*, 134th edition, 2009

B: LP&M = sum of labour, plant and material

After discussions with the project team, it was agreed that when using a prefabricated doorset method of construction, the number of doorsets being damaged on average due to ongoing trade work is three. Fewer doorsets than door leaves are damaged as the prefabricated systems are delivered to site at a later stage in the construction programme and segregation is already complete, reducing the amount of waste generated through damage and offcuts.

Total cost of construction of prefabricated doorsets is £356,400 (Table A12).

Total cost of disposing of damaged prefabricated doorsets is £13 (Table A13).

Total cost of replacing damaged prefabricated doorsets is £3325 (Table A14).

Total value of prefabricated doorsets wasted is £2340 (Table A15).

Table A12 Alternative design – cost of construction

Element	Total number of doors	LP&M unit rate	Total LP&M cost
Door type 1	148	£800	£118,400
Door type 2	170	£1400	£238,000
Total	**318**		**£356,400**

Table A13 Alternative design – cost of disposing of damaged doorsets

Element	Number of doors damaged	Tonnes of waste	Volume of waste (m^3)	Cost of disposal (£)
Door type 1	1	0.11	0.15	2.60
Door type 2	2	0.42	0.60	10.62
Total	**3**	**0.53**		**12.62**

Table A14 Alternative design – cost of replacing damaged doorsets

Element	Number of doors damaged	Unit rate for replacement (L,P &M)	Cost of replacement
Door type 1	1	£765	£765
Door type 2	2	£1280	£2560
Total	**3**		**£3325**

Table A15 Alternative design – value of materials wasted

Element	Number of doors damaged	Cost per door	Value of materials wasted
Door type 1	1	£520	£520
Door type 2	2	£910	£1820
Total	**3**		**£2340**

Table A16 Summary of quantitative analysis

Element	Base design	Alternative design
Total cost of construction	£362,680	£356,400
Number of damaged doors	12	3
Total cost of disposing of damaged doors	£40	£13
Total cost of replacing damaged doors	£12,784	£3325
Total value of materials wasted	£9584	£2340

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